Key Challenges in Geography
EUROGEO Book Series

Kostis Koutsopoulos
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Karl Donert *Editors*

Geospatial Challenges in the 21st Century

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Chapter 1
Key Challenges in Geography Research with Geospatial Technologies

Rafael de Miguel González, Kostis Koutsopoulos and Karl Donert

Abstract Geospatial challenges in the twenty-first century is an initiative of the European Association of Geographers (EUROGEO), addressing relevant topics in the wide field of geography, which connects the physical, human, environmental, and technological sciences to enhance teaching, research, and decision-making. In recent years, geography as a discipline has been changing due to several essential factors, in particular, thanks to the deployment of geospatial technologies. Thus, geography is also changing in the research methods, data collection, processing, and representation it uses. This chapter will try to answer three main relationships between geospatial technologies in geographical research: geospatial challenges and geographical problems, geospatial challenges and geographical skills, and geospatial challenges and geographical knowledge.

Keywords Geospatial technologies · Geography · Research · Challenges

1.1 Introduction

Geospatial challenges in the twenty-first century is the first book of the Series *Key Challenges in Geography*. This is an initiative of the European Association of Geographers (EUROGEO), an organization examining geographical issues from a European perspective and representing European Geographers working in different professional activities and at all levels of education. EUROGEO's goal and the

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core part of its statutory activities are to make European Geography a worldwide reference and standard. The Series *Key Challenges in Geography* addresses relevant topics in the wide field of geography, which connects the physical, human, environmental, and technological sciences to enhance teaching, research, and decision-making. Geography provides answers concerning how aspects of these sciences are interconnected such that they form spatial patterns and processes that impact on global, regional, and local issues and thus affecting present and future generations. Moreover, Geography by dealing with places, people, and cultures, explores international issues ranging from physical, urban, and rural environments and their evolution, to climate, pollution, development, and economy.

In recent years, Geography as a discipline has been changing due to two essential factors. On the one hand, there are new spatial challenges that must be analyzed in order to understand the complexity of the current world: globalization, climate change, sustainable development goals, smart and livable cities, migration crisis, twenty-first century geopolitics, spatial inequalities, oceans, natural resources, world trade, or landscape and ecosystems evolution are, among others, key topics for an increasingly interdisciplinary research.

But geography is also changing in the research methods, data collection, processing, and representation it uses. Geospatial technologies, GIS, remote sensing, virtual globes, and geomedia linked to social media have also recently altered the very foundations of geography as a research field. Some authors have defined the neogeography as a new paradigm based on digital mapping technologies and the social networking practices. Regardless of the use of GIS and other geospatial techniques by nonprofessional academics or geographers, it is undeniable that geospatial technologies are essential tools for current geographic research, due to: the large amount of geographical information they can manage, the possibilities of spatial analysis and determination of spatial patterns, their contribution to the definition of spatial processes, as well as the quality of spatial representations through multiple visual formats.

The combination of both challenges, geographical and thematic, is what this first book in the Series *Key Challenges in Geography* seeks to integrate. Nowadays, it is difficult to carry out a geographical research of quality without using geospatial technologies. But also the other way around: the use of the most modern GIS techniques is only meaningful when a specific geographical problem is posed with its basic attributes: location, distribution, regionalization, systemic interaction between physical environment and human action, impact on the landscape and land uses, ecological footprint, sustainability, etc. Thus, the subsequent chapters respond to this double concern and they demonstrate, in most cases, that advanced geospatial analysis and representation techniques correspond to complex models of geographic information processing, because they investigate complex models of spatial organization.

This complexity is reflected in many of the contributions, which reflect common issues that arise for researchers, who face key challenges of a geographical nature through geospatial technology: What are the key skills needed by geographers to create an empirical and geographical knowledge based on spatial evidences? Which are the most accurate models and methods to process geospatial information needed to analyze specific geographical challenges? Can detailed geospatial information provide enough certainty to the research outcomes, while the discussion of these results, as well as the conclusions, often require cognitive processes of abstraction and a change of scale? How can geospatial technologies be effective to the spatial planning decision-making processes? These and other questions will be answered by an eminent group of scholars and researchers in geography throughout this book, that is divided into three parts. Facing the general question about geospatial challenges in the twenty-first century, several authors have guided their research toward the geographical problems underlying geospatial challenges. Some others focused their work on geographical skills to understand and to intervene in the space. Lastly, chapters preferred to explain how geospatial technologies contribute to a strengthening of geographical knowledge.

1.2 Geospatial Challenges and Geographical Problems

The first part of the book collects some chapters about traditional geographical problems, but from a renewed perspective, and also in proposing innovative solutions based on geospatial analysis and geovisualization. Most of them belong to classic issues from physical geography, such as natural risks and hazards, forest ecosystems, rivers and lake ecosystems, ocean ecosystems, water management and climate change, or from human geography such as economic development, tourism, urban sprawl, urban ecosystems, cultural heritage. Through this wide diversity of geographical issues, the authors develop different case studies based on the use of GIS and geospatial tools, providing powerful information to reduce the negative effects of natural impacts, or just the opposite, to increase the opportunities of sustainable development and harmonious growth.

Aragoneses and Minguez (Chap. 2) assess the vulnerability of a Spanish municipality to different natural hazards (flood, earthquakes, and landslides) by calculating different statistical models and creating a map series. These are especially valuable to determine social vulnerability and cultural vulnerability (spatial concentration of housing and heritage sites), but also to establish some guidelines for local urban planning.

Geospatial technologies are revealed as a very important tool to define the distribution and quality of ecosystems. Nita et al. (Chap. 3) establish a cause-effect relationship between the quality of ecosystems and the quality of life in Romania. Their chapter presents the main types of data required by geospatial technologies and the data sources for mapping diverse ecosystem distribution and management, including map techniques that result in a better understanding of urban ecosystems and allow more open and participatory urban planning processes.

The Ocean ecosystem has been the main object of study by Hruby, Ressl, and Borbolla (Chap. 4). They present the concept and techniques of Geovisualization Immersive Virtual Environments for specific geographical ecosystems as coral reefs. This chapter underlines the importance of the relationship between virtual and physical realities, that is, virtual and real geography. 3D models help to understand spatial distribution and environmental effects for these fragile ocean structures dramatically affected by climate change.

Geospatial technologies are also important for human-applied geography. Sarafova (Chap. 5) shows how geospatial modeling is valuable for business location and economic development. Based on the results of a case study for sustainable tourism practices in Bulgaria, the research seeks to create a replicable spatial model based on multi-criteria decision analysis including natural, social, economic, and historical data sources. The resulting maps define economic potential areas for added value activities in concrete locations.

Some similarities for tourism activities are exposed in the following chapter, but from the opposite point of view: rather than being based on the offer, they are assessed from a demand perspective. Encalada et al. (Chap. 6) use geospatial technologies to understand the complex geographical patterns of tourist hotspots. For this, the authors explain the potential of big data to increase geography research methods with GIS. In an era of Volunteer Geographic Information, geolocation data retrieved from mobile phones can be applied to get virtually instant statistics of population, for example, tourist flows inside a metropolitan area like Lisbon, and so they allow more accurate spatial analysis and the definition of geographical patterns.

GIS can also contribute to the effective management of a water distribution network. Abdelbaki et al. (Chap. 7) demonstrate how geospatial technologies are tools for both design and management of drinking water, even more powerful than classic CAD software traditionally used by architects and civil engineers. Geospatial technologies reinforce the role of location as layering allows more useful geographic information to be obtained for the design of water pipelines (and also pipeline materials) taking into account elements like relief (digital elevation model), soil characteristics, urban growth, and land use, or identifying irregularities in the urban cluster network of an Algerian city.

The last chapter of first part of Geospatial challenges in the twenty-first century comprises another important natural resource: tropical forest and its role as a thermal regulator. Popoola et al. (Chap. 8) use remote sensing to assess the spatial and temporal variation in land surface temperature from s case study in Nigeria. Despite the reduced access to variable sources of remote sensing data, the authors conclude the chapter showing the close relationship between vegetation loss and land surface temperature increase (about one degree for the last 30 years), and therefore to climate change.

1.3 Geospatial Challenges and Geographical Skills

Second part of Geospatial challenges in the twenty-first century deals with skills needed in order to cope with or possibly resolve spatial problems. Here, the greatest number of book chapters is gathered and skills that go beyond the technological domain of GIS are exposed. Many of these chapters are concerned with geographical skills needed to resolve social problems. So geospatial technologies are seen only as a means, and not an end, to develop actions to increase participation in spatial decision-making, to help the deployment of citizen science, or to enable geographical training itself.

One of these skills derived from the application of GIS is that of decision-making in spatial planning. Johansson et al. (Chap. 9) perform a study similar to the previous chapter: the linkage of tropical vegetation with climate change. However, this case study is not about Nigeria, but about Kenya. Not of natural vegetation, but of cultivated plants. This allows the authors to suggest strategies to intervene in the agricultural environment with the aim of improving the landscape, increasing irrigation, and mitigating the effects of climate change. Even though this case study does not use very complex geospatial technology (Story Maps on ArcGIS Online), but the outcomes are very effective for developing geographical skills for spatial management.

Chapter 10 (Pitarch) deals with another geographical skill, the awareness of spatial inequity, as well as the search for spatial justice. This case constitutes a state of the art about the role of the new geospatial technologies in the study of "old geographical issues" so clearly defined by scholars as David Harvey or Edward Soja. Pitarch suggests GIS can play a role in renewing geography as a social science, not as a descriptive discipline, but based on the usefulness of its knowledge. After analyzing a large number of papers that integrate spatial equity and GIS terms into the keywords, the author concludes that geospatial technology contributes to measuring spatial inequity in very specific aspects: location of different types of public services, analysis of accessibility to assess the degree of equity in a specific territory, analysis of socioeconomic and demographic characteristics a resident population (at different scales), among others.

Geospatial technologies can help resolve issues of applied geography, such as territorial disputes of a geopolitical nature. Perko et al. (Chap. 11) use GIS, LIDAR, and other techniques for border determination. In the case of the Slovenia–Croatian border, multilayered maps are used to visualize the changing course of the Drava River—in theory, natural border—in the last 200 years. This helps to understand the disagreements between the cadastral border and the natural conditions in order to facilitate the lives of people along the border, in particular the farmers there, and to make possible effective measures against natural disasters, especially floods.

Amodio (Chap. 12) exposes the added value of geospatial technology in the development of a citizen campaign in favor of collective knowledge and the recovery of cultural heritage in the Italian city of Salerno. In addition, the creation of a citizen application for mobile devices based on the geo-referencing of monuments, that allows the interaction of citizens and tourists. This has allowed a greater offer of cultural activities and better spatial planning and decision-making by local authorities regarding the historic center of the city.

A similar geographic skill-geospatial technology to increase public participation in urban planning is developed in the following chapter by Jankowski et al. (Chap. 13). The authors present two such methods belonging to the category of a Geoweb, called geo-questionnaire and geo-discussion. They were developed by the researchers and deployed in a number of case studies involving public participation in urban land use and transportation planning problems in two agglomeration areas in Poland, Poznań, and Łódź.

The Quest to Define the Knowledge and Skills Needed by Geospatial Professionals is a key contribution to the book. Johnson (Chap. 14) reviews the efforts to recognize geospatial technology as an industry and define the knowledge, skills, and competencies needed by geospatial professionals. Her chapter describes advances in technology affecting the profession and the development of curriculum for geospatial technology programs, in particular in the United States.

Two following chapters coincide in highlighting a challenge in geographic skills challenges for geospatial researchers and practitioners: identifying and utilizing mechanisms for addressing uncertainty and integrating these approaches into common geospatial practice. Wechsler, Ban, and Li et al. (Chap. 16) explain some factors of this uncertainty: error as a consequence of scale, semantic uncertainty, data uncertainty, etc. A case study about the semantic uncertainty of the exurbanization concept in Los Angeles County helps to understand that exurbanization can be defined by various geographical characteristics of a region and by various GIS visualizations. The Chapter concludes with the assertion "the goal of geospatial information is to provide a deeper understanding of the world", and for this reason error should be minimized, at the same time that the level of uncertainty should be measured, developed, and applied routinely as a part of spatial analyses and the communication of results. García Álvarez et al. (Chap. 15) provide a complementary approach of uncertainty challenge from the perspective of land use cover change tools, as verified in some European city examples.

1.4 Geospatial Challenges and Geographical Knowledge

The last part of the book is a set of contributions that have in common the role of geospatial technologies, not only for the acquisition of spatial thinking, but also for the systematization of geographical knowledge. Thus, Zaleshina et al. (Chap. 17) research the relationship between spatial orientation and navigation behavior with GIS.

Doufexopulou (Chap. 18) writes a theoretical paper about the renewed meaning of space, after the eruption of geospatial technologies, from the rational mapping perspective, the professional perspective, the postmodern geographical perspective, and also from a philosophical perspective. Space is a very polysemous concept, but a key concept for the creation of geographical knowledge.

García González (Chap. 19) compares spatial analysis and visual analysis in the new context of neogeography and democratization of geographic information. This opens a discussion over the nature and purpose of geographic knowledge, as well as social access to such knowledge changes. There are more maps and tools in which both spatial and visual components are fundamental. But it is also an undeniable fact that different technological advances are separating people's geography from academic geography more than ever. So, maybe geographical knowledge offered in school education should be reconsidered.

The growth of geospatial technologies has seen geographical analysis become one of the key tools for the effective management of business and government, allowing the development of tools for scenario modeling, decision support and planning. Glackin (Chap. 20) describes, in an Australian context, a specific tool (ENVISION) to analyze urban sprawl. This new spatial software is a technology was included in the municipal housing strategy to obtain accurate urban knowledge, later involving different stakeholders—from property owners and housing industry to local community and local government—in order to foster a sustainable land use redevelopment model.

1.5 Conclusions

Throughout this book, it has been possible to confirm that geographic research is increasingly dependent on geospatial technologies. The different authors have reiterated the need to have innovative tools with which to perform complex spatial analysis. The challenges of the contemporaneous world are physical, economic, political, social, or cultural, but they are challenges that occur in a specific geographical space, whatever the scale may be. In this way, the possibilities offered by GIS, remote sensing, GPS, etc., both in terms of data collection and in its visual representation, allows us to analyze at the same time different geographical factors in an interdisciplinary and crosscutting approach.

Second, almost all the chapters have affirmed that geospatial technology is only a means of obtaining, processing, and representing geographic information. In short, the geospatial challenges of the twenty-first century are, above all, geographical challenges that society must face in order to achieve a more balanced and sustainable development. Thus, the geographical research collected in the different chapters of this book shows that geography, as a discipline, is applying geographical understanding, as geography that is useful to the human groups that inhabit a place. In this respect, spatial analysis is really most meaningful when it is designed to improve the geographical space itself by implementing spatial planning actions. Many of the case studies that appear in the chapters of this book are good examples of breakthrough technologies and first-order geospatial innovations. And the authors explain that the developments arise as a consequence of the need to analyze a specific territory for a particular need, taking into account further spatial decision-making processes.

Besides this, the book offers the opportunity to know the world in real time, to understand which are the main questions that are posed to the geographer researcher. As a committed social scientist, the book reflects the geographer's concerns regarding the great spatial challenges of today's world. From the innovative approach of new geospatial technologies, the classic themes of geographical research are revived, but renewed and updated: climate, water, oceans, vegetation, landscape, risks and hazards, economic activities, cities, transportation, housing, borders, and also population.

This book is an initiative of EUROGEO and it seeks to understand geospatial challenges in the twenty-first century based on the work of European geographers. Thus, many European countries are represented by chapter authors or by case studies. However, the book also includes geographical challenges contextualized in America (the United States and also countries of Central America), Africa, and Oceania. In short, the book that reinforces the idea that we live in a global world, that geographical challenges are also global, and so geospatial technology uses universal languages (numbers, shapes, and colors) that are capable of replicate the understanding of interconnections that occur in the world system.

Part I
Geospatial Challenges and Geographical Problems

Chapter 2
The Geographical Systems Information: Tools for the Effective Management of the Cultural Heritage from Natural Disasters

Javier Aragoneses and Carmen Mínguez

Abstract Cultural Heritage is gaining more and more attention because of its value as a sign of identity and because of its important role in the economy of many regions. This can be seen in how different administrations have developed tools for the proper management of their heritage. However, a new awareness has emerged in recent years, driven by international institutions seeking new methodologies based on prevention. In this phase, geospatial information and Geographic Information Systems play a fundamental role as instruments for territorial analysis, which not only allow the evaluation of impacts but also establish preventive strategies and facilitate on-site intervention. This paper is a methodological essay that examines cultural heritage and natural risks. Through a series of analyses, models will be established to allow the identification of different degrees of exposure to different natural hazards calculated with different statistical models. Consequently, data on territorial vulnerability and its relation to heritage will be obtained. This study has been carried out at two levels in the municipality of Lorca which was struck by a strong earthquake in 2011.

Keywords Cultural heritage · Natural disaster · Territorial vulnerability · Lorca

2.1 Introduction

The interest in cultural heritage, as an element of identity, social cohesion and wealth generator has motivated the responsible administrations in each country to develop instruments and regulations for their correct management in order to ensure the conservation of properties by reducing the impacts of an anthropic nature and the ones derived from risks of natural origin. The first ones have been especially important

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during the last century, distinguishing two important facts: (i) Armed conflicts, which cause a significant negative impact on the patrimony since, in addition to being destroyed by its symbolic character, it is looted to finance the conflicts; and (ii) The strong growth in tourism. The latter has been tackled with different measures such as musealization, the closure of sites, the creation of replicas, or the establishment of limits on tourist capacity. However, there are fewer actions related to the prevention of natural risks, which are increasingly relevant and directly related to the effects of climate change, which is currently the concern and attention of international organizations such as UNESCO.

This institution highlights the increasing vulnerability of World Heritage sites to disaster risks and more specifically to the impacts of climate change and the possible implications for global tourism (UNESCO 2014). A concern that can be extrapolated to all cultural properties and sites, not only those included in the World Heritage List. The relationship between climate change and the conservation of these properties is still not understood by some experts, who maintain a Eurocentric vision, forgetting the characteristics of the environments and also the techniques and materials used for the construction of sites in other continents and even in northern latitudes within Europe. Despite this, recent events such as the earthquakes of Assisi (1997), Bam (2003), L'Aquila (2009), Haiti (2010), Lorca (2011), Amatrice (2016), and Mexico (2017) or the floods of the Seine in Paris (2016 and 2018) have motivated a greater sensitivity in relation to the effects of natural risks, some of them derived from climate change. The normalization of catastrophes is unavoidable and these events, aside from the human cost, generate a considerable amount of damage to the sites so it is necessary and more cost-effective to work in preventive campaigns (Ballart Hernández and Juan i Tresserras 2001; Querol 2010).

In Spain, due to the autonomic decentralization, the regional governments are the institutions with full power to manage the assets in their territorial area. For this reason, they are responsible for its management, for which they have their own instruments and equipment. Despite this, since the second half of the 1980s, the Spanish Ministry of Culture (under different names) has designed and implemented a series of sectoral Plans at the national level. All of them have been elective in nature and have been aimed at addressing the processes of deterioration suffered by different types of cultural heritage sites. Good examples of these Plans are The Spanish National Plan for Preventive Conservation, approved in 2011, and the National Plan for Emergencies and Risk Management in Cultural Heritage, sanctioned in 2015. The latter was born in response to a need expressed on May 11, 2011 after the earthquake that struck the town of Lorca, which has proven to be a turning point in the management of heritage sites in Spain. Proof of this is that most of the Autonomous Communities have created Emergency Groups in Cultural Heritage that represent an important commitment to heritage and early warning systems.

The National Plan of Preventive Conservation has the goal of developing a strategy for the conservation of cultural heritage through systematic work that identifies, assesses, detects, and controls risks over cultural properties. Consequently, their deterioration or loss and the need to undertake more costly and drastic measures are avoided. In relation to these interests, and according to the Spanish Land Law of 2008, risk maps acquire great relevance. These are created with the purpose of knowing which agents are involved and also the risks that cause the deterioration, in order to assess them and define the priorities for their monitoring and control. In addition, the National Plan for Emergencies and Risk Management in Cultural Heritage aims to design measures and procedures for the protection of cultural heritage in the face of the possibility of a natural catastrophe. It identifies as well the phenomena and establishes an action methodology to minimize the damage that could occur. In addition, it defines the concept of "preventive emergency" as the way of preventing a situation of risk that may affect the integrity of the cultural heritage.

Both plans highlight the need for prevention and, consequently, the development of methodologies that allow us to know the degree of vulnerability of each territory in order to avoid or minimize the effects of catastrophes. A need shared by organizations such as UNESCO and ICOMOS and which up until now had not corresponded to real actions. For this reason, the authors considered the need to design a special base methodology. A spatially based methodology makes it possible to identify different degrees of vulnerability on the territory if different risk factors occur in areas with cultural heritage sites, areas of interest for management and protection of cultural heritage. The subject of this study arose because of these needs and is presented in the Master's Thesis "Prevention of risks in the Historical Heritage Site of Lorca in the face of Natural Disasters" as part of Master in Geographic Information Technologies of the Complutense University of Madrid.

This methodology is designed with GIS that, due to its characteristics, are a fundamental tool since they facilitate the handling of information, consultation, analysis, visualization, and generation of data (Mínguez García and Capdevila Montes 2016). In addition, these systems allow the implementation of more information and the capacity to analyze it quickly, which allows for evaluating and diagnosing with great speed.

The work has focused on the municipality of Lorca because of the symbolism offered by a place that has suffered a major earthquake with significant human, social, and economic implications. Also for being, since then, a pioneer in prevention and intervention projects on a European level. But the methodology presented here can be extrapolated to other places, regardless of their location, geographic, and heritage characteristics. This paper presents a first methodological approach centered on the municipality of Lorca, although it can be applied to other places. It is of utmost importance to know the different degrees of vulnerability to natural risks of a site and how to relate them to their cultural heritage. It is useful because it helps the different stakeholders which are the most vulnerable to different types of risks. This allows us to establish prevention strategies and even correct the intervention needed in the event of the occurrence of a natural disaster.

2.2 Literature Review

2.2.1 Definitions

Nowadays, vocabulary from other areas of work has been incorporated into the heritage sites management and it requires precision in its definition. Natural hazards, catastrophe, natural disasters, threats and vulnerability, address different and complementary issues, although in many cases they are used as synonyms.

Natural risks refer to the probability that a certain physical phenomenon of natural origin will happen (Ruiz Pérez 2011), which can generate a series of diverse losses in a period of time. Precisely, the catastrophe is the effect that causes an extraordinary natural phenomenon on a territory. It is considered a disaster if the magnitude of the natural episode causes an interruption of the normal functioning of daily life, producing impacts and losses (Gil Olcina and Olcina Cantos 2017).

Different authors suggest that the risk is the result of the combination of other factors. Therefore, according to Francisco Ayala, it depends on: hazard level, exposure, and vulnerability (Ayala-Carcedo 1990). On the other hand, the United Nations Office for Disaster Risk Reduction (UNISDR) defines risk as "the combination of the probability of an event occurring and its negative consequences" (UNISDR 2009: 29). This idea is also assumed by UNESCO, which defends that natural risks are the result of threat and vulnerability; being the threat the phenomenon that has the capacity to generate damages and vulnerability the intrinsic susceptibility of a place, that is, the degree to which that event can affect the population (Rangel-Buitrago and Posada-Posada 2013).

Therefore, natural hazards are dangerous phenomena for the environment and the World Meteorological Organization establishes a classification according to the disasters that they may cause. Among them are those of meteorological, geological, astrophysical, biological, human origin or climate change nature. While vulnerability refers to the internal characteristics of a population, in a way that unites physical and social factors.

Therefore, risks are a problem that cannot be eliminated, since currently there is no capacity to mitigate threats. However, it is possible to control or reduce vulnerability, through what is called risk management. The importance of this fact has led to increasingly higher incidence of research on vulnerability to risks, which aim to recognize the different degrees of impact of each catastrophe in order to reduce them (Ruiz Pérez 2011).

2.2.2 Cultural Heritage and Natural Risk

There has been an increase in the number of disasters around the world in recent years which can be attributed to two causes: (i) The increase in exposure of the population (construction in unsuitable places, deterioration of the ecosystem, etc.)

and (ii) Effects of climate change that have increased the frequency and intensity of meteorological phenomena (UNISDR 2009; Olcina 2009). This generates important human, economic, and patrimonial losses. The latter are not included in the statistics due to their difficult quantification and are only considered in economic terms and not social (identity, social cohesion, sustainable development, and resilience) or functional (change of uses). More specifically, they are quantified considering a Replacement Rate, that is, what it would cost to return the asset to its pre-disaster state (García Erviti et al. 2014).

The economic losses (direct and indirect) derived from the decline in assets are very important, which is why the responsible institutions show concern and why their management is an important challenge. In 1983, UNESCO presented at the 22nd General Conference, held in Paris, the desirability of approving an international instrument on the protection of the Cultural Heritage against natural catastrophes and their consequences. The so-called "risk management" begins to arise in the Brundland Report which highlights the importance of risk assessment. It correctly predicted already in 1987 that these would be greater in the future as it has been later demonstrated. Along these lines, the United Nations Office for Disaster Risk Reduction (UNISDR) was created in 1999 to oversee the International Strategy for Disaster Reduction. After that, initiatives focused on risk management of cultural heritage emerged, in which UNESCO, ICOMOS, ICCROM, and ICOM collaborated and which resulted in meetings, training, and awareness campaigns, conferences, and publications (Stovel 1998; Jorquera 2017). One of the most important initiatives was the creation, in 1996, of the International Committee Blue Shield (ICBS) that aims to "work to protect the world's cultural heritage threatened by wars and natural disasters" and the Strategy for Risk Reduction at World Heritage Properties, adopted by UNESCO in 2007.

Currently, risk management in cultural heritage is considered as a global plan that involves and coordinates all stakeholders involved (administration, owners, civil society, and military emergency unit in the Spanish case). It entails an important change in the management of cultural heritage, giving less importance to restoration and recovery and focusing more on the prevention and mitigation of the risk (Jorquera 2017). In addition, it must cover three phases of action: before (prevention), during and after the disaster. In this sense, new entities are being created at the national level in Spain, as the Emergency Groups in Cultural Heritage, and at the international level, as the European Civil Protection and Humanitarian Aid Operations, which has demonstrated its interest and sensitivity with the cultural heritage by organizing in 2017 an Advisory Mission with European experts to help the Mexican government with the recovery of cultural heritage.

Despite the institutional and media interest, there are still few scientific publications on this subject (Wu et al. 2014; Wang 2015). Some research and papers focused on specific heritage sites are worth mentioning, such as the one that studies minor or vernacular heritage (Jorquera 2017), which is especially vulnerable due to its physical characteristics (construction techniques and materials), due to the functions they perform and their ownership, normally private and linked to small owners with few resources.

It also begins to be present in theses and final projects of master degrees from different disciplines such as Architecture (Ortiz Calderón 2014) or Geography. In all of them, the GIS acquires great relevance and becomes the key element to be able to interpret, map, and define actions.

2.3 Research Design: Methods and Data

2.3.1 Study Area

Lorca is a town located in the south of the Region of Murcia, in the Southeast of the Iberian Peninsula (Fig. 2.1). With an area of 1,676 km^2 and a population of 91,730 inhabitants, most of its economy is based on agriculture, this activity occupies an important part of its surface.

It is located in an area considered at risk, essentially for two reasons: (1) Its proximity to the contact zone of the European and African plates and (2) Because it is in an area that is periodically affected by the meteorological phenomenon of isolated depression in high atmospheric levels (cold air pool), known in Spain as a

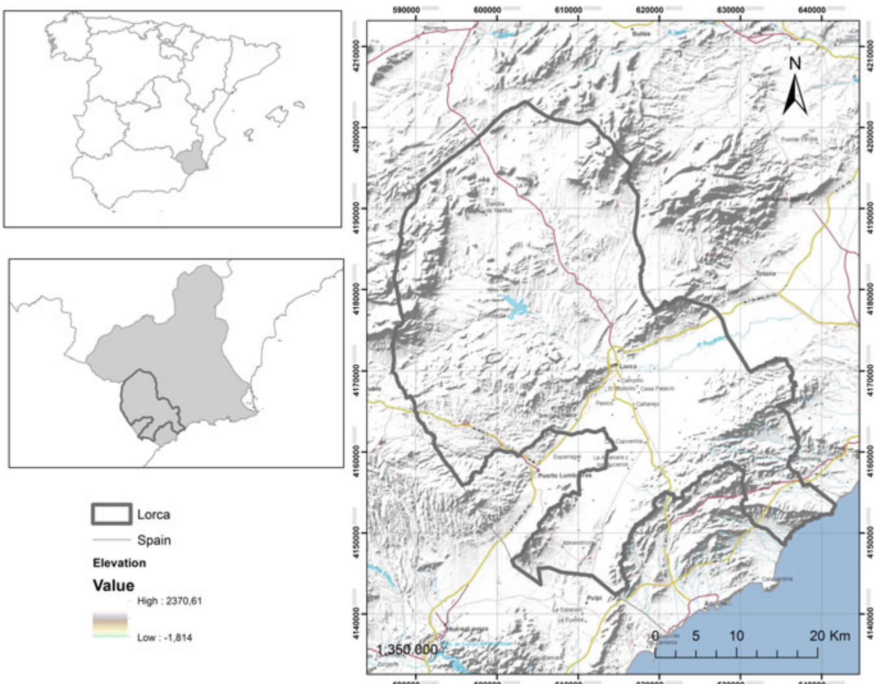

Fig. 2.1 Location of the borders of Lorca within the Spanish and regional context

cold drop. Also, according to the European Spatial Planning Observatory Network (ESPON), in 2013, the Region of Murcia was shown to be highly vulnerable to climate, a consequence of the potential impacts of climate change and its economic capacity to adapt to them.

Lorca preserves evidence from the Paleolithic that show that it is an area that has been populated since then. This has led to the creation of an outstanding and varied heritage, which has been conserved and hidden thanks to the strong sedimentation of the region. The cultural heritage of Lorca is composed of 394 archeological sites (from different stages: from the Paleolithic to modern times) and 273 buildings of cultural significance. The caves with Rock Art are of special importance and were included in the World Heritage List in 1998, within the nomination "Rock Art of the Mediterranean Basin on the Iberian Peninsula".

On May 11, 2011, the town was affected by several earthquakes of magnitude 5.2 and 4.6 MW and intensity VI according to the EMS, which were followed by a series of aftershocks. They affected 80% of the buildings in the urban center; with a total of 260 buildings declared to be unsalvageable due to the structural damage they suffered (González López 2016). At that time, a management and organization system was put in place which coordinated the work of the City Council, the General Office of Cultural Assets of the Region of Murcia, the Civil Protection force, as well as the Emergency and Risk Management Unit under the Institute of Cultural Heritage of Spain (IPCE), which belongs to the General Directorate of Fine Arts and Cultural Assets of the Ministry of Culture. This system had three objectives: the evaluation of buildings to determine habitability; the adoption of security measures derived from the poor state of the properties and the restoration of basic services (García Martínez 2016; Muñoz Cosme 2016). For this purpose, the cartography with the urban classification of the current Municipal General Plan was taken as a basis and some cards were drawn up indicating the state of each building and its characteristics through color codes. This process revealed the discrepancies between the different competent institutions in the emergency situations and, at the same time, it made the need to establish a specific definition for the concept of "emergency" evident (García Martínez 2016).

Afterwards, the Master Plan for the Recovery of the Cultural Heritage of Lorca was drafted and approved thanks to the initiative of the Emergency and Risk Management Unit of the Institute of Cultural Heritage of Spain. This document, considered as an international benchmark, had the objective to define the intervention methodology that would allow an effective recovery of the affected cultural heritage sites (Barceló de Torres et al. 2016). It shows the importance of coordination between stakeholders and establishes a methodology that guides the decision-making and that allows to prioritize.

2.3.2 Design of the Project and Data Preprocessing

As it has been pointed out in the Literature review section of this paper, the effects of natural risks on cultural heritage sites are very costly in human lives as well as economically, although up to now it has not been a topic that it has been frequently addressed by researchers. This paper presents a first methodological approach centered on the municipality of Lorca, although it can be extrapolated to other places. Its objective is to establish different degrees of vulnerability to natural risks and relate them to their cultural heritage. In this way, it is determined which elements are exposed to the different types of risks in order to determine which ones require more attention. Therefore, the secondary objectives of this work are: (i) To calculate the Vulnerability by Exposure as a consequence of the Territorial exposure and the Value of the territory; (ii) Geo-localize heritage sites according to different categories and (iii) Map of the results obtained.

In order to analyze all the heritage sites, we have worked with two scales: one territorial and one urban, limited to the so-called "Sector II" within the Special Protection and Rehabilitation Plan (PEPRI according to local laws). These two scales are based on the type of data available, the type of analysis that will be carried out and the level of detail associated with the two previous aspects.

For this purpose, the first parameter calculated is the Territorial Vulnerability by Exposure, which considers the exposure of the territory to certain phenomena and the value that said territory has linked to the heritage it contains. To this end, an adaptation of the usual Integrated Territorial Vulnerability formula has been made, which does not include social vulnerability (Ruiz Pérez 2011):

$$\text{Territorial vulnerability by Exposure} = \text{Territorial exposure} * \text{Value of the territory}$$

Consequently, by means of a series of analyses and maps made with the Arc Map 10.4.1 program and displayed below, the distribution of the exposure will be shown, where the declared sites are located and the relationship that exists between them, as well as the degree of vulnerability of each asset in the face of different threats. This information will be useful in order to establish management and intervention measures that reduce vulnerability and, accordingly, it relates the catalogue data to different natural risks.

The Territorial exposure is calculated through a Multi-criteria evaluation and it is expressed as the probability of an event happening. The result is presented on a scale with a maximum value of 100 and a minimum of 0. This is defined by three types of threats: hydro-meteorological, geological, and biological. In this paper, we have analyzed the threats corresponding to the first two: exposure to floods, earthquakes and, as one of its consequences, also to landslides. With all this information, a series of exposure maps have been created.

- Flood exposure. The Guadalentín river flows through the town of Lorca with a very low average flow of 0.1 m^3/s, except in conditions of isolated depression in upper atmospheric levels (cold air pool), when it increases remarkably, even reaching in 1,899–2,000 m^3/s like its tributaries, usually dry. Due to this hydro-meteorological phenomenon, the watercourses of the entire municipality have been obtained from a Hydrographic Model created on the Digital Terrain Model-DEM. In addition to this, basins have been found and the flood index has been calculated, on a scale of 0–100 (Fig. 2.2).

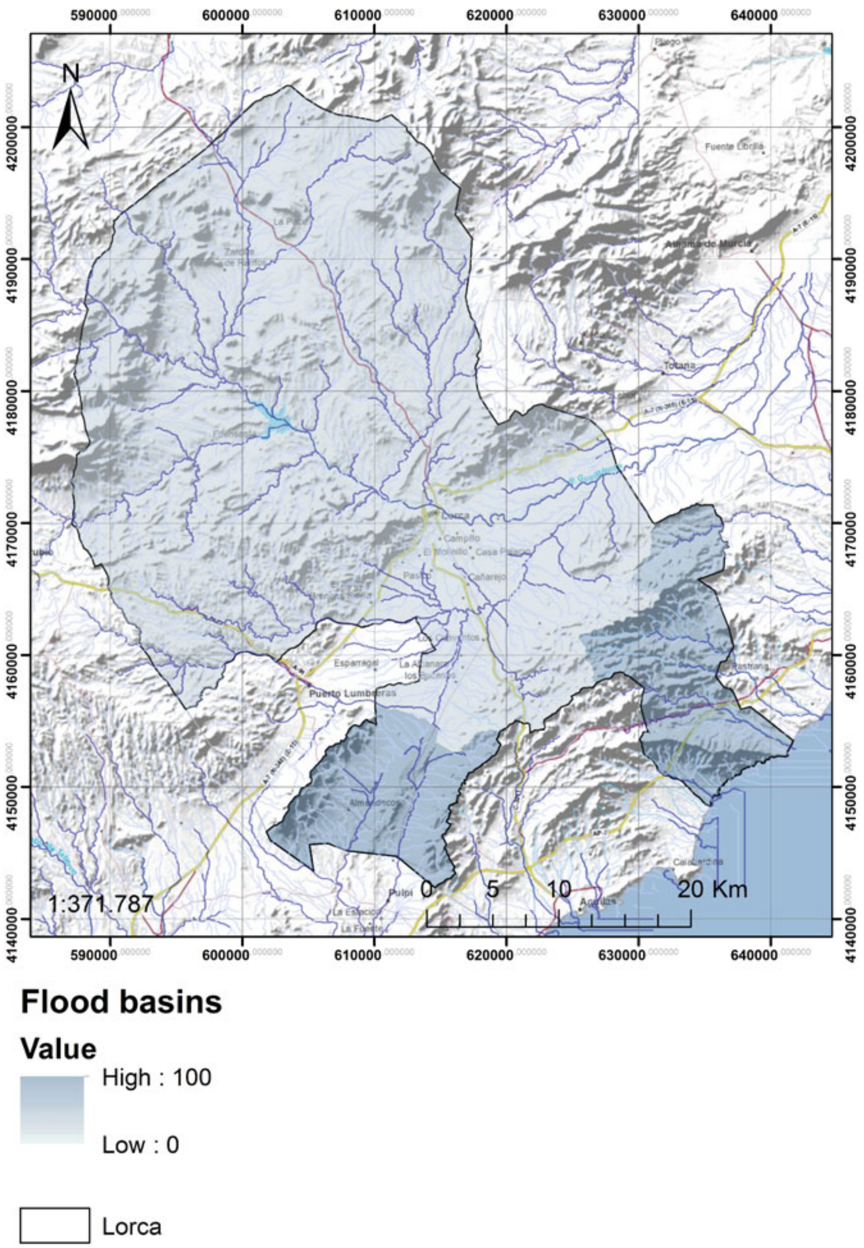

Fig. 2.2 Degree of exposure to flood in Lorca

- Exposure to earthquakes. All events recorded from January 2011 to September 2017 in Lorca and neighboring towns have been taken into account in order to have a significant sample (Fig. 2.3). As the seismic activity is constant but not

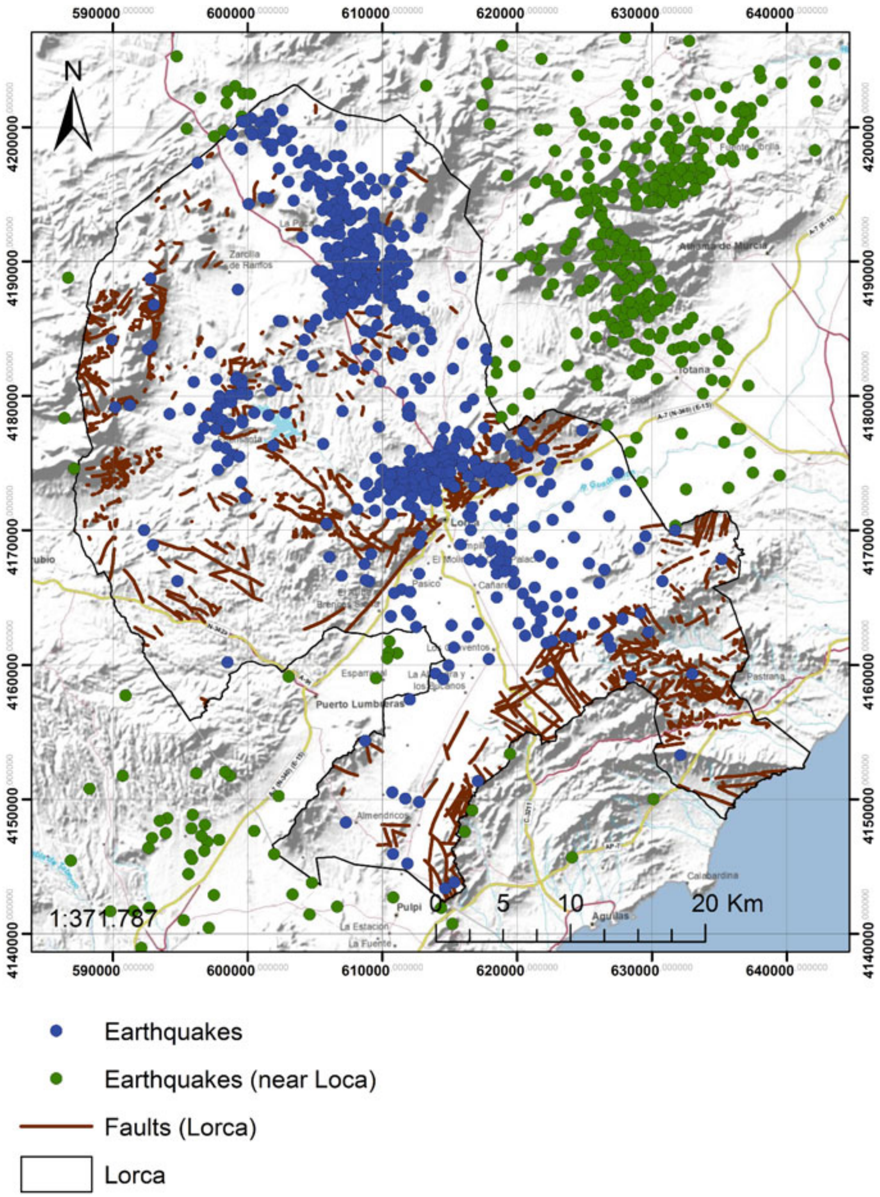

Fig. 2.3 Location of earthquakes and degree of exposure to earthquakes in Lorca

very high, no restrictions have been applied. To identify the areas of greatest activity, the density of the events was considered according to their magnitude measured in MW (Fig. 2.4).

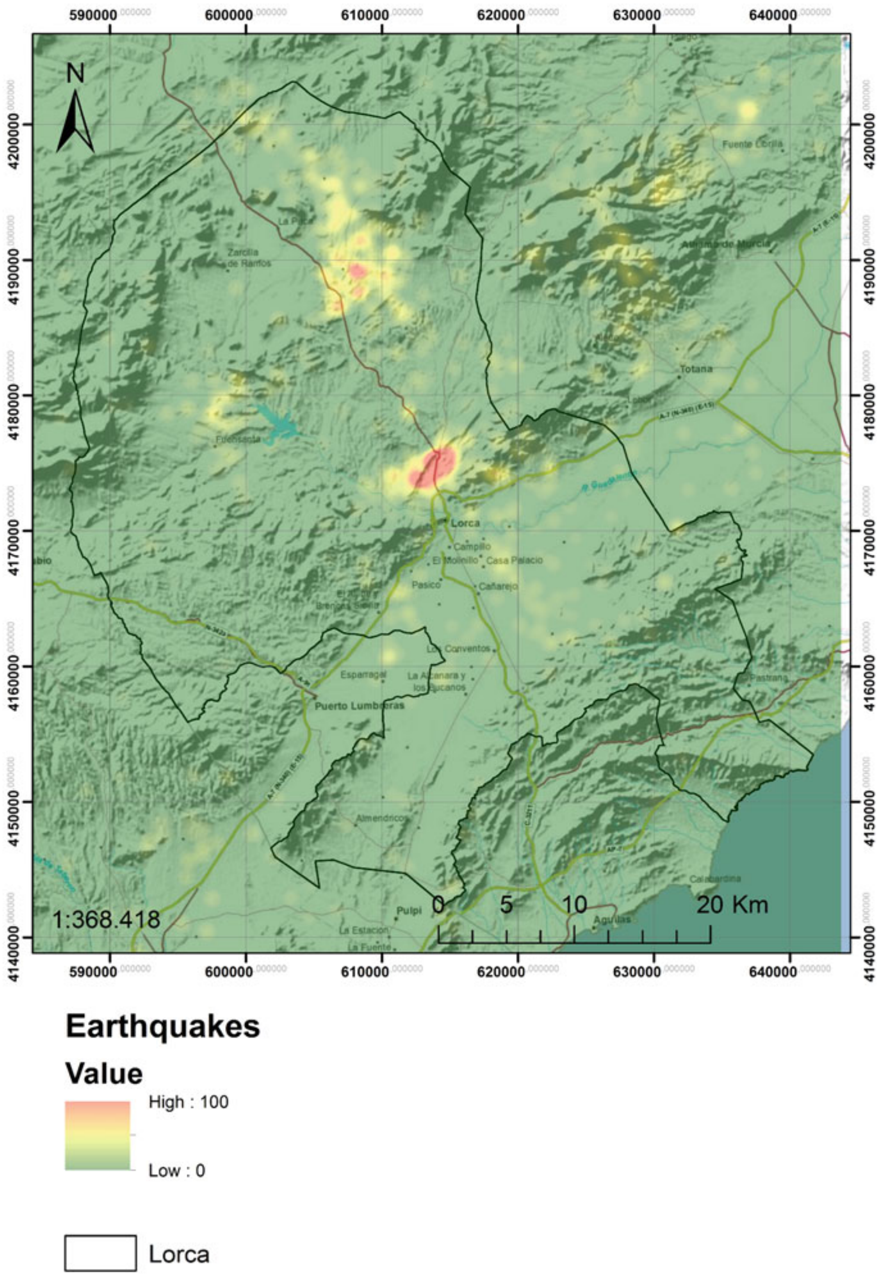

Fig. 2.4 Location of earthquakes and degree of exposure to earthquakes in Lorca

- Exposure to slope landslides. The experience in the terrain shows that this phenomenon is always a significant threat but more so in the case of Lorca, due to its topographic and geological characteristics. In addition, it is strongly exacerbated by floods and earthquakes, being one of their most important consequences. It poses a serious risk to human lives, so its stabilization requires very significant and expensive investments. This stabilization depends on the materials but also on the presence of patrimonial elements such as the archeological sites. To determine the risks associated with gravitational processes, a deterministic methodology based on mechanical processes has been used. Exposure to slope landslides is the result of the combination of three factors: slopes (obtained with the MDT), land uses (with information from Corine Landcover) and geological units. As in the previous cases, the result is expressed in an index with values from 0 to 100 (Fig. 2.5).

The value of the territory would depend on its geographic context and the characteristics of the place (Cardona 2003), in this case the type of heritage it contains. To carry out the assessment of the territory, the archeological sites scattered throughout the town and the buildings located within the urban space and defined in Sector II of the PEPRI have been studied independently.

In the case of the archeological sites, the time and function of them have been considered, as well as their level of protection and value, but other criteria such as the physical emergency could be included. A higher value has been granted to the most representative archeological sites due to their exclusivity. The awarded score ranges from 1 to 4:

1. It has been used for archeological sites for which data are not available.
2. For those whose function or period is indeterminate.
3. For those with functions/periods with a number of archeological sites higher than the average (8.4 sites in the case of the function and 15.78 in the case of the period).
4. For those whose function or period is poorly represented in the territory, with a number of archeological sites lower than the average.

After that, both criteria (function and period) have been added obtaining values between 2 and 8.

The legislation of the Region of Murcia establishes a series of classification categories, which are reflected in the catalogue of Sector II of the PEPRI, for the protection of cultural assets. In order to assess the different areas that make up Sector II, the following has been taken into account: the status of the plot, the qualification that they have in the catalogue and the degree of protection established. Accordingly, the following criteria have been applied:

State:
3 = Sites of Cultural Interest (BIC)
2 = "Protective environment", "Deforested plot—archeological evidences" and "Excavated archeological site"
1 = "Supervised deforestation" and "Excavated plot"
0 = Spaces that have no protection.

Catalogue Qualification:
3 = C: Included in the catalogue of protected goods of the PGOU (general land use plan) Catalogue
2 = CLA: Qualification A
1 = CLB: Qualification B
0 = No rating

Degree of protection (established in the PEPRI):
3 = Degree of protection 1
2 = Degree of protection 2
1 = Degree of protection 3
0 = Elements with no degree of protection

The value of the territory is expressed numerically, from 0 to 9, and is defined by the sum of the scores assigned to each element, according to the previous criteria (Fig. 2.6).

Finally, the Vulnerability by Exposure is the consequence of the relationship between the layers resulting from the Territorial Exposure and the Territorial Value. For this, an analysis has been carried out at two scales: territorial, to study the archeological sites, and urban, for the cultural sites in sector II.

In the case of archeological sites, territorial vulnerability has been assessed in the following way: The area of influence of the archeological sites has been calculated with the Thiessen polygons tool. The layer of Territorial Exposition has been broken into sections by converting it into a layer of points after which an intersection of said points was made.

In the case of Sector II, an attempt was made to use the same layer of "Territorial Exposition" points from the previous case, together with the digitized layer of Sector II that includes the "Territorial Value" data. But when calculating the intersection between them, the pixels of the "Territorial Exposition" are very large for the area of the sector, which caused problems when carrying out the intersection. To solve this, the Thiessen polygons of the "Territorial Exposition" have been calculated first and it was afterwards when the intersection of these two layers were made.

Since the result of these overlays gives us different exposure ratings for each archeological or heritage site in the Sector II, a summation with the different exposure values has been made in each case by means of a "Sumarice" and it was in that way that the average value was obtained with the use of the "Raster Calculator" tool.

2.4 Results and Discussion

After creating the different layers corresponding to the different indexes that make up the Territorial Exposition (floods, earthquakes and landslides), it has been contemplated that there are different ways to combine them to obtain the Territorial Exposition. The simplest way would be to add the results of each layer, using a linear sum (Fig. 2.7), but it has been observed that sometimes the results of each index are imprecise when considering their values globally. For example, if there are two very low values and another one is very high, it appears that the exposure is lower than it actually is when in fact there is a large exposure to one of the risks, but this fact is masked by the other values.

For this reason, other statistical methods of territorial analysis have been applied, specifically: the ordered weighted average and the maximum value of each cell (Figs. 2.8 and 2.9).

In the first one (weighted ordered averages), the two highest values for each cell have been obtained and weighted with 0.6 for the highest value and 0.4 for the second. In this way, those areas that are more vulnerable to one of the analyzed phenomena are identified more easily, since low values do not disguise them (Fig. 2.8). In the second method (maximum value) in each cell, the highest value of the three indexes is exclusively identified. Thus, the greatest exposure is reflected, but only for one of the three threats (Fig. 2.9).

To calculate the weighted ordered averages, we obtained the two highest values for each cell (between flood, fire, and earthquakes) and these were weighted with 0.6 for the highest value and 0.4 for the second highest. In this way, those areas that are more vulnerable to one of the analyzed phenomena are identified more easily, preventing the lowest values from being masked by the results (Fig. 2.8).

To apply the Maximum Values method, in each cell, the highest value is exclusively selected (floods, slope landslides or earthquakes). Thus, the greatest exposure is reflected but only to one of the three threats (Fig. 2.9).

With three models—linear sum, weighted averages, and maximum value—the vulnerability by exposure has been found. The results are similar and provide interesting information that may be useful for the management of cultural sites. With this, an independent analysis of each site has been made before each threat to know its degree of vulnerability. Consequently, in regard to the archeological sites, three main zones can be distinguished: one located in the center of the municipality that is affected mainly by earthquakes. Another one to the south that is related to the flood basins, which are areas where the water courses are near the mouth of the sea, where large quantities of materials could be dragged in and, finally, a northeast area of the town that could be also exposed because it is a mountainous area with a steeper slope. In relation to the sites located in these spaces, it should be noted that those of the prehistoric era are the most vulnerable due to their location and characteristics, followed by those from the medieval period, which although less numerous, are better preserved (Figs. 2.10, 2.11 and 2.12).

The areas with the highest vulnerability values are those that have a high valuation, such as Sites of Cultural Interest or the ones from the medieval era (Figs. 2.13, 2.14 and 2.15).

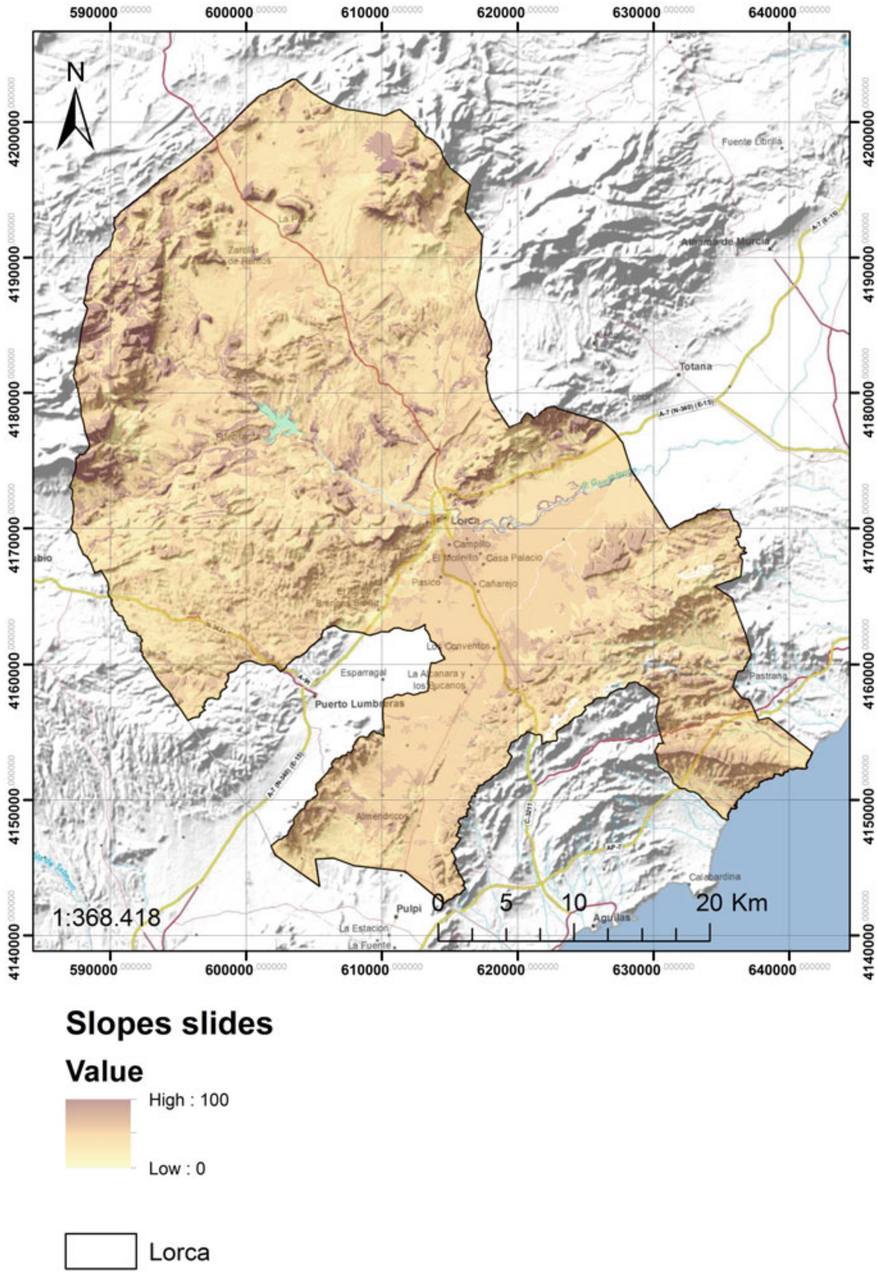

Fig. 2.5 Degree of exposure to slope landslides in Lorca

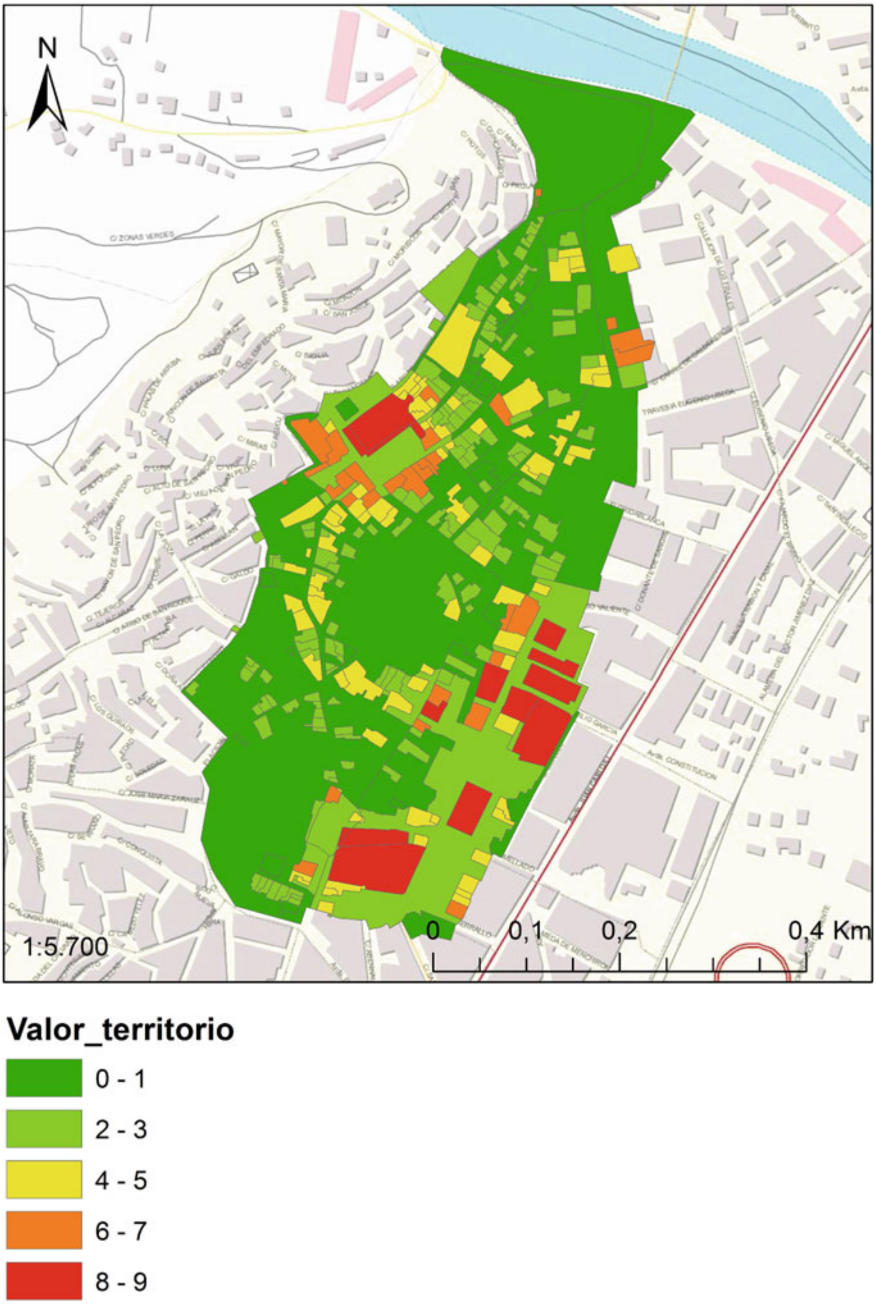

Fig. 2.6 Value of the territory in Sector II of the historic center of Lorca

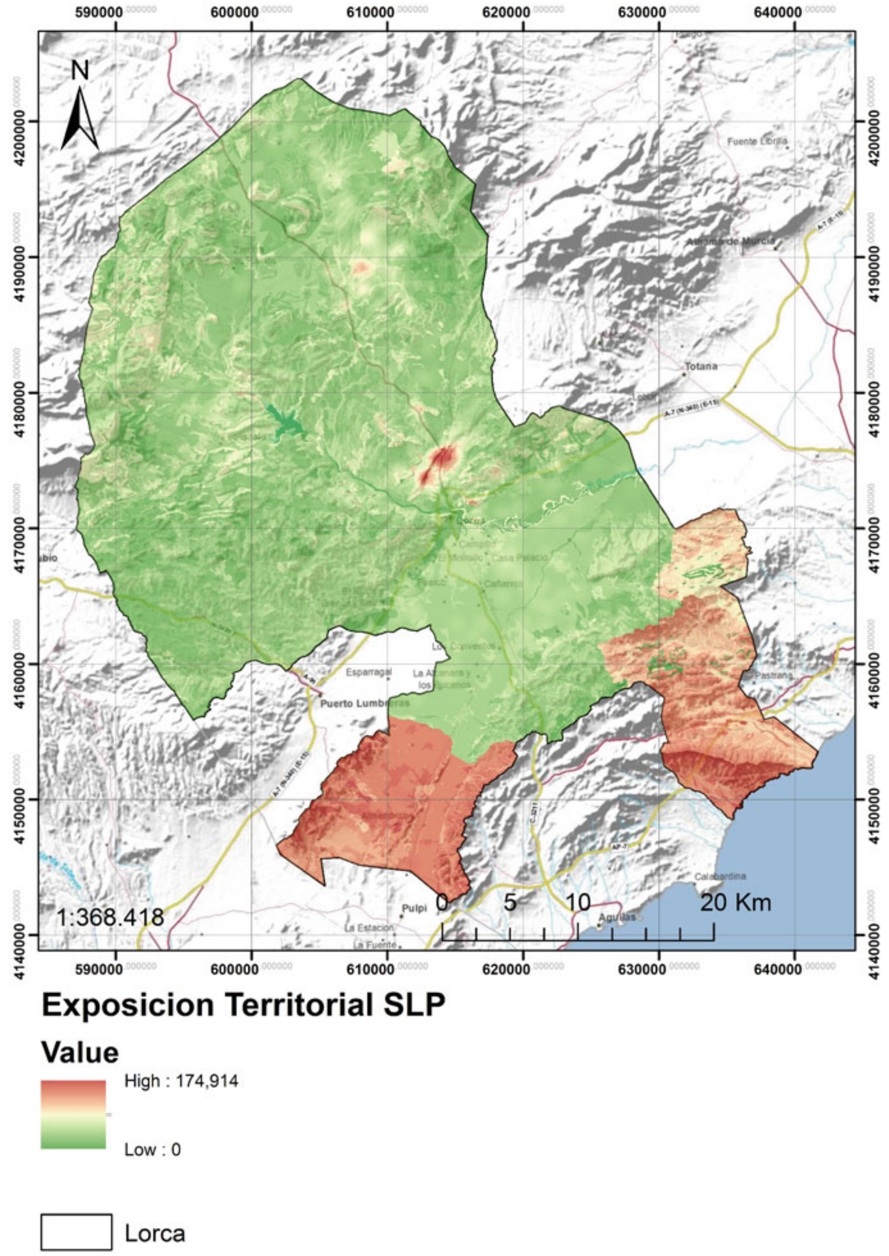

Fig. 2.7 Territorial exposure by means of linear sum

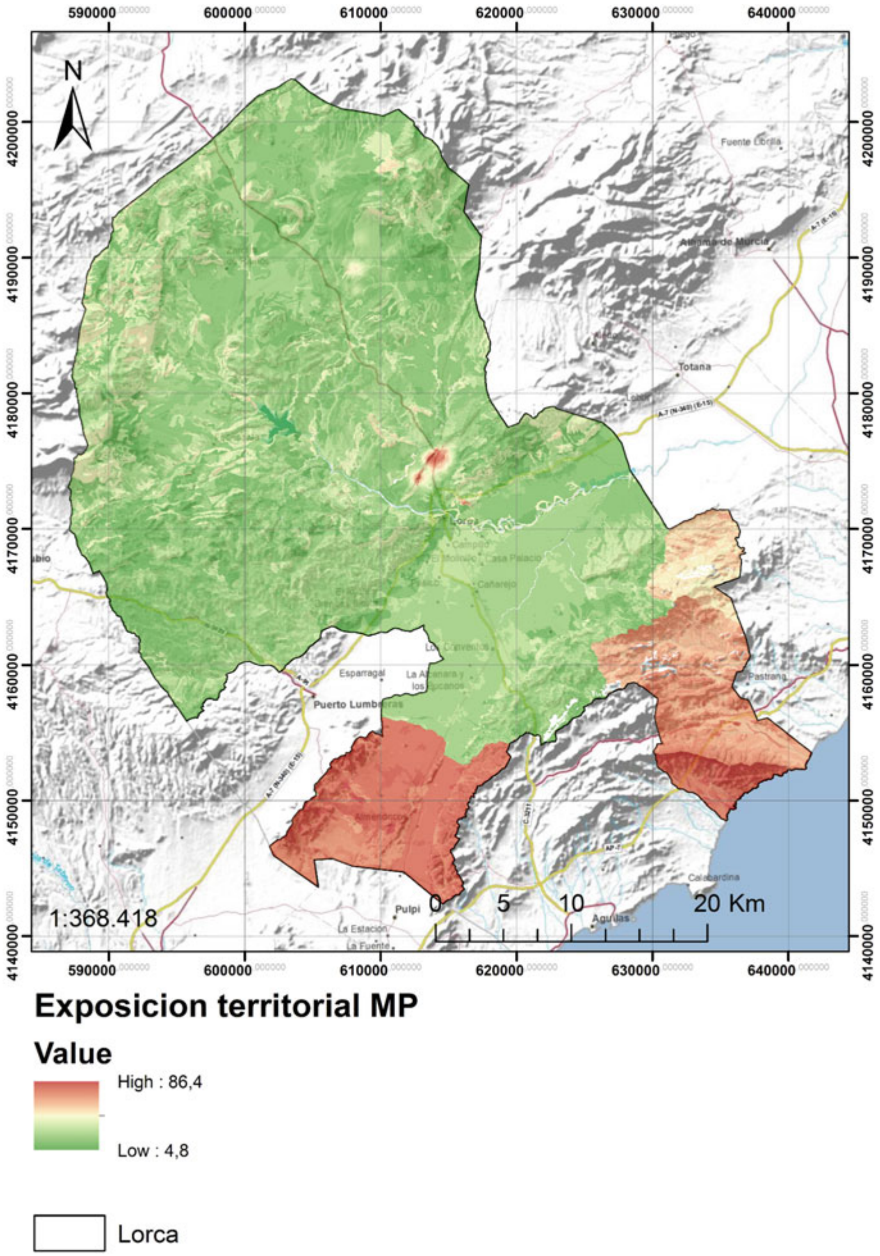

Fig. 2.8 Territorial exposure by weighted average ordered and by maximum value

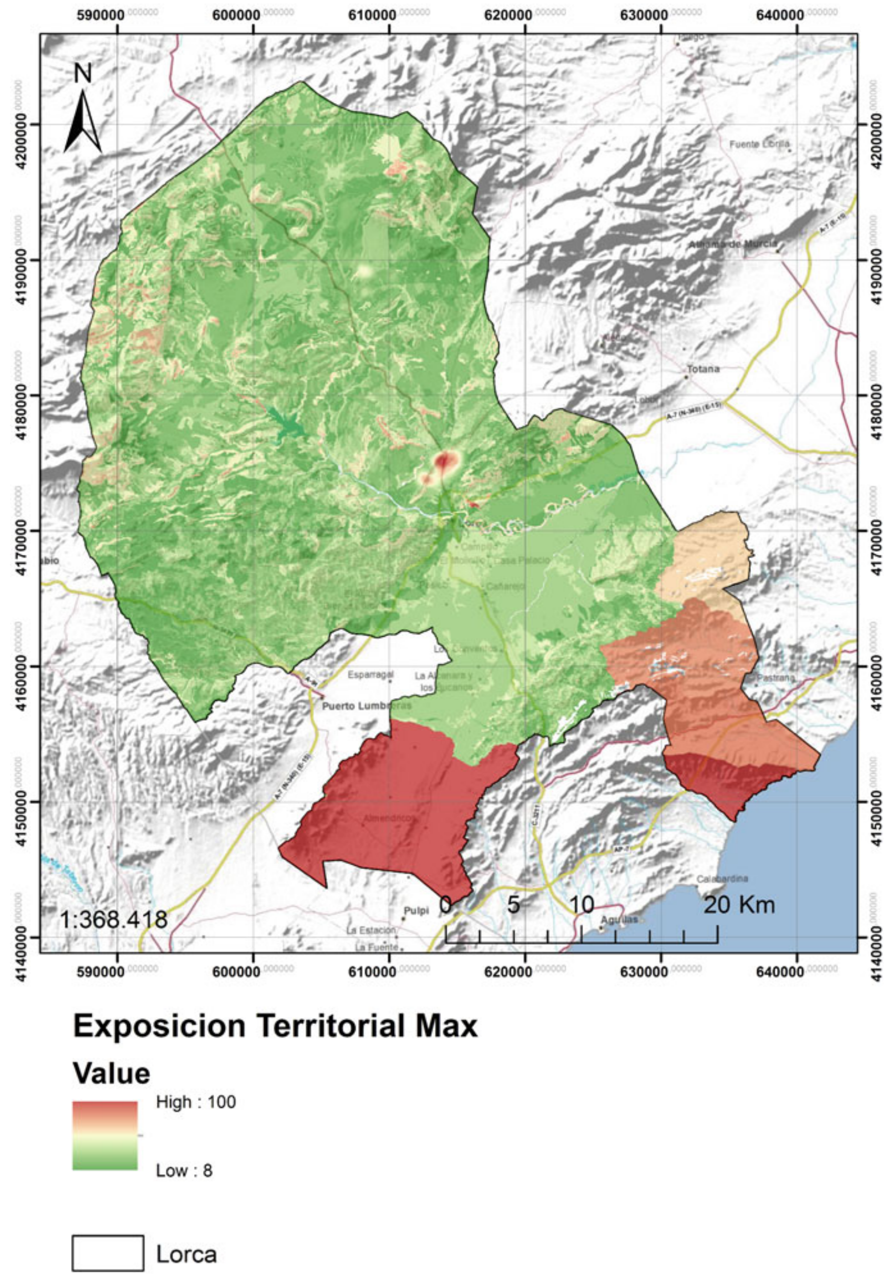

Fig. 2.9 Territorial exposure by weighted average ordered and by maximum value

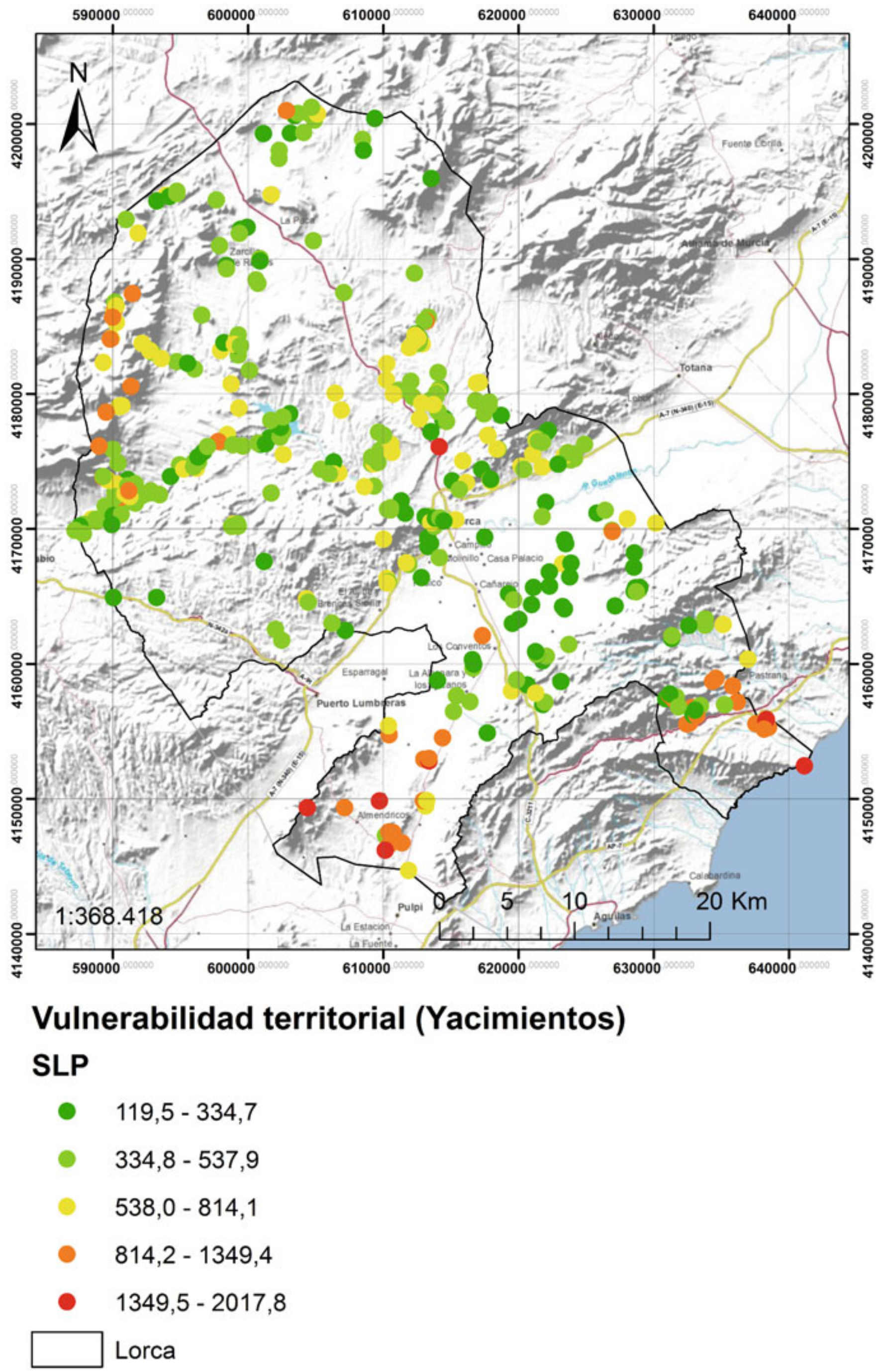

Fig. 2.10 Vulnerability by territorial exposure in archeological sites calculated by linear sum and weighted ordered averages

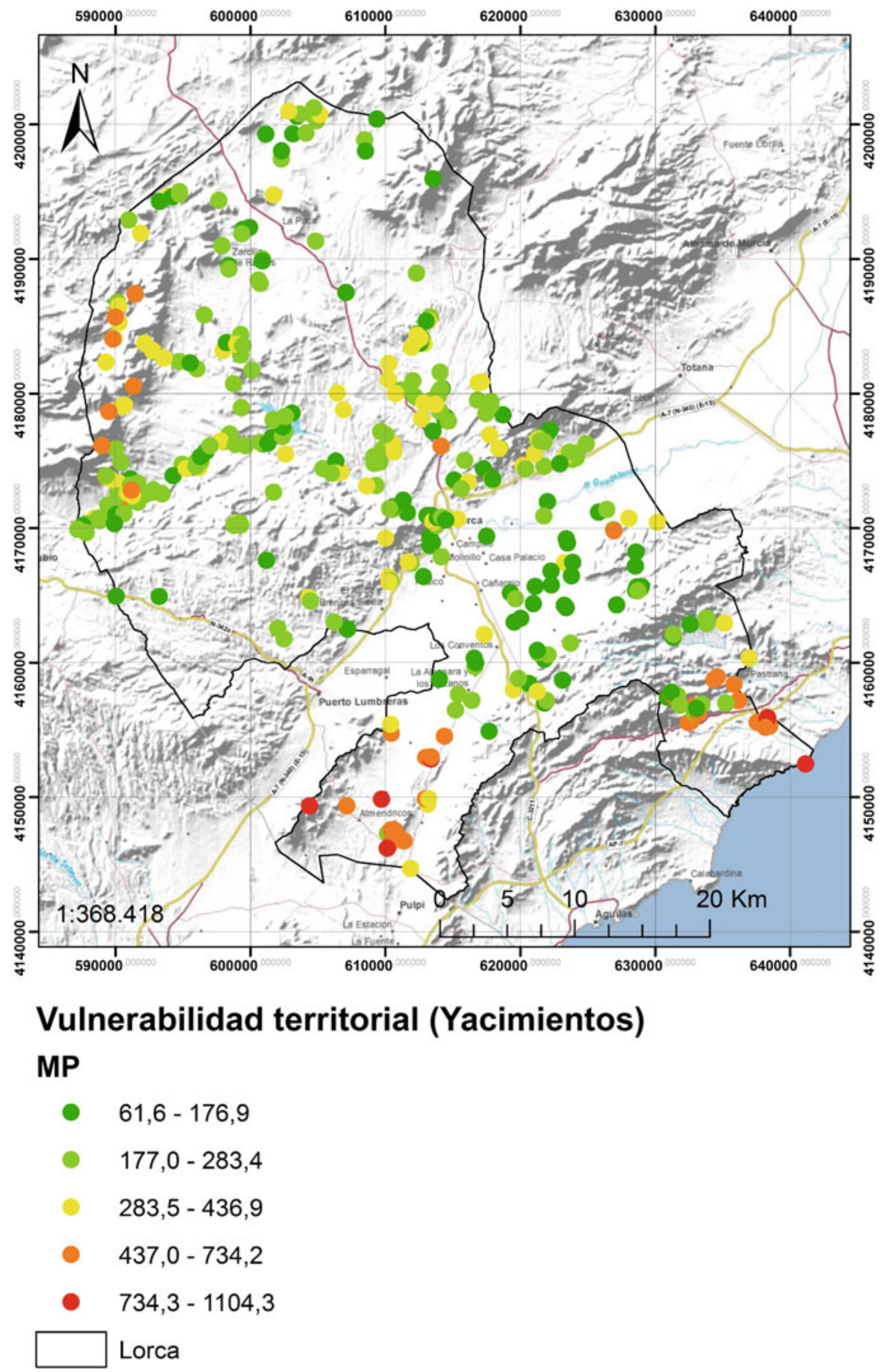

Fig. 2.11 Vulnerability by territorial exposure in archeological sites calculated by linear sum and weighted ordered averages

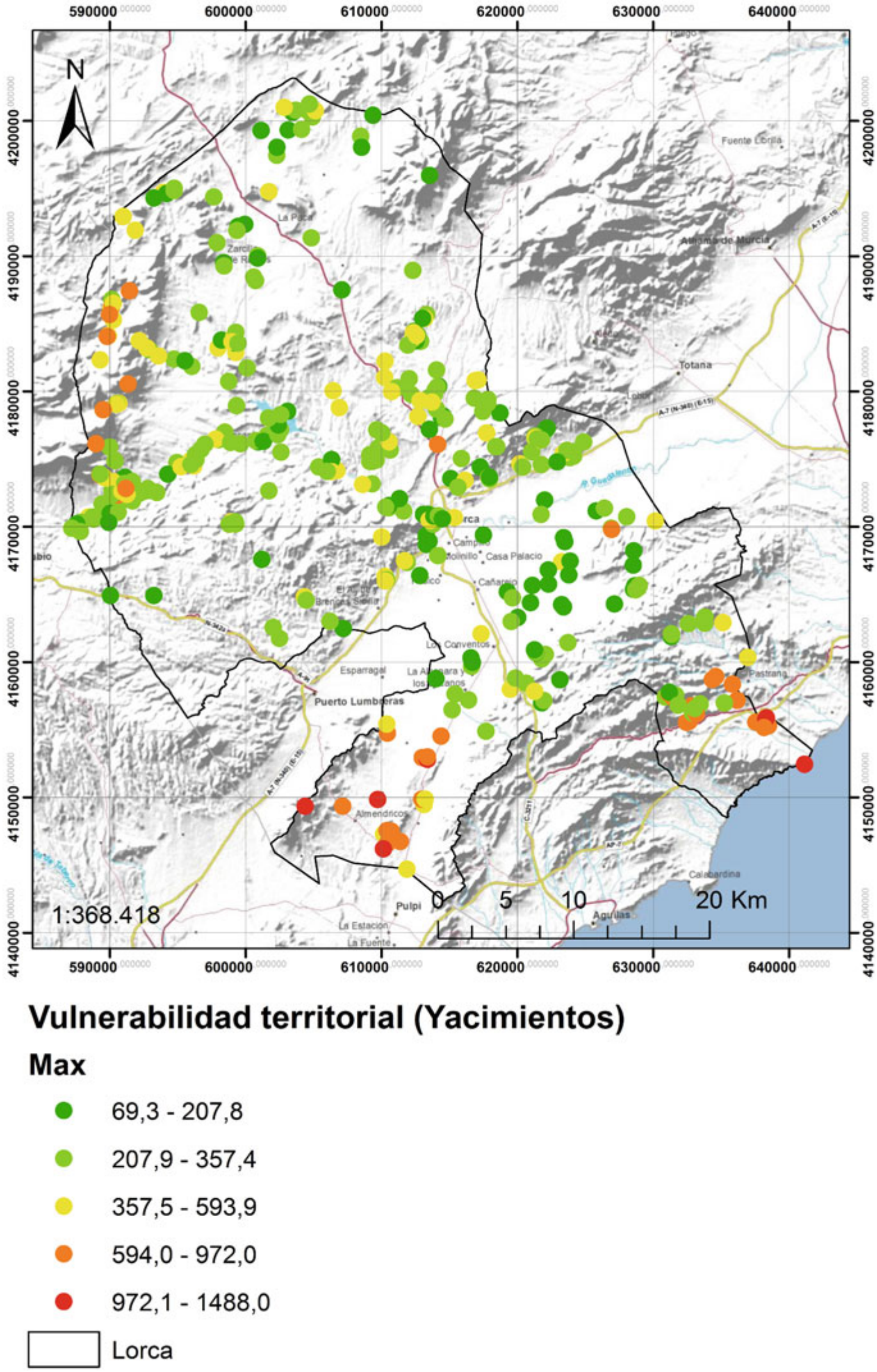

Fig. 2.12 Vulnerability due to territorial exposure in archeological sites through the maximum value

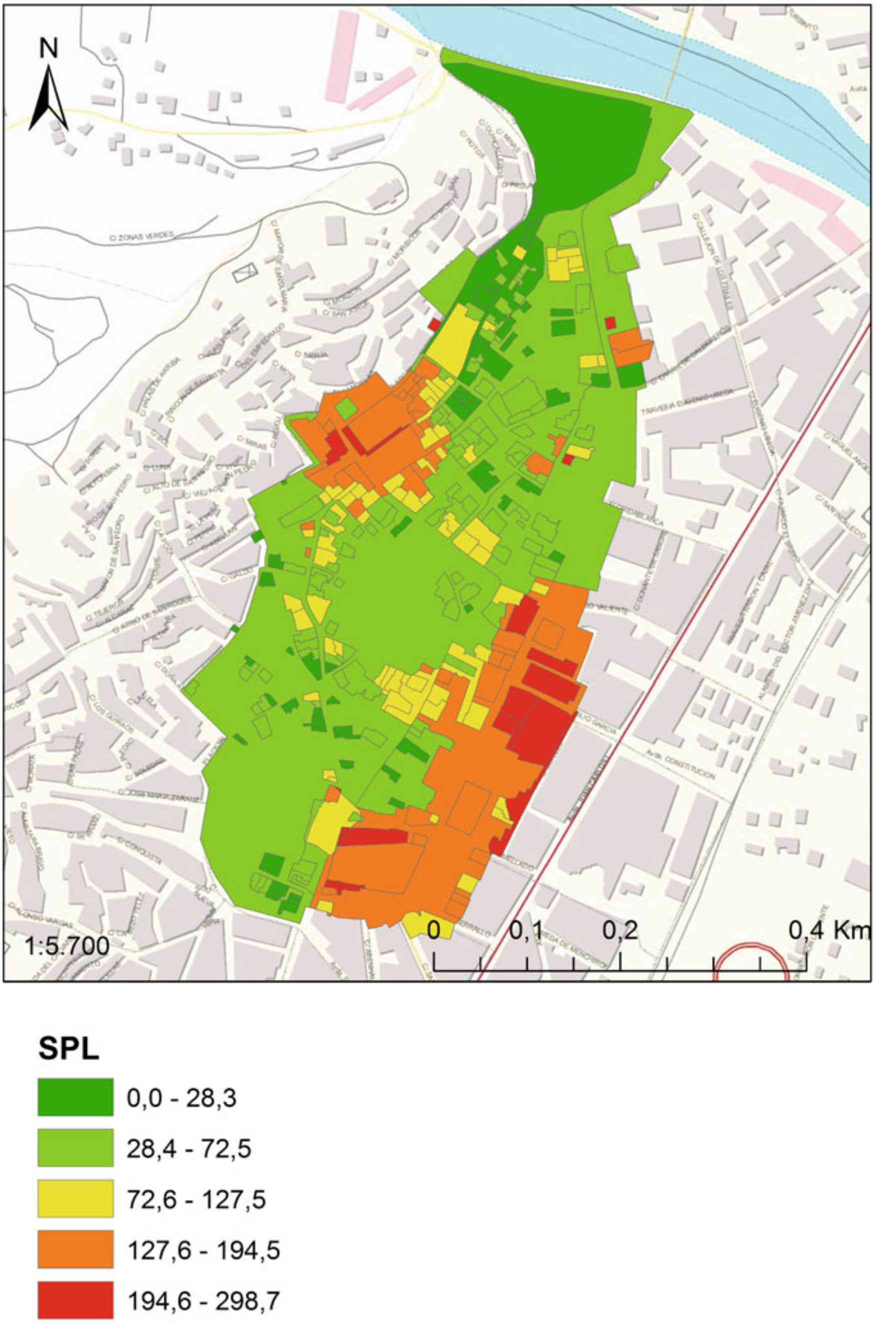

Fig. 2.13 Vulnerability due to exposure in Sector II through Linear Sum

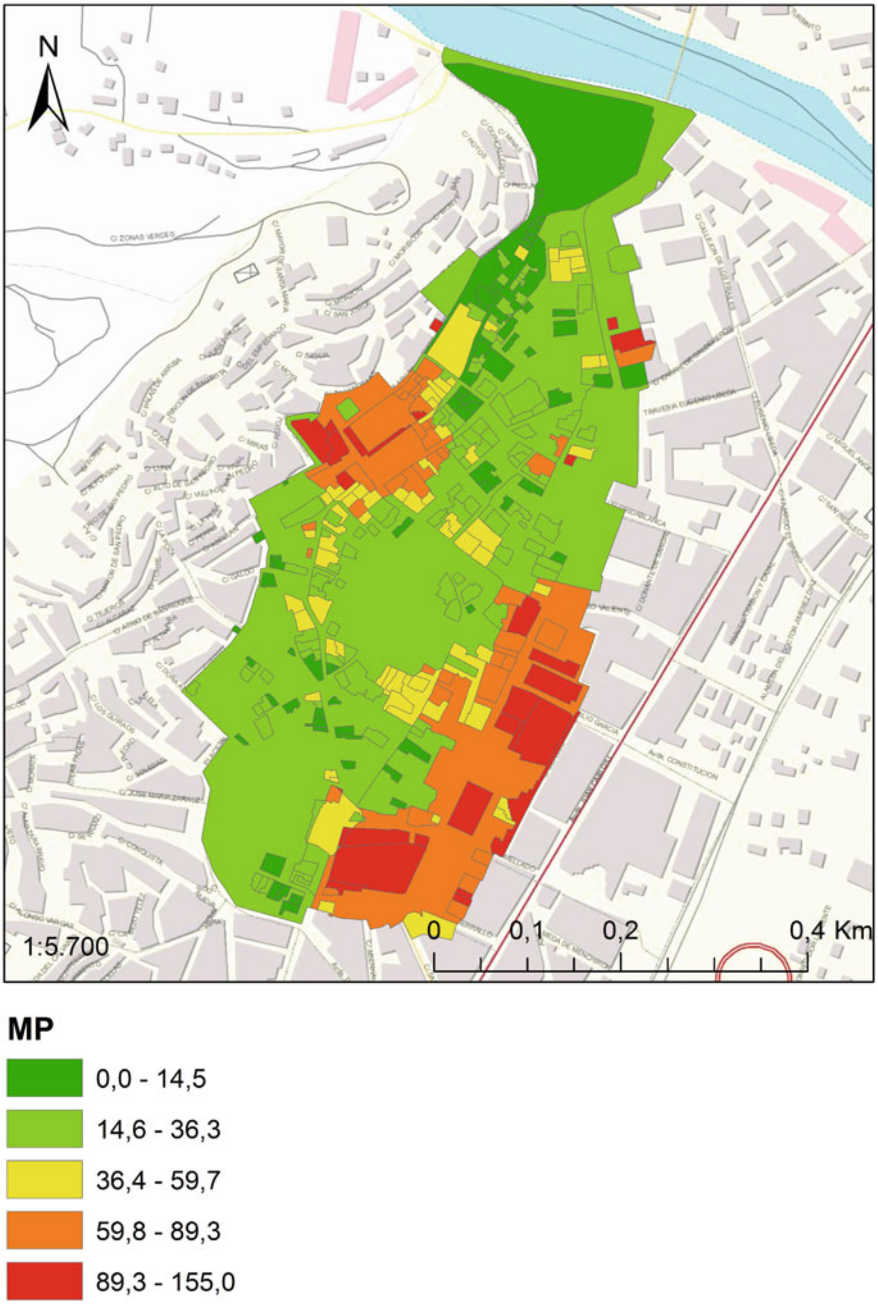

Fig. 2.14 Vulnerability by exposure in Sector II by ordered weighted averages and maximum value

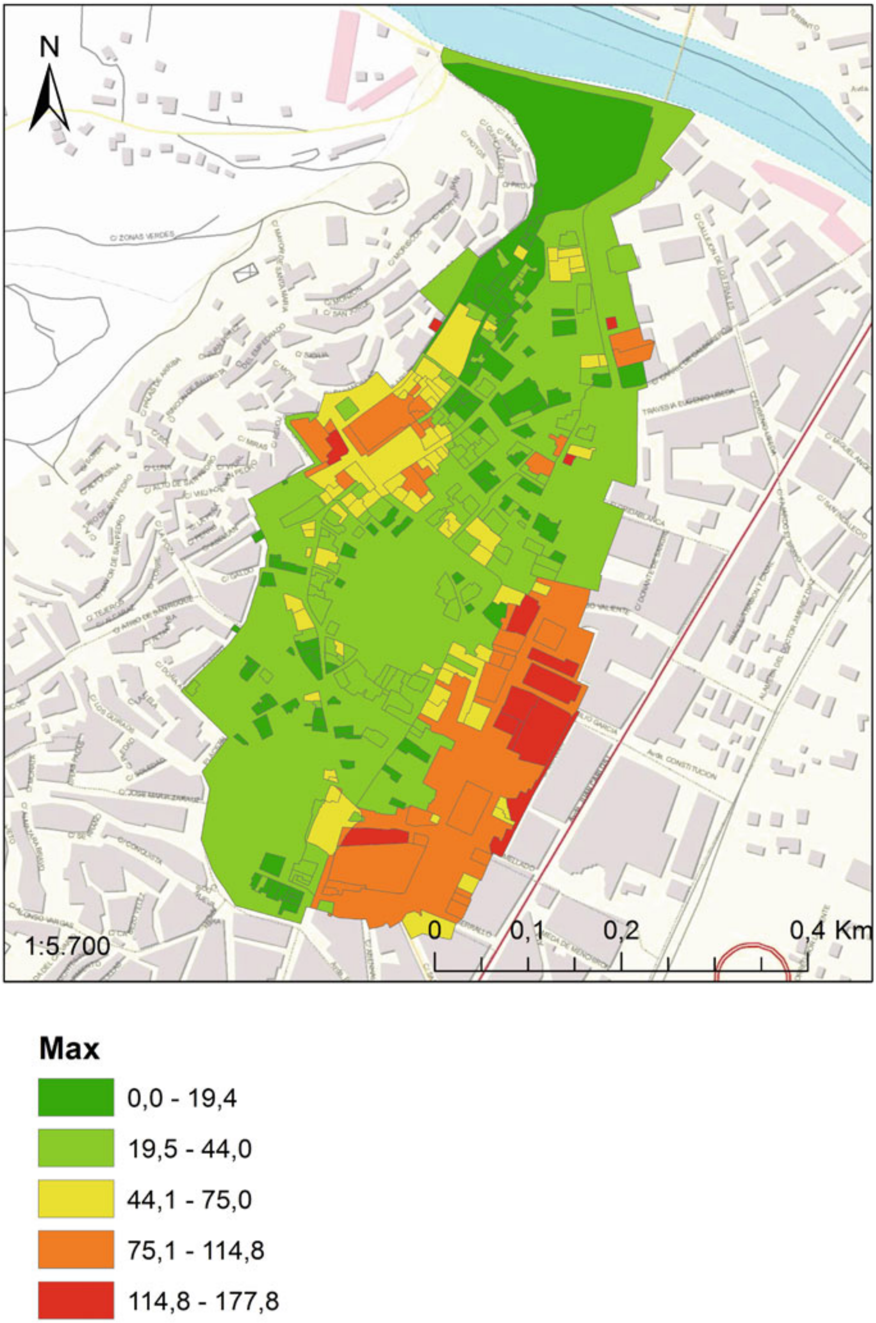

Fig. 2.15 Vulnerability by exposure in Sector II by ordered weighted averages and maximum value

2.5 Conclusions

There is a great awareness nowadays, both on the part of the public administration and on the part of individuals, of the need to protect their cultural heritage from possible threats.

One of the most significant threats, due to its frequency and destructive capacity, is natural risks. The relationship between cultural heritage and natural risks is a very broad topic that represents a great opportunity for researchers since knowledge and methodologies of action are still being developed.

The Geographic Information Systems allow the handling of large amounts of data, georeferenced and of great diversity (territorial, patrimonial, social, etc.). In addition to this, these systems allow the incorporation of more information as research progresses. Consequently, in a very simple and quick way, complex analyses can be made with great speed. And they also make it possible to quantify and establish measurements, which is very useful; especially for the government and other public institutions that, after a catastrophe, demand measurements to be able to make forecasts. Thus, methodologies such as the one presented in this paper are important for territorial management and, more specifically, for the protection of heritage sites. And it is necessary to emphasize that society values its heritage more and more as an essential part of its identity. In addition, this is an important element of social cohesion and is essential for the development of daily life, since we must not forget that cultural heritage is alive.

Although there are limitations in the research, such as the need to complement it with a more exhaustive fieldwork or the incorporation of social vulnerability which refers to those internal factors that are specific to the population, the benefits of this study are numerous. It is a methodology that can be extrapolated to other territories regardless of their geographical and geological characteristics. Knowledge and control of vulnerability make it possible to establish preventive measures that save human lives and economic resources since restoration or reconstruction are much more expensive. Therefore, the scope of this work is very broad and can be very useful for a large number of territories.

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Chapter 3
Using Geospatial Technologies in Mapping the Distribution and Quality of Ecosystems

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Abstract In the context of present environmental changes, human society is continuously looking for ways to evaluate the status of ecosystems and determine human-induced modifications on their structure and functionality. A clear overview of ecosystems is fundamental in choosing the appropriate measures in our search for sustainability and improving the quality of life. The aim of the chapter is therefore to underline how geography can respond to the need of mapping the distribution and quality of ecosystems. This is easily done by using geospatial technologies, helping to a better understanding of the relation between the spatial distribution and management of ecosystems. The chapter presents the main types of data required by geospatial technologies and the data sources for mapping ecosystems. Challenges in gathering reliable data are also presented besides various methods of overcoming the difficulties. There is a strong emphasis on differentiating the available geospatial technologies for mapping the distribution of ecosystems and for representing their quality. The use of different geospatial technologies in mapping the distribution and quality of specific ecosystems was highlighted through case studies of urban ecosystems, water bodies and forests. We also aimed to identify the causes that determined certain ecosystem approaches, and the potential of geospatial technologies in providing to geographers and other scholars the possibility to explore processes from

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the past, present, or modeling the future. As geographical assessments require a "cause and effect" approach, we aimed to emphasize how geospatial technologies are used in identifying the causes that determined certain planning policies, shaping the current geographical landscape, the effects of these policies, and the future outcomes of newly implemented or proposed planning policies. The current potential of geospatial technologies gives access to complex diachronic analysis, providing the geographers and other scholars the possibility to explore the various processes that occur in the geographical landscape. The chapter demonstrates how geography and geospatial technologies can help policy and decision makers, local administrations, or stakeholders evaluate the distribution and quality of specific ecosystems.

Keywords Geospatial technologies · Mapping · Ecosystems
Environmental changes

3.1 Introduction

Global and local ecosystems are profoundly being changed to cater the growing population and economic development. Technological evolution of human society finds its grounds in the permanent transformation and use of landscape, increasing living standard and comfort. Since the dawn of human society, ecosystems have been under continuous pressure. In this context, the assessment of the human-induced modifications in the structure and functionality of ecosystems is vital in the elaboration of subsequent planning policies, directed to environmental protection.

Policies and strategies were drawn to stop the natural ecosystem degradation. The most ambitious initiative is included in the Convention for Biological Diversity, which specifically refers to vulnerable ecosystems such as protected area, wetlands or aquatic ecosystems (CBD) (UN 1992). In the same direction act the EU Water Framework Directive and the 7th Environmental Action Plan (EC 2013). There are also numerous international projects aiming to conserve biodiversity and reduce habitat loss and ecosystem degradation.

Mapping the distribution and quality of ecosystems (often described by the amount and diversity of ecosystem services) lately represents one of the main focuses in science and policy on a global level (Roussel et al. 2017). Initiatives like IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) and MAES (Mapping and Assessment of Ecosystems and their Services) tried to draw a framework applicable at global, regional, and local level, but there are currently still many issues that must be overcome.

Considering the chosen scale, the spatial representation of ecosystems implies specific challenges and restrictions. For wider scales, continental or global, the mapping and evaluation of the ecosystems reside on the mainland use classes and large structural units, leaving out important ecological characteristics. Therefore, it is recommended to represent ecosystems more thoroughly (Blasi et al. 2017), considering the significant factors that produce discontinuities, properties of the environment (soil type, hydrographical basin), or different spatial relations (home range, species migration). The limits of ecosystems may be established by considering the place where a number of these discontinuities converge.

Ecosystem mapping is mandatory for land use planning, environmental impact assessment, and conservation as they demand spatial outcomes for proper decision-making (Ershov et al. 2016). Maps that represent the relevant ecosystem for the existence of a population will be totally different than maps showing the impact of human activities over the same ecosystem. Since ecosystems are dynamic entities, their morphological and structural evolution through time is meaningful. Land use planning and decision-making are greatly improved by more precise and accurate spatial data regarding ecosystems (Blasi et al. 2017).

Geospatial technologies provide the means to work with multiple layers of information, showing distinctive characteristics of the environment, everything being at the same time accurately represented in space. Contemporary geospatial technologies are extremely well suited to represent ecosystems in their high complexity, not only through simple models. In order to differentiate between ecosystems, we can use key criteria, such as the density of relations, but in practice, apparent homogeneity is a more adequate alternative. If multiple characteristics are to be used at the same time to delimitate the spatial extension of an ecosystem, geospatial technologies can manage information in different layers, representing landforms, soil's category, or vegetation groups but also to produce a composite map by joining the layers using different algorithms.

The chapter presents the main types of data required by geospatial technologies and the data sources for mapping ecosystems. We also provide different examples of how geospatial technologies could be used to emphasize specific features of ecosystems. We focused on emphasizing the differences that occur by using different geospatial techniques to assess similar features, the differences being dependent on the quality of raw data, or the processing solution used in the analysis.

3.2 Data Sources for Mapping Ecosystems

The input data for geospatial technologies are much diversified and may be provided by various sources, from remote sensing (imagery and data collected from space or airborne platforms) to databases created by specialists. The smartphone technology is proving to be a valuable tool for ecosystem data collection by the wide public through applications that use GPS to accurately map the information (Edsall et al. 2015). Data availability, accuracy, and resolution have greatly improved, and further progress is expected to satisfy increasing and more specific needs. Some of these sources provide data at a global scale, while others register detailed aspects of the ecosystems.

At the global level, the most widely used data are the ones provided by satellites systems. They have the advantage of spatial and temporal coverage; the images being generated at global level with a daily frequency. The most used sources for remote sensing are images produced by Landsat-MSS, TM, ETM+ and SPOT-HRV, Aster Terra (Turner 2010). The most important platform for this type of images is the US Geological Survey (https://earthexplorer.usgs.gov/). The main software solutions for image processing is ENVI 5.3, and ArcGis 10.x for spatial analysis. Raw satellite images should be processed through some filters to eliminate some geometrical distortions using software solutions such as ERDAS Imagine before being used for classification (Badar and Romshoo 2008).

For European land use and land change studies, the Corine Land Cover (CLC) database (available at http://www.copernicus.eu/) is widely used by researchers. As it records land cover type from 1990, 2000, 2006, and 2012, the database is a useful product in emphasizing landscape dynamics throughout the continent (Feranec et al. 2010, 2007). However, this dataset is not sensitive for changes that occur within an area of less than 25 ha as this is the minimum mapping unit. For the CLC 1990 and 2000, the satellite data were provided by LANDSAT-5, respectively LANDSAT-7 sensors and the proposed thematic accuracy of at most 85% was achieved only for the 2000 version. For 2006 and 2012 versions, satellite data were provided by SPOT 4/5 and IRS P6 LISS III respectively IRS P6 LISS III and RapidEye sensor and the thematic accuracy has not been checked yet. The Copernicus platform also offers a wide range of products designed for the analysis of specific ecosystems.

Besides the global and regional datasets there are national products that provide land use data generated either from military topographical maps or orthophoto maps. Often, these products are used to calibrate the global and regional datasets as they have a better resolution and accuracy (Pătru-Stupariu et al. 2015; Iojă et al. 2011).

For many years, the main challenge of geospatial data was related with resolution, since the products with 120, 60 or even 30 m resolution do not present enough detail to map distinct ecosystem features, like ecotones between different ecosystems (e.g., the shoreline, urban expansion in protected habitats). Currently, new technologies facilitated the acquisition of images with high spatial and spectral resolution and improved radiometric and temporal coverage. However, as Bishop et al. (2012) underline, sensor improvements rise issues related with data volume, storage capacity, memory and processing speeds, increased information variability, algorithm suitability, data integration, analysis, and visualization. Accuracy and effectiveness of data retrieved from online sources are other issues that permanently occur in spatial analysis. Some online platforms, like Open Street Map, are based on voluntary participation therefore the data quality is not fully validated.

3.3 Geospatial Technologies for Mapping the Distribution of Ecosystems

According to the American Association for the Advancement of Science (2017), geospatial technologies refer to a range of modern tools contributing to the geographic mapping and analysis of the Earth. The main categories of geospatial technologies are related with:

Remote Sensing—images and data which are collected from space or airborne cameras and sensor platforms and are subsequently processed to extract the distribution or quality of different ecosystems or elements like vegetation, water bodies or built areas (United States Geological Survey 2017).

Geographic Information System (GIS) represents an ensemble of software tools which can be used for mapping and analyzing data. The raw data processed through GIS solutions must be georeferenced which means every information has assigned a specific location on Earth.

Global Positioning System (GPS) is a global navigation satellite system owned by U.S. Department of Defense which provides geolocation (position on Earth) and time information for military and civil use. Currently, there operates another satellite system managed by the Russian Federation (GLONASS), while the European Union, China, and Japan are preparing to launch their own systems.

Internet Mapping Technologies comprise software programs like Google Earth and web features like Microsoft Virtual Earth which allow visualization and sharing of geospatial data.

The main characteristic of geospatial data is represented by the spatial reference information assigned to each location which can be represented by geographical coordinates, addresses or other types of spatial attributes.

Accurate and consistent mapping of the distribution of ecosystems must rely on proper definition and classification for the ecosystems themselves. The scope, time frame, and the scale of such classifications are also extremely important for the subsequent mapping of ecosystems distribution.

Scale is relevant when mapping the distribution of ecosystems from several perspectives. Classifications can be done either by subdivision (top-down approach) or by agglomeration (bottom-up approach). From a scale-based reasoning, maps can emphasize from the distribution of major ecosystems (e.g., biogeographical zones), down to the smallest relevant ecosystems (e.g., a pine forest or an oasis). The level of detail is directly dependent on the scale, but adequate geospatial technologies can present the ecosystems at varying scales, depending on the resolution of the input information. Scale is also relevant when trying to establish the limits of an ecosystem.

Mapping the distribution of different ecosystems is best achieved by tools specifically designed for them, since ecosystems are extremely different, with specific key characteristics that need to be properly evaluated (Pagella and Sinclair 2014). Mapping the distribution of forest ecosystems needs a totally different set of indicators than mapping the distribution of river ecosystems (Remmel and Perera 2017). Using the available geospatial techniques greatly improves the efficiency of the ecosystems' distribution mapping, when not trying to differentiate between ecosystems with minor differences. The outcome usually consists of probability maps that need further confirmation through field evaluation.

3.4 Geospatial Technologies for Mapping the Quality of Ecosystems

Geographic Information System (GIS), Global Positioning System (GPS), and Internet Mapping Technologies are primarily used to identify the distribution of ecosystems, while Remote Sensing can also directly provide a great amount of information about their quality. Once identified the distribution, the first three solutions can be used to store different characteristics of the elected elements (in our case categories of ecosystems) and model them through spatial or geostatistical analysis (e.g., modeling the air pollution in relation with the ecosystem services provided by different categories of land cover (Salata et al. 2017) or geo-computation (techniques, including cellular automata, that permit the representation and prediction of complex phenomena (Bishop et al. 2015) like space and time dynamics of a geo-ecosystems in Mediterranean areas (Nainggolan et al. 2012))).

Remote sensing is widely used for mapping natural resources, analyzing land cover and land use dynamics, and assessing ecological, soil, geological, hydrological, and cryosphere systems (Bishop et al. 2015) all of these uses being related with ecosystem mapping.

Among the biophysical properties of vegetation that can be derived through remote sensing, there are some as green biomass, leaf area index, chlorophyll concentration, leaf moisture, biochemical, canopy structure, height, and basal area (Chen et al. 2003) that can be related with the quality of ecosystems (Table 3.1).

Table 3.1 Review of the most common aerial imagery products used for ecosystem assessments

Imagery	No.	Resolution (m)	First launch	Last launch
WorldView (DigitalGlobe)	4	0.31–0.46	2007	2016
IKONOS (DigitalGlobe)	1	0.84–4	1999	–
SPOT (AIRBUS Defence and Space)	7	1.5	1986	2014
LANDSAT-15 m (NASA)	8	15	1972	2013
Sentinel (AIRBUS Defence and Space)	5	10	2014	–
MODIS (Santa Barbara Remote Sensing)	2	250–1000	1999	2011
ALOS (Jaxa)	1	2.5	2006	–

3.5 Using Geospatial Technologies for Mapping Distinct Ecosystems

3.5.1 Forest Ecosystems

Throughout history, forest ecosystems have changed their status, from being natural landscapes features to becoming ecosystems that require special management plans to keep providing the required ecosystem services (Pukkala 2013). The Food and Agriculture Organization of the United Nation (2012) considers **forest** as "*land spanning with more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds* in situ". Crown cover percentage or the tree canopy cover (TCC) represents a central element in many definitions given to forest ecosystems. The minimum TCC for considering a landscape to be a forest ecosystem varies for the European countries from 5 to 30% as well as the minimum surface that varies from 0.5 to 2 ha (Kleinn 2001). Choosing a forest definition based upon to assess forest ecosystems can firmly influence the estimates of deforestation and forest degradation areas or the recognition of their drivers (Chazdon et al. 2016). A forest ecosystem must be considered as such, based on more than crown cover, area, or width; it should consider the biodiversity within and the amount of ecosystem services it provides (Thompson et al. 2016).

Forest ecosystems are subject for a complex policy making and management process (Fig. 3.1). The modern management of woodlands consists in assessing their potential to provide ecosystem services and the pressures they face dictate how to exploit the ecosystem services in a sustainable way, what conservation methods are the best for a certain ecosystem, and to establish a monitoring plan for it.

The availability of geospatial technologies towards the large public has made forest management easier and more efficient and in the same time more complex because it has opened the door for other scholars, besides foresters to provide their know-how, making forestry an interdisciplinary domain (Cushing et al. 2008). These technologies have taken the woodland analyses and management from a local perspective to a national and even a global perspective, by enhancing the possibility to process huge amounts of data (Hansen et al. 2013). The valuable field observation made by foresters, biologist, or other researchers is now completed with data obtained from remote sensing and GIS techniques.

Geospatial technics have been used to assess the rainforest ecosystems and their resilience mostly towards land use change (Souza et al. 2013; Pinheiro et al. 2016), to emphasize deforestation patterns and trends (Hansen et al. 2010, 2013) due to selective logging and forest fires (Souza et al. 2013; Pinheiro et al. 2016) or to identify driving forces for forest degradation (Morales-Barquero et al. 2015), or just to map the degraded forests by processing several indicators (Pfeifer et al. 2016) or the fragmentation degree (Dong et al. 2014). In the same time, geospatial techniques were also used to map and quantify the amount of ecosystem services provided by forests and elaborating conservation plans for the areas of high natural value (Mura et al. 2015).

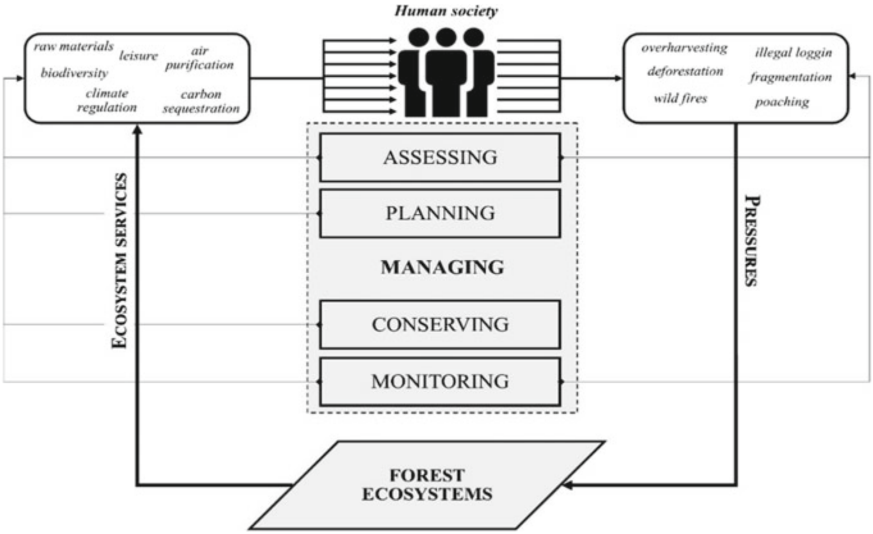

Fig. 3.1 Forest ecosystem management in relation with the society's needs

The contribution of remote sensing procedures and GIS-based solutions in forest ecosystem assessments has encouraged researchers to develop specific tools and indicators. The knowledge about the present challenges, the causes, and their effects over forest quality have increased, enhancing the decision and policy makers to take better measures to maintain and improve the forest ecosystems. Geospatial solutions stood at the roots of several products, commonly used by scholars and different stakeholders in achieving sustainability in regard to forest management. These products cover global, regional, and local scales providing alternatives for their users depending on their objectives.

Shimada et al. (2014) developed a product representing forest and non-forest cover at a global scale using ALOS PALSAR (Advanced Land Observing Satellite—Phased Array Type L-band Synthetic Aperture Radar) data. This product was made available for the wide public thorough JAXA (eorc.jaxa.jp) website. ALOS PALSAR data were used by numerous researchers, focused on regional or local studies such as mapping forest cover (Thapa et al. 2014), mapping forest degradation, and loss (Whittle et al. 2012) or estimating aboveground biomass (Cartus et al. 2012).

Another product that provides tree cover density at global scale is the one generated by using the methods described by Sexton et al. (2013) who developed a 30 m resolution dataset by rescaling MODIS (Moderate-Resolution Imaging Spectroradiometer) vegetation continuous fields (VCF) tree cover layer using LANDSAT images (available on Global Land Cover Facility website glcf.umd.edu/).

Probably the best-known product regrading global forest ecosystems is provided by Hansen et al. (2013) who offer a 30 m resolution datasets recording global forest loss and gain, available on Global Forest Watch online platform (globalforestwatch.org). The product was developed using LANDSAT and MODIS imagery and allows researchers and decision makers to understand the dynamic of forest areas between 2000 and 2012 and to identify the areas that need special attention in terms of conservation and sustainable management.

At European level, the Corine Land Cover dataset classifies forest land cover in broad-leaved forests (code: 311), coniferous forests (code: 312), and mixed forests (code: 313) (Bossard et al. 2000). The limitations related with spatial resolution of the dataset affect less the forest ecosystems than smaller ecosystems, and the errors generally affect the edges.

Through the Copernicus Programme another dataset was elaborated, exclusively for forest ecosystems such as the tree cover density (TCD) from which it derived the forest type (FTY) dataset for the year 2012, having a spatial resolution of 20 m. However, TCD includes land uses that are not considered forests according to the forestry definition such as orchards, parks, and alley trees and group of trees within urban areas (Langanke 2013).

The Joint Research Centre (JRC), European Commission's science and knowledge service has provided forest cover maps for 1990, 2000 and 2006. For 2006, they have also provided forest type datasets. For 1990 and 2000, JRC used the LANDSAT sensors resampled to 25 m resolution and CLC were used as ancillary data and for 2006, they used SPOT-4 sensors instead of the LANDSAT sensor. The methods used to generate the 2000 forest cover map are described by Pekkarinen et al. (2009) where they state that the resulting forest/non-forest map was validated with three independent datasets. The forest cover maps and data are available for download on the European Commission online platform (forest.jrc.ec.europa.eu) along with information and data regarding tree species distribution and projected distribution for the future. JRC also provides data and information about European forests' pattern and fragmentation, forest fires, forest in relation with climate change, forest ecosystem services, or land use change of forest ecosystems.

3.5.1.1 Case Studies

Different datasets providing information about forest ecosystem differ in terms of the same indicator values. For instance, we used several datasets and products to estimate the amount of forest surface for the Romanian Carpathians in accordance with FAO definition (Fig. 3.2). The data were selected to emphasize the forest vegetation cover in 2000 using the JRC and CLC database and the ones proposed by Hansen et al. (2013) and Sexton et al. (2013). The generated maps enhance differences among the four data sources. The JRC and CLC data are more similar as they were resulting using similar base maps and satellite imagery and the same goes for the Sexton and Hansen datasets. The differences in forest vegetation surfaces between the minimum and the maximum value are of 0.75 million ha. As we mentioned before, there is a clear border between what we consider forest and forest vegetation cover. Most of the products generated through remote sensing procedures reveal forest vegetation land cover, which is not the same as the areas considered forest by foresters and

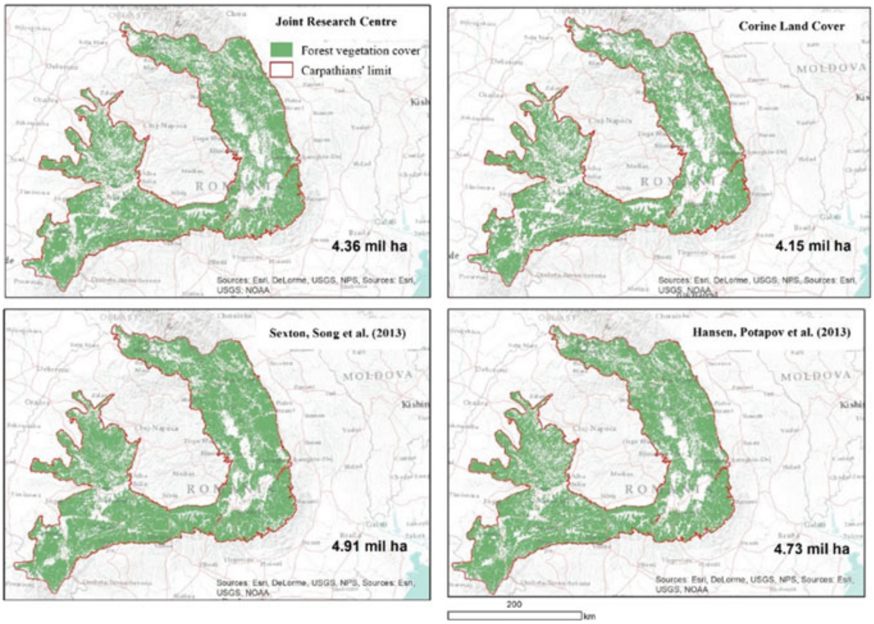

Fig. 3.2 Forest vegetation cover in the Romanian Carpathians extracted from different data sources (2000)

forest managers. This confusion may lead to biased conclusion when referring to deforestation degrees, illegal logging, or forest cover dynamics.

The discrepancy among the surface values provided by the datasets is generated by the resolution of the base maps used to generate these products, whether talking about satellite imagery, orthophoto maps, or high-resolution spatial representation (Table 3.2). However, a preliminary analysis can indicate a pattern regarding the forest vegetation dynamics in the Romanian Carpathians by using all the abovementioned products. By averaging the surface indicated by each product per year, we can draw a preliminary conclusion that forest vegetation cover had a decreasing trend in the last 30 years (Fig. 3.3).

Our aim was to provide a brief review of the available geospatial technologies most commonly used in assessing forest ecosystems and we used the available, scientifically endorsed products to emphasize the dynamics of forest vegetation cover in the Romanian Carpathians. The results have revealed significant differences between different databases, enforcing the need of complementary research method when assessing forest ecosystems. Geospatial technologies should be used along with other specific methods to establish the quality of forest ecosystems. Such examples are provided by several authors that combined field methods and geospatial technologies to assess forest ecosystem in different study areas in the Carpathians (Teodosiu and Bouriaud 2012; Pătru-Stupariu et al. 2015).

Table 3.2 Forest vegetation surfaces from different data sources—forest vegetation in Romanian Carpathians

Sources	Year										
	1990	2000	2005	2006	2007	2008	2009	2010	2012	2015	
DTM	6.38	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	million ha
JRC	*No data*	4.37	*No data*	3.82	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	
Hansen	*No data*	4.73	*No data*	*No data*	*No data*	*No data*	*No data*	4.67	*No data*	*No data*	
Sexton	*No data*	4.91	4.87	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	
CLC	*No data*	4.16	*No data*	2.51	*No data*	*No data*	*No data*	*No data*	3.07	*No data*	
ALSPLS	*No data*	*No data*	*No data*	*No data*	4.60	4.70	4.67	4.88	*no data*	4.75	
ORTO	*No data*	*No data*	*No data*	*No data*	*No data*	3.88	*No data*	*No data*	*No data*	*No data*	
Copernicus	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	4.37	*No data*	

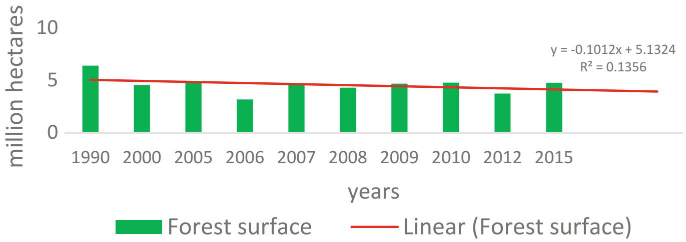

Fig. 3.3 Forest vegetation surface evolution in the Romanian Carpathians—forecast generated through the aggregation of different datasets

We emphasize that using geospatial technologies in forest ecosystem studies has proved to boost the knowledge of these ecosystems. However, the need to crosscheck the accuracy of the results driven by using these technics is crucial for describing certain phenomena occurring in forest ecosystems.

3.5.2 River Ecosystems

River ecosystems have a specific linear topology and their map representation width at certain scales must be exaggerated, in terms of proportionality with reality, to make them visible. To set the limit of an ecosystem, an arbitrary criterion which offers higher contrast is sometimes chosen as the delimitating factor, since the ecosystems do not have clear-cut boundaries.

In some methodologies, the specific criteria used for the ecosystem classification serve to delimitate areas with those ecosystem characteristics (Gao et al. 2015). The set of criteria defining an ecosystem as a classification category is used to find the territories with these characteristics and the proper ecosystem defined as such. Some of these characteristics are inextricably linked to the territory where they appear or are best described through spatial distribution, using maps.

Mapping river ecosystems reveal distinct challenges. Determining the linear pattern and flow direction are among the most important variables. The physical parameters and the composition of the ecosystems are continuously changing along their length. River ecosystems are dynamic since water is in a state of constant movement along the length of the river. Further, water is also changing its properties through interaction with all the other components of the river, such as the stream bed lithology or the vegetation. While along a river there are segments with different properties, resulting in different ecosystems, to establish where one ecosystem ends and another one begins is a more challenging task, since there always is a fading transition between such river ecosystems. Moreover, the water flow keeps transferring some of the energy and matter and thus some characteristics from one river segment to the following. Consequently, the delimitation between the ecosystems of a river must be performed in an arbitrary fashion, considering the variation of a chosen key indicator or through expert opinion.

The Water Framework Directive explicitly emphasizes that the member states shall submit to the Commission a map or maps, in a Geographical Information System (GIS) format, of the geographical location of the types consistent with the degree of differentiation required under systems of classification described in the Directive. The classification of the water bodies in accordance with these criteria can be greatly improved by using geospatial technologies. Some of the indicators can be directly determined or calculated using GIS (e.g., altitude, slope, distance from river source). Satellite images offer opportunities to determine other specific indicators (e.g., mean water depth).

The Water Framework Directive methodology includes not only modalities to classify water bodies but also indicators for evaluating the water ecosystems quality. These indicators quantify the general biological, hydro morphological, physical and chemical, and specific pollutants (synthetic and non-synthetic) properties of the water. Some data cannot be obtained through geospatial technologies and there is the need for field surveys and laboratory analysis. For example, among the quality elements for the river classification of the ecological status, the composition, abundance and age structure of fish fauna is one of the main indicators that cannot be determined but through field sampling. Still, this data can offer more insights if it is collected and treated as spatial data. Further processing is also greatly improved, as it is data presentation through maps.

3.5.2.1 Case Studies

Today, GIS techniques and remote sensing are commonly used in river management. Field data can easily be computed using modern geospatial technologies, emphasizing issues that should be looked upon. We provided an example of how several fundamental characteristics of a river basin can be mapped by using geospatial techniques.

Our case study is represented by the Olt river basin, the major inner river of Romania. We used the digital elevation model (DEM)—20 m resolution to calculate the slope degree and orientation in Olt hydrographic basin (Fig. 3.4). These two characteristics are very useful in river management as a high slope degree means faster water flows, potentially turning into torrential phenomena, leading to floods and material damages. The slope degree and orientation were calculated using ArcGIS 10.3. by using *Slope* and *Aspect* tools from ***Spatial Analyst*** toolbox. Using the data provided by this analysis the decision-making process regarding flood management and river management is streamlined.

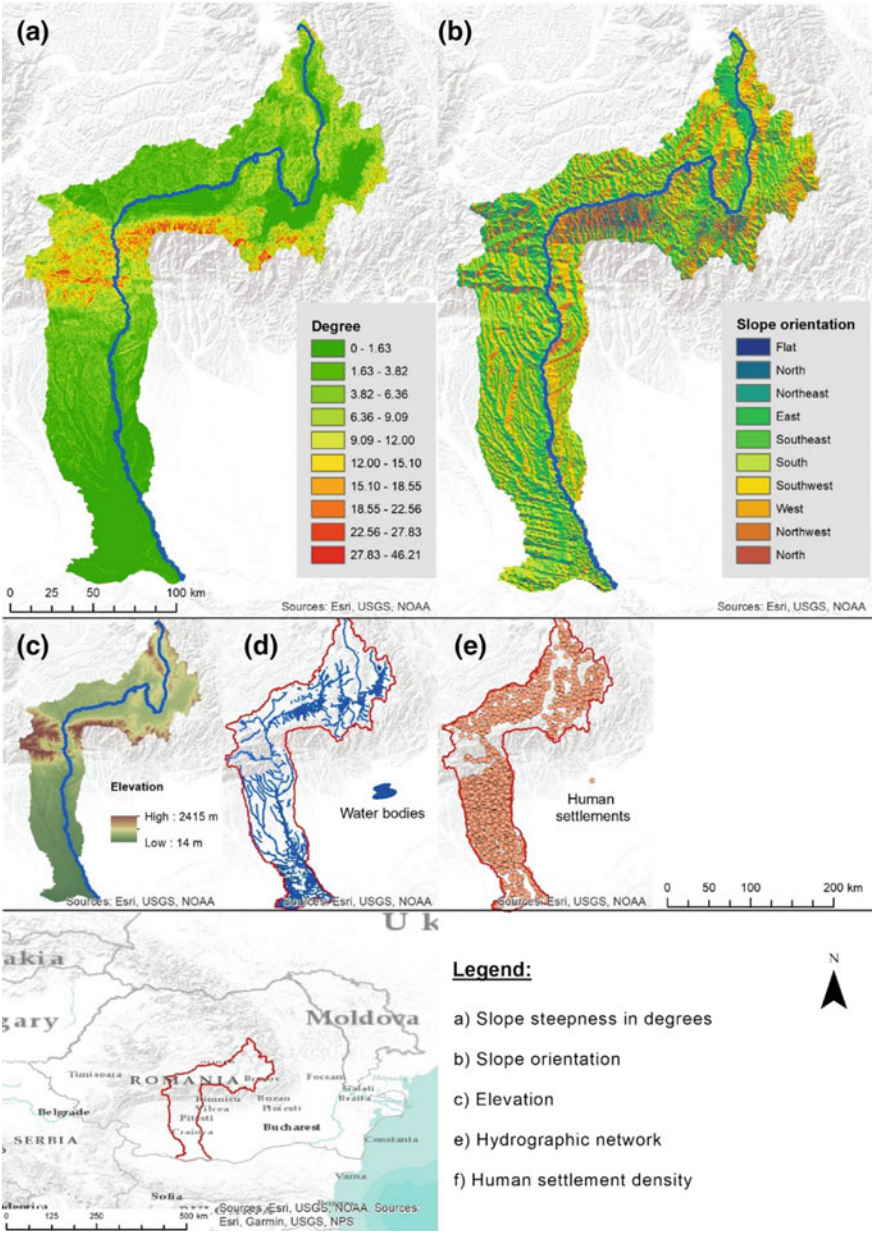

Fig. 3.4 Different characteristics for Olt hydrographic basin represented using geospatial techniques

3.5.3 Lakes Ecosystems

When mapping lake ecosystems, as it is also the case of the river ecosystems, there should be made the distinction between the actual water ecosystem and the riparian ecosystem that is usually found in the proximity. The riparian ecosystem is strongly integrated with the water ecosystem it borders, influencing the functional processes and the structure of the aquatic communities, extending for 50 m or more from the water surface (Angradi et al. 2016).

Mapping and evaluating the spatial variability of the lake ecosystems can be achieved efficiently by using habitat distribution maps at different scales, from 1: 50000 to 1:5000 and satellite imagery. When using satellite imagery to establish the distributions and the extension of the lake ecosystems, filed validation is necessary.

Besides Corinne Land Cover, a suitable database for mapping lake ecosystems is Copernicus Pan-European High-Resolution Permanent Water Bodies, available on the Copernicus official web platform (land.copernicus.eu). It contains five land use categories, at 20 m resolution, Lambert projection, ETRS-8: forest, pastures, water bodies, wetland, and built area. Using this database to delimitate ecosystems needs a pixel-by-pixel validation stage based on satellite imagery in order to eliminate errors that might have been generated when the initial processing was performed (EEA 2016). The CLC dataset cannot record water bodies with surfaces below 0.25 ha, and for more detailed analysis, more accurate datasets are required.

CORINE database is not sensitive whether the lake ecosystem is natural or artificial, such as sewage or industrial water basins. The input data for Copernicus is IRS-P6/Resourcesat-2, SPOT 4 and 5 satellite images, further improved using IRS, SPOT and Landsat 7 ETM+ satellite images. Compared to the CORINE, the Copernicus dataset is much more detailed and the number of identified lakes is much larger (Fig. 3.5).

Evaluating the degradation of aquatic ecosystems through remote sensing and GIS techniques is proving to be a useful approach (Gao et al. 2016; Al-Fahdawi et al.

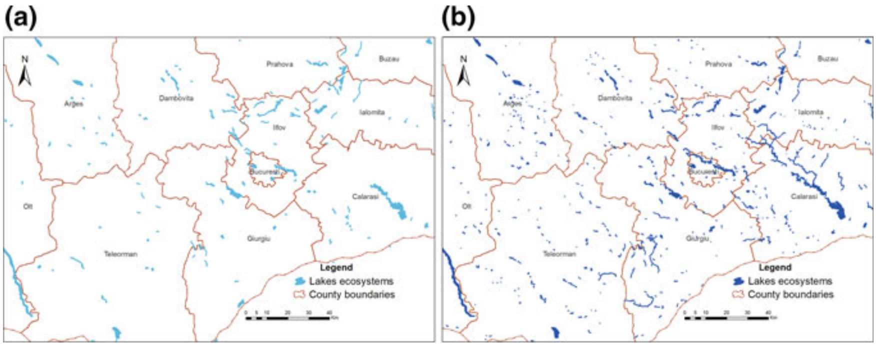

Fig. 3.5 Lake ecosystems in South of Romania: CLC 2012, code 512 (**a**) and Copernicus databases (**b**)

2015). Also, identifying and delimiting aquatic ecosystems, including the lakes, through remote sensing methods such as Multiband Spectral Relationship, Normalized Difference Water Index (NDWI), and Tasseled Cap transformation (Gao et al. 2016) is proving to be successful in many situations. To extract lake position and extension, Landsat-8 OLI imagery offers good results, by processing an initial binary image and further applying a Normalized Difference Water Index (NDWI) (McFeeters 1996), eliminating by supervised classification the adjacent surfaces (Gao et al. 2016).

A series of 30 m resolution satellite images that can also be used for lake ecosystem analysis are accessible by USGS Global Visualization Viewer (Turner 2010). These data provide good territorial coverage and are available in the form of different periods of time datasets. They offer information for areas with limited accessibility and allow for comparative analysis in time. Remote sensing and satellite imagery are cost and time saving, considering the amount of data produced (Al-Fahdawi et al. 2015). Spatial resolution is still a limitation in the case of the aquatic ecosystems (Hestir et al. 2015). The size of the image pixel, compared with the size of the covered habitat is extremely important (Hestir et al. 2015).

3.5.4 Urban Ecosystems

Urban ecosystems can be defined as an integrated ensemble of connected built (sharing built or paved infrastructures) and green infrastructures (Burkhard and Maes 2017). Geospatial technologies have a critical role in the analysis of urban ecosystems quality since they can be used for mapping, spatial analysis and modeling. The diversity of databases, available in the last decade, and the high quality of sensors, and improved image resolution offer the opportunities in urban ecosystem assessment and sustainable urban planning for the future.

As more land is being urbanized and natural landscapes are shrinking, sustainability in urban planning has become a common topic within the scientific community (Gavrilidis et al. 2017). The complexity of "urban ecosystems" entails advanced methods for assessing the relations and process within a city. Geospatial technics have proved to be useful for a wide range of urban studies related to planning, environmental, or social issues. Remote sensing analysis and GIS technics used in urban analysis enhanced the role of geographers in this field of research.

Remote sensing has a critical role to play in the analysis of the interactions that occur between people and urban environments that may help shape our understanding of humans and the principle environment in which they live. Improved sensors, more exacting resolutions, the rapid convergence of earth observation systems, geographical information systems, and spatial statistics have expanded the scale and scope of remote sensing applications across human geography, the social sciences, and in the real world of public policy (Gatrell and Jensen 2008). The availability of geospatial technologies made possible different approaches in assessing urban sprawl and acknowledge when this phenomenon occurs in the world's cities. Bhatta et al. (2010) examined several methods based on remote sensing technics and their suitability for sprawl measurements, concluding that some of the methods borrowed from other research domains are not as efficient in urban sprawl assessments. Even though the topic regarding urban sprawl is highly theorized, the use of geospatial technologies has enhanced the measurements of the phenomenon (Grădinaru et al. 2017; Jaeger and Schwick 2014).

Geospatial technologies have been used to assess, measure, and map different processes and phenomena within the urban settlements and their surrounding such as air pollutants dispersion (Fishman et al. 2008) and sources of pollution (Wang et al. 2013), built-up dynamics (Gavrilidis et al. 2015), occurring environmental conflicts and functional incompatibilities (Iojă et al. 2014b; Niţă et al. 2013), assessing and mapping urban landscape and urban landscape features (Inostroza 2017; Gavrilidis et al. 2016), planning and assessing urban green infrastructures (Gavrilidis et al. 2017; Iojă et al. 2014a), or assessing and mapping of the ecosystem services generated by different urban features (Burkhard and Maes 2017; Cvejić et al. 2015). High-resolution satellite images have been very useful in extracting information about different urban land covers. These images have often been used to extract data about urban green areas or areas covered with vegetation. Mathieu et al. (2007) mapped the private gardens from Dunedin (New Zeeland) using the technique of object-oriented classification on multispectral Ikonos images. The authors were among the first researchers to reach this degree of detail analysis as previous studies focused over the large green urban areas. Since present days, satellite imagery resolution evolved simultaneously with the assessment methods.

Air quality assessment is usually done by using in situ measured data at ground level in monitoring networks, by satellite measurements or modeling, or by a combination of the measurements and modeling approaches. Satellite data due to their large space coverage provide information on the distribution of pollutant concentrations (Fishman et al. 2008), estimation of the pollutant emission (Streets et al. 2013) and for air quality applications (Duncan et al. 2014).

Urban green infrastructures are a modern concept that assesses urban green space in an integrated way, in accordance with the amount and variety of ecosystem services they provide. From emphasizing the diversity of urban green infrastructures (Badiu et al. 2014), through assessing the connectivity within an urban green infrastructure (Niță et al. 2018) and finally to plan increasing and improving an urban green space network based on the human needs (Gavrilidis et al. 2017; Cucu et al. 2011), geospatial technologies have provided an useful tool for researchers focusing on urban environments.

3.5.4.1 Case Studies

Multiple studies that assessed urban dynamics or urbanization processes included land use and land cover analysis. Gavrilidis et al. (2015) emphasized the influence that a raw resource can have over the urbanization process of a city by correlating the land use and land cover changes with the dynamics of the economic activities in the

Table 3.3 Green space and built-up dynamics between 2005 and 2010 in Ploiesti (Romania)—data extracted from aerial images

Year	Green spaces	Percent of administrative area (ha)	Built-up area	Percent of administrative area (ha)	Administrative area
2005	416.6	8.10	2229.71	43.37	5140.66
2010	693.87	11.47	2500.04	41.34	6047.84

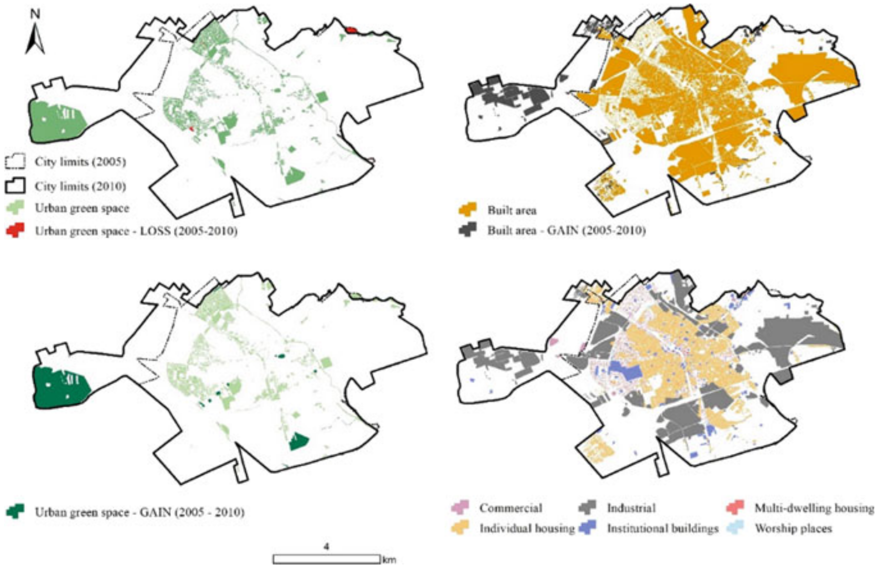

Fig. 3.6 Green areas and built-up areas land cover distribution in Ploiesti (Romania)—extracted from aerial imagery (2005 and 2010)

last 100 years. Several studies have used the land use and land cover dynamics for assessing the sprawling patterns of cities (Sperandelli et al. 2013), as the information used for establishing a certain land use or land cover type were extracted from various base maps such as old topographical maps or aerial images. However, these studies are relevant only to settle landscape change patterns and they cannot be used for detailed analysis. For detailed scale analysis, high-resolution maps or imagery are required and for assessing land use and land cover dynamics at a precise level, same scale base maps are required too (Table 3.3; Fig. 3.6).

As emphasized in the examples above, using geospatial technologies to spot a certain dynamic of the urban land cover patterns generates "three-dimensional" results, providing spatial, quantitative, and qualitative outcomes that further can be developed, offering more depth to the analysis of urban areas and their surroundings. The availability and use of geospatial technics in urban planning have opened the door for participatory planning, thus the stakeholders, local authorities, citizens, and researchers can express themselves towards the processes that occur in an urban landscape.

3.6 Conclusion

Mapping different processes, phenomena or *status quos* helps indicated the spatial location of an issue, making the intervention process easier. Geospatial technics made mapping more accurate and easier, being a tool used not also by geographers, but also by scholars from different domains. As all geospatial technics assumes geographical knowledge, this new technological age in which location tagging and mapping became widely used is the perfect time for skillful geographers to prove their inputs in other research domains.

However, the use of geospatial techniques in ecosystem assessments could become biased without field data and observation to confirm the processed findings. This could be considered an important challenge for geography and geographers in future decades as the need to achieve results very fast in order to respect multiple deadlines. Thus, field observation could become more and more neglected and the dependency on geospatial techniques to provide field observation can alter the reality and further the effects of the decision-making process. We conclude this chapter by underling that geospatial techniques are useful tools in modern analysis that provide useful outcomes, improving the management of ecosystems but the development of these technologies should not substitute the classic assessment techniques, especially field observation which represents the basis of geographic research.

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Chapter 4
Linking Real Geographies and Virtual Realties with Immersive Geospatial Technologies

Florian Hruby, Rainer Ressl and Genghis de la Borbolla del Valle

Abstract Due to the quantity of information available in the early twenty-first century, big data has become a frequently emphasized factor, and particularly so in the geographical research agenda. However, more data and information do not necessarily result in improved awareness of spatial problems: Communication of geographical knowledge (e.g., on environmental issues) is also complicated by geographical, temporal, and psychological distance between cause and effects, leading users to perceive spatial problems as taking place "later" or "elsewhere". In this text, we discuss how immersive virtual reality (VR) technologies can help to overcome these different kinds of distances. Two broad topics are addressed: The first, covered in Sect. 4.2, explores the idea of immersion from a technological perspective and also discusses the main differences between immersive and current desktop-based geovisualization VR systems. The second, presented in Sect. 4.3, concerns the potential of immersive VR from the perspective of the user and introduces the concept of spatial presence. Against the theoretical background of Sects. 4.2 and 4.3, a working method defining how geospatial data can be visualized in immersive VR systems under current technological conditions is presented in Sect. 4.4. We argue that current geographic information systems (GIS) are not yet directly compatible with VR output devices, challenging both theoretical and practical models of GIS-based spatial data. The method proposed is set into practice in Sect. 4.5 using the example of a coral reef ecosystem. As is clear from these theoretical and practical considerations, immersive VR technologies can provide powerful tools to facilitate a better understanding of spatial problems in the twenty-first century.

Keywords Geospatial technologies · Virtual reality · GIS · Real geographies

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4.1 Introduction—Distance in Twenty-First Century Geography

Distance has been always a basic element of academic geography's self-conception. Traditionally, geographers pay particular attention to spatial distance, as Tobler put it most prominently in his first law of geography (Tobler 1970). However, since the present volume focuses on "Geospatial challenges in the 21st century", a more general understanding of the meaning of distance is required.

To begin with, the century is a temporal concept and can be described in terms of temporal distance, where the upcoming months and years are closer to us than the end of the centenary. Just as with spatial distance, temporal distance can thus also be subject to cause-and-effect relations: actions in the immediate geographic environment can impact more distant regions, and short-term decisions may likewise have an influence in the long run.

From these action-dependent causalities, another dimension of distance, known as psychological distance, emerged only recently

> Psychological distance is a subjective experience that something is close or far away from the self, here, and now. Psychological distance is thus egocentric: Its reference point is the self, here and now, and the different ways in which an object might be removed from that point—in time, space, social distance, and hypotheticality—constitute different distance dimensions. (Trope and Liberman 2010)

The basic assumption of psychological distance is that people do not necessarily define their decisions based on how close in space and time a given problem is, but rather as a function of how close they perceive a problem to be. As cited above, this perceived psychological distance does not simply depend on spatial and temporal factors, but also on the dimensions of social and hypothetical distance. While social distance (e.g. "between self and other, similar and dissimilar others, […]", Liberman et al. 2007) is usually interlinked with spatial distance, hypothetical distance is associated with distance in time, since it is easier to forecast short-time events than issues in the long run.

Climate change provides a good example to illustrate the different dimensions of psychological distance, together with their practical meaning: At present, climate change is considered to be one of the major global challenges (cf. the Royal Geographical Society's platform on twenty-first Century Challenges[1]). However, many people perceive this issue to be one that is psychologically distant, geographically, temporally, socially, and hypothetically removed from everyday experience. Regarding spatial distance, people tend to perceive climate change to present greater risk to spatially distant regions (Spence et al. 2012). With respect to temporal distance, the concrete impacts of climate change (e.g., sea level rise) are considered as future rather than present-day issues (Leiserowitz 2005). In this case, even if one accepts that climate change is already underway and affecting one's homeland, one still might perceive that change as a phenomenon that is more relevant to less affluent social

[1] https://21stcenturychallenges.org/.

groups (e.g., developing countries, Roeser 2012). Finally, people perceive climate change as a hazard with undetermined consequences: for instance "40% of the British public supporting the idea that the climate system is too complex and uncertain for scientists to make useful forecasts." (Spence et al. 2012).

As with the case of climate change, psychological distance has an effect on other twenty-first century geospatial challenges as well, be it in the realm of nature protection, geopolitics or demography and migration. In any case, increased psychological distance is paralleled by a decreasing awareness of the particular problem. Consequently, issues perceived as distant neither increase the disposition to participate in problem-solving strategies that involve a modification of personal behavior, nor claims for solutions at the policy level.

Current geographical research is devoted to the study of problems involving all four of the aforementioned dimensions of psychological distance. Hence, knowledge of how to overcome psychological distance is of central importance to effectively conceptualize and communicate research and its results. In the subsequent sections of this text, we will argue how virtual reality technologies can help to reduce distance among laymen, academia, and the geospatial challenges of the twenty-first century.

4.2 Immersive Geospatial Technologies

During recent years, virtual reality (VR) has become a frequently emphasized topic on the geovisualization research agenda. However, there is as yet no available universally applicable definition of VR in the realm of geospatial technologies. In order to provide a terminologically solid context for the following arguments, we will briefly discuss three main frameworks that have been built around the idea of VR in geovisualization. As we shall see, in spite of significant conceptual differences, these frameworks can be integrated under the umbrella term of desktop virtual reality.

Against the concept of a desktop VR we will then try to develop a narrower understanding of virtual reality by introducing immersion as a defining criterion, which allows us to avoid terminological ambiguity and facilitates a reconnection with the issue of psychological distance developed in Sect. 4.1.

4.2.1 Desktop Virtual Reality

4.2.1.1 Virtual Globes (VG)

The concept of virtual globes (VG) was coined by the publication of Google Earth in 2005 (Dehn et al. 2016). While the term itself is now firmly rooted in current academic and everyday speech, its definition is not without difficulty: On the one hand, VG are not globes in the traditional cartographic sense of terrestrial globes representing global phenomena. Rather, VG can be understood in terms of geobrowsers that allow the user to navigate and explore a variety of (usually) large-scale datasets (Liao et al. 2017). On the other, Google Earth and comparable platforms could just as well be described as digital globes (Riedl 2007), since the label virtual is not yet justified by the virtual reality features of VG. Regardless of the aforementioned points of critique, we can state that current VG is designed for use on flat (mobile and desktop) computer displays.

4.2.1.2 Virtual Reality Geographic Information Systems (VRGIS)

In order to argue for a direct connection between VR and geographic information systems (GIS), the label VRGIS is increasingly used in scientific literature (Lv and Li 2015; Lv et al. 2016). The connection of ESRI's City Engine with head-mounted displays (HMD) such as the Oculus Rift is an example that is frequently cited to illustrate the feasibility of VRGIS (Boulos et al. 2017). However, these case studies cannot hide the fact that current GIS software is not yet VR ready. Rather, due to a lack of data compatibility, middleware (e.g., game engines like Unreal Engine or Unity) is required to make GIS data virtually explorable using HMD. Hence, VRGIS applications such as the aforementioned example are in fact prototypes, developed with considerable technical effort for very specific scenarios. These prototypes are still very distant from the usability and graphics quality of commercial computer games, as well as the rich functionalities that standalone GIS offer. In practical terms, GIS—even when labeled as VRGIS or WebVRGIS (Lv et al. 2016)—remain desktop-based applications.

4.2.1.3 Virtual Geographic Environments (VGE)

Compared with virtual globes and VRGIS, VGE provide a broader conceptual framework, merging "geographic knowledge, computer technology, virtual reality technology, network technology, and geographic information technology" (Lin et al. 2013). Typically, VGE have four components: (a) data, (b) simulation and modeling, (c) interaction, and (d) a collaboration module (Zhang et al. 2016). Well-founded on the theoretical side, VGE suffer from the same practical shortcomings as VRGIS: Given the limited compatibility between GIS and VR-ready output devices, most VGE are desktop applications; however, virtual reality technology is currently only used for prototyping.

4.2.2 Immersive Virtual Reality

While we have discussed geovisualization desktop VR in a nutshell, it has become clear that the concept of VR is being interpreted ambiguously: On one hand, virtual globes such as Google Earth do not aspire a visualization on VR displays. On the other, VRGIS and VGE are theoretically built upon VR capabilities, but in practice rather GIS-driven approaches, thus failing in the current VR-disabled GIS. In order to avoid further conceptual blur, and to clearly distinguish between digital and virtual visualization, we will now propose a more specific definition of VR, terminologically identified by the amendment “immersive”.

4.2.2.1 Immersion

In accordance with recent literature (Skarbez et al. 2017; Slater 2009), we can define immersion as a technological and, hence, objective characteristic of VR applications, describing “the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant.” (Slater and Wilbur 1997, p. 3). Inclusive means to fade out the user’s physical environment, e.g., by using a HMD. Extensive means to address different human sensory systems through the VR visualization, e.g., vision, hearing or touch. Surrounding means to provide the user with a panoramic field of view, comparable to human vision in the physical reality. Finally, vivid indicates the level of realism presented by the VR application, and is dictated by image resolution and update rate, for example.

Creating this kind of illusion of reality, the qualities of an immersive VR system depend on several features, which have been recently analyzed by Cummings and Bailenson (2016) within a meta-analysis of more than 80 empirical studies. Accordingly, the following features are decisive:

- *Positional tracking* coordinates physical-world with virtual-world movement. If this coordination is perfect, the user is provided with six degrees of freedom (6DoF) allowing movement and rotation along x, y, and z axes.
- *Update rate* refers to frequency at which VR scenes are rendered. This frequency should match human vision, since image jitter will disturb the illusion of reality.
- *Stereoscopic displays* simulate binocular human vision by providing each eye with an image rendered from a slightly different angle, hence facilitating the perception of depth and three-dimensionality in a VR system.
- *Field of view* describes the extent of the virtual world observable at a glance. A field of view comparable to the human visual field, as provided by current HMD such as the Oculus Rift (used for the VR application presented below) or the HTC Vive, benefits the immersive quality.

4.2.2.2 Technical Components

Considering the aforementioned features, e.g., stereoscopic display and tracking system, it is clear that desktop-based VR systems are non-immersive by definition, and will thus be excluded from further consideration in this chapter. For immersive VR, the main technical components are listed below (Schulze et al. 2011):

- *3D stereo displays* provide the users with the illusion of being situated exclusively in a virtual 3D space, while the real world's physical environment is shut out from visual perception. Since autostereoscopic displays cannot offer such exclusive perception, HMD are a necessary component of current immersive VR.
- *Tracking systems* coordinate the user's motion (e.g., of the head) with the information provided in the virtual environment (e.g., of the visual information rendered on the HMD). Current HMD usually feature 6DoF optical tracking systems, consisting of infrared markers and constellation sensor(s).
- The *graphics rendering unit* generates the virtual scene on the fly as a function of the information provided by the tracking system, sending the resulting images to the stereo display. High end, discrete graphic processors are required to perform this task (cf. Goradia et al. 2014).

4.2.3 Psychological Distance Versus Spatial Presence

From the previous sections, we can derive the assumption that immersive VR systems should facilitate overcoming of the different dimensions of psychological distance discussed at the beginning of this text: Taking the example of a VR representation of a coral reef (as further detailed below), we could reduce the spatial distance to these underwater ecosystems by submerging the user within an immersive VR replica of the reef. Likewise, temporal and hypothetical distance could be diminished through simulations of (probable) past and future scenarios (e.g., coral bleaching). In order to substantiate this assumption, we shall subsequently complement the technological concept of immersion with the cognitive concept of spatial presence on the user side.

4.2.3.1 Spatial Presence

"Spatial Presence is a binary experience, during which perceived self-location and, in most cases, perceived action possibilities are connected to a mediated spatial environment […]", (Wirth et al. 2007; cf. Skarbez et al. 2017). With this definition in mind, research on immersive VR is built on two core assumptions

- Spatial presence facilitates understanding: "An increased sense of presence is often thought to […] increase the effectiveness of mediated environment applications (e.g. the practical use of such environments as tools for entertainment, learning, training, or therapy." (Cummings and Bailenson 2016)
- Highly immersive VR technology facilitates the formation of spatial presence, i.e., the user's perception of being there (e.g., Seibert and Shafer 2018; Ahn et al. 2016; Bailey et al. 2016).

While promising for the communication of twenty-first-century geospatial challenges, spatial presence on the user side is by no means the necessary outcome of every immersive VR application. On the one hand, different components of a VR system impact differently upon the perception of spatial presence, with tracking level, interactivity and stereoscopy the main enabling technological factors (Cummings and Bailenson 2016). On the other hand, spatial presence is not an exclusive product of highly immersive VR, but can also emerge from other media products (e.g., novels; Schubert and Crusius 2002). Hence, in order to provide a better understanding of the formation of spatial presence, the following two-step model proves useful.

4.2.3.2 Formation of Spatial Presence

To formalize the formation of spatial presence, a two-level model has been presented by Wirth et al. (2007), where the user first "must draw upon spatial cues to perceive the mediated environment as a plausible space. Second, the user must also then experience his or herself as being located within that perceived space." (Cummings and Bailenson 2016).

In accordance with this model, as a first step, VR users construct a mental model of the virtual environment provided. Based on this model, the user answers the question: "is this stimulus a space/room?" (Wirth et al. 2007). Both the VR application (e.g., its attracting features) and the user (e.g., their interest or spatial abilities) will influence the answer to this question. In the affirmative case, a so-called spatial situation model (SSM) will be constructed (ibid.).

In a second step, users are required to prefer virtual to physical reality as their primary frame of spatial reference, thus also answering the question "am I located in this space/room?" (ibid.) in the affirmative. Again, both technological (e.g., update rate) and human (e.g., attention) factors define whether the state of spatial presence is achieved and sustained.

Regarding suitable ways to measure spatial presence, numerous methods have been proposed (Laarni et al. 2015). Subjective approaches, where the user introspectively describes his experience (e.g., using post-test questionnaires; Garau et al. 2008) can be distinguished from objective measures, e.g., of pre-test and post-test performance (IJsselsteijn et al. 2000). With particular focus on the aforementioned process model (Wirth et al. 2007) a spatial presence experience scale (SPES) has been presented by Hartmann et al. (2015).

4.3 Geovisualization Immersive Virtual Environments (GeoIVE)

In the previous sections, we have seen that twenty-first-century geography faces different dimensions of distance. Moreover, we provided a definition of immersive VR and argued how VR technology can facilitate overcoming psychological distance through the formation of spatial presence. In this part of the text, we will describe a

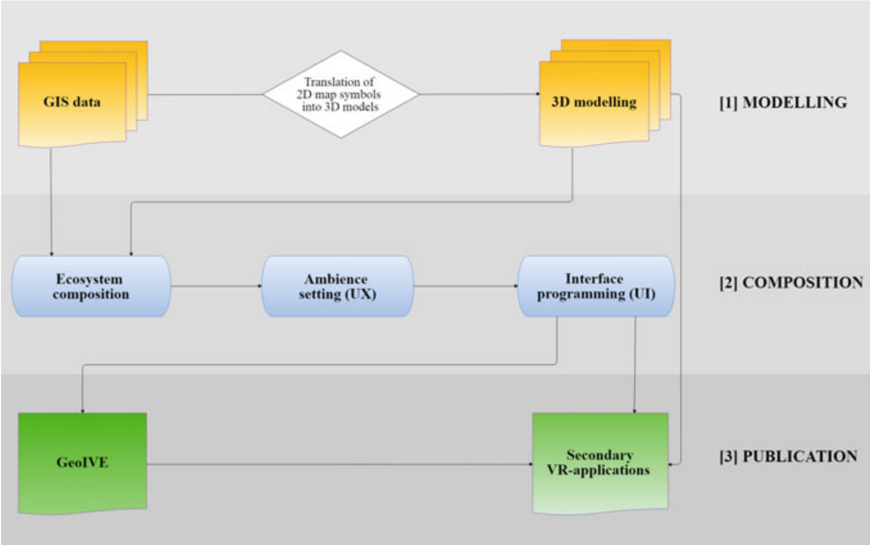

Fig. 4.1 From GIS data to GeoIVE

working method that allows us to visualize geospatial data in immersive VR systems under current technological conditions. For terminological clarity, the concept of Geovisualization Immersive Virtual Environments (GeoIVE) is introduced, defined as a subcategory of immersive VR applications. As such, GeoIVE must provide interactive navigation and stereoscopic view, allowing users the experience of spatial presence. Unlike other types of VR systems, GeoIVE visualize geographic environments in a (prototypically) generalized but realistic manner, at a scale of 1:1. Figure 4.1 summarizes this working method in graphical form, while further details will be specified below.

4.3.1 Modeling

In order to build realistic VR representations of real geospace, GIS are the starting point of each geovisualization immersive virtual environment (GeoIVE). Relevant GIS data include both digital terrain models necessary to visualize the relief of the environment tridimensionally and thematic information (e.g., on land cover), which has to be translated into 3D object models (e.g., of particular land cover species). While the export of terrain data into 3D graphics software (at least of small regions) is quite straightforward (e.g., in the form of height maps), realistic 3D models of geospatial features (e.g., species of flora and fauna) cannot as yet be created with GIS. This is due both to missing GIS functions and the lack of data models, which would allow the appropriate description of realistic 3D models at a 1:1 scale.

Hence, 3D modeling of individual features has to be performed in 3D computer graphics software on the basis of reference materials (e.g., photos and videos). While realistic modeling is still a time-consuming procedure, photogrammetric close-range imaging techniques such as structure from motion (SfM) represent a promising approach to the automatic generation of high-quality (both regarding 3D object morphology and texture) models (Schonberger and Frahm 2016). Recently presented mobile devices with (stereo) pairs of cameras could convert SfM-based modeling into a common and ubiquitous form of 3D data acquisition in the near future.

4.3.2 Composition

Since the current GIS are unsuitable for GeoIVE 3D modeling, GIS data and 3D models generated in graphics software need to be blended at the beginning of the composition pipeline (cf. Fig. 4.1), in order to correctly (in terms of geographic coordinates) position 3D models in VR space. To facilitate the formation of a spatial situational model, a realistic user experience (UX) and ambience setting must be ensured. This implies, in the case of GeoIVE for example, the simulation of atmospheric parameters (e.g., light, wind) and environmental sound. Moreover, the interaction between users and GeoIVE needs to be defined (ideally at a 6DoF level). Since neither the composition of a given geospatial situation (e.g., an ecosystem), nor ambience setting or user interface (UI) can be performed with GIS, game engines—beyond to the current set of common geovisualization tools yet—provide powerful tools with which to close this gap between GIS and immersive VR.

4.3.3 Publication

Stereo displays are a technical prerequisite for the publication of immersive VR applications. Hence, the GeoIVE resulting from the aforementioned composition phase must be rendered in real time and in the form of a stereo image paired to the HMD used (e.g., Oculus Rift, HTC Vive). While the GeoIVE visualized on a HMD implies high demands on the graphics hardware, the 3D models generated during the modeling and composition process (cf. Fig. 4.1) can also be published through secondary, less- or non-immersive, geovisualization products (e.g., in 3D web libraries such as Sketchfab or as smartphone or desktop applications). Again, it should be noted that middleware (e.g., game engines) is necessary to link GIS input data with HMD output devices in terms of immersive VR systems.

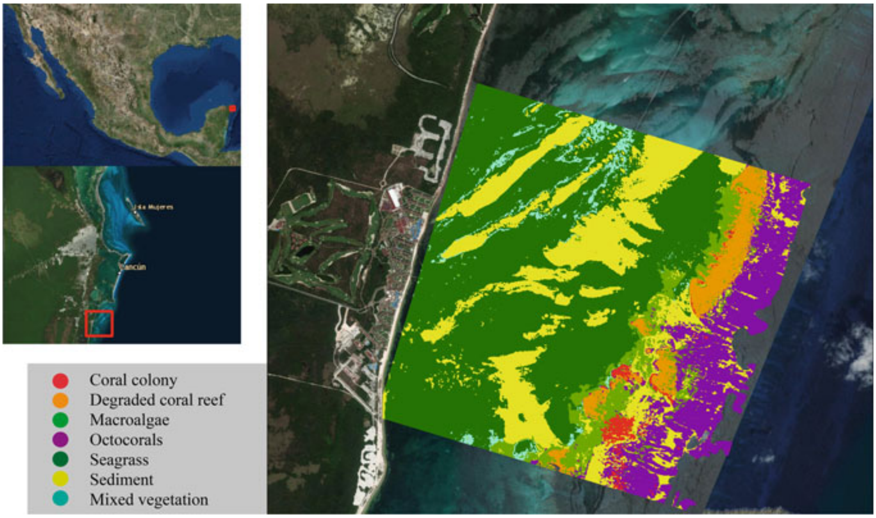

Fig. 4.2 Mexico VR—a case study of GeoIVE: benthonic habitats and study site in its national and regional context

4.4 Mexico VR—A Case Study of GeoIVE

In the preceding section, we briefly presented the three main stages (e.g., modeling, composition, and publication) each GeoIVE must pass through. In order to depict this working method in further detail, including the intermediate steps shown in Fig. 4.1, the visualization of a coral reef will be discussed below. Coral reefs provide a fine example for the importance of psychological distance, since most people, even those familiar with the sea, have never experienced these underwater ecosystems directly.

The site chosen for this project forms part of the Mesoamerican Reef System, the world's second largest barrier reef. Within this reef system, an area of 3.5 × 3.5 km (Fig. 4.2), located in the National Marine Park of Puerto Morelos near Cancun (Mexico), was modeled in terms of a GeoIVE.

4.4.1 Coral Reef Modeling

4.4.1.1 GIS Data

To represent the reef floor (incl. its major zones of fore reef, reef crest, and back reef) at a level of detail necessary for immersive visualization at a scale of 1:1, bathymetric data was construed from WorldView-2 satellite imagery with a pixel size of 4 m and a vertical resolution of 10 cm between neighboring pixels. For the study area, depths of up to 20.9 m were measured.

Fig. 4.3 Species modelling and texturing, using the example of the great barracuda (*Sphyraena barracuda*)

Benthic coverage, the most relevant thematic information for this project, was derived both from WorldView-2 data and on-site information (including video and photo material), and aggregated into a seven-part classification of reef communities (Fig. 4.2). It is worth mentioning that the study area includes the "Limones reef", one of the last spots of the reef system with a high presence of elkhorn corals (*Acropora palmata*; Rodríguez-Martínez et al. 2014; cf. Fig. 4.4).

4.4.1.2 3D Modeling

Figure 4.2 represents the study area's benthic coverage with traditional, two-dimensional cartographic symbols (in this case, through colors). In order to visualize this information in a GeoIVE, classes of benthic coverage first have to be disaggregated into lists of (the most representative) species. In the present project, these listings are derived from the National Biodiversity Information System (SNIB), developed by CONABIO.

Each species is then modeled tridimensionally with 3D computer graphics software (here: Blender). The method used for 3D modeling in this project is based on guide images: These images, taken from the side-, back-/front- and top-/bottom views, are used to fit basic geometry objects (e.g., cuboids) to the identifying features of the species to be represented. Moreover, the same images serve as reference material to define realistic textures of the VR models. Finally, skeletal animations are applied to simulate the active and passive movements typical for each species (Fig. 4.3).

4.4.2 Coral Reef Composition

To merge both the GIS data and 3D models generated during the aforementioned modeling phase into a format suitable for an immersive visualization on a HMD, game engines (in this case: Unreal Engine (UE)) provide powerful middleware with which

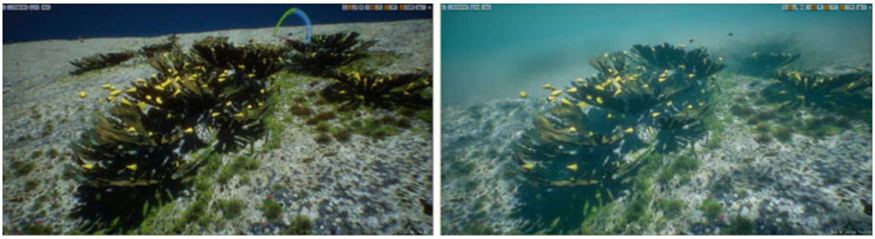

Fig. 4.4 GeoIVE before (left) and after (right) ambience setting

to compose a realistic VR application. In accordance with Fig. 4.1, the following intermediate steps can be distinguished:

4.4.2.1 Ecosystem Composition

Pre-georeferenced GIS data can be directly imported into a game engine software. Digital terrain models are converted into a 3D mesh to provide a geomorphologically correct basis for the GeoIVE. On this basis, thematic layers prepared in a GIS can then be applied to the 3D mesh as 2D textures, conserving spatial relationships between the basemap and ecosystem components. In order to also represent the ecosystem tridimensionally, 3D models are imported and distributed on the 2D texture, according to the real-world distribution area of each species. Figure 4.4 illustrates this procedure using the example of the *Acropora palmata*'s 3D representations, which are spread on the bathymetry model in accordance with the distribution area documented in the GIS (cf. Fig. 4.2).

4.4.2.2 Ambience Setting

As shown in Fig. 4.4 (left scene), ecosystem composition in terms of 3D model distribution usually does not produce visualization that is suitable for forming a sensation of spatial presence. Instead, a more realistic ambience setting must also consider the environmental effects (e.g., atmospheric parameters). In this case study, water with characteristics typical of a Caribbean coral reef is simulated in accordance with reference photos and videos through color (by UE's post-process-volume function) and visibility range (UE's exponential height fog). An animated material applied to the principal light source simulates caustics, while wave movements are generated by UE's virtual wind function. To further facilitate the formation of spatial presence, stereo scuba sounds are included to support site-appropriate ambience also through auditory perception. Figure 4.4 illustrates how ambience setting can significantly improve the realism of a GeoIVE.

4.4.2.3 User Interface

The six degrees of freedom (6DoF) in terms of interaction with and within the VR systems are an important element for achieving immersion and the experience of spatial presence. The techniques of navigation, selection and manipulation and user perspective have to be considered.

Regarding techniques of interaction, the input device chosen is crucial. Since common input tools such as mouse and keyboard are not suitable for 6DoF navigation in a 3D space, an optical tracking system is used in this project. This system tracks the user's head, translating head movements in congruent views within the GeoIVE, so that users see the sunlight when looking up, or the sea floor when looking down, for example. Handheld motion controllers allow users to explore the virtual ecosystem.

Regarding user perspective, navigation in this project is based on the flying vehicle control model metaphor (cf. Duan et al. 2015). Alternatively, it would be possible to put the user not into the perspective of a neutral observer but rather into the role of a protagonist within the GeoIVE (e.g., as an avatar of a given species or human actor). Recent studies indicate that VR applications produce higher engagement, when people interact from the perspective of an avatar; this so-called embodiment increases users' involvement with environmental issue, as shown by the example of ocean acidification (Ahn et al. 2016).

4.4.3 GeoIVE Production

Game engines (here: Unreal Engine) allow packaging of the final VR application for all of the (still few) HMD systems currently available on the market, rendering stereo images of the GeoIVE on the fly (cf. Fig. 4.5). However, in order to provide maximum immersion and spatial presence, both HMD and powerful graphics hardware are required. Since this constellation is not yet accessible for most users, we are also publishing parts of the GeoIVE built in this project as less- or non-immersive applications.

A less-immersive but more readily accessible solution is offered by VR-enabled applications, where a head-mounted smartphone provides the display and processor of the VR system (e.g., Google's Cardboard). In the present project, we took advantage of this alternative in the form of a smartphone app, where the user can experience all modeled reef species tridimensionally with a head mount for a smartphone. It should be noted, that standalone HMD, with no external PC or smartphone attached (e.g., Oculus Go), promise a more widespread coverage of highly immersive VR applications in the near future.

Fig. 4.5 Stereo-scene of the final GeoIVE, rendered for a HMD

Finally, for those users with no type of HMDs at hand, a non-immersive desktop VR application of the coral reef was built by the game engine in order to provide an even broader public with the information generated. Both the GeoIVE and all secondary VR applications generated during this project are available online.[2]

4.5 Conclusion

Growing volumes of data, paralleled by increasing computer processing power, allow us to look ever further in time and space. As we have seen at the beginning of this chapter, these different dimensions of distance create psychological distance, complicating the transfer of knowledge that pertains to policy and actions and thus participation in the solving of geospatial problems. Moreover, these data are frequently put into numbers (i.e., quantitative), while user studies indicate that people are rather "numbed by numbers" (Slovic 2007). Immersive VR technologies convert the numbers of big data into qualitative scenarios that one can experience and comprehend, reducing distance through the formation of spatial presence in GeoIVE of present, past, and future geographies.

GeoIVE have not yet been included in the set of core geospatial technologies (GST; Baker et al. 2015). The benefits are obvious though: Developing spatial-thinking abilities via GST is frequently mentioned as a central learning target in geography education (Donert et al. 2016; Otero and y Torres 2017). GeoIVE provide a new technological framework to integrate established GST like GIS and remote

[2] http://www.biodiversidad.gob.mx/geoviz.

sensing into complete learning lines (cf. Donert et al. 2016), not only facilitating geospatial skills like asking geographic questions and acquiring geospatial information (National Research Council 2006) but also to "explore and visualize real-world, critical problems" (Tsou and Yanow 2010) in a virtual environment. For these purposes, GeoIVE are fine instruments: They not just allow to explore and visualize geospatial problems distant in time and/or space, but also produce engagement and involvement with the problems visualized, thus stimulating a quite Socratic concept of thinking, where understanding and taking action are tightly connected. Furthermore, it is worth recalling that we have proposed to use game engine software to connect GIS with immersive VR output devices. Consequently, GeoIVE can also be conceptualized as computer games and hence provide a genuine link between GST and gamification approaches (Boulos et al. 2017; Freina and Canessa 2015).

In this paper, it has been argued that geospatial technologies are not yet VR ready, challenging geographers both in theory and practice. On the theoretical side, the relationship between virtual and physical reality (with the latter the traditional subject of geographic research) has to be questioned: It is often assumed that immersive virtual environments are not real, but rather mere simulations and representation of reality. However, this assumption does not necessarily hold true (cf. Dilworth 2010; Brey 2014) and geographers are required to define, to what extent shall virtual space be a field of research in twenty-first-century geography. Addressing this question is all the more urgent since the aforementioned considerations are not limited to virtual reality in the narrow sense discussed in this paper. Rather, a theoretical framework is required that also includes future options of augmented reality (AR), where physical reality is blended with VR elements.

On the practical-technical side, we have seen that the compatibility of current GIS with immersive output devices such as HMD is limited. This is not only due to missing stereoscopic real-time rendering of GIS content, but also the predominant spatial data models, which are not designed to represent geodata at a 1:1 scale necessary to provide users with spatial presence in an immersive environment. Overcoming both technological and theoretical shortcomings will be a challenge for twenty-first-century geographers that must be overcome in order to effectively link real geographies and virtual realties with immersive geospatial technologies. The main purpose of this text was to indicate how geography could benefit from linking virtual and real.

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Chapter 5
Location Is Value: Spatial and Business Modeling Integration

Eugenia Sarafova

Abstract A business model describes the rationale of how an organization creates, delivers, and captures value. Value proposition seeks to solve customer problems and satisfy their needs. All organizations, no matter they are pure business or public bodies, have their own business model to serve their customers. For example, all the people who live in a municipality are its customers and benefit from its value. The municipality has its own business model to create, deliver, and capture value not only for all the people who live there, but for all those doing business, tourists, etc. Spatial modeling on the other side assists users in the process of decision-making and helps them solve any type of spatial problem. Since 2009 location data from millions of people holding devices in their hands is being accumulated and analyzed. One of the greatest sources of data today are not the geospatial datasets of the companies, but the ordinary people. Crowds now have the power to capture, store, and even analyze spatial data and all that could be explained by one word, which emerged just 12 years ago—crowdsourcing. This changed in an amazing way even the most traditional business models, created new ones and shaped whole industries.

Keywords Location · Spatial modeling · Business modeling · GIS

5.1 Introduction

A business model describes the rationale of how an organization creates, delivers, and captures value (Osterwalder et al. 2010). Value proposition seeks to solve customer problems and satisfy their needs. All organizations, no matter pure business or public bodies, have their own business model to serve their customers. For example, all the people who live in a municipality are its customers and benefit from its value. The municipality has its own business model to create, deliver, and capture value not only for all the people who live there, but for all those doing business, tourists, etc.

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Spatial modeling on the other side assists users in the process of decision-making and helps them solve any type of spatial problem. Since the first mobile phone with Global Positioning System (GPS) integration was launched (iPhone 3 in 2009), location data from millions of people holding devices in their hands is being accumulated and analyzed. One of the greatest sources of data today are not the geospatial datasets of the companies, but the ordinary people. Crowds now have the power to capture, store, and even analyze spatial data and all that could be explained by one word, which emerged just 12 years ago—crowdsourcing. This changed in an amazing way even the most traditional business models, created new ones and shaped whole industries.

It is believed that we are now living in the times of the Fourth Industrial Revolution. Klaus Schwab has associated it with the "second machine age" in terms of the effects of digitization and Artificial intelligence (AI) on the economy (Schwab 2016).

Disruptive business models using Geospatial Technologies are emerging to provide powerful spatial knowledge to their customers. Automotive industry is an excellent example, as we are seeing some drastic changes in the way companies are changing their value proposition in two directions. First, mobility is seen not as a car, but as a service and second, developing new, environmentally friendly engine requires a reorientation of previous vehicle concepts. It is crucial that car manufacturers and suppliers reposition themselves for the two paradigm shifts (Lemmer 2017).

Global influencers nowadays share common ideas about the changes that geography is facing—it is becoming more and more complex, interdisciplinary, technological, and intelligent. The power of global connectivity and its consequences for the people around the world are reshaping the whole understanding of how our planet is going into the future (Khanna 2016). Spatial analysis, modeling, and mapping are now shifted by a new and more precise term—location intelligence (LI). LI is an emerging methodology for turning location data into business outcomes, helping businesses solve their most complex questions and challenges (de la Torre and Giraldo 2017). It plays an increasingly important role for organizations and businesses by providing accessible insight into where things happen, why they happen, and what the next best move is.

LI is believed to be the driver of significant changes in the geospatial industry. The main building blocks of that process are

- Mastering big data: satellites, sensors, crowdsourcing data are shifting the industry from "where-to-find-data" to "how-to-analyze-it" paradigm. Big data from sensors (Internet of Things or IoT) and Big data from people (Internet of People or IoP) combined form the last huge idea for the World Wide Web—Internet of everything or IoE;
- Tailoring location analysis to better serve different industries, public bodies or projects;
- No direct costs for hardware improvement due to the usage of cloud computing services and analysis;

LI has a direct connection with Business Intelligence (BI), which is related to the analysis of business data. LI is now significant part of BI and companies such as Mapbox, founded in 2010, and Carto, founded in 2011 are proof for that. They are Software as a Service (SaaS) providers and are using cloud computing for web spatial analysis and mapping.

In this study, business modeling tool and its integration with the results from spatial modelling are demonstrated for assisting the decision-making process in the field of sustainable tourism. The Business Model Canvas was used for modeling the as-it-is and to-be business models of Municipality of Kyustendil, Bulgaria. The particular area was chosen according to the requirements of the Tourism Act in Bulgaria, which defines local government bodies as entities with specific responsibilities for tourism development. Kyustendil Municipality was selected because of the dynamics of socioeconomic processes that occur in this part of Bulgaria—on one hand depopulation in rural and border areas, unemployment, and on the other hand a major natural, cultural, historical, archaeological, and ethnographic wealth.

5.2 Study Area

Kyustendil Municipality is located in the western part of Bulgaria and is one of the nine constituent municipalities of the Kyustendil region. The municipality borders with Bulgaria's neighbors Serbia and Macedonia, as well as with Treklyano, Nevestino, Bobov Dol, Zemen, and Radomir municipalities (Fig. 5.1). Its border passes through the mountains Osogovska, Chudinska, Kobilska, Izvorska, Zemenska, and Konyavska as well as through the Zemen gorge of Struma river.

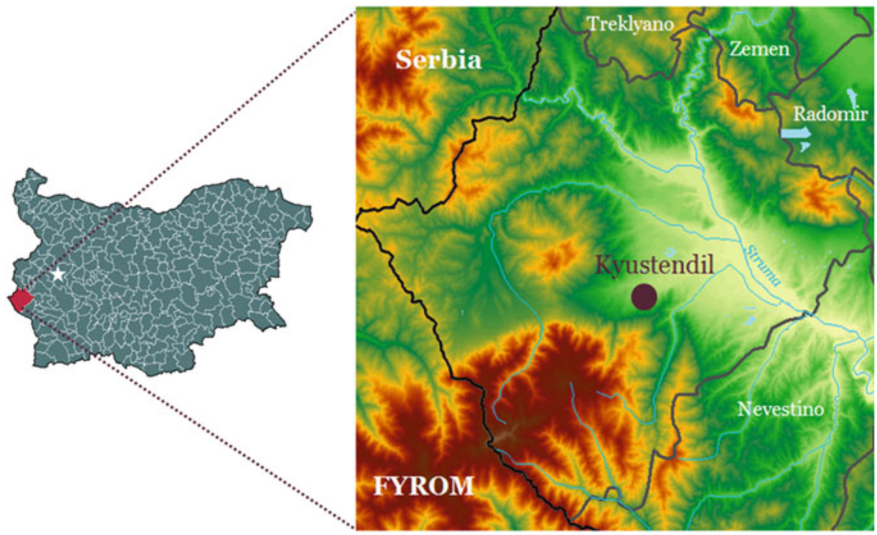

Fig. 5.1 Kyustendil municipality and its neighbors

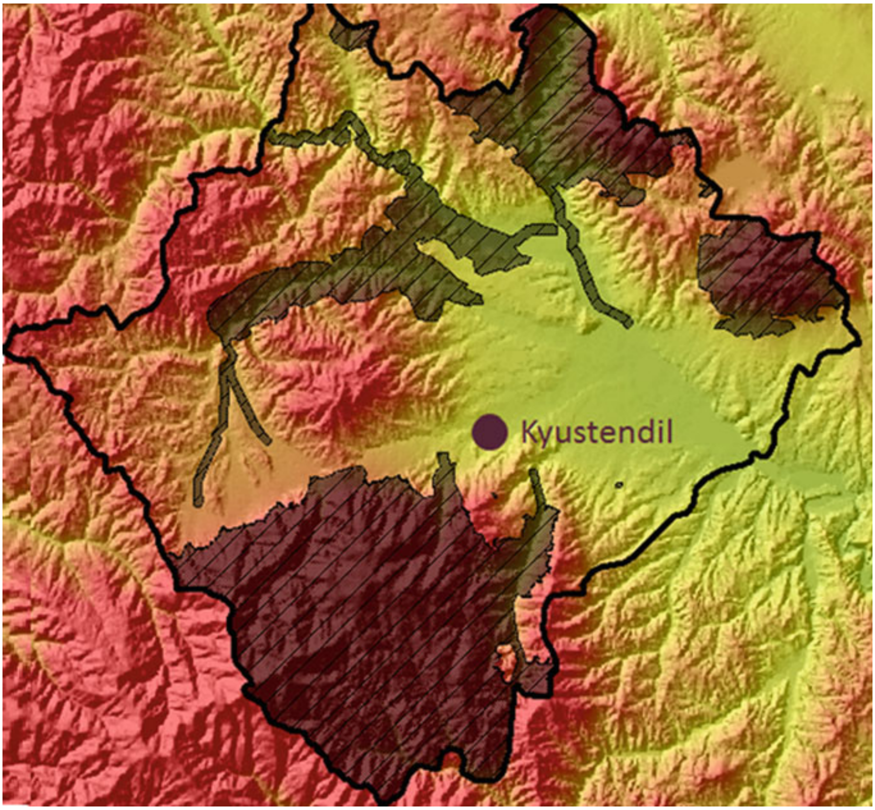

Fig. 5.2 Protected areas in the territory

The geographical location of Kyustendil determines the existence of rich natural and anthropogenic tourism resources. It is located on ancient trade routes, has a variety of well-preserved natural areas and has the potential for development of various types of tourism, including ecotourism.

The presence of karst in the area (in Zemenska and Konyavska mountains) is an opportunity for the development of tourism sector, because thanks to these processes many interesting rock formations, caves, and other sites have been formed that have a great attraction value.

One of the biggest natural resources of the municipality are the mineral springs, which have glorified the town's name as a SPA resort since the time of the Roman Empire. They are factor that determines the great opportunities of the town of Kyustendil to become a year-round resort. The municipality also has a great potential for development of ornithological tourism, because one of the main routes for birds' migration from Europe to Africa via Aristotelis passes through its territory. It has the second largest number of migrating birds in Bulgaria after Via Pontica near Black sea. Approximately 50 species of birds pass on the migration route, using the Zemen gorge and the area around Choklyovo swamp for resting and feeding. In addition, there are very rare plant and animal species in the protected areas. This proves the excellent conditions for practicing alternative sustainable forms of tourism in the territory of Kyustendil Municipality.

39% of the territory is under the protection of NATURA 2000 or The Protected Territories Act of Bulgaria (Fig. 5.2). This is more than the average number in Bulgaria (33%) and the EU (18%).

Kyustendil is one of the few towns in the country that has heritage from all historical periods—prehistoric, Thracian, Roman, Byzantine, Ottoman, as well as remarkable examples of the Bulgarian medieval and Renaissance art.

The combination of natural, cultural, and historical heritage in the municipality implies great potential for development of various forms of tourism, especially in the archaeological reserve "Pautalia–Velbuzhd–Kyustendil". The modern holidays, festivals and other cultural events enrich and complement it.

5.2.1 Kyustendil in the Context of Tourism Industry in Bulgaria

The National Strategy for Sustainable Development of Tourism in Bulgaria 2009–2013 defined the following strategic objective: "To promote the introduction of modern information technologies and marketing of cultural heritage." In the SWOT analysis of the Bulgarian tourist product as a threat was defined the severe lagging of the penetration of new information technologies. One of the activities that support the strategy was linked to the introduction of modern information technologies to create and modernize the national systems and networks. The Strategy for Sustainable Development of Tourism in Bulgaria 2014–2030 also defines a similar vision for the integration of advanced high-tech solutions in the process of analysis and evaluation of tourism resources and their presentation to tourists in digital form. The vision that is defined at the beginning of the document states: "Bulgaria - a well-known and preferred year-round tourist destination with clearly recognizable national identity and preserved culture and nature, occupying a leading position among the top five destinations in Central and Eastern Europe." This statement is completely overlapping with the ideas for ecotourism development with specific requirements and criteria in several regions in the country. According to the data from the above-mentioned strategy, ecotourism is placed on the fifth place among the other forms of tourism in the country with only 4.6% of the total tourism product, and as the main factor that determines the destination for ecotourism is the attractiveness of the nature. It is obvious that information technologies allow easy and efficient access to wide variety of information, maps, and other products that could play a big role in attracting tourists to a destination, its marketing, and promotion among target users.

The current international political situation in Europe and in the whole world has an adverse impact on the inflow of tourists from countries, which traditionally had a large tourist flow to Bulgaria. Because of that and many other reasons, in early 2015 the Ministry of Tourism launched the campaign "50 Little-Known Tourist Sites in Bulgaria", and its main idea was to encourage domestic tourism—to compensate for the declining number of foreign tourists and revive some of the lagging regions in the country. In November 2015, the Ministry of Regional Development and Public Works started public discussion called "Targeted Investment Program for Supporting the Development of Northwestern Bulgaria, Rhodopes, Strandzha-Sakar border and Mountainous undeveloped areas - Section I". The program aims at revitalizing the regions with the weakest economic and social indicators. One of the measures contained in it is an investment in tourism infrastructure. This shows that it is necessary that investments in alternative types of tourism to be made in the country, because Bulgaria has excellent conditions for its development in many rural areas.

As the alternative tourism activities are becoming more and more attractive, they are potentially good choice for strategic development in non-industrial territories. Many rural regions in Bulgaria have protected natural and archaeological sites, unique culture and traditions, but still do not have good economic development. Tourism could be the only alternative for the people living in those regions for prosperity. The complex international situation on the Balkans and in Europe is threat for the mass tourism in Bulgaria, so the stimulation of the domestic tourist activities is very important.

5.3 Spatial Modeling

The main objective of spatial modeling was to analyze the ecotourism potential of the territory using satellite images and GIS. The results were integrated after that into a business modeling tool—The Business Model Canvas.

In a number of scientific works authors define the most important principles of spatial modeling—Ferrier et al. (2002), Roy and Thill (2003), Ferrier and Guisan (2006), Aplin (2005) and many others. Very good understanding of the modeled objects and processes in the real world is crucial in the context of spatial modeling using Remote Sensing data and GIS. In the field of geoinformatics and GIS concepts of "modeling" and "models" are used primarily with two main meanings—as data models and as process models. We should add to this the traditional understanding of modeling in cartography.

Spatial modeling of ecotourism potential was performed by using Remote Sensing data, GIS and was based on the Analytic Hierarchy Process (AHP). To achieve this goal, three main steps were defined

- Research for the most up-to-date concepts and methods for spatial modeling for the purpose of ecotourism.
- Research for basic concepts and factors that determine ecotourism potential and the opportunities for application of satellite imagery and GIS data for its evaluation.

– Integrating the methodology for assessing ecotourism potential with data from satellite images. Testing the proposed methodology with data from the municipality of Kyustendil in Bulgaria and integration of the results with Business Model Canvas (Fig. 5.3).

The first step was preliminary study of the territory and its main features, based on scientific literature, statistics data, and historical maps. The information that was gathered helped in the process of indicators definition on a later phase. Geodatabase was created for the needs of ecotourism evaluation and all the data gathered from the preliminary study was stored there, both in geometric and attribute form, depending on its type. After the initial gathering of data, the as-it-is Business Model Canvas was created.

The Analytic Hierarchy Process (AHP) was used for comparison and analysis of the eight ecotourism indicators that were defined in the Research and Development phase of the study. It is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s. Users of AHP first decompose their decision problem into a hierarchy. Its elements could relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well or poorly understood—anything that applies to the decision at hand. AHP includes combination of interviews and mathematical synthesis of the results for each indicator (Saaty 2008). Making hierarchy is a way of stratification and organization of people, ideas, objects, etc., where every element of the system, except the main goal, is subject to one or more other elements (Saaty 2010).

AHP has been used before in numerous studies related to the environment worldwide Bunruamkaew (2012), Oladi and Taheri Otghsara (2012), Shahabi et al. (2012),

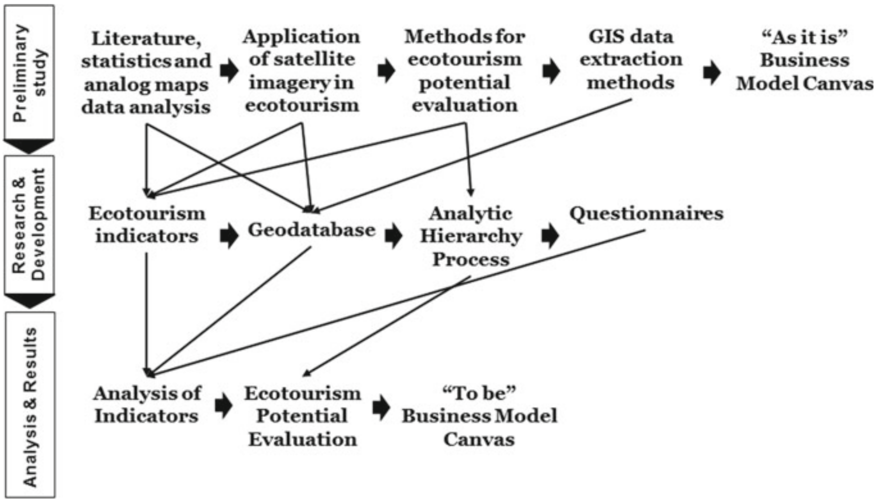

Fig. 5.3 The process of spatial and business modeling

Bozorgnia et al. (2010), Tola (2010), Abdus Salam et al. (2000), and others. Geographic Information Systems are widely used for the preparation of spatial models and maps, but unlike them the application of satellite imagery in this area still has not been studied well enough. The spatial modeling of the real world through GIS includes processes for determining the primary purpose of modeling, selection of the most appropriate data for each object that will be included in the geodatabase, identifying the most important properties of it and their correlated attribute values, and selecting appropriate cartographic methods for visualization of the model in its final form.

Software tool, developed by Oswald Marinoni in 2006 for usage in ArcGIS, was used for AHP modeling in spatial analysis. The app uses ArcMap raster files, previously generated for each criteria, and calculates their weights from the results of the questionnaire to the final result of the modeling process.

In order to define the criteria that determine the ecotourism potential of the municipality, indicators from various sources for ecotourism development were considered. This included the indicators presented by the International Ecotourism Society and European Tourism Indicators System for sustainable destination management.

The selection of criteria for Kyustendil Municipality took into account the natural, socioeconomic, and historical characteristics of the territory. Support for the selection of criteria was also provided by tourism experts working in other municipalities in Bulgaria who shared valuable experience, the Bulgarian Tourist Union, the Bulgarian Association for Rural and Ecological Tourism, members of the Osogovo Tourist Society. The criteria were grouped into three large groups: (1) natural (2) socioeconomic and (3) historical. In order to comply with AHP, each indicator received weight and evaluation, based on interviews with experts in that topic. All criteria were modeled as layers in ArcMap, where the final result was calculated (Fig. 5.4).

All eight raster layers were used to perform the analysis using the ArcGIS 10.0 and the AHP plugin. The resulting raster is shown on Fig. 5.5.

AHP, combined with data from satellite imagery and GIS data, was an excellent way to analyze the ecotourism potential of the municipality as it is possible to make a comprehensive overview of all aspects of ecotourism. Further spatial analysis with various tools was conducted in order to achieve greater precision and accuracy of the spatial modeling.

5.3.1 Customization of the Model

In twentieth century *Pinus sylvestris* and *Pinus negra* were widely used for reforestation in areas, located nearby settlements, where it was necessary to limit the erosion process. In the municipality of Kyustendil there are no natural forests of coniferous species and they create unusual ecological conditions. Therefore, these territories were excluded from the areas with high potential for development of ecotourism. This analysis was made by using data from Landsat 8 and the result is shown at Fig. 5.6.

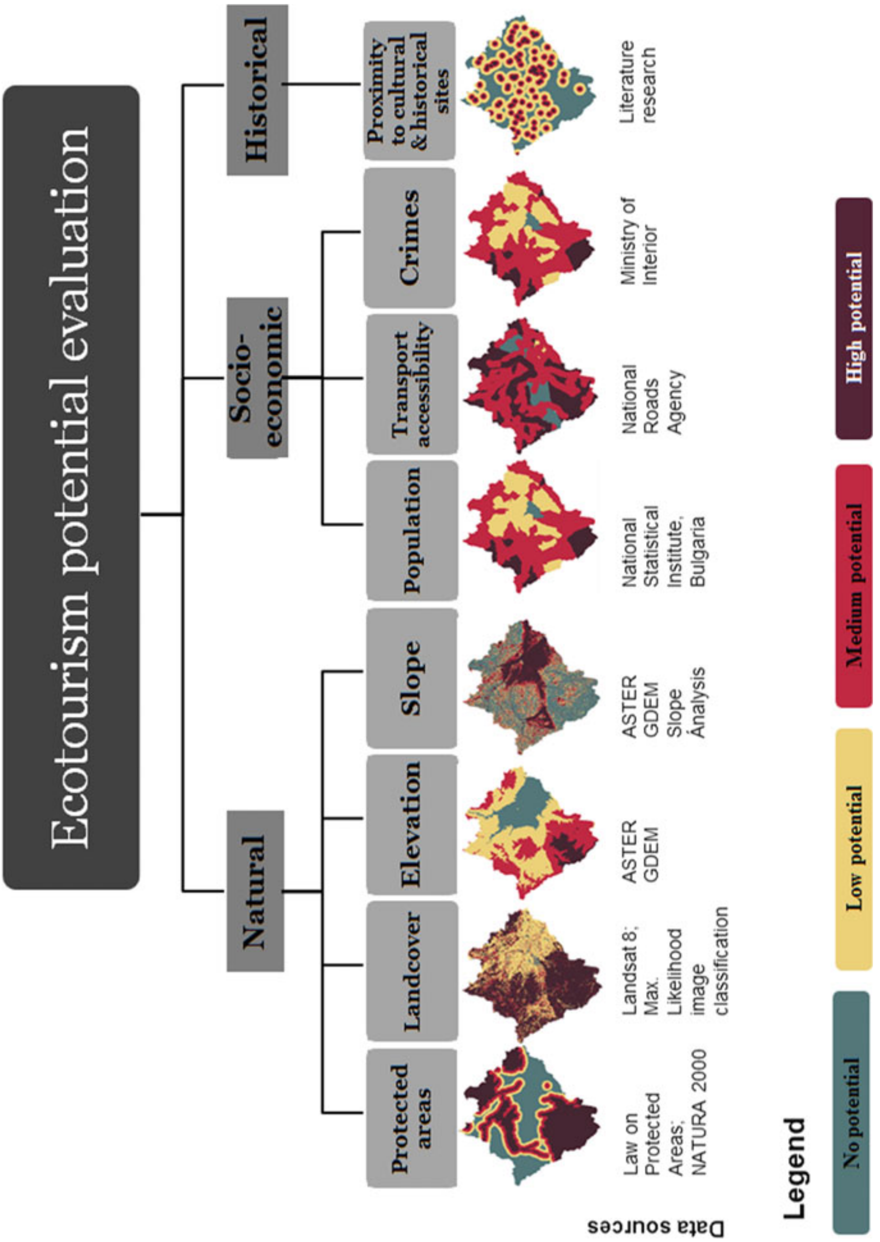

Fig. 5.4 The process of spatial and business modeling

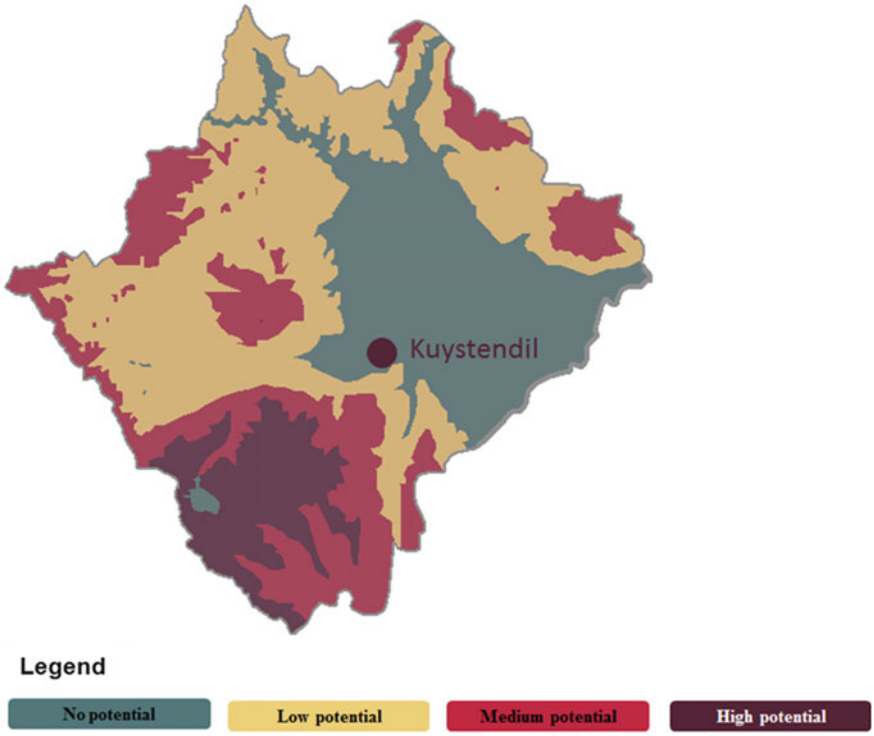

Fig. 5.5 Ecotourism potential visualized after AHP modeling in ArcGIS 10

Analysis of the visibility from several tourist routes, which tracks were collected with GPS, was also performed. Visual qualities of landscapes are of great importance for ecotourism. After the analysis, it turned out that 16 mountains, more than 2000 m high, located in Albania, Serbia, Macedonia and even the remote Mount Olympus in Greece, can be seen from the highest peak in the municipality (Fig. 5.7). This was verified by on-site field observations.

Another example of using satellite imagery in spatial analysis was comparing the border areas in Bulgaria and FYROM (Fig. 5.8). We can see very clearly the positive side of depopulation and poor economic development of the Bulgarian border areas—the Bulgarian side of Osogovo mountain is green, and its Macedonian part—deforested. This situation can be seen also in the Bulgarian border mountains near Serbia and Greece. The reasons for this are the measures of Bulgaria's neighbors to actively develop their rural and remote areas.

There are many places in Municipality of Kyustendil with concentration of cultural, historical and natural landmarks, which is a prerequisite for excellent conditions for development of eco and other forms of sustainable tourism.

Fig. 5.6 Territories with coniferous forests

5.4 Business Modeling

Business Modeling is already a widespread idea, defining the analysis and improvement of business processes in organizations. It is also topic that emerged due to the dynamic changes in the business environment. Modeling gives the management of organizations a clear picture of the whole business—internal and external processes, data flow and people.

Modern tool to simply visualize the business model of an organization is the Business Model Canvas, proposed by Alexander Osterwalder in 2008. In “Business Model Generation” from 2010 the authors crowdsource the idea to 470 practitioners from 45 countries and co-create the concept for the nine building blocks that show the logic of how a company intends to make money. The nine building blocks cover the four main areas of a business: customers, offer, infrastructure, and financial viability (Osterwalder 2010):

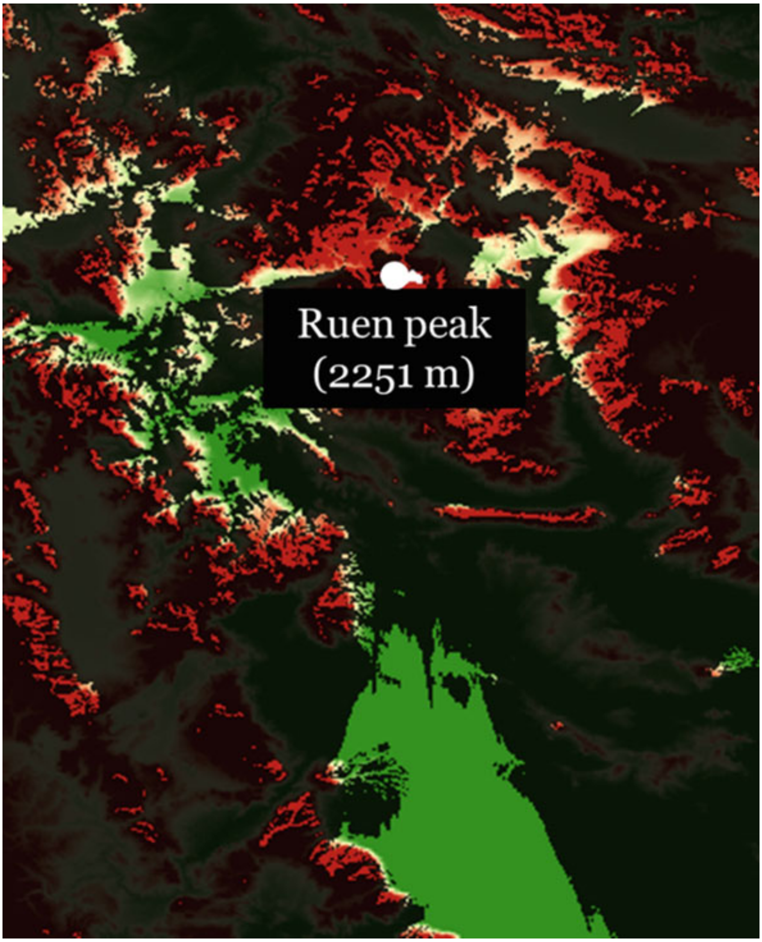

Fig. 5.7 Visibility analysis showing the territories that could be seen in light and those that could not be seen in dark

- Customer Segments
  An organization serves one or several Customer Segments.
- Value Propositions
  It seeks to solve customer problems and satisfy customer needs.
- Channels
  Value propositions are delivered to customers through communication, distribution, and sales channels.
- Customer Relationships
  Customer relationships are established and maintained with each customer segment.

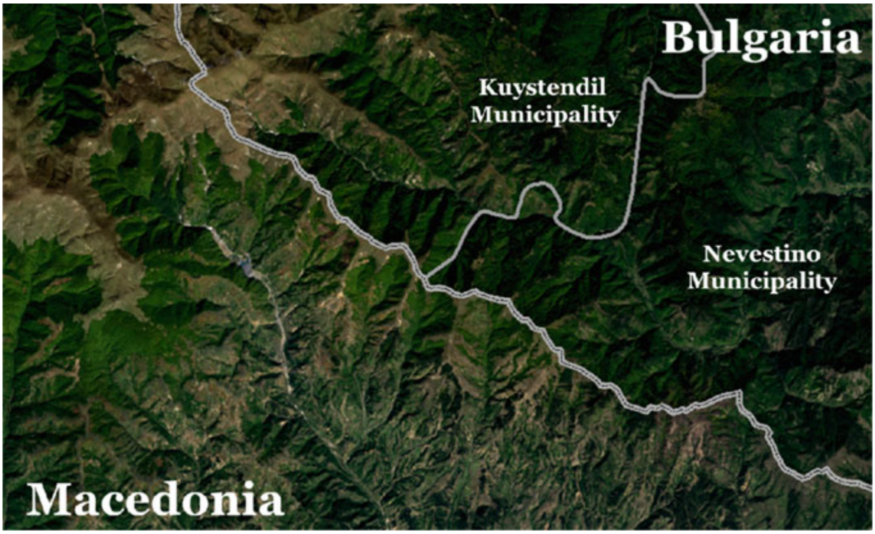

Fig. 5.8 Satellite image from Landsat 8 (14.08. 2014), Bands 4 3 2

– Revenue Streams
  Revenue streams result from value propositions successfully offered to customers.
– Key Resources
  Key resources are the assets required to offer and deliver the previously described elements.
– Key Activities
  The activities that are being done to maintain the previously described elements.
– Key Partnerships
  Some activities are outsourced and some resources are acquired outside the enterprise.
– Cost Structure
  The business model elements result in the cost structure.

Business Model Canvas could be used in two different ways. The first shows the current situation and is defined as as-it-is, and the second is used to shape the future possibilities for the organization and is defined as "to be". In this study, first the as-it-is canvas was used as a basic tool for understanding the building blocks of the organization. Second, the results of the spatial analysis provided the information about the key resources and value the organization is providing to its customers. Third, the "to be" Business Model Canvas was used to define the strategy of the organization for its development in a specific area, taking into account the results of the spatial modeling.

The Business Model Canvas was used for visualization of the current elements of Kyustendil's as-it-is together with the proposed changes in green boxes in to-be Business Model (Fig. 5.9).

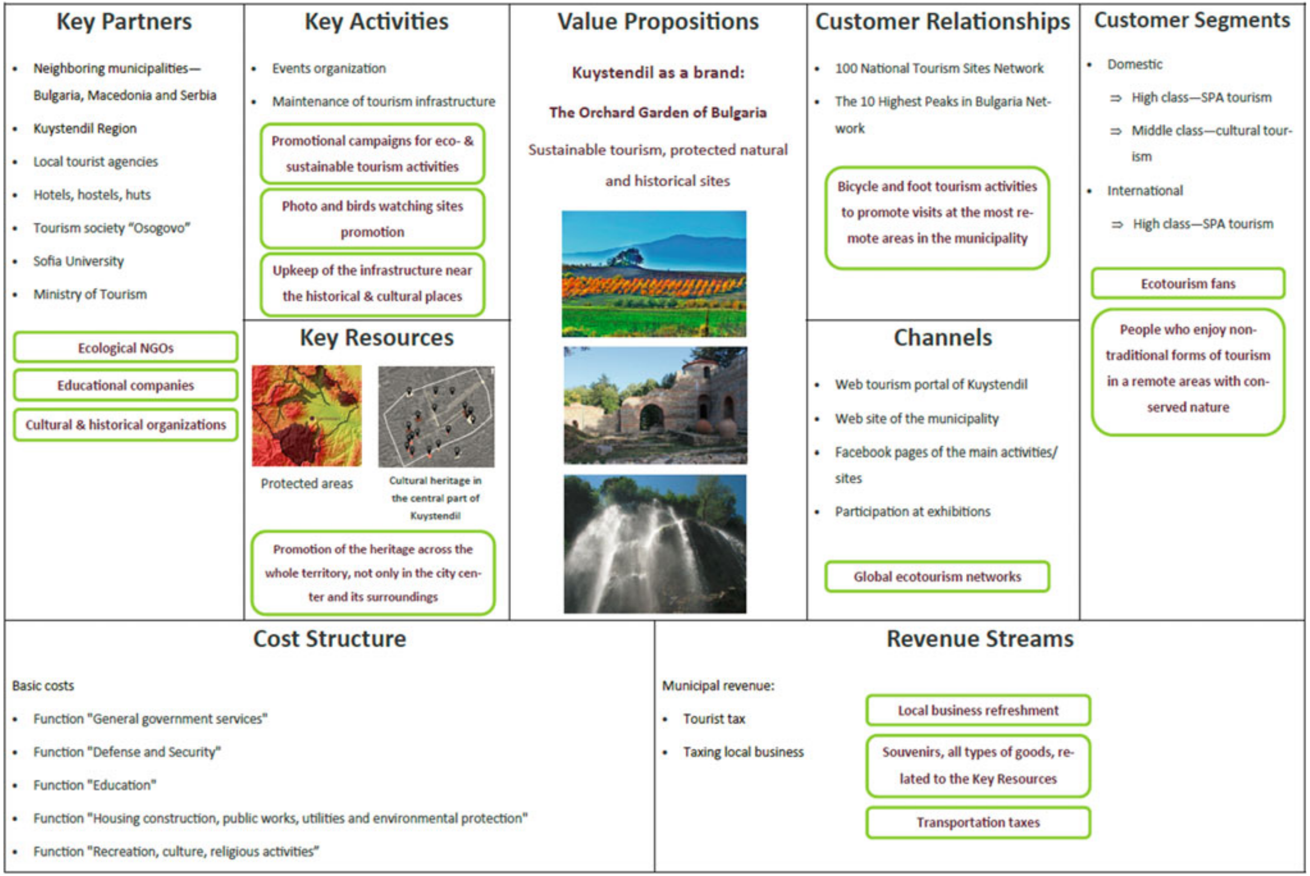

Fig. 5.9 As-it-is Business Model Canvas of Municipality of Kyustendil regarding to ecotourism and proposed changes in to-be Business Model Canvas in green boxes

Key Partners

For the municipality these are the companies working in the sphere of servicing, including travel agencies, transport companies, and accommodation. In addition, all the neighboring municipalities, from Bulgaria, but also from Serbia and Macedonia, should be listed here as they are able to partner with each other in cross-border projects or tourist services. Sofia University, and in particular the Faculty of Geology and Geography, has a major role in the promotion of the area around the Zemen gorge due to the University's Center for field studies, located nearby. The Ministry of Environment and Water and the Ministry of Tourism are institutions that play an important role in the management of the protected areas in the municipality and its positioning as a tourist center.

Key Activities

Key Activities are directly related to the development of the tourism industry. This is the most important segment of the business model pipeline and includes all the organization's work, marketing, and tourism infrastructure maintenance activities.

Key Resources

Due to the specifics of the ecotourism activities, the most important resource is the nature, which should be well preserved and attractive. Cultural, historical, and archaeological heritage are important for promoting the territory as an interesting and valuable complex product to tourists. If the region has its own well-preserved traditions, folklore as well as unique characteristics, they should be used for marketing and promotion of the destination.

Customer Relationships

Customer Relationships represent activities that bind clients (tourists) to the product/service they use. Such are, for example, the Bulgarian Tourist Union's initiatives "100 National Tourist Sites" and "Conqueror of the Ten Mountain Leaders in Bulgaria". Municipality of Kyustendil has been part of these national initiatives since many decades and has tourist sites in both of the lists.

Customer Segments

Tourists who visit the municipality can be divided into several categories that reflect the current situation with the industry in the region. If we take into account, their origin we could separate them into two major groups—domestic and international. The ideal customer for eco- and sustainable tourism activities could be described as adventurous, nature lover or person who does not want to stay in crowded, noisy places for mass tourism. This means that boutique forms of tourism activities with small groups, personal attitude, and a specially tailored program based on their specific needs will give the best value for those Customer Segments.

Channels

Channels are all tools of communication through which the municipality promotes its tourist resources. At the moment these are places on the Internet like websites and Facebook pages, as well as physical places in the real world—Tourist Information Center in the center of Kyustendil and participation in tourist fairs in Bulgaria and abroad.

Cost Structure/Revenue Streams

The financial balance of the municipality is a very complex mechanism in which it is difficult to separate a special segment for the tourism sector. This is because there are extremely many types of activities and infrastructure such as road and rail networks, public safety and security, taxes, which are related to tourism industry. However, tourism leads to diverse revenue streams, such as tourist taxes, business taxes, related to tourist services and trade, etc. They undoubtedly increase the economic and social development of the area.

Value Propositions

Value is the heart of the business model because it includes answers to questions such as “What are the issues of customers (travelers) we solve?”, “What products or services do we offer to each customer segment?”, “What type of customer needs are we meeting with our products and services?”. Building a strong brand “Kyustendil” is very important when it comes to a sector like tourism, even more so for the specific needs of ecotourism. It is important to promote everything related to the environmentally friendly way of life, the green initiatives of the municipality, the protected areas and their characteristics, etc.

After everything listed above, we can conclude that the municipality has favorable conditions for the development of ecotourism. In order to maximize the benefits of the natural and cultural heritage available, a number of strategic resources should be highlighted in order to be used in a sustainable way. Successful models for ecotourism development are linked to places with clear individualism—a combination of unique nature and local traditions. The municipality of Kyustendil offers an attractive combination of such factors and the development of alternative tourism activities could be the key for solving problems like depopulation and unemployment in the area. Ecotourism is a fast-growing sector at international level and the interest in it is increasing. That is why it is necessary consecutive steps to be followed for its popularization at both national and local level.

5.5 Results and Discussion

The results of the study show that there are unlimited possibilities for combination of spatial analysis tools in GIS. Based on the specific needs of each particular organization, it is possible a variety of criteria and conditions on which its strategic development depends to be defined and analyzed.

Any aspect that has spatial expression, like Kyustendil Municipality's potential for ecotourism development, can be successfully modeled in GIS. On the other hand, the results of spatial modeling should not only remain in the research papers, but be implemented through integration with various tools for business analysis, such as the Business Model Canvas. Through it, it is possible to focus the attention of all stakeholders on specific aspects of the development of the organization and the territory it manages.

In the twenty-first century, we are witnessing an increasing availability of open data that can be used in the decision-making process. This phenomenon, known as Big Data, leads to new opportunities for adding diverse data sources to all types of research activities. Ecotourism analysis for example could include also a number of weather, hydrological, satellite data, GPS tracks, and local sensor information. Another emerging source of data is the mobile applications that give us the opportunity to interpret consumer behavior and act on time.

Due to the rapid popularization of modern ideas and technologies, such as crowdsourcing and mobile services, satellite data, etc., it is possible to derive maximum benefit from any territory as long as it is innovative and smartly managed. The economic development of municipalities, regions, and even countries today is not only dependent by its physical resources, but also by their proper use, promotion and positioning on local and world markets. For the modern consumer the location, history, and the environment have great value, but on the other hand, location is losing its importance when it comes to promoting these sites, both locally and globally.

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Chapter 6
Mining Big Data for Tourist Hot Spots: Geographical Patterns of Online Footprints

Luis Encalada, Carlos C. Ferreira, Inês Boavida-Portugal and Jorge Rocha

Abstract Understanding the complex, and often unequal, spatiality of tourist demand in urban contexts requires other methodologies, among which the information base available online and in social networks has gained prominence. Innovation supported by Information and Communication Technologies in terms of data access and data exchange has emerged as a complementary supporting tool for the more traditional data collection techniques currently in use, particularly, in urban destinations where there is the need to more (near)real-time monitoring. The capacity to collect and analise massive amounts of data on individual and group behaviour is leading to new data-rich research approaches. This chapter addresses the potential for discovering geographical insights regarding tourists' spatial patterns within a destination, based on the analysis of geotagged data available from two social networks.

Keywords Geotagged photos · Geography · Social networks · Big data
Data mining · Spatial analytics

6.1 Introduction

Information and communications technologies (ICTs) enables to advance with new research questions that facilitate a better understanding of ourselves and the

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surrounding environment (Manovich 2011; Dalbello 2011). The last two decades have brought multiple tags related to the vast quantities of data made available by ICTs, e.g., "big data", "data avalanche" (Miller 2010), "exaflood" (Swanson 2007).

Geographers have been dealing with some of the issues raised by big data (Barnes 2013), questioning its theory and related practices shifts (Floridi 2012; Boyd and Crawford 2012; Crampton and Krygier 2015). Yet, it still has to be done a substantial and continued effort to understand its geographic relevance, as is in the case of the connection between big data and geography (Graham and Shelton 2013).

Despite big data puts challenges to conventional concepts and practices of "hard" sciences, where Geographic Information Science is included (Goodchild 2013; Gorman 2013), the predominance of big data will undoubtedly lead to a new quantitative turn in geography (Ruppert 2013). This is clearly a new paradigm shift in geography research methodologies: a fourth—data-intensive—paradigm (Nielsen 2011).

Geographic technologies are now integrated into social sciences, and promotes the value of geography to a wider audience. There is a growing list of applications of Geographic Information Systems (GIS) that expose its potential for handling the data deluge. Making sense of big data requires both computationally based analysis methods and the ability to situate the results (Berry 2012). Yet, it brings together the risk of plunging traditional interpretative approaches (Gold 2012). The big data era calls for new capacities of synthesis and synergies between qualitative and quantitative approaches (Sieber et al. 2011).

This paradox alliance between "poets and geeks" (Cohen 2010), can be a unique opportunity for geography, stimulating wider efforts to create a bridge over the qualitative–quantitative crater (Sui and DeLyser 2011) and enabling smart combinations of quantitative and qualitative methodologies (Bodenhamer et al. 2010; Daniels et al. 2011; Dear et al. 2011).

The emergence of critical geography, critical GIS and radical approaches to quantitative geography, fostered the idea that geographers are well prepared to combine quantitative methods with technical practice and critical analysis (Lave et al. 2014). This proved to be not quite true, but currently big data opens, specially through data mining, new possibilities for spatial analysis research (Michel et al. 2011) and can extend the limits of quantitative approaches to a wide array of problems usually addressed qualitatively (Lieberman-Aiden and Michel 2011; Michel et al. 2011).

It is a similar case to the rebirth of social network theory and analysis where due to the growing availability of relational datasets covering human interactions and relationships, researchers managed to implement a new set of theoretical techniques and concepts embracing network analysis (Barabási and Pósfai 2016).

Surveys are an example of this new paradigm shift. This method to collect information can exemplify the crisis of those widely used methods facing some difficulties regarding its utility often caused by the decline of response rates, sampling frames and the narrow ability to record certain variables that are the core or geographical analysis, e.g., accurate geographical location (Burrows and Savage 2014). Gradually, self-reported surveys quantifying human motivations and behaviours are being study and compared with non-traditional data (Struijs et al. 2014; Daas et al. 2015).

Such limitations are still more pronounced while considering that: (i) the majority of social survey data is cross-sectional deprived of a longitudinal temporal facet (Veltri 2017); and (ii) most social datasets are rough clusters of variables due to the restrictions of what can be asked in self-reported approaches.

Big Data is leading to advances on both aspects, shifting from static snapshots to dynamic recounting and from rough aggregations to data with high (spatial and temporal) resolution (González-Bailón 2013; Kitchin 2014).

Understanding social complexity requires the use of a large variety of computational approaches. For instance, the multiscale nature of social clusters comprises a countless diversity of organizational, temporal, and spatial dimensions, occasionally at once. Moreover, computation denotes several computer-based tools, as well as essential concepts and theories, varying from information extraction algorithms to simulation models (Cioffi-Revilla 2014; Alvarez 2016).

Big data and its influence on geographic research has to be interpreted in the context of the computational and algorithmic shift that may progressively influence geography research methods. To understand such shift, a distinction between two modeling approaches has to be addressed (Breiman 2001; Gentle et al. 2012; Tonidandel et al. 2016): (i) The data modeling approach that assumes a stochastic model in which data and parameters follow the assumed model; and (ii) The algorithmic approach that considers the data as complex and unknown, and is focused on finding a function that imitates the mechanism of the data-generation process, reducing the statistical model to a function, and keeping out any assumption about the data, e.g., data distribution assumptions (Breiman 2001; Veltri 2017). Whereas the former evaluates the parameters values from the data and then uses the model for information and/or prediction, in the latter there is a move from data models to algorithms properties. Here, what matters the most is an increased emphasis on processes rather than structures.

Big data introduces the possibility of reframing the epistemology of science, presenting two potential paths underpinned by disparate philosophies, Empiricism, and Data-driven science (Kitchin 2014).

6.1.1 Embracing "Big" Changes Beyond Traditional Methods of Data Collection

The label "big data" points to three features, also known as the 3Vs: (i) volume, regarded as the quantity of captured and stored data; (ii) velocity, intended as the quickness at which data can be collected; and (iii) variety, incorporating both structured (e.g., tables and relations) and unstructured (e.g., text and photographs) data (Kitchin 2014; Tonidandel et al. 2016). A fourth V, Veracity, has been added but, as denoted by Kitchin (2014), the term "big data" goes further and describes a type of analytic approach.

This is precisely the type of data created from immense complex systems simulations, e.g., cities (Miller and Goodchild 2015) but a big percentage of it, is provided by sensors and/or software that collect a wide range of social and environmental patterns and processes (Graham and Shelton 2013; Kitchin 2013). The sources of this spatial and temporal data embrace location-aware tools such as mobile phones, airborne (e.g., unmanned aerial vehicles) and satellite remote sensors. Automated data is also generated as digital traces recorded on social media, among others online platforms (Miller 2010; Sui and Goodchild 2011; Townsend 2013).

There is in big data an enormous potential for innovative statistics (Daas et al. 2015). Geolocation data retrieved from mobile phones records can be used to get virtually instant statistics of tourism and daytime/nighttime population (de Jonge et al. 2012). Simultaneously, social media can serve as the background to produce indicators of human mobility (Hawelka et al. 2014). Big data can also be used to replace or complement historical data sources, e.g., surveys, inquiries and governmental data. For instance, inquiries about road usage may become obsolete if detailed traffic data obtained by sensors on the road come to be available (Struijs and Daas 2013).

Part of big data sources, including social media, are made of empirical data and are not intentionally planned for supporting data analysis, i.e., they do not have a clear structure, a well-defined target population and/or proved quality. In this context, it is problematic to make use of statistical methods based on sampling theory, i.e., traditional methods (Kitchin 2013; Daas and Puts 2014a). Specially, the unstructured facet of several of the big data sources makes exponentially difficult to (data)mine significant statistical information. In numerous of these sources, the data explanation and its relations with social phenomenon's are still a very fuzzy field of analysis (Daas and Puts 2014b; Tonidandel et al. 2016).

In a broader perspective, there is another issue regarding the human and technical capacity required for processing and analyzing big data. Contemporary data researchers are probably better prepared than traditional statisticians are. Perhaps the upmost importance is the necessity for a distinct mind-set because big data points toward a paradigm shift (Kitchin 2014), comprising an increased and improved use of modeling practices (Struijs and Daas 2013; Daas and Puts 2014a).

Before big data, random sampling was the main approach to deal with information burden. This method works well, but has its own fragilities: it only performs well if the sampling is representative. Moreover, the sampling basis, i.e., a procedure for numbering and selecting from populations, may be tricky if numbering is performed imperfectly.

Sample data is also very attach to the objective it was first intended. Since randomness is so important it may be difficult to reanalyze the data with different purposes than those for which it was collected (Mayer-Schonberger and Cukier 2014). By the contrary, several of the new data sources do not rely on samples but in populations. Yet, populations have the problem of being tendentially self-selected rather than sampled. For instance, all people having smartphones, all people who engaged "Flickr" or any other social network, or all vehicles traveling in the City of Lisbon between 17:00 and 21:00 on a specific day. In addition, tweets can be a striking source of information (Tsou et al. 2013; Hawelka et al. 2014) but only a part of them are actually geo-located. Despite the specific characteristics of any of these groups may remain to be clarified; it is possible to generalize them to the populations they were sampled from (Encalada et al. 2017).

Nevertheless, some care should be taken since some information people voluntarily provide could not reflect a "real measurement" about their activities (e.g., digital traces of commuting behaviours). Furthermore, selection biases can also occur in the information people volunteer about their surrounding environment. For example, Open Street Map (OSM) is frequently recognized as a popular Volunteer Geographic Information (VGI) venture. Many places around the world, including those in developed countries, have been mapped through OSM with a noteworthy degree of accurateness. Nonetheless, some places such as tourist locations are mapped faster and/or better than others of less interest to OSM users, such as slums (Haklay 2010).

Of course biases also exist in official maps, because the governments (even the developing nation's ones) frequently do not map unconventional settlements such as slums and/or do not update regularly the existent cartography due to budget restrictions. Yet, the biases in VGI maps are probable more subtle. However, VGI platforms such as OSM facilitate tools for data cleaning and validation, so the users (acting as creators and co-creators) are able to remove the fuzziness as much as is conceivable. Goodchild and Li (2012) discussed the challenges regarding the quality of VGI. They concluded that both, traditional and non-traditional geographic information depend on multiple sources and on people expertise to draw together a cohesive image of the landscape. For instance, surface information may be collected from photogrammetry, terrain measurements, historic sources and crowdsourced data. From this synthesis process, the resulting map might be more truthful than any of the original sources by itself, i.e., the all is more than the sum of the parts.

6.1.2 The Analytic Background of (Big)Data Mining

Defenders of big data suggest that it generates thrilling prospects. Though detractors consider it to be more propaganda than reality (Franks 2012; Savitz 2013). Furthermore, big data analysis can be disapproved as a form of "dust-bowl empiricism" (Ulrich 2015; McAbee et al. 2017). Thus, there is a significant breach in our understanding of both the potential and threats of big data (Tonidandel et al. 2016).

Much of the geographic knowledge is based of formal theories, models, and equations that need to be processed in an informal manner. By the contrary, data mining techniques require explicit representations, e.g., rules and hierarchies, with straight access deprived of processing (Miller 2010).

Geography has a history of a relation between law-seeking (nomothetic) and description-seeking (idiographic) knowledge (Cresswell 2013). Wisely, physical geographers get away from these debates, but the nomothetic-idiographic tension keep on in human geography (Sui and DeLyser 2011; DeLyser and Sui 2012; Cresswell 2013). Possibly without surprise, geography has been censured for invalidated theories, results that cannot be reproduced, and a division amongst practice and science (Landis and Cortina 2015). Putka and Oswald (2015) indicate how geography could benefit by implementing the data algorithmic philosophy, and claim that the actual data modeling philosophy prevents the ability to predict results more accurate, and generates models that do not integrate phenomenon's key drivers, without incorporating uncertainty and complexity in a satisfactory manner.

Big data provides chances to detect genuine relations patterns (Dyche 2012). It is realistic to conceive that big data would allow to clarify some of the residual variance. This incremental legitimacy can arise from improved predictors, e.g., Internet footprints (Youyou et al. 2015).

As denoted by Tonidandel et al. (2016), multiple regression is undoubtedly the most widely used statistical approach. Multiple regression assumes that the model being performed is the most correct. Regrettably, the background theories are hardly ever satisfactorily developed to include the most pertinent variables. Also, many often researchers do not even know what can be the missing variables. Hence, researchers test a limited set of variables, and face the possibility to embrace mislaid variables with implications in the model accuracy, and thus in the conclusions drawn from the data (Antonakis et al. 2010).

In opposition to this traditional methodology, the data analytic approach trusts on multiple models or group of models. While the former focuses on selecting the best model and accept that it properly defines the data-generation process, the later analyses all the possible models to be resultant from the existing set of variables and combines the results through a multiplicity of techniques, e.g., bootstrap aggregation, support vector machines, neural networks (Seni and Elder 2010). The subsequent group of models achieves better results, deriving higher accurate predictions (Markon and Chmielewski 2013; Kaplan and Chen 2014). Big data analytics rooted in machine learning techniques can automatically detect patterns, create predictive models and optimize outcomes, facilitating traditional forms of interpretation and theory building. However, in some cases, the new data analytic techniques may not improve outcomes assessed by using more traditional techniques (Schmidt-Atzert et al. 2011).

Big data is supported by a theory platform and it could not be other way. Rather than compare big data to "dust-bowl empiricism", it leads to what Kitchin (2014) describes as data-driven science. Moreover, as denoted by Miller and Goodchild (2015), a data-driven geography may be emerging.

The notion of data-driven science defends that the generation of hypothesis and theory creation resemble an iterative process where data is used inductively. "Dust-bowl empiricism" stopes after the data mining process whereas the process of data-driven science goes on by coupling the inductive and deductive methods (as an iterative process). Hence, it is possible to name a new category of big data research that handles to the creation of new knowledge (Bakshy et al. 2014). Since the inductive process should not start in a theory-less void, preexisting knowledge guides the analytic engine in order to inform the knowledge discovery process, to originate valuable conclusions instead of detecting any-and-all possible relations (Kitchin 2014).

In spatial analysis, the tendency in the direction of local statistics, e.g., geographically weighted regression (Fotheringham et al. 2002) and (local) indicators of spatial association (Anselin 1995), characterize a concession where the main rules of nomothetic geography can evolve on their own way, across the geographic space. Goodchild (2004) sees GIS as a mix of both the nomothetic and idiographic approaches, retained, respectively, on the software and algorithms, and within the (spatial) databases.

Despite it is possible to go for geographic generalizations, space still matters. Both spatial dependency and heterogeneity generate a local context that shapes the processes that occur at the Earth surface. Geography has this believe for many years now, but this has been strengthened by the recent developments in complex systems theory, i.e., local interactions drive to emergent behaviors that are impossible to understand singularly and independently if they are analyzed from a sole (local or global) perspective. The co-created knowledge derived from the interactions between agents within a certain environment links the local and the global perspectives (Miller and Goodchild 2015).

Briefly, there is not a drastic breakdown with the tradition on geography when researchers move to data-driven geography, especially, in applied research. There is a long-lasting confidence regarding the significance of idiographic knowledge per se and its contribution on creating nomothetic knowledge. Even though this confidence is sometimes weak and questioned, data-driven knowledge discovery offers the chance to advance the relationship amongst idiographic and nomothetic geography. Still, despite the fact that complexity theory supports this idea, it advises at the same time that data-driven knowledge discovery may have intrinsic limitations, i.e. emergent behaviour is unpredictable by definition.

6.2 Big Data from Social Media and Its Potential for Spatial Analysis of Urban Tourism Activities

6.2.1 Tracking Tourists' Itineraries: Non-traditional Data Sources

Most of statistical systems supporting the analysis and understanding of the tourism phenomenon in an urban context are based on the use of three indicators: tourist arrivals; overnights; occupation in accommodation units (Heeley 2011). These indicators allow a generic and dynamic reading of the demand flows associated with city tourism. On the other hand, traditional statistical tools and methods can only measure the participation of tourists in "controlled sites" (e.g., museums, hotels, etc.). Both are, however, very limited when a more in-depth analysis of the phenomenon is sought on an intra-urban scale (Ashworth and Page 2011).

Understanding the complex, and often unequal, spatiality of tourist demand in the urban space requires other methodologies, among which the information base available online and in social networks has gained prominence. This, being increasingly georeferenced, allows a more realistic and informed perception about tourist geography(ies) on urban destinations: places of greater/lesser attractiveness; mobility patterns; etc. Such information reveals an advantageous and complementary option to official data (Goodchild and Li 2012), mainly due to its diversity, quantity, timeliness, and continuity.

Greater access to information—facilitated by new Information and Communication Technologies and a profile of tourists seeking more and more frequent online content—coupled with a growing predisposition to share information in social media, have allowed a greater knowledge of the characteristics and behaviour of tourists (Buhalis and Law 2008; Tussyadiah 2012).

Crowdsourced data, coming from social networks, contributes to the understanding of the fruition/consumption of space within urban destinations. The geotagged photos published by users on "Panoramio" and "Flickr" social networks, during their visit to the city of Lisbon, allow us to present a quantitative and geographic reading of urban tourism spatial production and consumption. Particularly, the data extracted from these sources provides meticulous information, of great value, for the identification of places of concentration, in dense and complex areas.

The emergence of Web 2.0 enabled the use of the Internet as a communication channel, by generating a vast collection of digital platforms, as those identified as social media. Social media is defined as any digital platform where users can participate, create and share content. Kaplan and Haenlein (2010) distinguished the following *media*: blogs, content communities, social networks, websites of recommendations and evaluations (Consumer review websites), instant-messaging sites and photo-sharing, etc. (e.g. Viajecomigo, Tripavisor, Twitter, Facebook, Flickr, Panoramio).

The extensive use of the Internet has increased the influence of the content shared in these platforms, on user behaviour and, more specifically, on the behaviour of tourists (MacKay and Vogt 2012; Tussyadiah 2012). Its impact has been significant in the tourism industry (Leung et al. 2013), denoting a growing tendency for tourists to share their experiences by publishing their recommendations, reviews, photos, or videos about a destination, activity, or service, particularly in social networking sites (Buhalis and Law 2008).

ICTs platforms, sensor networks, and wireless communication systems contributes the integration and data exchange. We are experiencing a new era, where information is produced in part by users. This type of information is referred to as User-generated Content (UGC) or Crowdsourced Data (Kaplan and Haenlein 2010), Volunteer Geographic Information (VGI)—most commonly used in the field of geography—or Community-contributed Data (Goodchild 2007; Andrienko et al. 2009).

In the context of geographic information, online content accessible on these media platforms has become part of the set of data sources available for data gathering, overpassing the condition in which the information was produced and distributed exclusively by the official authorities (Sui et al. 2013).

UGC, as opposed to top-down methodologies, has promoted individuals themselves as information generators with high spatial and temporal resolution, boosting the framework of alternatives to track their location (Sui and Goodchild 2011). Georeferenced information constitutes one of the most important types of UGC. Geospatial technologies enabled social networks with positioning and mapping tools, which have led to a massive volume of georeferenced data.

When tourists use their mobile phones, their credit cards, or through access to social networks, leave behind large amounts of digital traces about their activities within a destination (Buhalis and Amaranggana 2014; Hawelka et al. 2014). These digital traces are often openly available. While traditional methods on geographic data collection were based on technically demanding, accurate, expensive and complicated devices, non-traditional sources offer cost-effective information acquired through everyday devices such as mobile phones (Li et al. 2016).

A valuable feature of the UGC grounded on social media is its continuous availability, almost in real time, which means, in most cases, information can be used to analyse current issues which require continuous observation, allowing to change the analytical meaning of a static approach to a more dynamic monitoring process (Sui and Goodchild 2011; Díaz et al. 2012).

This information can be used as a proxy to find patterns in the spatial distribution of visitors within a destination. For instance, several authors have performed analysis based on data extracted from social networks and other online platforms (e.g., wikipedia, wikitravel, and Foursquare) to identify points of tourist interest in different areas of the world (Tammet et al. 2013).

Besides current developments in storing, processing and analyzing this information, it presents some challenges as the lack of assurance regarding its quality (Li et al. 2016), contrary to what happens with information from official sources, since the latter is collected and documented through well-known established procedures (Goodchild 2013). However, this type of data might play a useful role to drive exploratory analysis of a phenomenon (Goodchild and Li 2012).

All this innovation generated by ICTs in terms of data sources has emerged as an additional and complementary support tool for the more traditional (data) sources. Therefore, non-traditional data should not be regarded as a substitute for official data or data collected through traditional scientific methods, but complementary (Goodchild and Li 2012).

The identification of tourist patterns/behaviours/preferences that express themselves through the digital imprints generated in the tourist destination fill a relevant gap in the knowledge about intra-destination mobility and, generally, on the more informal and less documented fruition of the tourist space.

Although the opportunities provided by online information shared by tourists are plenty and prone to unveil some geographical features in a place or a region (through GIS and spatial analysis), this is a recently open field (Zhou et al. 2015) and still hindered by several constraints (data volume, velocity, variety and reliability, among others) and also by some suspicion as a novel research tool, using new information sources in tourism.

The objectives of this chapter are to highlight consistent patterns of tourism production and consumption, in what can configure different tourist geographies of the city of Lisbon, perceived from the analysis of non-traditional data available in social networks platforms, and at the same time try to understand how this new paradigm of big data and mining techniques will affect the future of geographic analysis.

6.2.2 Urban Analytics: The City of Lisbon and Lisbon Metropolitan Area

The city of Lisbon, centrally located in the metropolitan area of Lisbon (LMA). The LMA is composed of five touristic official regions, covering the municipalities of Oeiras, Amadora, Odivelas, Loures, Mafra, Almada, and Lisbon (Fig. 6.1).

In an attempt to demonstrate the novel opportunities of non-traditional data as complementary (data)sources for applied research, we refer to six indicators of tourism activity, based on data made available by one of the three Portuguese Mobile Phone Operators, i.e., NOS®, about foreign users visiting and moving around the

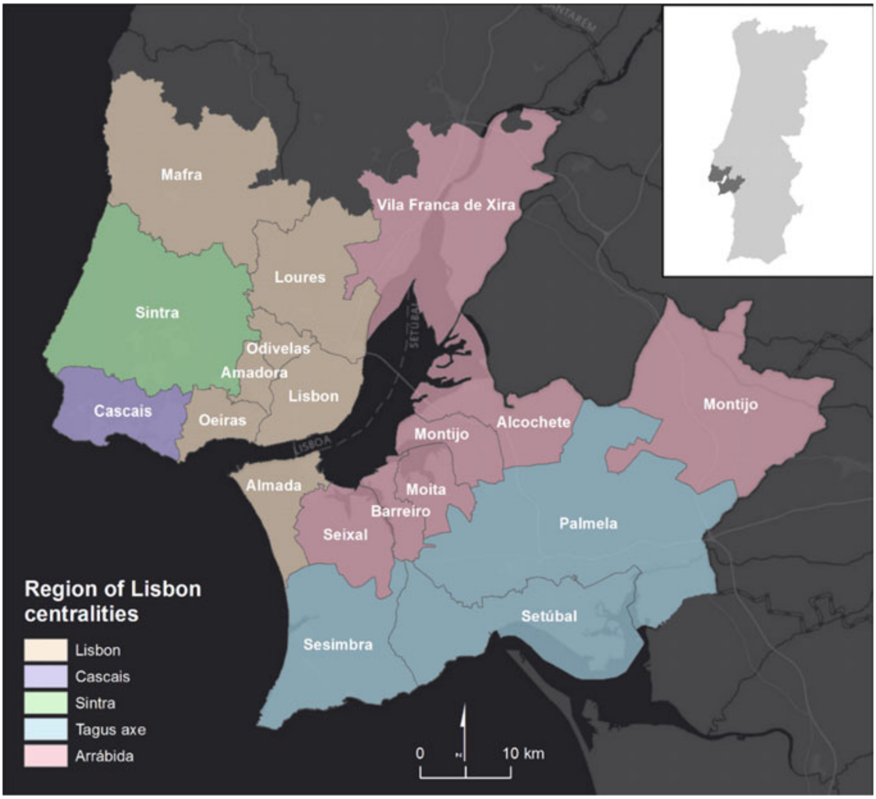

Fig. 6.1 Tourism centralities in the Lisbon metropolitan area

Fig. 6.2 Tourism density by municipality, in Lisbon metropolitan area (2017)

LMA and Portugal. Tourism density values (number of distinct tourists by km^2), an index in a standardized scale of 1 (minimum) to 4 (maximum), show a predominant area within the LMA (Fig. 6.2) which corresponds to the Lisbon centrality. Almost all the cities corresponding to this region (having a tourism density equals to 4) are also in the top ten of Portugal municipalities with highest densities: Lisbon (1); Oeiras (3); Amadora (4); Almada (7); Odivelas (9) and Cascais (10).

As specified by the Tourism Observatory of Lisbon (OTL), "City & short break" is considered the largest motivation for visiting Lisbon (Observatório de Turismo de Lisboa (OTL) 2016). Besides, the weekenders' index (Fig. 6.3) suggest a higher tourist presence on the weekend. This index represents the ratio of the daily average number of tourists at the weekend comparatively to the week, in a month (a value greater than 100 means more tourists on the weekend than on the week). Despite its importance, Lisbon does not take the lead when compared to other cities in the LMA. The two main municipalities are located in the south bank of Tagus River: Sesimbra (156) and Almada (153). They have both a long tradition of sun-and-beach tourism for short periods. This pattern is still supported by the municipalities which

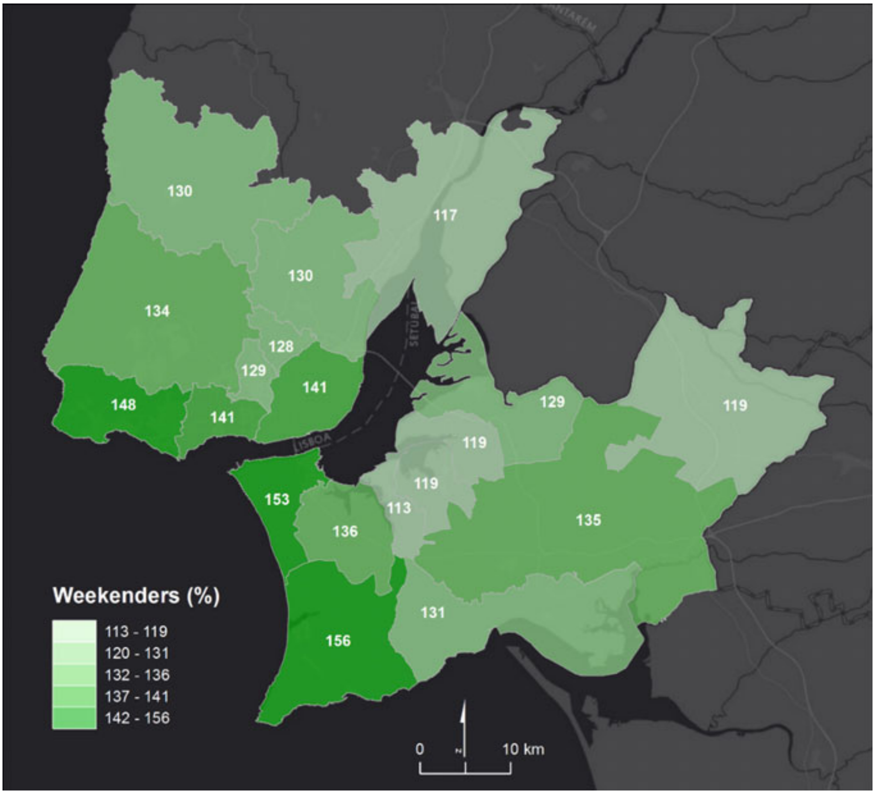

Fig. 6.3 Ratio of weekenders by municipality, in Lisbon metropolitan area (2017)

ranked third and fourth, Oeiras (141) and Cascais (148), both situated in the north Shore of Tagus River and with similar characteristics of the southern counterparts. The only non-beach municipality in the top five is Lisbon (141), which embodies the idea of "City & short break" attractiveness. Yet, these values are very far from the national top ten, denoting the importance of municipalities from the interior, mostly the North interior, of mainland Portugal.

With regards to tourism demand statistics, in 2016, the average stay of foreign guests in Lisbon was up to 2.6 nights. This value is similar for the LMA but lower than mainland Portugal (Instituto Nacional de Estatística (INE) 2017). Besides, the statistic from the mobile phone operator shows a slight increase in 2017, with an average stay of 3.2 nights (Fig. 6.4a). The average number of foreign overnight stays is still one of the lowest in the LMA and from Portugal.

The municipalities leading the national ranking are, as expected, located in the islands of Azores and Madeira. Nonetheless, there are two LMA municipalities in the top ten, i.e., Odivelas (5.1) and Moita (4.6). Both have a vast immigrant population that runs through extended visits from relatives and friends.

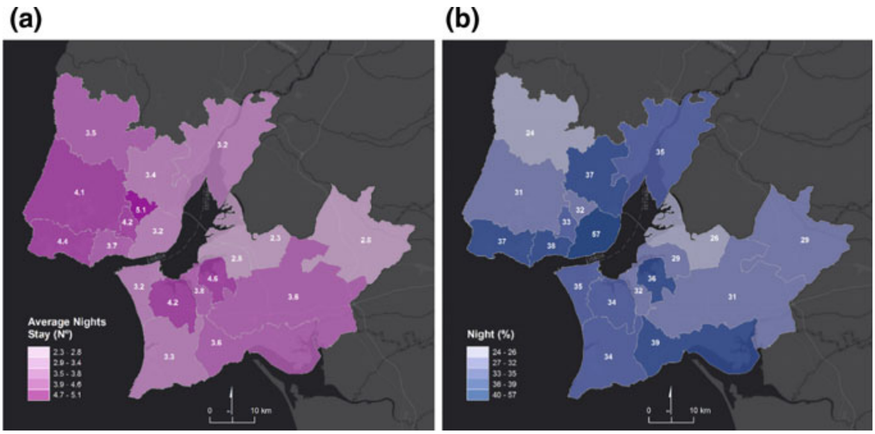

Fig. 6.4 Average number of night's spent (**a**) and night attraction (**b**) by municipality, in Lisbon metropolitan area (2017)

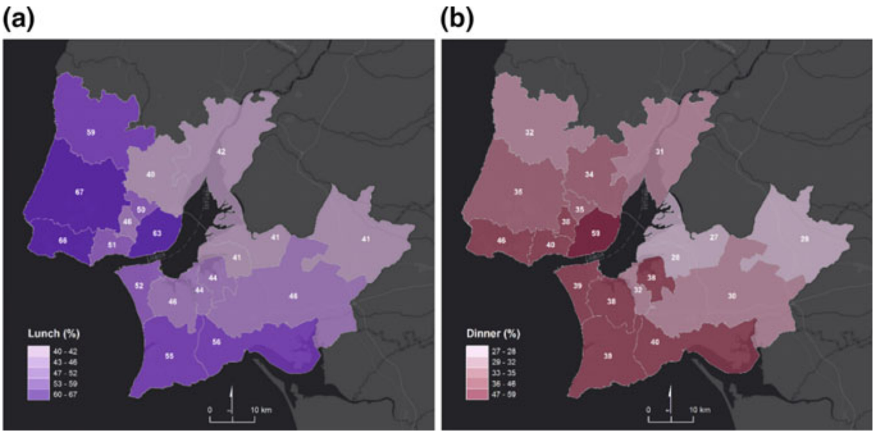

Fig. 6.5 Lunch (**a**) and dinner (**b**) attraction by municipality, in Lisbon metropolitan area (2017)

When considering the night attraction index (it calculates the percentage of tourists at night compared to the total amount of tourists, in a month), Lisbon clearly stands out in the metropolitan area (Fig. 6.4b), being also the second municipality in the national context. Once again, the municipalities with higher night attraction scores are the ones from the Islands. However, in this case, Oporto (tenth) is also in the national top ten.

Finally, lunch (Fig. 6.5a) and dinner (Fig. 6.5b) attraction indexes show different patterns. Both, represent the percentage of tourists at lunchtime/dinnertime in relation to the total number, in a month. Despite having a high lunch attraction (62%), Lisbon stays behind Sintra (67%), a world heritage village, and Cascais (66%), a famous destination for sun-and-beach tourism. On the contrary, when looking at the dinner attraction, Lisbon takes the lead in the metropolitan area. Roughly, values from both indexes may suggest a commuting pattern within the region. It seems that some tourists visiting Lisbon travel to Sintra-Cascais (also known for its landscape-protected area) for spending the day (as denoted by the lunchtime index) but coming back at the end. So far, these outcomes illustrate an interesting flow that should be further explored.

6.2.3 Data Collection of Online Footprints from Social Networks

Recently, researchers have shifted their attention to social media as an alternative data source for collecting information about tourist activities. Here, we explore the value of geotagged data from two social networks in studying tourist spatial behaviour. We use data from "Panoranio" (in 2007 Google acquired Panoramio and closed it down, in late 2016) and "Flickr". Both social networks provide access to the online data through their Application Programming Interfaces (API). In addition to the users' photos (images), metadata information such as users' identification, timestamps and geolocation, is available as well.

According to the protocols from each APIs, the retrieving process must be forwarded through a HTTP request, by setting some parameters (e.g., defining a bounding box to overlap an area, a valid data format, etc.) and data specifications (e.g. a time window, a set of keywords, etc.). Since there are some restrictions to retrieve data (e.g., "Panoramio" allowed to retrieve information up to 500 photos *per* request, for a given area), the requests are usually implemented following an automated scheme (i.e., a recursive algorithm) that controls the iterative process.

The study area was segmented into smaller areas and, for each new unit, we downloaded the online data within its extents. All geotagged photos (and metadata) were stored in a database. "Panoramio" database reached more than 70,000 records (including the image, photo description, users' id, geolocation-coordinates, timestamps, numbers of views, etc.). Similarly, all geotagged photos from "Flickr" were more than 200,000 records.

The identification of photos uploaded by visitors was based on photos' timestamps, following previous works (Girardin et al. 2008; García-Palomares et al. 2015; Encalada et al. 2017). Geotagged photos were classified as belonging to visitors only if the difference (in days) between the timestamps of the first and the last photos uploaded by each user, do not exceed the average stay of foreign tourists within the city. Since the average stay for the last year (2016) of the time-series is close to 3 nights, only photos taken during a period of less than 4 days were cataloged as belonging to visitors.

The final dataset comprise 19,578 photos from "Panoramio" and 73,314 from "Flickr". Photos spatial distribution within the city of Lisbon is depicted on Figs. 6.6 and 6.7 "Panoramio" dataset contains photos from 2008 to 2014, and "Flickr" from

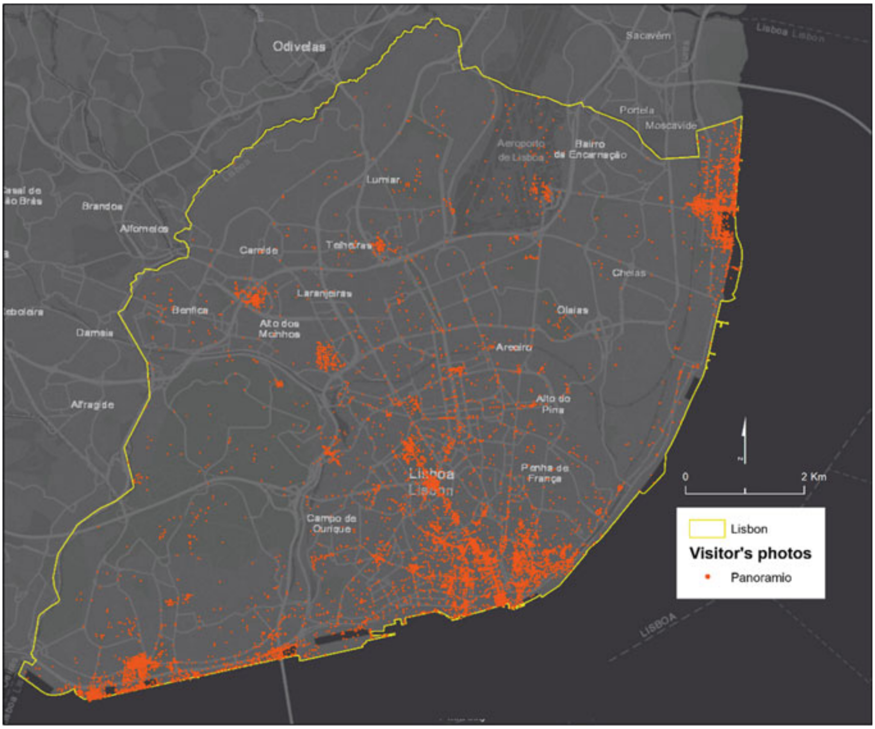

Fig. 6.6 Visitor's geotagged photos from 'Panoramio', from 2008 to 2014

2008 to 2016. These digital footprints belong to more than 15,000 users (from both social networks) considered as city tourist.

6.2.4 Addressing the Spatial Distribution of City Tourists

In this section, we refer to some (traditional) methods of exploratory analysis to discover significant patterns on spatial data. A brief analytical scheme, ranging from global to local metrics, is presented. Our selection criteria regarding spatial analysis techniques relies, mainly, on their generally wider applicability since we aim to reach a broader audience interested on this type of analysis. It should be noted that we keep spatial analysis tools at the simplest level, however, for more details readers should refer to (García-Palomares et al. 2015; Encalada et al. 2017).

When analyzing spatial data, the starting point is to validate the spatial autocorrelation and determine if the global distribution of the data is scattered, concentrated or random. This can be assessed using spatial autocorrelation indexes (e.g. Nearest Neighbor Index, Global Moran's I, Global Getis-Ord Index).

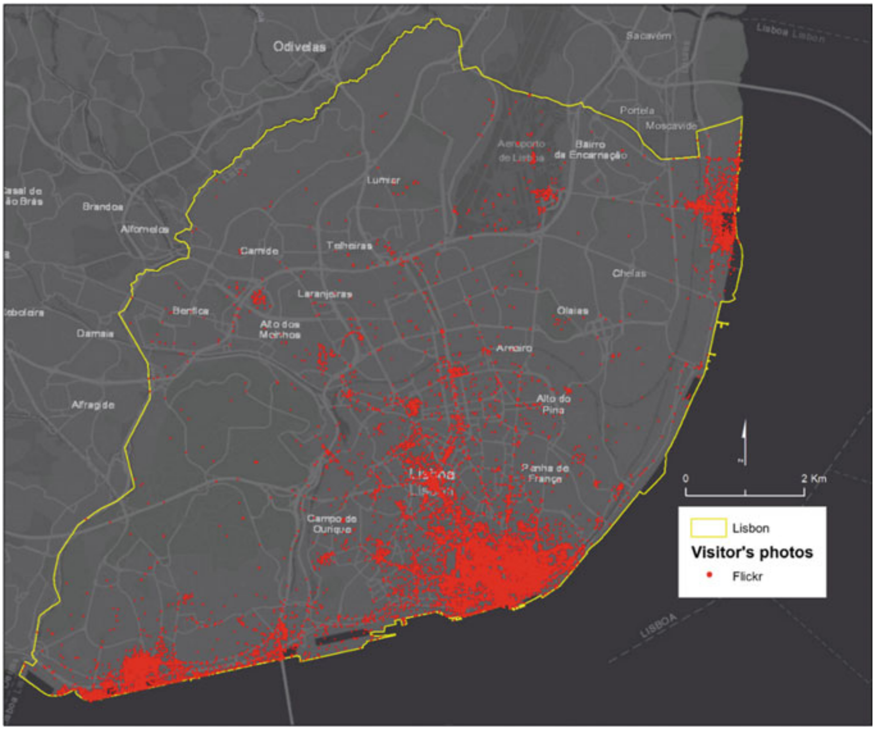

Fig. 6.7 Visitors' geotagged photos from 'Flickr', from 2008 to 2016

Global statistics are not able to measure how spatial dependence varies from place to place. In order to capture the heterogeneity of spatial dependence, statistics might be applied to the local scale. Although the geotagged photos show a roughly concentration on some areas (as depicted on Figs. 5.6 and 5.7), it is necessary to prove whether the observed pattern is statistically significant and, thus, supported by an underlying spatial process. Local indicators such as Local Moran Index and Getis-Ord Gi* lead the disclosure of spatial clusters (i.e. places of tourist concentration) that are statistically significant. The Local Moran Index indicates the spatial concentration of similar values as well as spatial outliers. To perform the analysis, it is necessary to define the neighboring area (i.e., distance threshold) and the nature of the spatial relationship between observations (i.e., the notion of proximity between observations, being reached, in most of the cases, by creating a spatial weights matrix.).

Another practice frequently performed for analyzing and visualizing point features is the Kernel Density Estimation (KDE). It calculates the magnitude per unit area of a given number of points (using the Kernel function), producing a smooth density surface over space by computing the features intensity as density estimation. The basis of these methods is the Tobler's first law which states that everything is related to everything but near things are more related than distant ones.

Furthermore, spatial patterns change over time. While the former techniques can handle the spatial context, other methods (e.g. Emerging Hot Spot Analysis) support the analysis of both spatial and temporal patterns emerging from a set of observations. Thus, in addition to discover significant spatial clusters, the seasonal pattern can be obtained as well (i.e., whether the hot pots are consecutive, sporadic, etc.).

To assess the geographical patterns of urban tourists within Lisbon, two methods were used, Clusters and Outliers analysis (based on Local Moran Index) and the Kernel Density Estimation. For the Cluster and Outlier analysis, data was aggregated to a continuous hexagon surface. Assuming that all photos within the study area may not be spatially related, a threshold for the neighborhood radius of influence was determined to run the analysis (a threshold distance equals to 150 m). Still, the inverse distance was chosen to conceptualize the spatial relationship, thus, the influence of the neighboring features will decrease as the distance between them increase. Besides, since Kernel function depends on a given distance parameter (e.g., increasing the value of the search radius results in a broader and lower kernel and, thus, showing the spatial tendency on a more global scale), similarly to the Local Moran Index parameters, it was defined a search radius of 150 m. The outcomes are presented in the next section.

6.2.5 Mapping the Spatial Distribution of City Tourists

The visual representation of geotagged photos shows a trend for clustering, mainly in the areas with more touristic appeal. Furthermore, the Local Moran Index outlines a more accurate picture while identifying the city tourist hot spots (i.e., statistically significant places of tourists concentration). Thus, the most relevant touristic sites are discriminated from the overall sample of points previously mapped and depicted on Figs. 5.6 and 5.7.

As expected, clusters are located nearby the well-known city tourist attractions (Figs. 5.8 and 5.9). In general, places of interest such as viewpoints, squares, monumental architecture, and other cultural and recreational attractions function as focus of spatial clusters. The historic center clearly stands out from other touristic areas (on Fig. 5.8, "Eduardo VII" park[3]; "Marquês de Pombal" monument[4]; "Rossio" square[5]; "Comércio" square[6]; "São Jorge" Castle[7]). A smaller number of significant clusters were uncovered over "Belém"—to the southwest (on Fig. 5.8, "Belém" Tower[1]; "Padrão dos Descobrimentos"[2] monument), and in "Parque das Nações"—to the northeast (on Fig. 6.8, Lisbon Oceanarium[8]).

The majority of significant clusters belong to the High-High category, corresponding to places with a large number of tourist's photos surrounded by similar high counts. On the contrary, there are few atypical clusters (Low-High) located in the surrounding areas of the identified hot spots. These outliers expose some places less visited when compared to the visitor's presence in its neighborhood.

Fig. 6.8 Clusters from 'Panomario' dataset

Fig. 6.9 Clusters from 'Flickr' dataset

The main difference between both maps (Figs. 6.8 and 6.9) comes from the fact that "Panoramio" users were more voted to upload photographs illustrating places (e.g., open space areas). Instead, Flickr's photos are more "relaxed" and depict memories about any topic (e.g., social events, daily activities, people, etc.). For instance, the Benfica stadium[3] corresponds to a significant cluster (Fig. 6.9) based on visitors photos from "Flickr", but it is not for "Panoramio".

From the analysis of both density maps (Fig. 6.10), visitor's activity shows a higher density in locals within the Tourism Micro-centralities (i.e., areas of major touristic interest identified by the City Tourism Office). Three areas are highlighted, "Belém" (southwest), the Historic Center and "Parque das Nações" (Northeast). By contrast, few sites with low densities in the inner part of the city reveal an irregular and lower (still significant) attention of city' visitors.

The heat maps effectively summarize some visitor' places of interest. Although "Panoramio" overall kernel density is slightly lower than the results from "Flickr", the hot spots areas match in both cases. For instance, "Comércio" square and "São Jorge" Castle, "Jerónimos" Monastery and "Padrão dos Descobrimentos" monument (southwest), and the Lisbon Oceanarium. Less highlighted places can be identified as well, such as "Rossio" and "Restauradores" squares, and "Marquês de Pombal" monument.

The cross-reading of the resulting maps from the KDE and Cluster analysis, points out that tourist attractions, in fact, are the focus of visitor's clusters. The spatial extent of areas with intensive tourist presence follows a pattern. While the tourist attractions show higher densities, their intensity decrease gradually as the distance to these cores increases. In many cases, the spatial extent follows the physical shape of tourist attractions (e.g., squares, pedestrian streets), expanding across those areas and beyond their perimeter to other nearby areas.

Empirical evidence suggests that urban tourism studies might benefit from geo-tagged digital data. These outcomes demonstrate that touristic areas can be properly identified and differentiated from others with lesser or non-related tourism activities and visitation.

6.3 Challenges Regarding the New Paradigm Shift in Geography Research

Spatial modeling and in a broad sense Geography, have shifted from a data-scarce to a data-rich environment. The critical change is not about the data volume, but relatively to the variety and the velocity at which georeferenced data can be collected and stored. Data-driven geography is (re)emerging due to a massive georeferenced data flow coming from sensors and people.

Data-driven geography raises some issues that in fact have been long-lasting problems debated within the research community. For instance, dealing with large data volumes, the problem of samples versus populations, the data fuzziness, and the frictions between idiographic and nomothetic approaches. Yet, the conviction that location matters (i.e, spatial context) is intrinsic to geography and serves as a strong motivation to produce refined methods on spatial statistics, time-geography, and GIScience.

Big Data has a huge potential to feed both spatial analysis and modeling, and the geographic knowledge discovery. Nonetheless, there are still some remaining issues, e.g., data validation, non-causal relationship guiding incorrect conclusions, and the creation of understandable data-driven models. The impact of big data and data-driven geography on society remains a current agenda (Mayer-Schonberger and

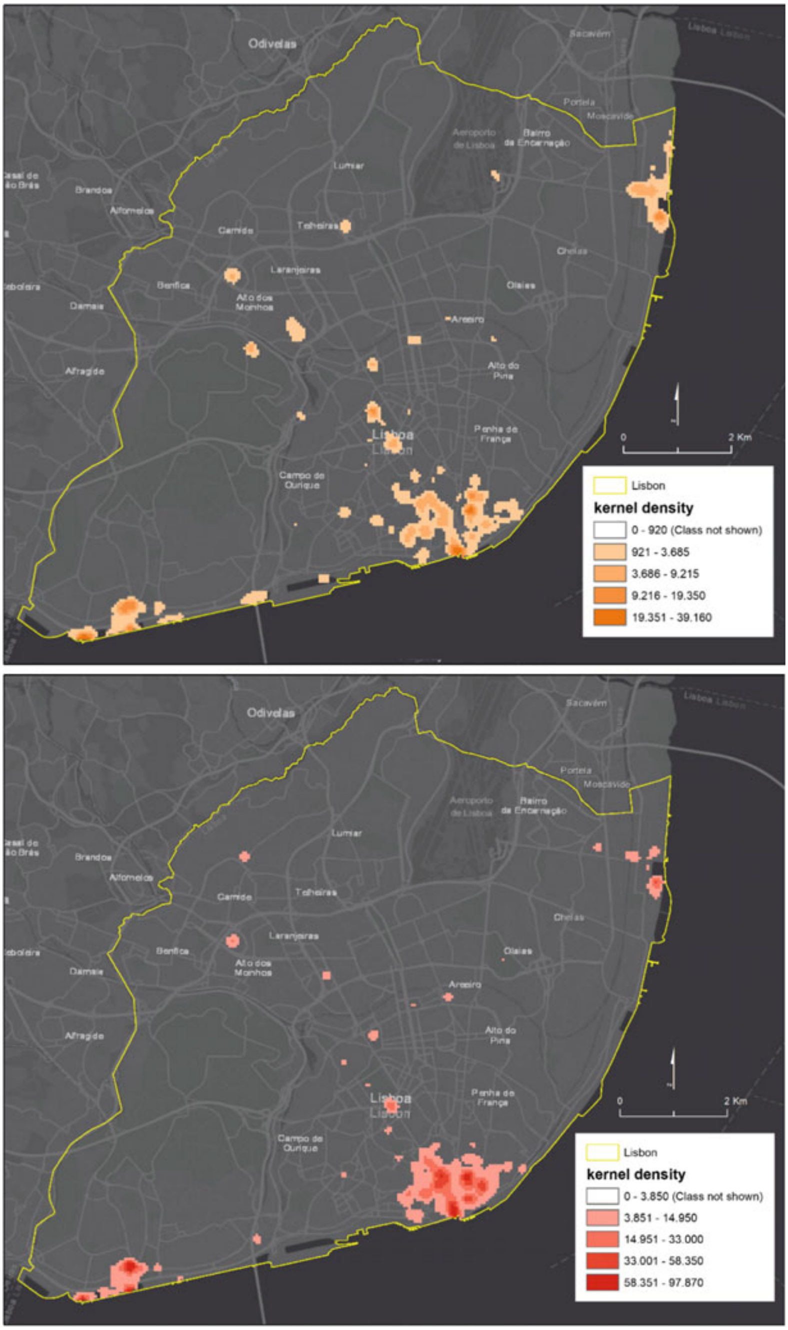

Fig. 6.10 Kernel density (photos/m^2) of geotagged photos from 'Panoramio' (top) and 'Flickr' (bottom)

Cukier 2014). The main concern is with privacy, not only because of the people but also because of the potential repercussions that may stop data-driven research.

Being big data more and more rooted into social-spatial decisions, processes, and institutions, the signifier-signified connection may come to be increasingly fuzzy. As long as we place even more trust in big data, and in the algorithms that are used to produce and analyse it, it is also more likely to lose sight of the big picture of such data represents while distorting the ontological-epistemological boundaries (González-Bailón 2013). This leads to a situation where it is normal to take decisions upon complex data, processed by black-boxed algorithms running in unopen software (Graham 2013).

Still, big data is no danger free, and there is the potential risk of simplifying human agency and the data production frame (Boyd and Crawford 2012; Tinati et al. 2014; Schroeder 2014). Some experiences tell us that, advancements in ICTs, far from being inclusive, often enlarge the socio-spatial roughness of both representation and participation, as evidenced on a variety of online datasets (Graham 2011; Haklay 2013).

Another big data ethical risk derives from what sometimes is designated as machine bias (Angwin et al. 2016). Whereas data are often assumed as objective, big data and the surrounding algorithms may not be. Muñoz and colleagues (2016) show prominent examples of how “bad” data (e.g., badly selected, incomplete, incorrect, or outdated) can lead to discriminatory (biased) outcomes. Keeping that in mind, some attention should be taken, because artificial intelligence can be just as biased as human beings, i.e., discrimination can exist in machine learning.

Indeed, extensive improvements on ICTs have augmented the multimedia narratives about the geographical representation of places, with important implications on the future of geography. Geographers integrating big data with current research paradigms have already transformed and promoted the study of geographical systems and, in the process, have developed new notions of space. This is an opportunity for new research techniques in both the qualitative and quantitative contexts. Big data and data analytics improve the understanding about the consumption of urban space (public or private), leaving physical and digital space, respectively fixed and fluid, while both of them overlap and coexist, each one shaped by the other and its users.

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Chapter 7
Contribution of GIS and Hydraulic Modeling to the Management of Water Distribution Network

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Abstract Increases in the growth of urban regions along with climate change have contributed to a scarcity in water resources. For arid regions, this problem may be aggravated by inadequate management plans and a lack of proper data collection related to the geographical location of water distribution networks. A possible solution is the utilization of a geographical information system (GIS) as a tool in decision-making process in the field of water distribution management. Coupling external hydraulic calculation models with GIS can further enhance this management tool. The current study utilized these tools in assessing the performance of a drinking water distribution network of an urban cluster in Tlemcen, Algeria. A methodology was developed by coupling GIS to a hydraulic calculation model (EPANET). The results showed that it is possible to obtain an alphanumeric description of the pipes, tanks, and all the accessories constituting the network. Design irregularities in the Tlemcen urban cluster's network were identified. The approach adopted in this chapter contributes effectively to the management of water distribution networks using GIS. This offers operators a management tool that allows for analysis of malfunctions with an instantaneous response, to study various solutions and to plan for future situations.

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Keywords Modeling · GIS · Water distribution network · Management

7.1 Introduction

Increased urbanization as well as droughts, floods, and wildfires can present major challenges to potable water managers and can interrupt the delivery of high-quality safe drinking water to customers (Deere et al. 2017). Furthermore, effective water resource systems planning and management require precise knowledge and technical data of the distribution structure (Loucks and Van Beek 2017). These requirements make it necessary not only to size the network but also to maintain it in a satisfactory state (Eisenbies et al. 2002). The collection and gathering of information related to the geographical location of the distribution network on the same computer medium then become necessary, even mandatory. Geographic information systems (GIS) provide a solution to this problem by creating a database of urban space (i.e., network plans) and containing information related to the hydraulic characteristics of the network and its behavior. The effective application of GIS in the field of water distribution requires coupling to hydraulic simulation models so as to support management goals. Combined with external models such integration enhances overall benefits.

As with other technical networks, water distribution systems belong to an urban and peri-urban environment in which they act and interact with other networks (Blindu 2004). The operator of a drinking water supply grid is usually faced with the difficulty of trying to understanding the network, given its diversity (Abdelbaki et al. 2012; Blindu 2004). To streamline the management of a water distribution network, it is necessary to know precisely all the relevant elements or components, to be able to prevent incidents, and to have a diagnostic tool to remedy incidents as quickly as possible. Thus, it is essential to keep track of what has been done so as to build a "memory" of milestones to best target programming and investment decisions (Blindu 2004).

Water distribution networks may experience increasing management constraints that require the use of more and more data representative of the entire network. This data is necessary for an efficient management so as to operate the grid continuously in a profitable way with a level of service adapted to the expectations of the customers. The implementation of a GIS for the drinking water network management with descriptive databases is essential and remains a prerequisite for any attempt at analysis.

The aim of the current work was to assess the performance of a drinking water distribution network using the Tlemcen urban cluster in Algeria as a case study. A GIS (MAPINFO) was coupled with a powerful calculation software model (EPANET). This chapter describes the system design and outlines the type of data used and their acquisition.

7.2 Design and Management of a Drinking Water Distribution Network Using GIS

The decisions to be made in the management services of water distribution networks go beyond simply posting a map or finding an address, it involves building equipment, developing or managing an area, managing a public service, or intervening in case of an incident occurring in the network. This means making decisions involving people and taking corrective actions. Indeed, it may be more cost-effective to set up information organized, maintained, and managed on a permanent basis, ready for several needs or for an unforeseen need, rather than reacting piecemeal with the means at hand. In this context, one of the essential prerequisites before embarking on the implementation of a GIS application is the questioning of the intended (or possible) use of geographic information. These possibilities can be grouped into several broad categories:

– *The accumulation of scattered knowledge*. It is often difficult for a given problem to acquire a fast and accurate knowledge of the terrain. The information is often distributed among several managers (networks, geology, etc.), of more or less ancient origin, possibly known to a small group of specialists (archaeological data). In this case, updating and knowledge of the accuracy of the data are imperative.
– *The operational use of updated plans*. The user wishes to have precise information (cartographic and alphanumeric) and homogeneous of the reality of the ground at the moment when it must intervene (for example, various pipes buried under a road). However, these data (erosion, modification of plots, modification of characteristics, etc.) evolve over time. Updating is essential; it means to have a traceability of the way how information is collected (Sauvagnargues-Lesage and Ayral 2009).
– *The representation of archived* "*shadow copies*". Some situations need to preserve the image of previous situations, especially for the study of evolutionary phenomena, whether for graphic data (for example, the evolution of a flooded area) or for descriptive data (evolution of population).
– *The simulation of events*. The study of the impact of an event (accident, development of a zone, effect of the closing of a valve of a network) requires a readability of the results and an operational character of the data. Modeling then requires the establishment of functional relationships between the data as precise as possible (topological relations in particular) (Tena-Chollet et al. 2010).

The large volume of information to be collected, the enormous quantity of documents to be inventoried as well as the diversity of the information regulating organisms represent a great difficulty in the process of developing a database (Abdelbaki et al. 2012; Blindu 2004). The inventory operation for the current report consisted of identifying, describing, and locating the cartographic data related to the drinking water supply network of the case study area, the Tlemcen urban cluster.

Data analysis consisted of determining the characteristics of the documents to be retained, in order to properly comprehend and represent the water distribution. It is difficult to define in advance all the possible uses imaginable that could be made by the geographical information system. Adding to these difficulties, there were numerous gaps in the mapping of the water distribution network. The most important were:

– Non-georeferenced map background;
– Absence of legend summarizing the conventional signs relating to networks;
– Old plans not updated;
– No mention of geometrical characteristics of certain sections of network;
– Different scale from one plan to another;
– Projection system not mentioned on plans;
– Date of establishment and date of update of plans not mentioned;
– Absence of directional arrow showing north; and
– Nonexistence of geodesic points which allow attachment of cartographic breaks.

For cartographic support to be exploited, it was necessary to remedy certain shortcomings, namely, georeferencing the background. This operation is of great importance for the digitization phase; correcting the contradictions presented by the plans by confrontation and crossing of the latter; need to correct some drawings in plans that do not conform to the documents selected; complete missing plan information from documents deemed reliable.

The traditional paper plans which are difficult to manipulate and complex to update were replaced by digitized plans. This method is best suited to the needs of this work because it allows a person to enter the geometry of basic graphical objects: point, line, or polygon. From a cartographic point of view, the network is represented by all segments along which the diameters, the material, the length, the state, and the date of commissioning have been indicated. All elements of the network such as valves, suction cups, poles and fire hydrants, types, and importance of driving (connection, main pipe, and artery) are listed and are identified by different codes. Figure 7.1 shows the procedure adopted to cover the background of the Tlemcen urban cluster in order to report the water distribution network. Figure 7.2 shows an excerpt from a prepared part to trace the water distribution network.

7.2.1 Choice of GIS, Creation of Database, and Correcting Errors

Faced with the numerous available geographical information systems for microcomputers, the choice was made to use Mapinfo and ArcGis so as to benefit from a set of high-performance and scalable products. This makes it possible to create, display, and modify all forms of geographically referenced information. Their main characteristics can be summarized as follows: overlay operations: superposition of thematic layers; statistical treatments; output types: cartographic representations, numeric or textual values, histograms, and graphs; availability of a library of symbols, lines, frames, and captions that can be edited interactively; data exchange

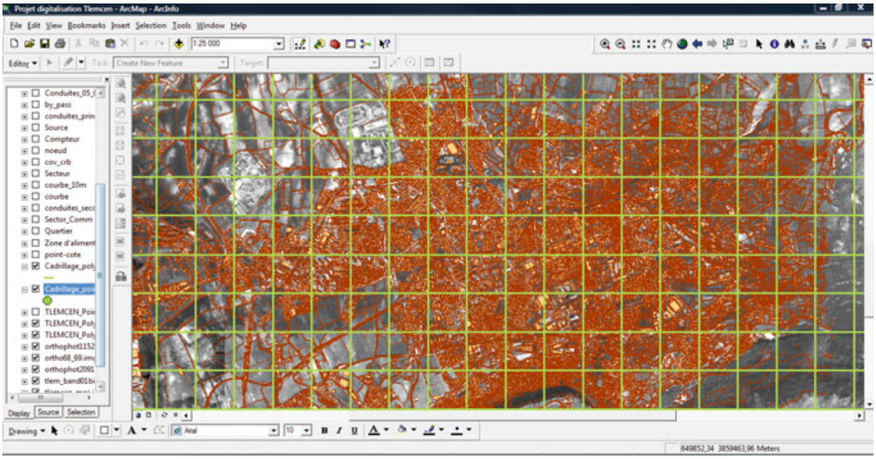


Fig. 7.1 Preparing the base map to trace the water distribution network

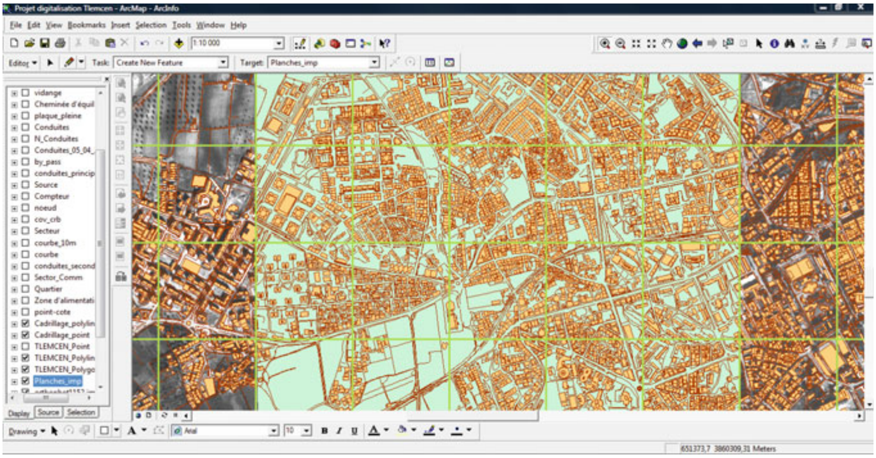


Fig. 7.2 Extract of plans to print

with CAD software such as AUTOCAD; and exístanse of extended SQL language for managing descriptive data.

Key features include also effectiveness in database management, graphics, powerful query language to mix graphic and non-graphical inputs, independence with regard to the choice of material, and ability to integrate external data and export data to other systems. Furthermore, after processing, useful information is obtained for the design of the database. The associated data is organized as tables. The attributed names are entered field by field according to their types (e.g., character, integer, floating point, fixed point, date, etc.). Each geometric entity (conduct) is related to

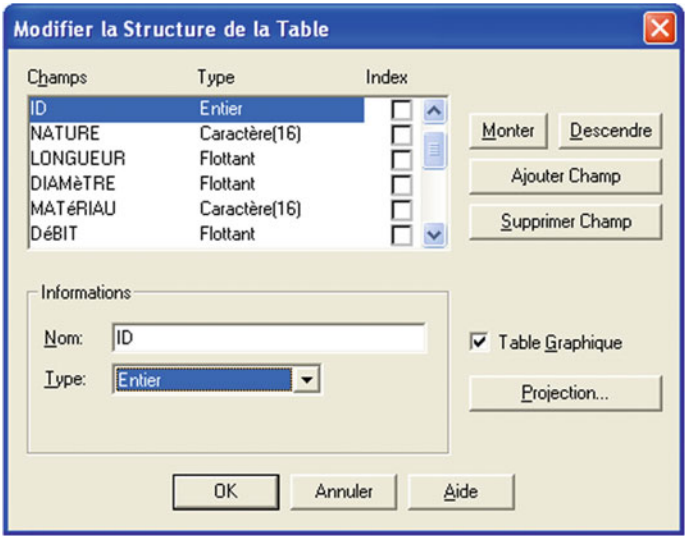
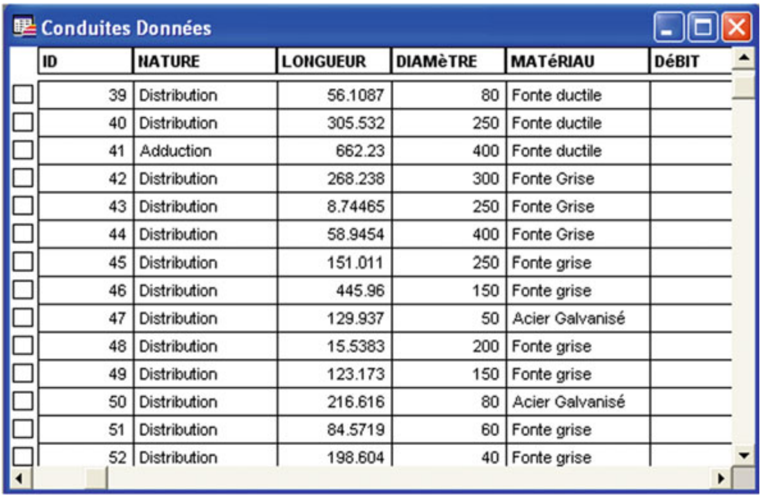


Fig. 7.3 Definition of structure of "pipelines" table


Conduites Données

ID	NATURE	LONGUEUR	DIAMèTRE	MATéRIAU	DéBIT
39	Distribution	56.1087	80	Fonte ductile	
40	Distribution	305.532	250	Fonte ductile	
41	Adduction	662.23	400	Fonte ductile	
42	Distribution	268.238	300	Fonte Grise	
43	Distribution	8.74465	250	Fonte Grise	
44	Distribution	58.9454	400	Fonte Grise	
45	Distribution	151.011	250	Fonte grise	
46	Distribution	445.96	150	Fonte grise	
47	Distribution	129.937	50	Acier Galvanisé	
48	Distribution	15.5383	200	Fonte grise	
49	Distribution	123.173	150	Fonte grise	
50	Distribution	216.616	80	Acier Galvanisé	
51	Distribution	84.5719	60	Fonte grise	
52	Distribution	198.604	40	Fonte grise	

Fig. 7.4 Structure of "pipelines" table

its description; this link is done by means of an internal identifier. Figures 7.3 and 7.4 show the definition and structure of the pipelines table.

All spatial features and their descriptive data may be subject to errors or inaccuracies. The operation consists of establishing the link between spatial and descriptive data in order to verify the following errors: Space entities are sometimes poorly positioned or have wrong forms such as a large number of duplicate pipes or nodes. Figure 7.5 illustrates an extract from the GIS of the water distribution network of the Tlemcen urban cluster.

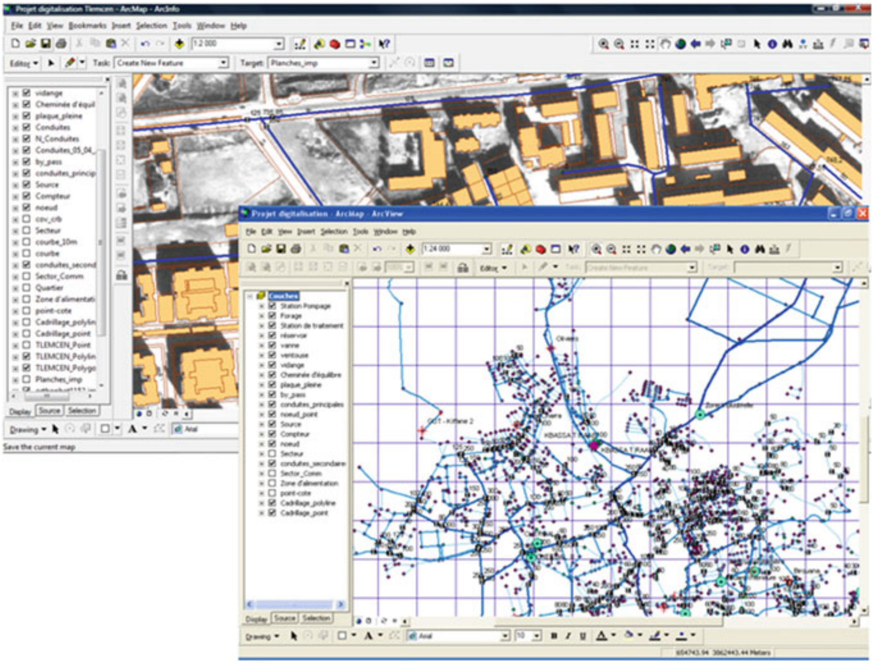


Fig. 7.5 Extracts from Tlemcen urban cluster water distribution network (Center City part, Kiffane) under GIS

7.3 Structure Query Language (SQL) Request and Thematic Analysis

Due to relational algebra and its set operators, it is possible to search for all the information that satisfies a set of criteria. These are alphanumeric or attribute requests. Structured Query Language (SQL) is used to formulate database queries based on relational algebra operators. The most important and semantically rich SQL command is the SELECT statement whose simplest form includes the clauses: SELECT, FROM, and WHERE. The SELECT clause makes it possible to express the projection on the list of attributes that one wishes to keep, the FROM clause makes it possible to quote the list of tables concerned by the SQL query and the WHERE clause groups together a set of conditions and also expresses the purpose of the restriction (Laurini 1993).

The implementation of the distribution network made it possible to analyze the network according to various criteria: diameter, construction materials, nature, and age of the pipes. Figure 7.6 shows a selection of pipes according to the construction material "galvanized steel (GS)". Figure 7.7 shows the result of the query concerning the classification of the pipes according to the "Discharge" function. Figure 7.8 shows pipelines with a problem of under sizing (diameter less than 80 mm). The results of

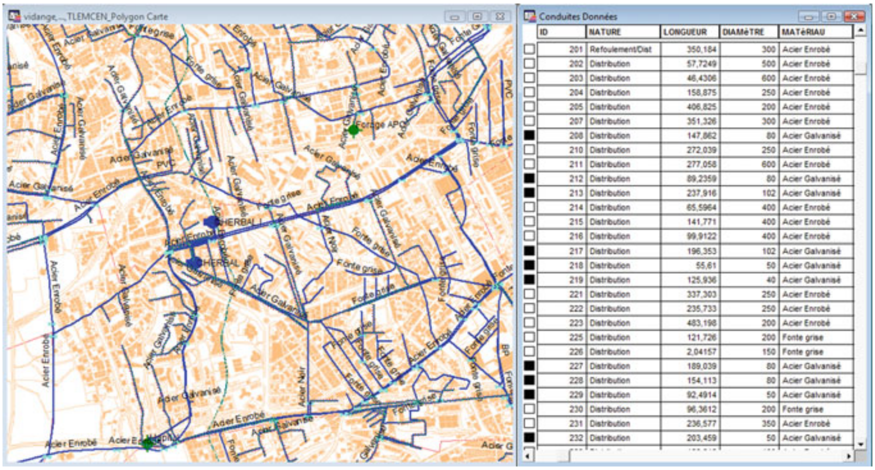


Fig. 7.6 Query result for galvanized steel pipe display

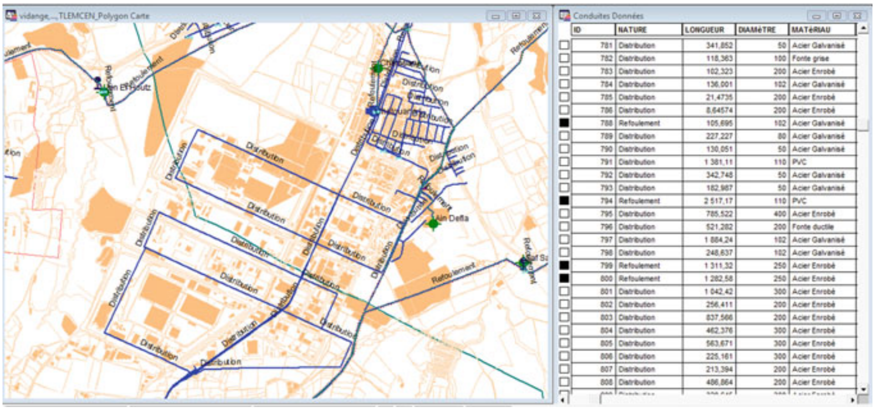


Fig. 7.7 Result of queries showing the discharge pipes

the queries obtained constitute the first form of diagnosis. By identifying the points of malfunction, the operator can first identify problematic areas of the network and make decisions to improve the state of the network (Blindu 2004).

The choice of diameters is based on the suppliers' catalogs. Given the high flows that the distribution pipes must convey, they are rarely of a diameter less than 0,060 m or even 0,080 m (Bonin 1986; Dupont 1979). The different extensions made at the Tlemcen urban cluster level are dictated by urgency and not based on a studied design (Abdelbaki et al. 2012, 2014). This is why 38% of the so-called main pipes have a diameter of less than 80 mm. Furthermore, given the high flows that the main pipes must carry, they are rarely less than 150 mm in diameter (Valiron 1994). The distribution of the pipes according to the diameters shows that 67% have a diameter

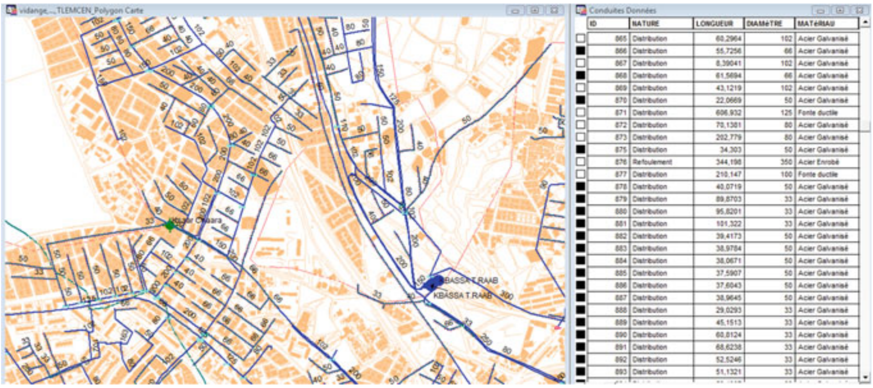


Fig. 7.8 Result of queries showing pipes with a diameter less than 80 mm

of less than 150 mm and only 31% have a diameter greater than 150 mm (Abdelbaki et al. 2012, 2014).

The choice of pipes used is a function of the pressure and nature of the ground, the costs of supply, and implementation, but also the ease of making connections, connections, repairs in the event of a leak (Bonin 1986; Valiron 1994). 15% of the pipelines are cast iron, these pipelines date from the 1950s. 47% of the pipelines are galvanized steel; they have a diameter of less than 100 mm, causing problems in the distribution of pressures in the distribution network. 38% of the remaining pipelines are of different materials [ductile iron for the renovated part (5%) prestressed concrete (24%), PVC (4%), and coated steel (3%)]. It can be noted that a significant portion of the pipes is in an advanced state of deterioration due to the discontinuous operation of the distribution (frequent draining of the pipes, etc.). And the poor condition of the installations (Abdelbaki et al. 2012, 2014).

The storage capacity supplying the Tlemcen urban cluster is 35 (ADE 2011) with a total storage capacity of 50,600 m^3. 81% of the storage capacities represent supply tanks and 19% remaining are the capacities which play buffer roles (Breeze Charge, dispatcher, etc.).

In the field of GIS, thematic analysis makes it possible to build thematic cartographies. These are geographical maps illustrating, by the use of various graphic parameters (color, symbolic, size, etc.), the behavior of a phenomenon in relation to its spatial location. An example of the Tlemcen urban cluster network is shown in Fig. 7.9. This example shows the distribution of diameters at the Tlemcen urban cluster's water distribution network.

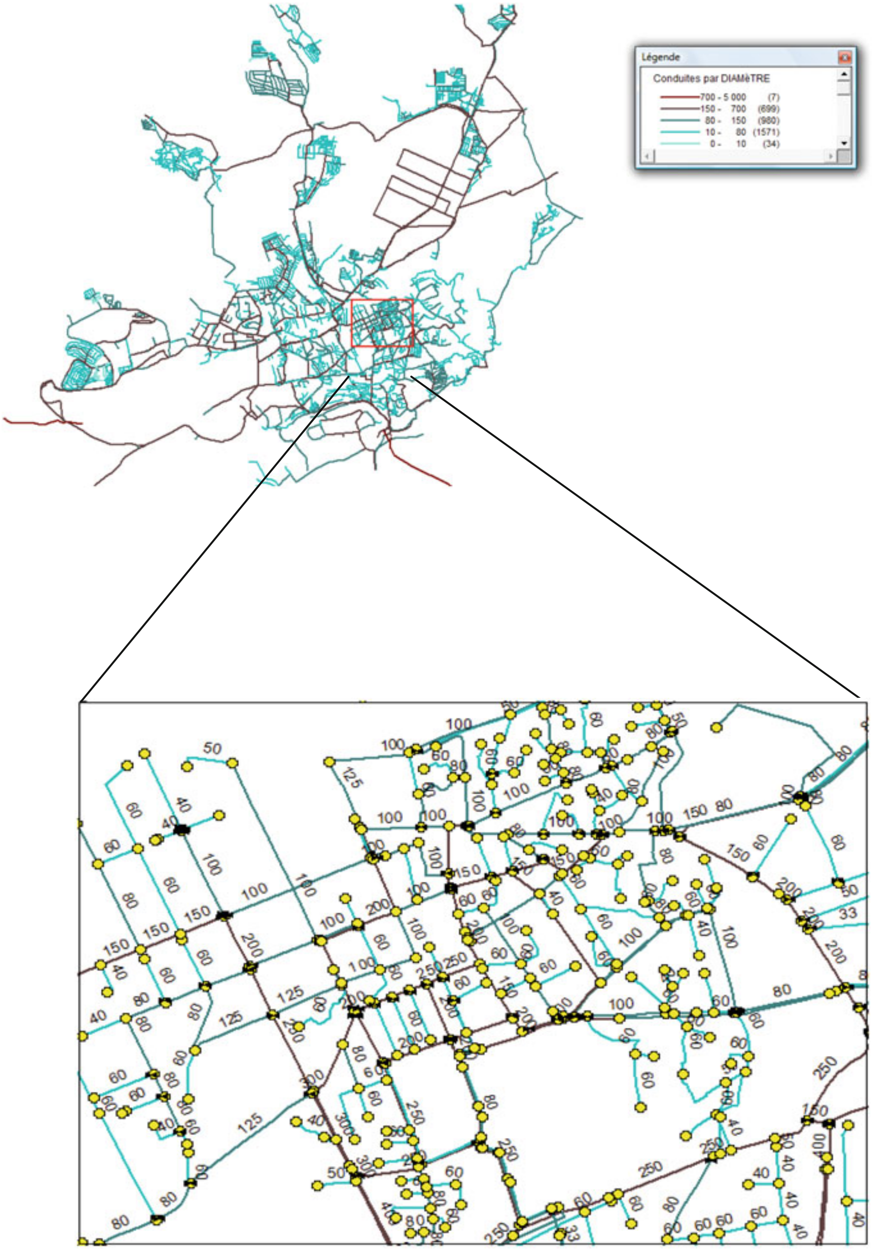


Fig. 7.9 Thematic analysis of Tlemcen urban cluster's network according to distribution of diameters

7.4 Creation of a Digital Model Elevation of the Tlemcen Urban Cluster

The Vertical Mapper tool was chosen for the creation of the digital elevation model (DEM) of the Tlemcen urban cluster. The interpolation method used was the irregular triangulation interpolation (TIN) for the construction of the DEM. Irregular triangulation uses an array of triangles as equilateral as possible that will connect the points in the data set. This triangulation is called Delaunay and is very useful for working on lots of data of any spatial distribution (Barbier 2002). The Tlemcen urban cluster's DEM was created from contour lines of 10 m equidistance and digitized coast points on the same maps. These curves were digitized from several topographic maps of Tlemcen urban cluster given at different scales (1/25,000, 1/50,000, 1/200,000); maps were obtained from the National Institute of Cartography and Remote Sensing. Figure 7.10 shows the different steps in creating the DEM. The result of the interpolation results in the DEM of the Tlemcen urban cluster, the superposition of the DEM, and the water distribution network is given in Fig. 7.11.

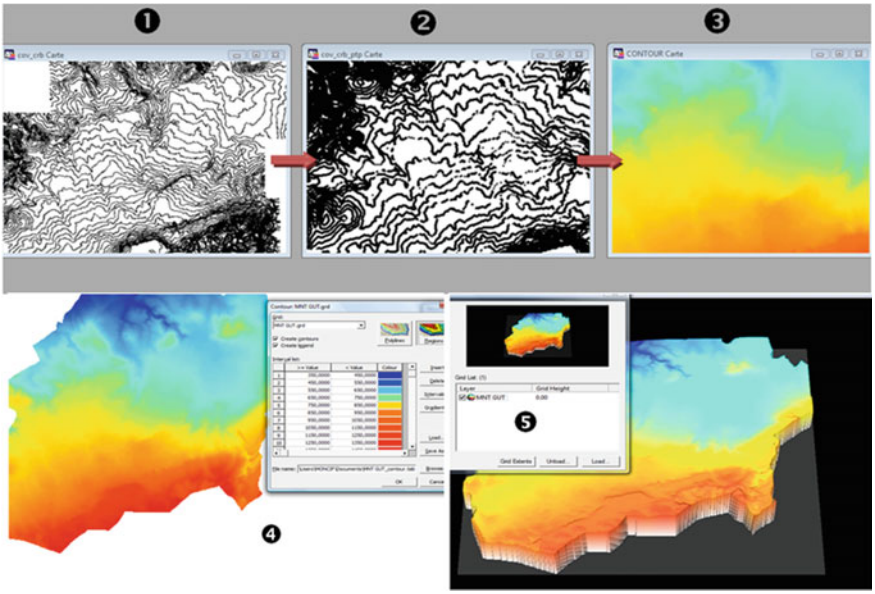


Fig. 7.10 Creation of the Tlemcen urban cluster's DEM

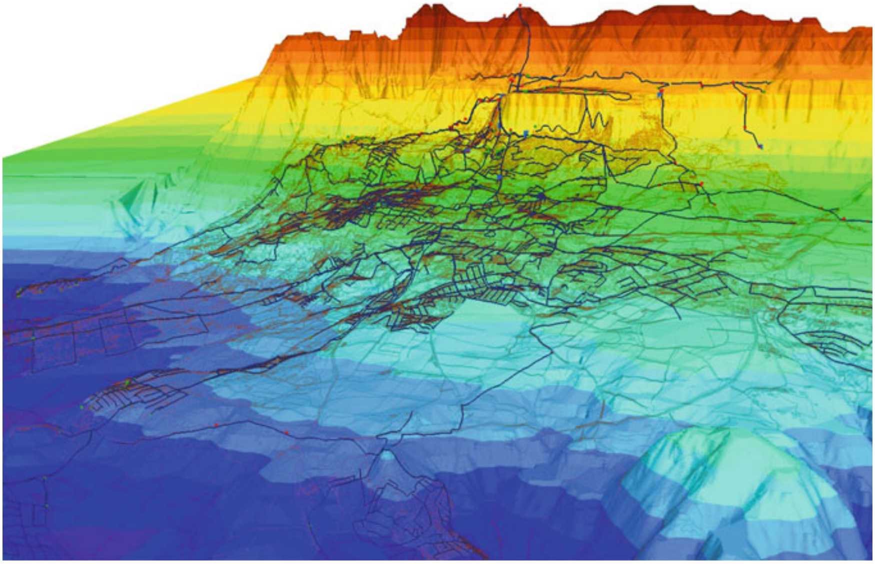


Fig. 7.11 Superposition of water distribution network and DEM of the Tlemcen urban cluster

7.5 Sectorization of the Tlemcen Urban Cluster's Network

Sectorization is the basis of any policy aimed at improving network knowledge about its functioning. This approach consists of breaking a network down into one or more subassemblies to make easy the global monitoring of distributed volumes and also incidents occurring. By making it easier to locate breakages or malfunctions, it makes it possible to prioritize repair or maintenance interventions by acting primarily on the most important leaks first. For example, the sectorization of the Tlemcen urban cluster's network was made by choosing two subassemblies, one with 24 zones and another with 18 zones. These distribution zones were created by manipulating valves (i.e., open/closed) on the network (Table 7.1). Figure 7.12 presents an extract from the sectorization scheme of the Tlemcen urban cluster's network. This operation is of great importance for network modeling. For each tank, the details of the valves, the arrival of the adduction, the departure to the distribution, the overflow, and the emptying are schematized. Figure 7.13 shows an example for the tank of SidiTahar.

Table 7.1 Network distribution sectors for Tlemcen urban cluster

No.	Sector
1	Sidi Chaker
2	Cherbal
3	Tombeau du Raab
4	Boudjmil
5	Sidi Tahar
6	Birouana 1
7	Birouana 2
8	Lalasetti
9	Boudhghène
10	Petit Mansourah
11	Koudia
12	Safsaf
13	Aindefla
14	Ain El Houtz
15	Oudjlida
16	Zone Industrielle
17	Chetouane
18	Ouzidane

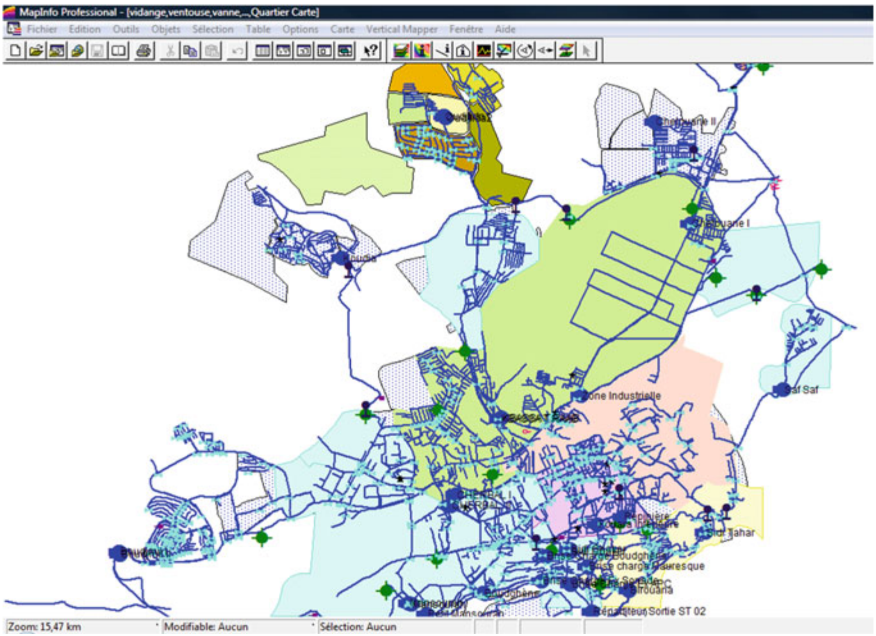


Fig. 7.12 Extract from sectorization of the Tlemcen urban cluster's network

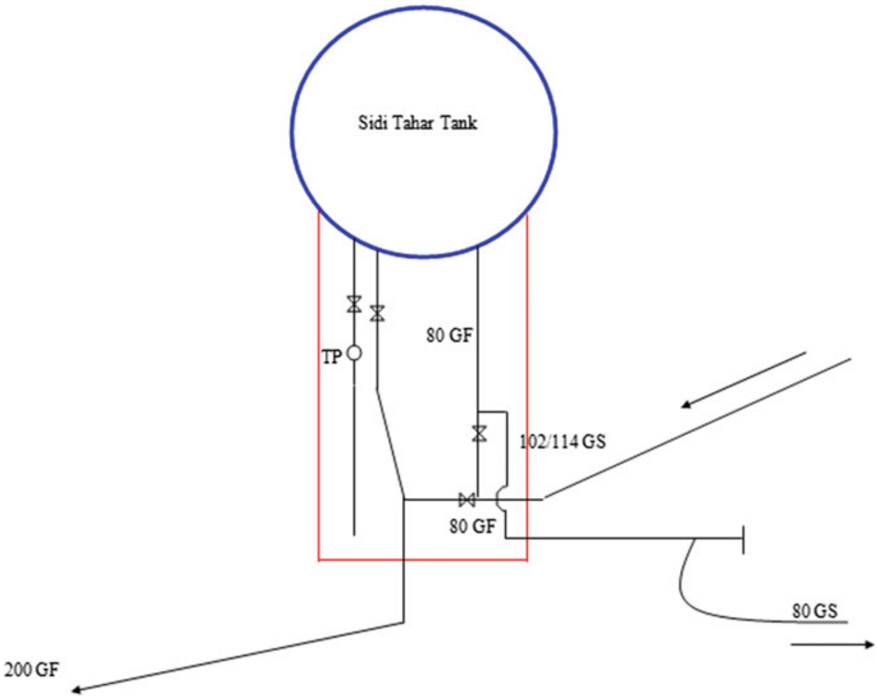


Fig. 7.13 Example of details of the valve chamber of the tank of Sidi Tahar

7.6 Coupling of GIS with Epanet and Analysis of Urban Cluster Network Operation

The scientific community is increasingly recognizing the usefulness of geographic information systems (GIS) coupling and behavioral models because it allows, among other things, the introduction of three-dimensional or spatial differentiation (via localized data) in the description of the processes studied in Pouliot 1999). GIS provides a flexible environment for localized data management (e.g., acquisition, structuring, storage, visualization, and dissemination), and it has very advantageous spatial analysis capabilities. The model contributes to the dynamic representation of the phenomena observed.

The EPANET computing model which was chosen for the current study is a simulation code for the hydraulic and qualitative behavior of water in water distribution systems (Rossman 2000). It aims to better understand the flow and use of water in distribution systems and can be used for different types of applications in the analysis of distribution systems. A water distribution network is defined by pipes (i.e., sections on the software), nodes (e.g., intersection of two pipes and end of an antenna) but also other components (e.g., tanks, pumps, valves, different types of valves). The models allow for calculating the flow through each pipe, the pressure at each node, and also the water level at any time of the day. The integrated hydraulic calculation engine makes it possible to process networks of unlimited size. It has several formulas for calculating pressure losses and includes the various individual pressure losses and models for fixed and variable speed pumps (Générale des eaux 2003). In summary, EPANET has the necessary tools to regulate pressures in the network, to detect deficit operating areas, allows for network dimensioning, and improves management of water equipment. The model has the same functionalities and possibilities as the other codes for drinking water networks such as Porteau or Piccolo. It has a user-friendly interface that makes it easy to access (Générale des Eaux 2003). EPANET has been used in various fields of research combined with GIS. The most recent work has been reported by Stefan et al. (2000); Burrows et al. (2000), Bell et al. (2000), Bartolin et al. (2001), Bahadur et al. (2001), Brown and Affum (2002), Daene and Ximing (2002), Gumbo et al. (2003), Alonso et al. (2004), Biagioni (2004), Ardeshir et al. (2006), Marunga et al. (2006), Zhang (2006), Zheng et al. (2006), Martinez et al. (2007), Yong et al. (2007), Vairavamoorthy et al. (2007), Jia et al. (2008), Jun et al. (2008), Bartolín et al. (2008), Tabesh et al. (2009), Kenneth and James (2009), Torres et al. (2009), Daoyi et al. (2010), Franchini and Alvisi (2010), Guidolin et al. (2010), Tabesh et al. (2010), Yu et al. (2010), Worm et al. (2010), Tabesh and Jamasb (2011), Zhou et al. (2011), Benson Andrew et al. (2012), Karadirek et al. (2012), Ramesh and Jagadeesh (2012), Tabesh and Saber (2012), Panagopoulos et al. (2012), Fattoruso et al. (2014), Furnass et al. (2013), Janke et al. (2013), Lynn (2013), Kurek and Ostfeld (2013), Nilufar et al. (2013), Padilla and Davila (2013), Roozbahani et al. (2013), Shafiqul et al. (2013), Sitzenfrei et al. (2013), Bach et al. (2014), Diao et al. (2014), Kanakoudis et al. (2014), Abdelbaki (2014), Choi and Koo (2015), Abdelbaki et al. (2017).

Coupling allows GIS to leverage the analytic capabilities of models with the models taking on the graphical and data management capabilities of GIS (Nyerges 1992). The aim for the network of the Tlemcen urban cluster was to facilitate access to the data of different databases, to ensure communication between the computer code and the user in the various tasks to be performed such as data loading, launch of calculation, modification, and display of results. It is necessary to control the network topology before starting geoprocessing. The GIS-EPANET passage (Fig. 7.14) was performed using the DXF2EPA tool (Salomons 2005). It is a program that converts all line and polyline elements (in DXF format layers) into a set of pipes and fittings under EPANET (Rossman 2000). Additional elements must be added manually to the model (Worm et al. 2010) such as tanks, pumps, and valves. The conversion program can calculate pipe lengths. Other network data such as node elevations, pipe demands, and pipe diameters must be manually entered into EPANET (Rossman 2000) after the converted file is loaded (Fig. 7.15). After the conversion of the different layers under EPANET (Rossman 2000), network data are entered, such as pipe diameters and roughness, elevations, and basic node demands as well as tanks and valves. Figures 7.16, 7.17 and 7.18 illustrate the loading of data for the different components of the Tlemcen urban cluster's network.

Network consumptions are defined at the nodes. The advantage of this step is to be able to establish a consumption profile specific to each part of the network from the demand of the nodes at its peak flow. Once the simulation options are defined,

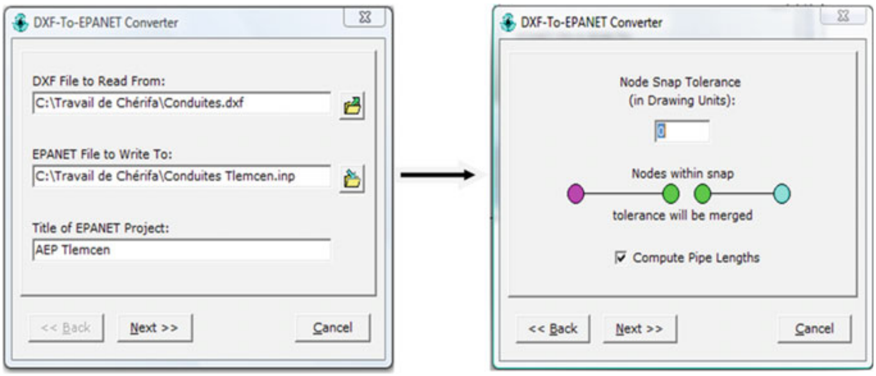


Fig. 7.14 GIS-EPANET conversion

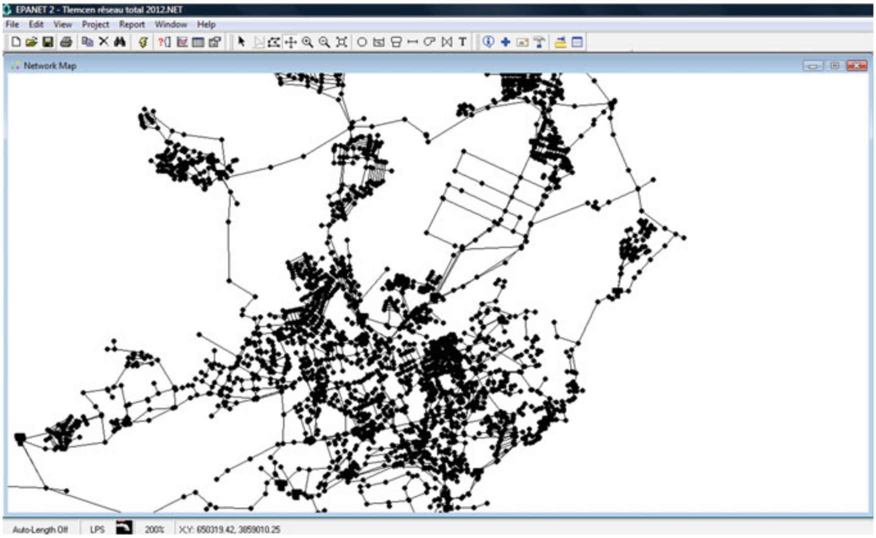


Fig. 7.15 The Tlemcen urban cluster's network imported under EPANET

the simulation is launched for each sector separately as well as for the entire network (18 sectors). Figures 7.19 and 7.20, respectively, show the start of a simulation and the result of the simulation for the operation of the water distribution network. Figures 7.21 and 7.22, respectively, represent the simulations for the areas of Abu Tachfine and Birouana. The aim of the calibration was to bring the behavior of the model closer to that of the real system. It was about making the model representative of reality. For this, pressure and flow measurements were performed at the tanks of the network. From these measurements made in given situations such as level in the tank, roughnesses values were assigned to the pipes.

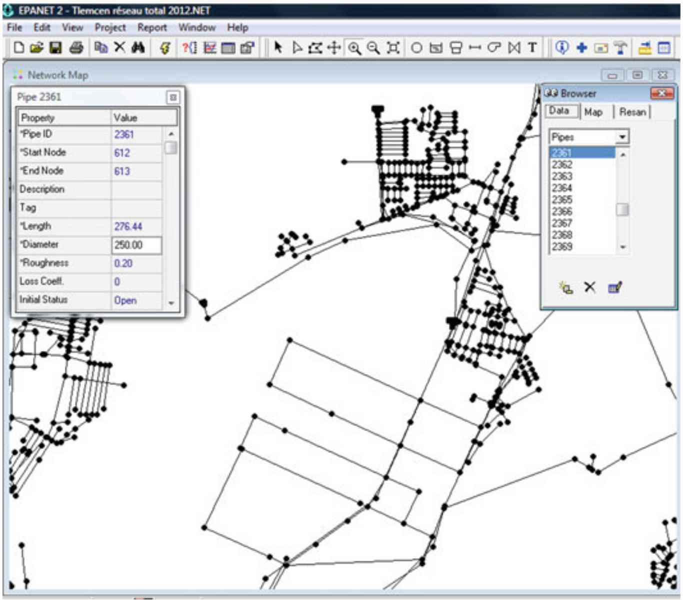


Fig. 7.16 Example of data input of pipelines

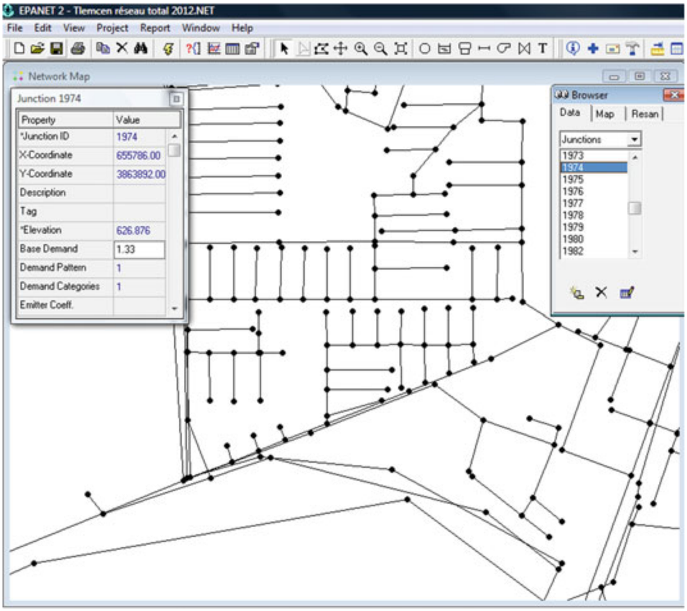


Fig. 7.17 Example of data input of nodes

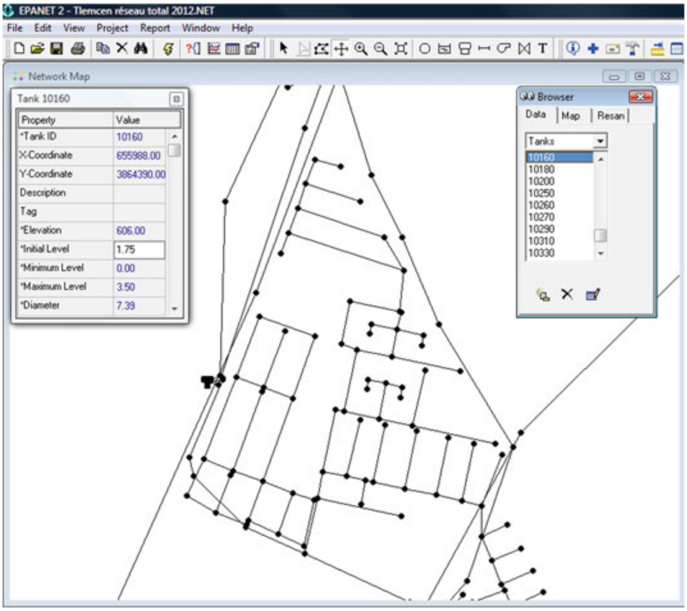


Fig. 7.18 Example of tank data input

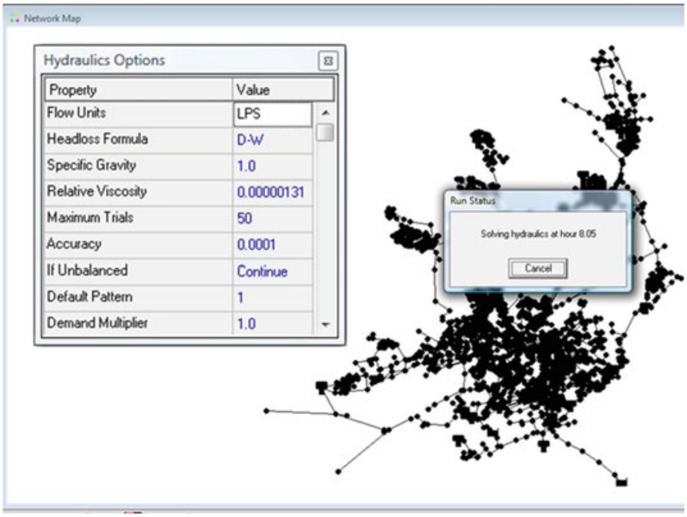


Fig. 7.19 Simulation options of the Tlemcen urban cluster's network

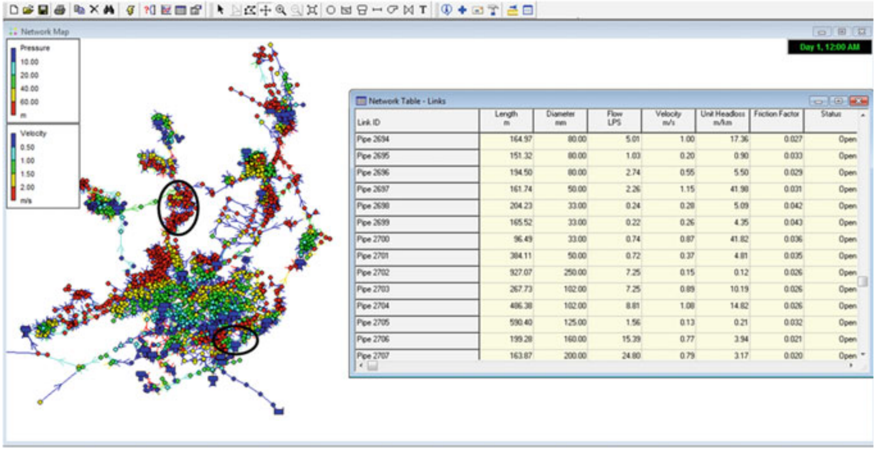


Fig. 7.20 Tlemcen urban cluster's network simulation results

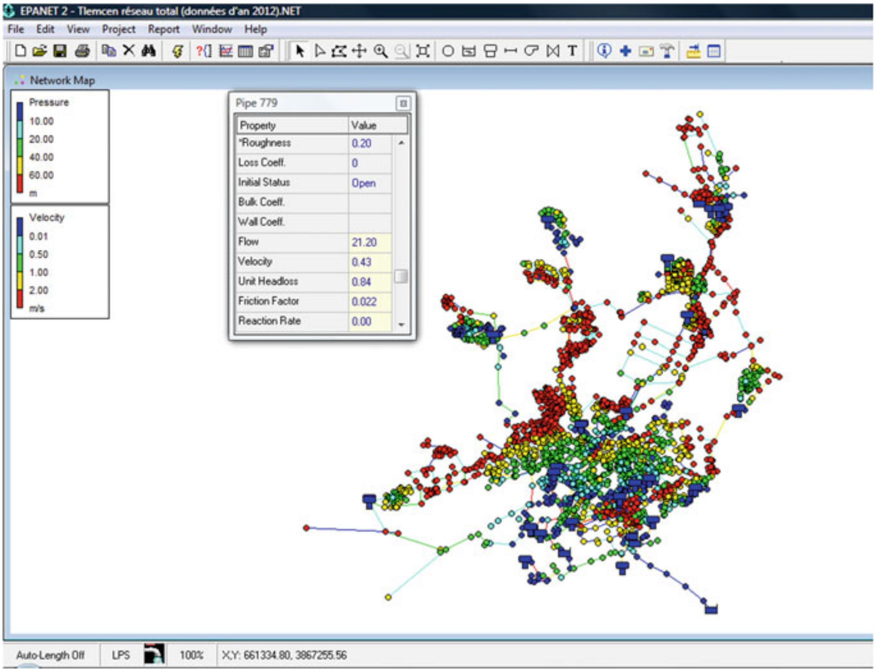


Fig. 7.21 Geometric and hydraulic characteristics of a pipeline

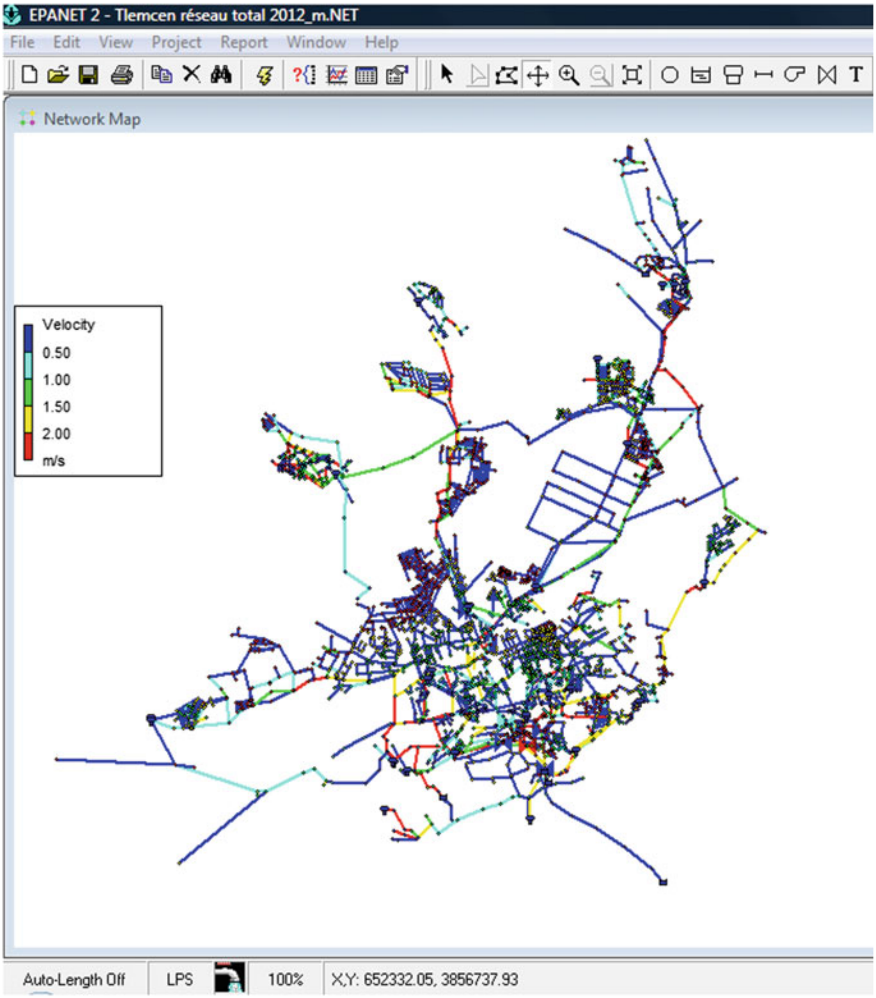


Fig. 7.22 Breakdown of rush hour velocities

7.7 Synthesis and Interpretations of Results

Several scenarios were studied, namely, rush hour network behavior and simulation scenarios during the day. Figure 7.21 shows the geometric and hydraulic characteristics of a pipe after the simulation. The parameters taken for the analysis of the operation of the network were flows, velocities, and pressures. The pipes must be able to transit the highest instantaneous flows, taking into account the peak flow. The velocity of the water in the pipes was of the order of 0.5–1 m/s. Speeds above 1.5 m/s, as well as velocities below 0.5 m/s, should be avoided (Dupont 1979). Low

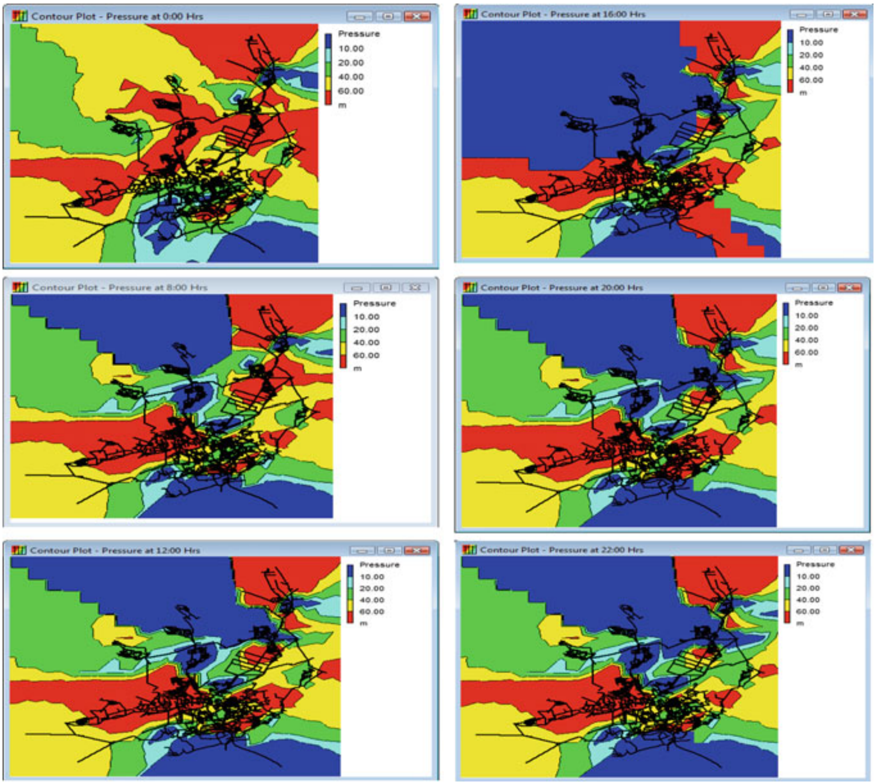


Fig. 7.23 Envelope pressures at the water distribution network for different simulation periods

velocities favor the formation of deposits, which are difficult to remove, and those above 1.5 m/s make it possible to envisage increases in consumption without the user becoming overly sulfurized (Valiron 1994). Figure 7.22 illustrates the distribution of velocities in the water distribution network during peak hours. According to the analysis of the water distribution network based on "rush hour velocity" criterion, 70% of the pipes, i.e., 2639 pipe sections, may have problems with deposits due to the low flow speeds (speed <0.5 m/s). 17% of the pipelines, i.e., 641 have a velocity between 0.5 and 1.5 m/s (in the norms) and 13% of the pipelines, that is to say, 489 are likely to have the problems of internal erosion following the high velocity ($v > 1.5$ m/s).

In view of the good behavior of the pipes, it is necessary to avoid in city pressures higher than 40 m which are likely to bring disorders (leaks) and some unpleasant noises in the indoor installations of subscribers (Dupont 1979; Gomella 1985; Bonin 1986). The pressure envelope at the Tlemcen urban cluster is given in Fig. 7.23 for different simulation periods. In 31% of the nodes of the water distribution network of the Tlemcen urban cluster, i.e., 1097 nodes, the pressure exceeds 60 m, which explains the considerable losses in distribution exceeding 50% (Abdelbaki et al. 2012, 2014). In 14% of the nodes, i.e., 481, the pressure is less than 10 m, which is at the origin of the limited service of the subscribers. In addition, there are health and hygiene problems resulting from the mode of operation and storage at the household level (Allal et al. 2012; Abdelbaki 2014). As for the remaining 55%, 1906 nodes, the pressures are between 10 and 60 m of water (in the distribution standards).

Based on the results obtained for the Tlemcen urban cluster's network, several recommendations can be made. The geometry of the network should be reviewed. Rehabilitation operations are essential to correct the geometrical characteristics of the network. This is of great importance to have satisfactory hydraulic characteristics for velocities and pressures. The installation of pressure regulating devices such as stabilizing valves for the areas where the pressures are greater than 60 m is essential. New storage capacities should be installed for Chetouane, Ain el Houtz, AbouTachfine, Koudia, and Oudjlida. A consumption model should be developed specifically to the Tlemcen urban cluster, to better represent the population pattern.

7.8 Concluding Remarks

This chapter described the development of a geographical database essential for the management of a water distribution network in an urban environment by coupling Mapinfo GIS and EPANET model. From the various data about the network such as pipe diameters, the network environment, and using GIS, it was possible to obtain an alphanumeric description of the pipes, tanks, and all the accessories constituting the network. Design irregularities in the urban cluster network were identified. The approach adopted contributes to enhanced management of water distribution networks and offers operators of such networks a tool that permits not only for a better understanding how a network functions by knowing, for instance, the state of a particular point or node, but it also allows for analysis of malfunctions and gives the ability to provide an almost instantaneous response for any incident that may occur. The coupling of GIS with a mathematical model thus provides an operating tool that allows managers and operators to diagnose their networks, to study the solutions to the problems encountered and to plan for future situations. While the advantages of such systems are well established, data collection and data entry require a considerable amount of work; however once completed, the stored information proves for effective and improved management of the water distribution network.

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Chapter 8
Remote Sensing Technology for Evaluation of Variations in Land Surface Temperature, and Case Study Analysis from Southwest Nigeria

Adebayo Oluwole Eludoyin, Iyanuoluwa Omotoso, Oyenike Mary Eludoyin and Kehinde Solomon Popoola

Abstract Recent studies have shown that evaluation of the changes in the Land Surface Temperature (LST) of any area can be a reflector of changes in urbanisation trend, industrial activities, population change and natural factors. Subsequently, many researches have evolved over time, especially with development in remote sensing, digital image processing and geographical information systems. This chapter is aimed at providing information on the relevance and challenges of remote sensing as a geospatial technology that is capable of being used for monitoring LST at different spatial and timescales. The case study analysis indicated that the results from the remote sensing processing of the imageries reflect significant influence of the spatial resolutions of selected imageries. The challenges of huge image data gaps, cloud cover, coarse spatial and temporal resolution, limited night-time data for evaluation of night-time urban heat island—for both technical and security reasons, influenced the reliability of the study results. The study recommended policies for improvement in the applications and utilisation of the geospatial technology in many developing countries, including Nigeria based on its strengths.

Keywords Image sensors · Land surface temperature · Image analysis · Nigeria

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8.1 Introduction

The Land Surface Temperature (LST) is an indicator of the degree of hotness or coldness of the earth surface, usually defined in terms of surface energy balance as well as an integrated thermal state of the atmosphere within the atmospheric boundary layer. It is a variable of the atmospheric temperature and is typically measured as a standard surface-air temperature with a device (thermometer), that is, until recently; probably due to improvement in instrumentation, often sheltered in a well-ventilated Stevenson screen (often constructed with its base at 1.5–3.5 m above a flat surface—with grass vegetation) (Sun 2011).

The LST is a key parameter in land surface processes, both as an indicator of climate change and as control of the surface sensible and latent heat flux exchange with the atmosphere. For the latter, energy exchanges at the land surface boundary are largely controlled by the difference between the skin temperature and the surface-air temperature. Also, surface heat fluxes can induce local convection in the boundary layer, producing changes in air temperature, surface winds, cloudiness and, possibly, precipitation (Aires et al. 2001). The LST is also key to detecting the amount of sunlight energy reflection, which is connected with surface energy balance and the atmospheric integrated thermal state within the boundary layer of the earth (Jin and Dickinson 1996). It is a key parameter in land surface processes often assessed to indicate variations and change in climate, and monitor sensible and latent heat flux exchanges within the atmosphere (Sun and Pinker 2003), where it is associated with surface heat dynamics (Aires et al. 2001). It is a primary variable to correctly represent the budget of surface energy and can be used to study the factors behind the variations in the two-way transfer of energy between the atmosphere and the earth's surface (Prata et al. 1995).

Studies (e.g. Matsui et al. 2003; Pinheiro et al. 2006; Sun 2011) have also reported relationships between LST and the variability of rainfall, soil moisture, among other land surface processes, and suggested that the LST is important for assessment of surface energy balance, monitoring of vegetation water stress and insect-vector disease proliferation, detection of land surface disturbances, among others. Also, Xiao and Weng (2007) demonstrated the use of LST for estimation of land-use/land-cover changes and classification in Guizhou Province, south of China while studies, including Streutker (2002), Akinbode et al. (2008), emphasised LST to identify urban heat islands in high urban concentration areas. Streutker (2002) commented on the helpfulness of remotely sensed temperature data in the study of heat islands of urban areas, in the comparative analyses performance and the ease of obtaining such data, especially for global studies. Tran et al. (2006) on part of Asia noted that remote sensing aids in providing insight on the environmental conditions residents of an area are living in.

Recently, with development in computing and satellite technology, the satellite-based surface temperature has become commonly available, globally. The satellite-based land surface temperature is regarded as an estimate of the kinetic temperature of the earth's surface skin as viewed by the sensor to a depth of about 12 μm (Sun

2011). From the satellite data, temperature is inferred from the thermal emission of the earth surface based on mean effective radiative temperature of various canopy and soil surfaces.

8.2 Objectives and Description of the Case Study Area

This chapter is aimed at providing information on the relevance and challenges of remote sensing approaches to the evaluation of LST in a typical developing country. The case study analysis is focused on: (a) evaluation of LST over a typical medium-size traditional town of Ile-Ife in Nigeria, from multi-date Landsat imageries and in situ surface temperature acquisition from a sling psychrometer; and (b) comparison of the efficiency of Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat imageries for the evaluation of variations in LSTs over Eti-Osa local government area, a coastal settlement, also in Nigeria. Ile-Ife is located within 7° 24′N 4° 27′E and 7° 33′N 4° 36′E while Eti-Osa local government area is located within 6° 27.5′N, 3° 36′E and 6° 27′N, 3° 36′E. Whereas Ile-Ife covers about 21,800 ha and has population of about 355,813 as of 2006 (NPC 2006) with a projected 5% annual increase, Eti-Osa with a total land area of 18,243 ha and a population of 283,791 (3.11% of the entire Lagos State) as of 2006 (NPC 2006) was expected to have increased by about 7.5% annually.

8.3 Remote Sensing Technology for Determining Land Surface Temperature

Remote sensing is generally defined as a method of data acquisition that involves the use of a system (including platform, sensor, detector and a ground control station) of device which collects information about an earth-referenced body (phenomenon or object) without physically contacting it. Remote sensing acquires information on its target within the wavelengths of the electromagnetic spectrum (Lillesand et al. 2004), and has been found applicable to many fields of study including the climate science. Recent studies have shown that remote sensing is more effective than traditional field-based surveys in spatial consideration of climate elements, especially because they have the comparative advantage to provide information for areas with poor gauging/monitoring network, difficult terrains from where in situ data collection is impossible as well as dangerous, security-threatened environment. For example, Luvall et al. (1990) argued that inaccessible regions, especially in the tropical forests, often limit the usefulness of the in situ monitoring, making remote sensing approach an important option. Nonetheless, some very high-resolution imageries can be very expensive to procure (Carver et al. 1995; Bastiaanssen et al. 2000), and embarking on a remote sensing mission often requires a huge budget.

Despite the difficulties associated with procurement of remote technology, studies have shown that agencies and government parastatals in many countries now make datasets and processing software available for researchers in developing countries available, freely (e.g. Landsat from the NASA archive) or at reduced cost (such as the Idrisi Kilimanjaro edition in the 2000s, and recently ArcGIS software). With the availability of the data, scenarios can now be explained in terms of temporal changes (e.g. Foody and Curran 1994; Clevers 1997; Popoola 2016).

In the area of climate investigations, remote sensing data have been used to complement in situ climatic data. In situ climatic equipment are usually fixed or mounted to a place (an observation station that is classified geometrically as northings and eastings or longitude and latitude; *x*, *y*) from where rainfall, temperature, wind or any other climatic elements are measured. Constructing the observatories, maintaining and monitoring them in large but developing countries such as Nigeria, Ethiopia (Africa) and India (Asia) can be very expensive (Mallick et al. 2008), and as such would require the construction of meteorological stations in large numbers, which is not really feasible; and with limited number of the climate stations, representative meteorological conditions may be difficult to retrieve (Southworth et al. 2004), but to this, the remote sensing approach provides an opportunity to resolve.

In addition, the remote sensing possesses a comparative advantage as a source of data, covering large areas and at varying (small to high resolution) and for a very large number of time periods. Analysis of remotely sensed data can also be easily regulated through users' defined algorithms to provide focused decision support results. For the purpose of obtaining LST, thermal sensors are predominantly used, and the appropriate waveband for analysing LST is the satellite thermal band. It is suitable for LST retrieval for several reasons. Thermal infrared sensors are widely used in retrieving land surface temperature, probably of its recognised contributions to the knowledge of processes on the land surface; it measures landscape and biophysical compositions' surface temperature and can infer comparison in body's responses to surface temperatures and fluctuations in energy (Sobrino et al. 2006). Thermal data can also be used to monitor the form of energy exchange between the atmosphere and the land surface and changes in surface temperature of a landscape (Hurtado et al. 1996).

8.4 Major Sources of Satellite-Based Land Surface Temperature

Satellite-based LST can be determined from thermal emission at different atmospheric windows wavelengths in either infrared or microwave. Satellite sensors known to capture thermal data include the Advanced Very High-Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Other popular sensors, including Quickbird-2, IKONOS-2 and SPOT 4 and 5, despite their high spatial and temporal resolutions, do not have thermal bands and thus cannot provide data to map LST.

Among all the well-known satellite sensors, other than Landsat, ASTER data possess comparatively (with many other available satellite products) high thermal band resolution. In addition, ASTER offers a product that provides temperature and reflectance values that can be used as direct inputs in LST studies. However, this data is not free and ASTER's temporal resolution period is 16 days like Landsat. Its LST value has also been found to be of limited accuracy (Liu et al. 2006). Also, ASTER data have been found to be more appropriate for research purposes than for purposes of operation, and it is used because of its extensive use and global applicability (Prata et al. 1995), such as in detecting urban heat islands (Peña 2009) while Landsat thermal data are used mostly for land-use/land-cover change detection (Mausel et al. 1993).

Of the Landsat sensors, Landsat 7 ETM+ appears to possess relatively higher thermal band resolution. Landsat imageries are characterised by a 16-day temporal that makes its data unsuitable for emergency situations. Unlike ASTER, Landsat does not offer high-level products like surface temperature values, which makes its users go through extra work in doing the computation. Despite these limitations, the capacity of Landsat data to sense different land-cover types separates it from the other satellite sensors and makes it possible to study how the different land-cover types relate to the temperature of the earth's surface (NASA 2013). Landsat Thematic Mapper (TM) thermal band acquires information within the range of 10.4–12.5 μm of the Electromagnetic spectrum.

8.5 Factors Influencing LST Retrieval from Remote Sensing Data

Several factors are considered when retrieving (calculating) LST from the thermal band of an imagery. The factors include soil moisture that is known to considerably influence the reflectance value—this will influence seasonal variations in reflectivity and albedo, especially in evaluating deforestation and desertification (van Leeuwen et al. 2011). Heat exchange is often suppressed or lowered in more vegetated areas than in less vegetated or urbanised areas (Oke 1987; Weng 2003). Inherent factors include vegetation density, roughness of the land surface—accounting for land surface roughness properties is a major reason why corrections are made to brightness temperatures used for LST computation (Snyder 2000).

Sensors' characteristics include the varying viewing angles of the satellite sensor has considerable effects on the radiance observed from space (Atitar et al. 2008). For example, −5 to 7 °C nadir and off-nadir-induced variations in surface temperature were observed in a study by Atitar et al. (2008). Rasmussen et al. (2011) argued that the highest emissivity occurs at nadir and decreases as the view zenith angle increases. Also, Zhang et al. (2006), comparing Landsat and MODIS imageries reported the need for atmospheric profile parameters as a major problem faced when retrieving LST from Landsat TM 5 thermal channel images, because the sensor which ‘does not have a robust set of thermal infrared bands that can be used to calculate atmospheric profile parameters’. Also, Alsultan (2005) argued that Landsat thermal channel is only one band unlike other satellite sensors that are not freely available (including MODIS) that have more than one thermal bands, and which subsequently provide a better assessment of accuracy.

Furthermore, climatic variables such as air humidity and cloud cover are important factors that required consideration while dealing with LST. Subsequently, the latter requires atmospheric corrections—aimed at removing the atmospheric effects, including humidity. Cloud cover, on the other hand, poses hindrances in the observation of bodies as its presence (thickness, distance) may prevent adequate/appropriate detection of the bodies; Ackerman et al. (1998) argued that with the presence of clouds over an area, only the temperatures at the top of the clouds are measured, not the land surface.

8.6 Studies on LST in the Nigerian Environment

Studies which investigated spatial and temporal dimensions of LSTs across Nigerian landscapes have explored the use of the ground-based devices, especially the sheltered thermometer, portable weather station and sling thermometers (Table 8.1). Climatic data from the sheltered thermometers were common until the early 2000s when Geography ceased to be a compulsory subject for some sets of students in the Nigerian curriculum for Senior Secondary Schools. With geography as a compulsory subject, a standard ‘Geographical Garden’ was required in the schools, and this was valuable for documentation of climatic data, especially rainfall, temperature and humidity at local stations.

These data sources are almost non-existing in the Nigerian environment in the recent time. A few numbers of studies used data from established monitoring weather stations in airport stations, specialised training schools and institutes (such as School of Agriculture, Akure, Ondo State which collected climatic data until mid-2005, Forestry Research Institute of Nigeria, Cocoa Research Institute, School of Aviation, Zaria) (Adebayo 1990; Akinbode et al. 2008). Towards the last decade (2000–2010), the Nigerian’s National Meteorological Stations were standardised operationally, and efforts were made to improve its spatial coverage under the management of the Nigerian Meteorological agency (NiMet). The NiMet has, in 2017, written letters to some Universities in Nigeria to revamp their moribund meteorological stations.

In addition, few studies have used data obtained at shift (temporary) or roving stations. Equipment used in these studies ranged from digital in situ-based fixed lascar temperature relation data logger and Thermochron iButton by maxim-c equipment

Table 8.1 Example of studies on land surface temperature determination over Nigeria

Approach	Study objectives	Sources of data and acquisition method	Reference
Ground data approach or in situ observation	Effect of urban growth on temperature of Benin City Nigeria	Data were collected from two synoptic stations and eight purposively located sites	Efe and Eyefia (2014)
	Rural–urban temperature difference and UHI function in Akure, Nigeria	In situ-based fixed lascar (EL-USB-2) temperature relation data logger	Balogun and Balogun (2014), Balogun et al. (2012)
	The impact of urbanisation on the spatial and temporal variations of temperature and humidity in Akure, Nigeria	In situ-based use of psychrometer to obtain temperature, relative humidity and dew point temperature across different land use	Akinbode et al. (2008)
	Spatio-temporal variation of UCHI and its relation to land use in Kano, Nigeria	In situ-based using Thermochron iButton by maxim-c to collect 24 h temperature of the day- and night-time at different points	Abdulhamed et al. (2012)
	Roles of urbanisation on surface-air temperatures within Owerri, Nigeria	Surface-air temperature measured using mercury in glass thermometers placed at vertical height of 1.75 m above the surface	Nwofor and Dike (2010)
	The temporal structure of the urban heat island intensity of Lagos state	Temperature data using the dry bulb were collected from four synoptic weather stations for a period of 1 year	Oluwamimo (2006)
	Characteristic of urban heat island in Enugu city during rainy season periods	Complementary use synoptic station data and hourly and averaged temperature measured at a period and fixed point	Enete and Alabi (2012)

(continued)

Table 8.1 (continued)

Approach	Study objectives	Sources of data and acquisition method	Reference
Remote sensing /geographic information system (GIS) approach	Influence of land-use/land-cover change on the surface temperature of Abuja, Nigeria	Multi-temporal imageries (Landsat TM and ETM+) of 1987, 2001 and 2006 (September to December)	Usman (2014)
	Mapping Enugu city's urban heat island, Nigeria	Multi-temporal Landsat imagery TM of October 2008 with 120 m pixel resolution.	Enete and Okwu (2013)
	Urban heat island (UHI) of Lokoja town, Nigeria	Multi-temporal Landsat ETM+ of 17th November 2001	Ifatimehin and Adeyemi (2008)
	Spatial extent of the heat island in Akure, Nigeria	Landsat ETM+ imagery collected of 3rd of January 2002 with 30 m spatial resolution	Aderoju et al. (2013)
	Intensity of surface urban heat Island in Lagos, Nigeria	Multi-temporal Landsat imageries Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) of 1984 and 2012.	Ayanlade and Jegede (2015)
	Land-cover change, land surface temperature, surface Albedo and topography in the Plateau, Nigeria	Multi-temporal Landsat imageries Landsat TM (1986) and Landsat ETM+ (2014)	Odunuga and Badru (2015)
	Analysis of temperature variations using remote sensing Lokoja, Nigeria	The Landsat TM image of 10th December 1987 with a 30 m spatial resolution	Ifatimehin et al. (2010)
	Urban land-use/land-cover surface temperature–air temperature Nexus in Makurdi, Nigeria	Multi-temporal imageries (Landsat TM/ETM+) for January, April and June of 1991, 1996, 2001 and 2006 and complemented with air temperature data from two weather stations	Tyubee and Anyadike (2012)

(Balogun et al. 2012; Abdulhamed et al. 2012; Balogun and Balogun 2014) to small less expensive, electromechanical portable and sling thermometer (Akinbode et al. 2008; Popoola 2016). The choice of instruments depends on their availability and accessibility (cost of purchase or hiring), both conditions that pose severe impediments to researches in Nigeria because most postgraduate students who are used for most of these researches often have limited (if any) access to funding. In fact, a rough estimate of more than 90% of researches by Nigerians living in Nigeria is self-funded.

With development in space technology as well as remote sensing and geographical information systems, the use of satellite-based approach to LST estimation has increased. The LST can be determined from thermal emission at wavelengths in either infrared or microwave electromagnetic spectrum windows. Satellite sensors with thermal bands from which LST can be determined include the Advanced Very High-Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the United States Geological Survey's (USGS) Landsat-5 Thematic Mapper (TM), Landsat-7 Enhance Thematic Mapper (ETM+) and Landsat-8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) (Wang et al. 2008; Prata et al. 1995; Omotoso 2017). Many other popular satellite sensors, including Quickbird-2, IKONOS-2, SPOT 4 and 5 and the Nigeria-owned NigeriaSat-2, despite their preferred higher resolutions, do not possess thermal bands for LST computation (Omotoso 2017).

Among all the satellite sensors with thermal bands, Landsat is the most popular among Nigerian researchers because the data are provided free in the archive of the USGS (http://www.earthexplorer.usgs.gov, http://www.glovis.usgs.gov). Landsat thermal data, on the other hand, has been increasingly used successfully in classifying land cover (Mausel et al. 1993; Wang et al. 2008), and of all its satellite sensors, Landsat 7 ETM+ possesses the highest thermal band resolution. However, its rich archive (from 1972) makes it useful for multi-temporal studies. Problems with the scan line corrector have degraded the quality of the image captured so that only the middle 20 km of the imagery is useful (Clark et al. 2003). Unlike ASTER (which unfortunately is costly), Landsat does not offer high-level products like surface temperature values; hence, LST must be computed from the thermal bands using some specified equations (Walawender et al. 2009).

8.7 Case Study: Materials and Methods

8.7.1 Data and Analyses

Data analysed for Ile-Ife were the multi-date satellite Landsat imageries; Landsat-5 Thematic Mapper (TM) acquired on 5th January 1991, Landsat-7 Enhance Thematic Mapper (ETM+) acquired on 12th December 2002 and Landsat-8 Operational Land

Imager/Thermal Infrared Sensor (OLI/TIRS) image acquired on 5th January 2015. For Eti-Osa, 1986, 1996, 2006 and 2014 Landsat data were analysed, and 2014 Landsat imagery was data (band 31, 32) for the same area.

8.7.2 Method of LST Extraction from Landsat Imagery

The mono-window algorithm method was used to retrieve the LST from Landsat imageries, following the following steps:

i. Conversion of Digital Number (DN) to AT Spectral Radiance
The digital numbers of the thermal band were converted into radiance values for each of the investigated years using the following Eq. (8.1):

$$\text{Radiance} = L_{\text{MIN}} + \left(\frac{(L_{\text{MAX}} - L_{\text{MIN}})}{Q_{\text{CALMAX}} - Q_{\text{CALMIN}}}\right) \times (Q_{\text{CAL}} - Q_{\text{CALMIN}}) \quad (8.1)$$

where

Radiance	(W/m^{2}ster μm)
L_{MIN}	minimum spectral radiance at Q_{CAL}
L_{MAX}	maximum spectral radiance at Q_{CAL}
Q_{CALMAX}	255
Q_{CALMIN}	0 (sometimes 1)
Q_{CAL}	digital Number (DN)

ii. Conversion to AT Reflectance

$$R_\lambda = \frac{\pi \times L_\lambda \times d_2}{\text{ESun}_\lambda \times \text{Sin(SE)}} \quad (8.2)$$

where

R_λ	at surface reflectance
L_λ	spectral radiance
π	3.142 (constant)
ESun_λ	sun elevation angle
d_2	earth–sun distance

iii. Conversion from Radiance to Brightness Temperature (in degree Celsius)
Thus, the thermal band radiance values were converted to a brightness temperature value using the Planck's function

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} - 272.3 \quad (8.3)$$

where

T	temperature (Celsius degree)
K_1	calibration constant 1 (W/(m^2sr μm))
K_2	calibration constant 2 (Kelvin)
ln	natural logarithm
L_λ	spectral radiance at the sensor's aperture (W/(m^2sr μm))

iv. Estimation of Land Surface Emissivity (LSE)
In estimating LSE, Normalised Differential Vegetative Index (NDVI) was utilised for emissivity correction,

$$\mathrm{NDVI} = \left(\frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}\right) \tag{8.4}$$

$$\mathrm{LSE} = 0.004\mathrm{Pv} + 0.986 \tag{8.5}$$

$$\mathrm{Pv} = \left(\frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}}\right) \tag{8.6}$$

where

Pv	proportion of vegetation, and it can be derived from equation *x*
NIR	near infrared band
Red	red band
$\mathrm{NDVI}_{\mathrm{min}}$	minimum value of NDVI
$\mathrm{NDVI}_{\mathrm{max}}$	maximum value of NDVI

v. Estimating LST

$$\mathrm{LST} = \frac{\mathrm{BT}}{1 + w} \times \frac{\mathrm{BT}}{p} \times \ln(e) \tag{8.7}$$

where

BT	at sensor brightness temperature
W	wavelength of emitted radiance

$$p = h \times \frac{c}{s}\left(1.438 \times 10^{-2}\ \mathrm{mK}\right)$$

H	Plank's constant (6.626×10^{-34} Js)
s	Boltzmann constant (1.38×10^{-23} J/K)
c	velocity of light (2.998×10^{8} m/s)
e	LSE

8.7.3 Retrieval of LST from MODIS

The MODIS/Terra Land Surface Temperature and Emissivity (LST/E) products provide per-pixel temperature and emissivity values in a sequence of swath-based to grid-based global products. The MODIS/Terra LST/E Daily L3 Global 1 km Grid product (MOD11A1) is tile-based and gridded in the Sinusoidal projection and produced daily at 1 km spatial resolution. The MODIS thermal infrared data (band 31, 32) were utilised to derive the land surface temperature (Wan and Dozier 1996).

$$T_s = C + \left(A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_{31}+T_{32}}{2} + \left(B_1 + B_2\frac{1-\varepsilon}{\varepsilon} + B_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_{31}+T_{32}}{2} \quad (8.8)$$

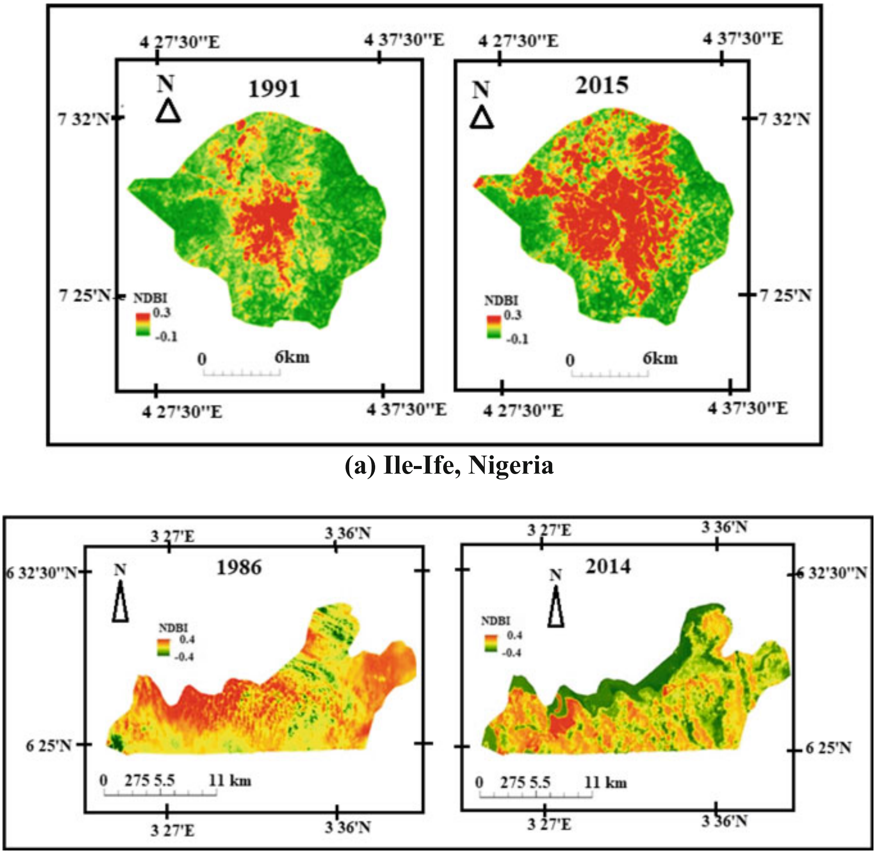
where
$\varepsilon = 0.5\ (\varepsilon_{31} + \varepsilon_{32})$,
$\Delta\varepsilon = \varepsilon_{31} - \varepsilon_{32}$ (mean, difference of surface emissivity's in MODIS bands 31 and 32),
T_{31} and T_{32} = brightness temperatures,
C = coefficients and
A_i and B_i; $i = 1, 2, 3$ (interpolated from a set of multidimensional look-up tables).

The LST values were obtained by linear regression of the MODIS simulation data from radiative transfer calculations over wide ranges of surface and atmospheric conditions.

8.8 Changes in Case Study

8.8.1 Changes in LST and Growth in Selected Case Study Areas

Both the land-cover classification and NDBI analysis indicate an increase in built-up areas and corresponding LST values at both Ile-Ife in Osun State and Eti-Osa LGA in Lagos State (Figs. 8.1 and 8.2). The NDBI values increased both temporally and spatially within the study period; average NDBI varied from a range −0.1 to 0.3 in 1991 to −0.3 to (−)0.2 in 2015 in Ile-Ife, and from −0.1 to 0.2 in 1986 to −0.1 to 0.4 in 2014 at Eti-Osa. Land-cover classes (water body, vegetation, built-up and peri-urban) around them also changed; vegetation decreased by 32.7%, built-up area increased by 28.9%; peri-urban and water body increased by 0.01 and 4.1%, respectively, with over 40% increase in built-up areas in Eti-Osa.



(a) Ile-Ife, Nigeria

(b) Eti-Osa, local government area in Lagos, Nigeria

Fig. 8.1 Change in normalised difference built index (NDBI) over Ile-Ife and part of Lagos in Nigeria

The spatial variations of LST at Ile-Ife indicated an increase from the inner region towards the outskirts, which appears to possess the multiple-nuclei model of city arrangement hypothesised by Hoyt (1933). Hoyt (1933) hypothesised an explanation of city development in which a place is characterised by more than one nucleus for development. In Ile-Ife, there is more than one nucleus. Ile-Ife, the traditionally acclaimed origin of the *Yoruba*s, was sub-grouped into subsections (Akodi) of communities which were under a royal head (Ooni). This traditional arrangement of settlement, siting of educational institutions (including the Obafemi Awolowo and Oduduwa Universities), communal daily and periodic markets encouraged the multi-nuclei arrangement, which have been linked with temperature trend patterns (Figs. 8.3 and 8.4). Eti-Osa Local Government Area (LGA) in Lagos State, is a typical coastal settlement which has significant urban growth due to increase population

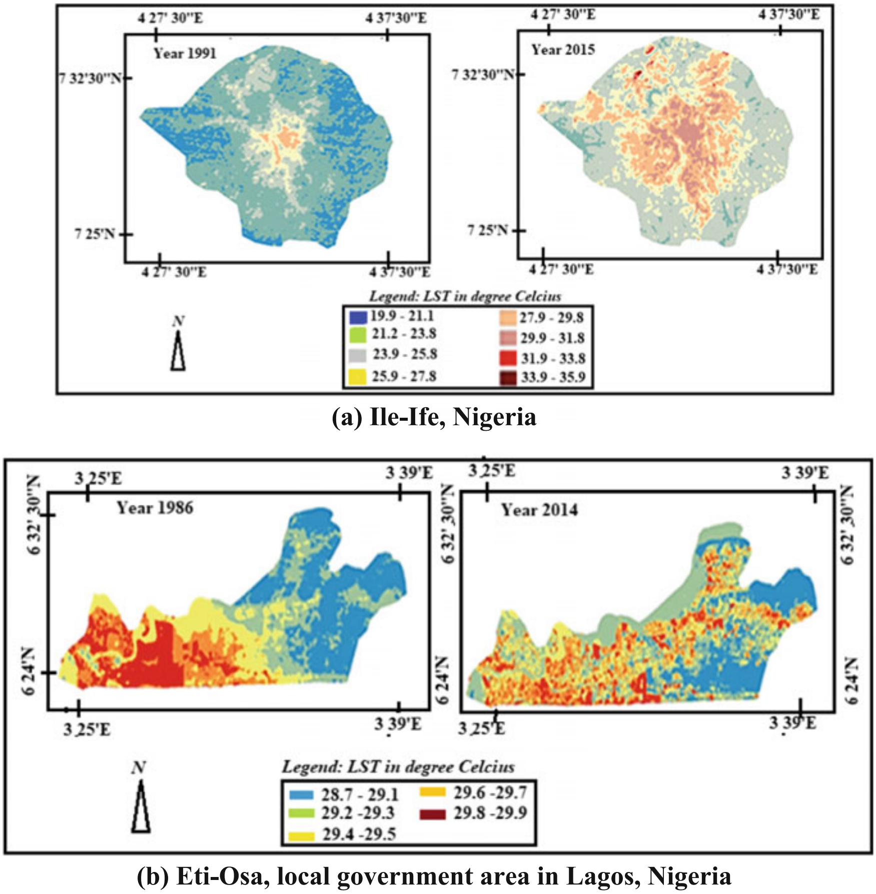


Fig. 8.2 Change in land surface temperature (LST) values over Ile-Ife and part of Lagos in Nigeria (representative sample)

and commercialisation, and this is probably why the results of NDBI and LST tend to be widespread, following less defined pattern like the experience in Ile-Ife. Comparatively, however, the lower LST values recorded at Eti-Osa (than Ile-Ife's) may be linked to the influence of the ocean around the settlement. Studies (e.g. Voogt and Oke 2003) have indicated that water acts as sink to reduce LST because of their low emissivity and high albedo.

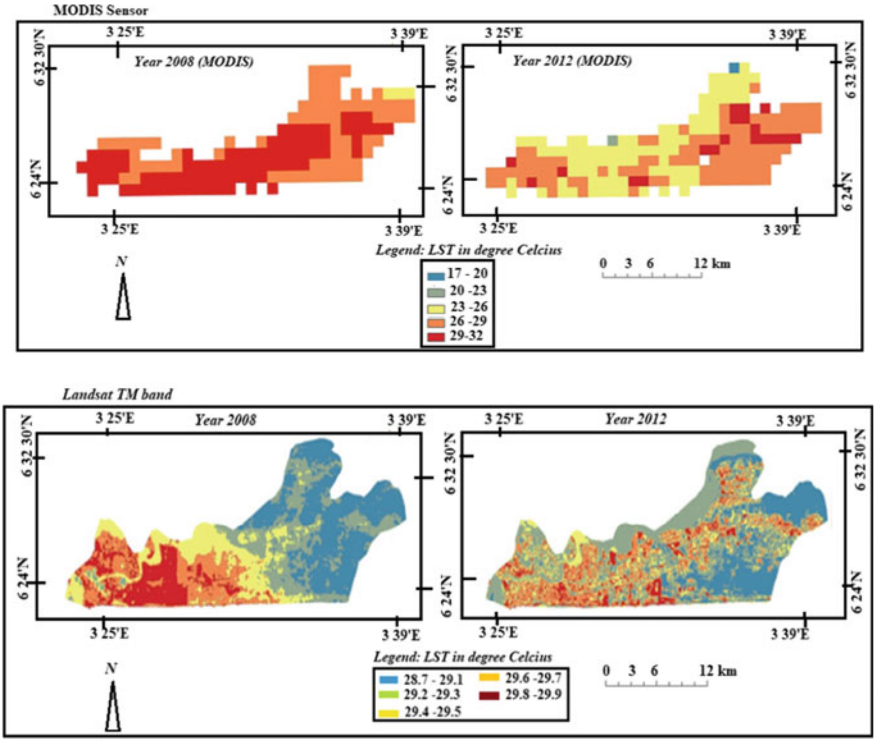


Fig. 8.3 Sample representatives of the effect of image spatial resolution and sensor on LST classification of Eti-Osa local government area in Lagos State, Nigeria

8.8.2 Effects of Spatial Resolution

Due to the limitation imposed by data availability and cost of data procurement, the commonly used satellite data, MODIS (1 by 1 km resolution) and Landsat (30 by 30 m resolution) were compared (Fig. 8.3). The results showed that the effect of spatial resolution on the results can be significant, especially in terms of the minimum and maximum temperature. Also, given the large instantaneous field of view (IFOV) of MODIS, the results can only be generalised. A simple comparison of the maximum LST values showed that while MODIS recorded 22.4 and 28.9 °C for 2008 and 2012, respectively, the values were 26.5 and 29.3 °C, respectively, with Landsat.

8.8.3 Effect of Season on LST Retrieval

Temperatures typically vary with seasons, as humid condition, water bodies and green vegetation tend to sink heat and reduce temperature (Ayanlade and Jegede 2015).

Table 8.2 Seasonal variation in LST in Eti-Osa, Lagos State, Nigeria

Year	Wet season		Dry season	
	Minimum – maximum	Mean ± standard deviation	Minimum – maximum	Mean ± standard deviation
1986	26.89 – 29.42	28.14 ± 0.5	28.16 – 29.69	28.8 ± 0.24
1996	28.67 – 30.03	29.25 ± 0.28	28.88 – 30.13	29.14 ± 0.21
2006	28.83 – 29.98	29.36 ± 0.26	28.67 – 29.92	29.29 ± 0.24
2014	27.66 – 29.12	28.65 ± 0.24	28.34 – 29.33	28.92 ± 0.19

Many existing studies on the Nigerian LST condition however rarely consider this impact and its influence on results. In the Eti-Osa case, Table 8.2 shows that LST values were generally lower in the wet season than in the dry season. A comparison of the average values indicated in Table 8.2 with the distribution in Fig. 8.4 suggests a non-uniform difference in the study area.

The spatial variations of LST within the study area indicate that higher temperatures were recorded in the southern part of the region at most period of the study, and hotspots, indicating the surface urban heat island occurred mostly in the south and western parts; more hotspots were shown to develop in the dry season than the wet season.

8.9 Conclusion and Recommendations

The geographical technology assessed in this chapter is remote sensing. The chapter has presented its usefulness in land surface temperature analysis as a measure of urbanisation effects on the microclimate of an area. Increasing trend in urban growth and expansion has been noted in many countries, and if this is not well monitored, its effects on the environment may be severe. Spatial and temporal variations in temperature as a result of urban growth are linked to reduction in sources of temperature sink such water bodies and vegetation in many urban areas. Subsequently, improvement in the application of the geospatial technology of remote sensing in many developing countries, where they are presently poorly accessed is recommended. Also, it is recommended that existing programmes on space technology advancement in many developing countries, including Nigeria, should step above mere political campaigns and creation of civil service jobs without specific goals. The use of remote sensing in many of these countries can be developed to an extent to be deployed to fight terrorism.

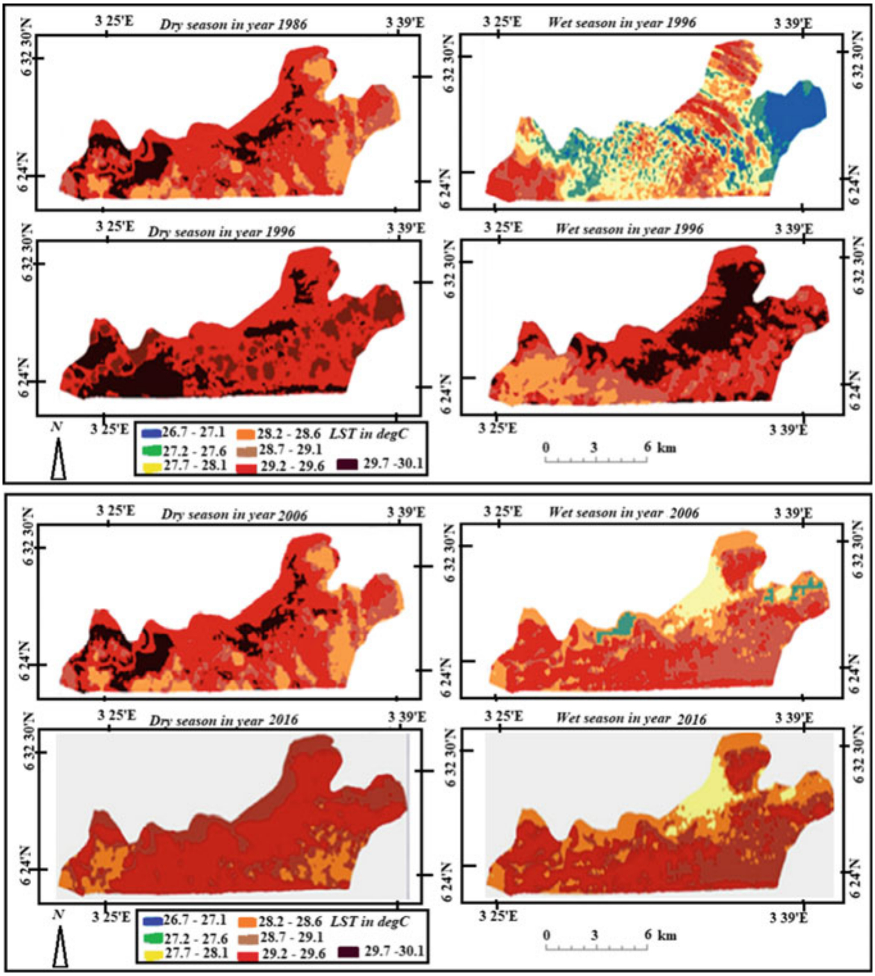


Fig. 8.4 Seasonal patterns of LST over Eti-Osa local government area in Lagos State, Nigeria, from Landsat thermal band

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Part II
Geospatial Challenges and Geographical Skills

Chapter 9
Web Map Application to Support Spatial Planning, Decision-Making and Transition Toward Climate-Smart Landscapes in the Taita Hills, Kenya

Tino Johansson, Janne Heiskanen, Mika Siljander and Petri Pellikka

Abstract There is a growing demand for geospatial technologies and skills in Kenya due to the ongoing devolution of government to the county level, development of GIS-based National Land Management Information System, and digitalization of information and maps to databases. Furthermore, the adaptation of agricultural production to the impacts of climate change, and its transition toward climate-smart landscape approach require support from geospatial technologies to stakeholders to sustainably manage land use interactions, such as soil, water, and nutrients along with agro-forestry, livestock, husbandry, and forest and grassland utilization at landscape level. A simple and visual Multifunctional Agricultural Landscape Mosaic (MALM) Story Map and Web Application was developed to support this transition and adoption of open access geospatial technology among the universities, government organizations, and NGOs in Kenya. The thematic content of the web application was designed to support climate change adaptation action planning in the target area with a focus on water resources, conservation agriculture, agro-forestry for the smallholder farms, and insect pest management. This chapter describes the emerging challenges of advancing geospatial technologies in Kenya, presents the results of a feasibility study of MALM and discusses its potential in supporting spatial planning and decision-making in climate change adaptation in the Taita Hills, southeast Kenya.

Keywords Geospatial · Web mapping · Spatial planning · Landscapes · Climate Kenya

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9.1 Challenges of Advancing Geospatial Technologies in Kenya

Advances in Geospatial Technologies have revolutionized the delivery of reliable and timely datasets and information about Earth. Open-source software, web mapping applications and data repositories gradually expand the reach of computer-based models and geospatial information to the Global South and help bridge the global digital divide in terms of access to, use of and impact of geoinformation on, e.g., monitoring climate and land change, and assessing situations during extreme events, as well as on planning and decision-making. In recent years, a wide range of web-based decision support services using mapping and GIS have been developed for environmental purposes, such as watershed management (Zhang et al. 2015), integrated pest management (Damos 2015), pest infestation (Lajis et al. 2016) and ecosystem services (Tayyebi et al. 2016). Transition to geospatial cloud computing removes the need to purchase or maintain in-house servers, and makes customized use of web-based GIS instantly and widely available (Cope et al. 2017) which can increase geospatial technology adoption in countries with limited economic resources for software and data storage.

Despite the accelerating global trend in the use of geoinformation, many countries in the Global South lack behind in this process mainly due to inadequate human capacity with Geospatial skills and information networks, especially in the rural areas. Kenya, which is a lower middle-income country and a leading trade and mobile technology hub in East Africa, provides an interesting case study for assessing the challenges and opportunities of advancing geospatial technologies in the twenty-first century. In Kenya, the transition from traditional paper-based mapping and planning to digital information-based technology in the higher education institutions, county governments, ministries, companies, non-governmental organizations, and extension services currently takes place at accelerating speed. This transition will have a huge impact in the Kenyan economy through increased availability and efficiency of geospatial information use in decision-making, developing services for ICT-based society and customers, and in generating businesses and jobs in this growth sector.

Many ongoing projects in Kenya underline and indicate the growth of geospatial technologies in both public and private sectors. During the First Medium Term Plan in 2008–2012 the Kenyan Government managed to develop 10% of the GIS-based National Land Management Information System which will provide a digitalized Land Registry once finalized. Geo-referenced land titles register will be more transparent, efficient and decentralized than the existing printed documentation system. The development of e-commerce in Kenya identifies GIS maps for all inhabited areas during the Second Medium Term Plan in 2013–2017. GIS also plays a key role for Kenya's infrastructure development as digitization and mapping the electricity grid network into a GIS utility database will be finalized by the year 2017, which makes maintenance and monitoring more efficient and effective and as a result will ensure more stable delivery of electricity across the country.

Demand and use of geospatial technologies, as well as the need to develop geospatial skills, are also increasing through the ongoing process of devolution of government which is implemented under the new Constitution of Kenya 2010. It gives powers of self-governance to the established country governments, such as the Taita Taveta County in southeast Kenya. The counties need to take up and facilitate many functions and responsibilities that earlier were under the national government and sectoral ministries. Availability of and access to geoinformation are critically important to these county governments, which adopt full responsibility for local natural resources management and food security under the new realities of climate change. The new Constitution's clause on Environment and Natural Resources further inform that the State will establish systems of environmental impact assessment, environmental audit and monitoring of the environment which will certainly increase the demand to use of digital geoinformation at the county level. However, the counties staff and other authorities require geospatial skills and knowledge to fully utilize such digital resources in, e.g., land management and planning.

The higher education sector in Kenya has not managed to keep pace in the provision of degree programmes on GIS, remote sensing and geoinformatics which would ensure the availability of high-quality professionals with geospatial skills to the labor market and business development. In Kenya, Master's degree training in geoinformatics, GIS and/or remote sensing is only provided in the capital city Nairobi by the University of Nairobi and the Jomo Kenyatta University of Agriculture and Technology. This lack of training opportunities in geospatial skills, which already are and will increasingly be of high demand in the counties as transformation into digital/information society proceeds, causes regional disparity and uneven capacity development in Kenya. Rural–urban migration has been the only option for young graduate students and in-service training staff to study geoinformatics in the country, assuming that they can afford the higher living expenses in the capital city. The University of Helsinki with support from the Ministry for Foreign Affairs of Finland launched a new M.Sc. degree programme in geoinformatics (www.helsinki.fi/en/projects/taitagis) in cooperation with the Taita Taveta University to support regional equality in geospatial and information technology skills and capacity in Kenya in the year 2018.

Political support to the modernization of higher education curricula is present and indicated in the long-term national policy called Kenya Vision 2030 (Government of the Republic of Kenya 2007) which encourages public and private universities to expand enrollment with emphasis on science and technology. One of the major goals of the Kenya Vision 2030 is to make the country a regional center of research and development of new technologies in Africa. The Universities (Amendment) Bill to the Senate in July 2014 proposes the establishment of public universities in each county to promote learning, knowledge, research, and innovation. The Bill states that the objectives of university education in Kenya will among other things advance knowledge through teaching, scientific research and investigation, support and contribute to the national economic and social development, disseminate the outcomes of the research conducted by the university to the general community, facilitates lifelong learning through adult and continuing education, and promotes gender balance and equal opportunity among students and employees (Government of the Republic of Kenya 2014). These policy statements lay the basis for the future advancement of technologies, such as geospatial that will support scientific research, decision-making and education in various disciplines in the country.

However, emerging challenges for the development of information and communication technologies, e.g., slow adoption of these services by educational, social and government institutions, lack of harmonized data management system, and inadequate information resource centers in rural areas may hamper their utilization (Government of the Republic of Kenya 2013). Sharing geo data within and across organizations has remained very limited so far. A detailed country-wide assessment of the challenges of advancement of geospatial technologies is not available, but being part of modern information and communication technologies (ICT) many of the identified challenges for their development may also be applied to geospatial technologies in Kenya.

The Second Medium Term Plan 2013–2017 of the Kenya Vision 2030 (Government of the Republic of Kenya 2013) identifies the poor state of infrastructure and equipment for research in higher education and training as an emerging issue and a challenge for the development of science, technology, and innovations. Web-based applications, however, may help overcome most of the infrastructure-related problems in geospatial technology adoption. This document further states that the emerging issues and challenges for the development of ICT are inadequate human capacity for research and development of ICT, slow adoption of ICT services by learning, social and government institutions, lack of harmonized data management system, inadequate information resource centers in rural areas, and low ICT skills. Nyangau (2014) points out that Kenya's higher education system should pay more emphasis on supporting the country's economic growth and development by "preparing well-educated highly trained workforce for industrialization, modernization and global citizenship". He summarizes that despite its rapid expansion Kenya's higher education system faces a number of serious challenges, such as curricula that are not responsive to the needs of modern labor market, lack of basic laboratory supplies and equipment, poorly equipped libraries and ever-growing demand of higher education. Innovative, user-friendly web map application that addresses some of the key challenges of advancing geospatial technologies in Kenya has been developed under the Adaptation for Food Security and Ecosystem Resilience in Africa project coordinated by the International Centre of Insect Physiology and Ecology in Nairobi, Kenya. The web map application will be described in detail later in this article.

9.2 Geospatial Technologies to Support Transition Toward Climate-Smart Landscapes

The experienced and projected impacts of climate change on agriculture in Kenya generate a major development challenge. Approximately 98% of the country's agricultural systems are rain-fed making them highly susceptible to increased variability of rainfall and other impacts of climate change. Agriculture contributes to 25% of Kenya's GDP and accounts over 65% of exports, so any negative trend in production will directly affect food security, employment, economic growth and poverty (Government of the Republic of Kenya 2017). To address these challenges, the country has recently launched the Kenya National Climate-Smart Agriculture Programme 2017–2026 which is expected to guide actions that are needed to transform and reorient agricultural systems to support food security under the new realities of climate change. Lipper et al. (2014) describe climate-smart agriculture as an approach which differs from business-as-usual approaches by emphasizing the capacity to implement flexible, content-specific solutions which are supported by innovative policy and financing actions. The aim of climate-smart agriculture systems is to increase farmers' adaptive capacity, resilience and resource use efficiency in agricultural production systems.

Emphasis on integrated land and water management approaches in climate change adaptation and mitigation has generated a concept of climate-smart landscapes (CSL) which includes a variety of field and farm practices in different land and tenure types that support both adaptation and mitigation objectives. The CSL approach aims at managing land use interactions, such as soil, water, and nutrient management along with agro-forestry, livestock, husbandry, and forest and grassland management techniques at landscape level. The key is to maintain high level of diversity: (1) to reduce risks of production and livelihood losses from erratic and changing climatic conditions, (2) to utilize certain areas of the landscape strategically as emergency food, feed, fuel, and income reserves, and (3) to sustain minimally disturbed habitats, such as forests, within the landscape mosaic that also serve as carbon stocks, and secure ecosystem functions (Scherr et al. 2012).

The successful implementation of climate-smart landscapes requires functional interactions of economic, ecological and social processes in the negotiated spaces where a diverse set of stakeholders identify, negotiate and manage the impacts of different land uses and management on other land uses and users at multiple scales in the landscape (Scherr et al. 2012; Minang et al. 2015). Geospatial technologies can be used in the facilitation of negotiation process among the stakeholders as these enable overlay visualization, queries, and other functionalities which help in understanding different landscape level phenomena and mapping risks.

In the Adaptation for Food Security and Ecosystem Resilience in Africa (AFERIA) project (http://chiesa.icipe.org/index.php/aboutaferia) funded by the Ministry for Foreign Affairs of Finland, a web map application, Multifunctional Agricultural Landscape Mosaic (MALM), was developed. It consists of authoritative maps compiled from scientific findings, stakeholder observations and prioritized community-based climate change adaptation actions to support current and future land use planning and decision-making for gradual transition to climate-smart landscapes in the Taita Hills, Kenya. The Coast Region, where the Taita Taveta County is located, has over time experienced third highest absolute poverty levels in the country. The Human Development Index (0.527) in the Coast Region was slightly below the national average (0.561) in 2009. (Friedrich Ebert Stiftung 2012). Taita Taveta County's vicinity to the coastline and connectivity with Mombasa has in recent years resulted in huge infrastructure development projects by the government, such as the standard gage railway between Nairobi and Mombasa and tarmac road establishment between Voi town and Taveta international border. These huge projects have impacts on the environment and communities located at the affected areas and surroundings. These large-scale changes in land use, housing, and industry area development, impact to ecology and wildlife, and increased human–wildlife conflicts, call for experts able to handle geospatial data for regional planning. Spatial information used in land use planning and environmental impact assessment for these infrastructure projects has so far been only available in the form of printed map sheets at selected authorities' and constructors' offices. Availability of, and access to such key information to support decision-making has been limited and negatively affected the transparency of land demarcation processes.

9.3 MALM Web Map Application to Support Spatial Planning and Decision-Making

The MALM web map combines authoritative maps with narrative text and images to tell a story on climate change adaptation themes, such as prioritized sites/locations for adaptation actions, drip irrigation, roof rainwater harvesting, farm forestry, conservation agriculture, and integrated pest management for certain staple and cash crops. The layers visualized include a summary of the observed land use/land cover changes, projections of future climate and prediction models of land use/land cover, and suitability analyses of intervention, thus providing an interface for local, regional and national users for communicating current and projected impacts of climate and land change. The web map will support land use planning and identification of key areas for climate change mitigation and adaptation actions in the Taita Hills, but may also be used in education for spatial citizenship (Jekel et al. 2015) throughout Kenya.

The geospatial visualizations for MALM include a Story Map and an additional Web App built using Esri ArcGIS Online platform (www.arcgis.com). ArcGIS Online is a cloud-based web-GIS platform to make, search and share web maps, web map applications, and geospatial data.

Using the MALM Story Map and Web App requires only a web browser. However, if the involved projects stakeholders want to prepare their own online services, they need to register to ArcGIS Online. ArcGIS Online can be accessed for free through a public account, which is not associated with any organization but offers a limited set

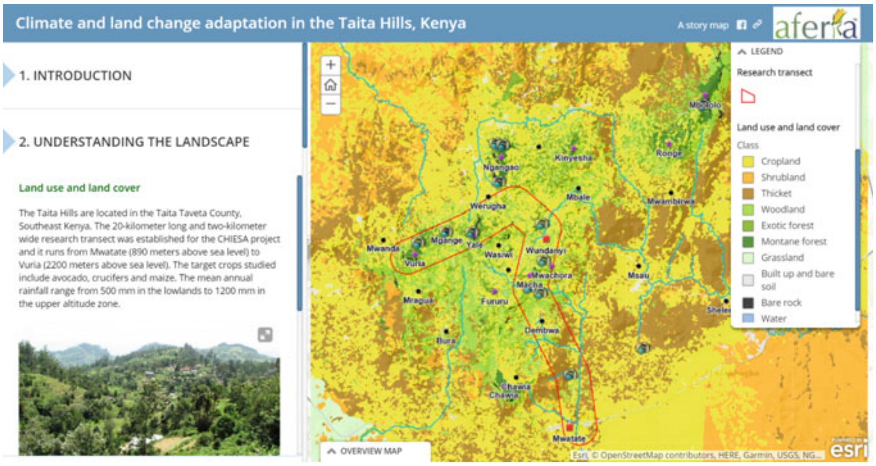

Fig. 9.1 An example view of "Climate and land change adaptation in the Taita Hills, Kenya" Story Map showing land use and land cover distribution for the target landscape in the main panel on right and text and images in the expandable panel on left. The Story Map is available online at (http://arcg.is/1qePWK)

of functionality. The public account allows users to utilize and create maps, and share maps and apps with others, and they can also add simple geospatial data in vector format to their maps. The organizational account provides more functionality and options for adding data to maps. As many of the AFERIA project outputs are in raster format, the organizational account is required for making the MALM visualizations.

Story Maps are one type of ArcGIS Online configurable Web App templates. The Story Map templates enable integrating web maps with text, images, videos and other web content into an interactive narrative (Fig. 9.1). In the selected template, a series of maps are presented with text and other contents in an expandable panel. Sometimes the main panel was replaced by images to improve the storytelling. The story is followed by clicking the titles, which expands the panel and reveals text and other contents. Each web map is prepared separately in the ArcGIS Online and embedded in the story map. In a typical web map, it is possible to pan and zoom the map and examine the content of pop-up windows that can be configured. However, it is also possible to embed Web Apps in the main windows, which enable additional functionality, such as, comparison of two or several maps by using a swipe-tool or spatially linked map comparison windows.

In addition to the Story Map, MALM geospatial visualizations include a basic viewer Web App for studying the MALM geospatial layers with an option for selecting visible layers and base map shown in the background, and including basic tools for measuring distance, area and position, and printing and sharing map views (Fig. 9.2). In contrast to Story Map, the Web App enables simple overlay analysis of the layers and preparation of personal map views.

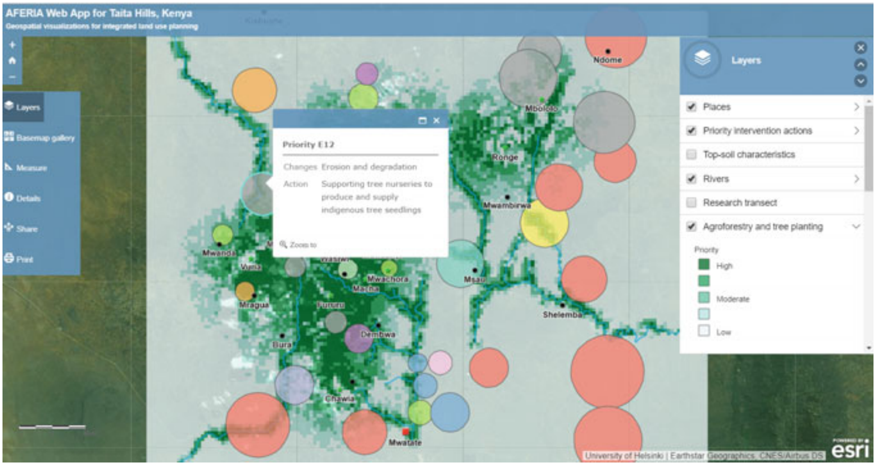

Fig. 9.2 An example view of AFERIA Web App for the Taita Hills, Kenya with results of the participatory priority intervention action mapping and results of the agro-forestry and tree planting priority area mapping. The Web Map application is available online at (http://arcg.is/0GOf5S)

The targeted user groups of the Story Map and Web App includes all the stakeholders of the project. The main purpose of Story Map is to disseminate scientific findings and recommendations to a wide range of stakeholders including farmers in the Taita Hills, local authorities, CBOs, NGOs and even the central government implementing the national strategies. The only requirement for using these applications is an internet connection. On the other hand, the Web App is targeted to the users who prefer more interactive display of the geospatial layers and basic tools to support land use planning and for implementing land management interventions.

The MALM applications utilize the remote sensing and GIS data collected and produced during the CHIESA (2011–2015) and AFERIA (2016–2017) projects. During these projects, a 20-km long and 2-km wide research transect was established for the Taita Hills running from Mwatate (890 m a.s.l.) to Vuria (2200 m a.s.l.). Most of the research activities took place in this altitudinal transect. However, for MALM, the area of interest was expanded to better cover the Taita Hills landscape. The work was also supported by the data, such airborne laser scanning data, gathered by other research projects of the University of Helsinki in the study area.

The most elementary geospatial data by CHIESA and AFERIA projects include satellite image-based land use and land cover (LULC) classification (Pellikka et al. 2018), the results of participatory mapping of the prioritized climate change adaptation action sites, and AFRICLIM 3.0 high-resolution ensemble climate projections for Africa (Platts et al. 2015). LULC layer was used for defining the extent of the study area. It is important for understanding the main landscape patterns such as distribution of agricultural land and remaining forest cover. In addition to LULC layer, the Story Map visualize LULC changes between 2003 and 2011 demonstrating the current trend of agricultural expansion (Pellikka et al. 2018), and the results of a scenario analysis carried out in AFERIA project to explore alternative ways of responding to the current environmental and societal challenges by the mid-twenty-first century (Capitani et al. 2018).

Participatory selection of climate change adaptation action sites by the stakeholders was part of the process of linking local and scientific knowledge. Data on the prioritized climate change adaptation action sites was collected with participatory GIS methods from the communities and stakeholders, visualized, and shared with the local partners to establish demonstration sites in the most optimal locations (critical areas where actions need to be taken against experienced impacts and negative changes). Representatives from different groups, such as government and county government, NGOs, water users associations, women's self-help groups, and disabled persons groups, actively contributed their observations and experiences in the areas and sites where urgent actions were needed. Later, the observations were digitized, converted into a geospatial layer and embedded in the MALM visualizations.

AFRICLIM 3.0 provides mid-century (2041–2070) climate projections of temperature, rainfall and rainfall seasonality at 1 km spatial resolution (Platts et al. 2015). For the Taita Hills, the climate projections predict a hotter future with wetter rainy seasons and drier or similar dry months. The predictions were visualized as changes in the mean annual temperature and rainfall between the baseline (1961–1991) and 2041–2070 period. In order to demonstrate uncertainties in the projections, the predictions based on two different Representative Concentration Pathways (RCPs) are shown and can be compared in the Story Map through the swipe tool. Furthermore, the layers were provided for the whole of Kenya so that users can relate changes in the Taita Hills to the national context.

In order to complement the results of the participatory mapping approach, a GIS-based suitability analyses were used for mapping priority areas for the key AFERIA interventions (i.e., roof rainwater harvesting, drip irrigation, agro-forestry and tree planting, conservation agriculture, and integrated pest management) (Fig. 9.2). The suitability analyses were based on multi-criteria overlay analysis. For each intervention type, a set of evaluation criteria were determined and corresponding decision rules and weights determined and applied to make the final maps. For example, the suitability of agro-forestry and tree planting was mapped based on LULC map to concentrate on agricultural areas, forest connectivity analysis to improve the ecological connectivity between the remaining forest patches, and distance to the rivers was used to support reforestation of the riparian areas. The scientific finding of CHIESA and AFERIA were used in the analyses when possible, particularly for visualizing the key areas for the biological control of maize pests.

Although the main method for accessing MALM geospatial layers is through Story Map and Web App, the geospatial layers, maps, and apps are also accessible through ArcGIS Online. By using the free ArcGIS public account, the stakeholders interested in tailoring their own web maps and applications can make such by combining AFERIA outputs, other public data in ArcGIS Online and their own data. For example, the user might want to combine data collected by GPS device in the field in text or GXP format with one the MALM layers. Data collection using GPS has been included in the GIS capacity development trainings earlier in the project, and many stakeholders now have such data on their own applications. Making web maps and apps in ArcGIS Online is relatively easy and does not require training in GIS.

As a part of the MALM geospatial visualizations, 1-day capacity development training was organized in the Taita Taveta University in November 2017. In the training, the participants presenting various stakeholders and Taita Taveta University staff assessed MALM Story Map and Web App, and learned how to access geospatial layers through ArcGIS Online and create simple web maps and applications. In addition to introducing the geospatial visualizations, the training aimed to discuss their contribution to climate and land change adaptation and land use planning, and make participants consider how such tools could be used for communicating landscape problems and possible solutions in their own applications. For the users interested in developing their own applications, MALM Story Map and Web App provide examples of the web GIS applications and some of their possibilities, and hence, have an impact beyond the Taita Hills project area.

9.4 Feasibility Study of the MALM for Spatial Decision Support in the Taita Hills

A feasibility study of the MALM Story Map and Web Application was carried out during the 1-day training in the Taita Taveta County, Kenya with 20 participants including local stakeholders and Taita Taveta University students and staff members. None of the participants had previous knowledge of Story Maps or Web Apps and only a few participants had used ArcGIS Online before. They came from various backgrounds from different organizations and most of them had no previous GIS knowledge. The assessment was based on a questionnaire that was filled in during the training. The questionnaire was structured in a *Four Way Analysis* manner so that the questions measured usability of the MALM Story map and the Web App for decision support. Questions were structured so that firstly respondent's basic spatial skills were investigated and then the ability to recognize spatial patterns and relations were tested. In the first section of the assessment, two specific climate change adaptation actions for the climate change impacts on rainfall (roof rainwater harvesting; Fig. 9.3 and drip irrigation; Fig. 9.4) had to be identified from the MALMs narrative texts and images. In the second part, respondents had to place the phenomena in the context by using the authoritative maps and finding out the locations were these two adaption actions mainly takes place in the Taita Hills. In the third part participants examined the qualities of the objects by assessing how the two adaptation actions are similar or different, and in the fourth part, space-time relationships between the objects and/or event were investigated. In addition, three questions were asked about the overall content of the MALM: (1) did the MALM visualizations improve your understanding on the landscape, landscape problems, and potential interventions; (2) how important were the maps for answering the questions; and (3) how important was the text in the Story map for answering the questions?

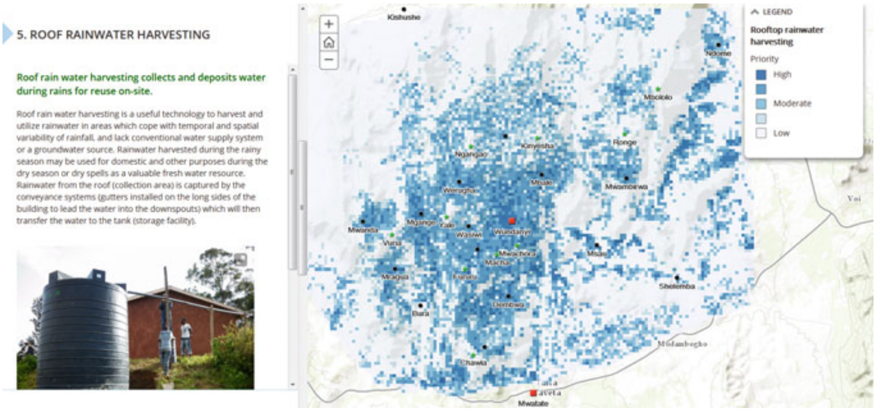

Fig. 9.3 Story map for prioritized roof rainwater harvesting action sites in the Taita Hills, Kenya

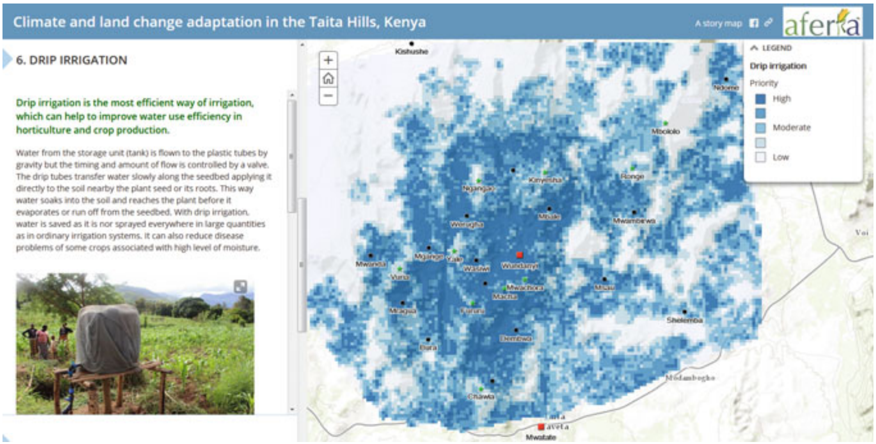

Fig. 9.4 Story map for prioritized drip irrigation action sites in the Taita Hills, Kenya

The results of the feasibility study show that despite the respondents' lack of prior experience in geospatial technology, the MALM web mapping application enabled them to explore the data, select layers and investigate the phenomena at different scales. The results indicate that the MALM helps enhance users' geospatial thinking in five main areas:

1. ***Identify the entity/event***: *MALM provides two specific adaptation actions for the climate change impacts on rainfall. What are these two adaptation intervention actions? What are two adaptation intervention actions for the climate change impacts on rainfall?*

Our result shows that 14 out of 20 of the respondents found drip irrigation and roof rainwater harvesting as the two specific adaptation actions for the climate change impacts on rainfall. Five participants selected roof rainwater harvesting, agroforestry, and tree planting, and one participant selected roof rainwater harvesting and setting-up roof catchments and tanks as the adaption actions.

2. ***Place the phenomena in the context****: Where are these two adaptation actions mainly located and what are the main geographical characteristics of these locations?*

Our result shows that respondents' answers varied a lot and some answered that adaption actions are located in the Taita Hills, Taita Taveta County. However, in this question we were looking for more specific locations were the adaptation actions have been prioritized to take place which could only be revealed by using the authoritative maps from the MALM. From these maps, some respondents only identified if the action took place in the highland or in the lowland areas. Luckily, most of the respondents interpreted more carefully the MALM maps and they mentioned the names of the subcounties or villages where the actions will mainly be located in the Taita Hills. When the main geographical characteristics of two different climate change adaptation action locations were asked, majority of the participants identified from the MALM maps that most suitable areas for the both actions are located at higher altitudes and in areas with higher rainfall. Students also explained that roof rainwater harvesting has higher suitability in areas with more buildings, long distance to the rivers, whereas drip irrigation has high suitability in areas with relatively short distance to the water sources (rivers and streams), cultivated areas and buildings.

3. ***Examine the qualities of the objects***: *How are these two adaptation actions similar or different, and do these features tend to occur together (have similar or different spatial patterns)?*

Most of the participants answered that the adaptation actions are similar as they are both helping to cope with changes in the reduced amount of rainfall and both actions promote water use efficiency. Respondents answers on how these two adaption actions are different, point out that they understood well that one action is focused on water collection and storage (rain roof water collection), and the other is focused on efficient utilization of water for irrigation as a scarce resource (drip irrigation). Majority of the respondents mentioned the difference in spatio-temporal patterns as rainwater is harvested during the rainy seasons, while drip irrigation is used in the dry season.

4. ***Space-time relationships between the objects and/or event***: *Open the Story map and study its content on "Climate change projections". How precipitation is projected to change in the Taita Hills; Where are the projected changes highest/lowest, and What areas are not impacted?*

From the MALMs narrative texts and maps, most of the respondents found out that according to the climate change projections the mean annual precipitation in the Taita Hills is expected to increase. In addition, the wettest quarter of the year will get wetter, whereas the driest quarter of the year will get drier. Highest precipitation change areas were identified from the map and most of the respondents identified the southern parts of the Taita Hills to be the area having a low change in precipitation. Some of the respondents analyzed climate change projections at the country level and found out that the highest projected changes are located around the central parts of Kenya and the lowest projected changes are along the western parts of Kenya.

5. ***Content of MALM visualizations***: *Did MALM visualizations improve your understanding on the landscape, landscape problems and potential interventions; how important were the maps for answering the questions; how important was text in the Story map for answering the questions?*

All respondents agreed that MALM Story Map and Web App improved their understanding on the landscape, landscape problems and potential interventions in the Taita Hills. Most of them found out that the maps provided a practical tool for both understanding and explaining the concept behind the MALM and it can be a useful tool to support spatial decision-making. Respondents also thought that the maps provided a broad visual scientific analysis of the adaptation intervention actions. However, some respondents thought that in the beginning, the maps were a bit challenging to fully understand and to make interpretations out of them. Therefore, in the parts where the maps seemed a bit complex, the text gave students a more detailed explanation of the prioritized climate change adaptation actions.

9.5 Easy-to-Use Web Application to Increase the Uptake of Geospatial Technologies

Use of geospatial technologies, especially open-source software and web mapping applications, in spatial planning and decision-making is a relatively new phenomenon in Kenya. GIS and geoinformation are not used much outside the universities and specific research institutes in the country. Harnessing the geospatial technology potential widely among the established county governments and other key stakeholders involved in planning, managing, monitoring and evaluating agricultural production, water resources, forests, and climate change adaptation and mitigation in Kenya would enhance information sharing across the sector lines of responsible ministries. Digital maps and updated data from repositories would be at hand to the decision makers when needed, not just to those authorities who happen to possess the only printed copy of the out-of-date thematic map of the target area. Unharmonized policies often prevent sustainable management of natural resources and enforcement of rules and regulations for their conservation in Kenya. User-friendly open access geospatial technologies, such as web mapping applications, could provide a solution for more transparent and efficient availability of information for policy-making if adopted widely among the local and national governments. Transition toward climate-smart landscapes requires well-coordinated collaboration among the multiple stakeholders to negotiate, design and manage land use interactions at the landscape level. Availability of information on different land use types, high-resolution climate projections, and geographical characteristics of the target area at different scales plays a critical role in the success of such negotiations and collaboration.

A simple and visual Multifunctional Agricultural Landscape Mosaic (MALM) Story Map and Web Application was developed in the AFERIA project to support the transition toward climate-smart landscapes and adoption of open access geospatial technology among the universities, government organizations, and NGOs in Kenya. The main principle is to provide a low cost and easy-to-use application for exploring, selecting, visualizing and interpreting geospatial data, without a need to have advanced geospatial skills. However, the application has functionalities which help develop geospatial thinking and generate interest for further learning. The thematic content of the web application was designed to support climate change adaptation action planning in the target area with a focus on water resources, conservation agriculture, agro-forestry for the smallholder farms, and insect pest management for maize, avocado, and crucifers. The objective of this geospatial application is to provide information on prioritized action sites for different interventions and technologies so that the users may use the available information in planning future adaptation actions in the area. Hands-on training was organized for selected end users to develop their basic geospatial skills and to enable them to tailor the application for their own purposes and data sets, which simultaneously develops their geospatial thinking and builds their capacity to adopt geospatial technology. According to the feasibility study targeting a small group of users from the Taita Taveta University and local stakeholder organizations, the application combining authoritative maps and descriptive texts was well received and successfully used in basic tasks requiring geospatial thinking. The feasibility study also showed the potential of a web map application to advance geospatial skills among non-experienced users and to facilitate access to geospatial data which supports decision-making. After the initial launch of the MALM web application, a series of promotional events and advertisement were organized to attract a growing number of users in the coming years in the Taita Taveta County and elsewhere in Kenya. We expect the application to support and be of use for those researchers, teachers, and authorities who continue to implement the Kenya National Climate-Smart Agriculture Programme 2017–2026.

One of the assets of MALM is that in addition to laptop and desktop computers, it can be operated with smartphones, which will expand its reach to a number of users who do not have computers available. This removes the obstacles created by the poor state of infrastructure and equipment in research and education. Smartphones are widely utilized by the Kenyans in both urban and rural areas. Network coverage and internet speed vary from region to region but generally, service is available in most universities, research institutes, and government offices. The MALM web application and Story Map can also be used for educational purposes in high schools throughout the country as the thematic content provides supplementary material and information to science education.

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Chapter 10
The Role of Geographic Technologies in the Measure of Spatial Equity. Twenty-First Century Solutions for Old Geographical Issues

María D. Pitarch-Garrido

Abstract In Western societies, the development of the Welfare State has been accompanied by the proposal of different models of spatial organisation that help to improve spatial equity, this being a priority object of all public policy because it clearly contributes to the achievement of a greater social cohesion. Geography has contributed, from Christaller to the present, to propose territorial models that help to optimise the location of activities and services, using spatial statistics and digital cartography. At present, the study of spatial equity is again receiving the attention of the academy, in particular as regards the provision of public services and facilities in urban and metropolitan areas linked to the development of new technologies and GIS that have given applied geography a new opportunity to advance in its contribution to society. Progress in this regard is linked not only to technological applications, but also to the idea of guaranteeing equity in all areas and ensuring that the provision of public services is adequate for all citizens, particularly those likely to be excluded. This is of great importance, not only because it demonstrates the usefulness of geographical science, but also because social concern for justice is reflected in an environment that generates inequalities that, because of the social pact, are not tolerable, since the objective is to ensure an adequate quality of life for all.

Keywords Geospatial technologies · Spatial equity · Geographical issues · GIS

10.1 Introduction

For geography, technological change has meant a fundamental advance for a simple reason, although it is not the only one: it has allowed an incredible qualitative improvement of its main form of transmission of information and results: the maps. Elements such as location accuracy, extensive detailed demographic, social,

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economic and environmental information, the reliability of the data and their usefulness combine to find a form of expression that generates an integral and efficient product in geographic technologies.

For not many years, some authors talk about the ‘spatial turn’ (*le tournant spatial*) to refer to the importance that space or place have acquired in social and humanistic analysis and studies when they try to explain human interaction, its identity and organisation, among other topics. This term is related to key concepts that were always the object of study of geography and that other disciplines, governments, civil organisations and the public in general, have incorporated in their daily life since the 1990s with the generalisation of the use of geographic technologies, particularly the Geographic Information Systems (GIS). The ability to analyse huge amounts of information in a differentiated and, at the same time, integrated manner meant that geography attracted the attention of other disciplines. The recognition by non-geographers is significant since it has made it possible to make research and study subjects that were always of the interest of the geographers visible.

It would be an exaggeration to say that the incorporation of the technologies associated with GIS has meant a radical change in geographical science and its study subjects. However, it is indisputable that it has opened new possibilities for progress in subjects considered classic objectives of geography, and at the same time it has allowed us to expand our recently developed field of study, almost always in collaboration with other disciplines.

One of these interdisciplinary fields is social equity. Its geographical aspect has come to be known as spatial equity. It is true that one does not exist without the other and geographical studies have been carried out on this subject since the 1960s. Harvey (1973) was one of the first geographers to define the term *spatial equity* or also referred to as *spatial justice*. Spatial justice must pursue the following objectives: respond to the needs of people in each territory, allocate resources in a way that maximises the spatial multiplier effects and allocate extra resources to help overcome the problems caused by the physical and social environment.

The question is whether this research topic, linked to spatial planning, is still a current problem for the geographers of the twenty-first century and, above all, if the geographical technologies have contributed to increased understanding about the aspects linked to this issue. The answer is linked to the reality and the practical application of geography. Even today, space introduces inequalities, therefore, there is still a wide margin for action and spatial planning. The GIS have significantly contributed to keeping the subject alive, because with the introduction of this technology, geography is in a good position to contribute to the improvement of the quality of life of people through the analysis of the territorial conditions that explain inequality, advanced location models and the consequent mapping of results. In the twenty-first century, applied geography has experienced a new impetus along with technological innovations.

This chapter aims to analyse the contributions that Geographic Information Systems and other related technologies have made in the area of spatial equity. As already pointed out, the question is old, but we are going to focus only on the contributions made in this century. The studies published on territorial (territorial) or spatial (in)equity have been developed in two large dimensions: spatial management and planning (location of public services, accessibility, transport, urban development, tourism, etc.), and theorisation on the problems related with equity (socio-spatial imbalances, mobility, territorial structure, etc.). The first one is directly linked to territorial management and strategic planning, and can be classified as applied geography, while the second contributes powerfully to scientific progress in this area and to the definition of the major spatial problems that still concern society today, such as quality of life, sustainability, governance and cohesion.

In order to develop this analysis, we have identified the articles published in the main international scientific geography journals that consider spatial equity (or synonyms such as space justice) as the main topic dealt with. We have worked with journals indexed in the Scopus database,[1] the majority are in English, but not all. The time period that has interested us the most is from the year 2000 until 2018.

The chapter has been divided into four subsections. The first section explains what is meant by spatial equity and its role in current geography. The second section briefly presents the most important innovations and changes that technologies have introduced in geographical theory. In the third section, both equity and geographic technologies in the twenty-first century are related, from the scientific articles published on the subject. Finally, some conclusions with special emphasis on the future of these type of studies before the acceleration of the incorporation of GIS in everyday life (internet of things, mobile technologies, etc.) and, of course, in academia (the so-called neogeography).

10.2 Is Spatial Equity a Subject of Study for Geography Today?

The term justice in geography refers to the impartiality of the geographical distribution of social benefits (Gregory et al. 2009). Justice only becomes a problem when there is a conflict of interests, and what is more, even though those involved are not the generators of the conflict. According to the Oxford Dictionary of Human Geography (Catree et al. 2013), space justice, unlike social justice, focuses on the disparities between places. Given the unequal spatial distribution of resources and rights (some places are better served than others), spatial justice seeks a better distribution or redistribution in order to ensure that those territories that present the greatest problems due to harmful social and economic practices can improve their relative position with respect to others.

From political science, Fainstein (2017) points out that justice incorporates in its own definition, the values of democracy, diversity and equity. This last concept goes back to the time of the Enlightenment, but more recently to Marxist, neo-Marxists,

[1] Scopus is a bibliographic database of the Elsevier publishing house, which includes some 18,000 titles of journals and scientific documents of more than 5000 international publishers. It is accessible by subscription.

critical and even liberal geography theories. Therefore, it is evident that the ethical or simply human principles to resolve possible conflicts are of a different nature and this is what defines the meaning of social justice.

A part of that justice is related to the territory. In reality, it is not about analysing social justice, but about injustice, that is, the inequality of opportunities. The concept, and therefore the problem, is very broad, but a considerable part has to do with location. There is talk of inequality in the distribution of income and other sources of satisfaction of the basic needs of the population. In this sense, it is necessary to consider, on the one hand, that personal differences (race, family, intellect, etc.) should not determine the happiness of individuals since they are fortuitous, and therefore, irrelevant to determine their rights; and on the other hand, that all this happens somewhere, that is, people are located in the territory, permanently or not and whatever their characteristics. Therefore, the place where a person lives should also not determine their right to equal opportunities above their contributions to the common good and their different needs, although the latter is the subject of discussion mainly by political theorists. Spatial equity, understood as the search for equal rights of the entire population, whatever their place of residence. We will focus on the definition of Soja (2010), which indicates that society produces injustice with reflection on space at the same time that space (location) is a source of injustice. In addition, territorial diversity is not opposed to justice or spatial equity. All this has been the subject of study in geography and among the specialised academics, it has generated a consensus regarding the need to guarantee the human rights of the entire population regardless of the characteristics of the territory that hosts them, therefore, a transformation of the territory and, with it, of society.

Geography has developed territorial models that help to reach adequate levels of territorial equity with greater or lesser success, in particular from the optimisation of the location of activities and services, for which it has used spatial statistics and cartography. Currently, the study of spatial equity is again receiving the attention of academia (Vadrevu and Kanjilal 2016; Stanley et al. 2016; Tan and Samsudin 2017; Jang et al. 2017; Livert and Gainza 2017; Pitarch-Garrido 2018).

This interest is linked to the development of new technologies and GIS that have given applied geography a new opportunity to advance its contribution to society. Progress in this regard is linked not only to technological applications, but also to the idea of guaranteeing equity in all areas and ensuring that the supply of public goods and services is adequate for all citizens, in particular for those susceptible to be excluded. Spatial planning constitutes an indispensable instrument to achieve an adequate level of equity. This is of great importance not only for evidencing the usefulness of geography, but also because it reflects the social concern for justice in an environment that generates inequalities that are not tolerable (remember that the degree of tolerance depends on the acceptance of a series of ethical principles) with a trend towards a change that makes us better as a global society. Thus, the development of the welfare state in many countries has been accompanied by the proposal of different spatial organisation models that help to improve spatial equity, this being a priority of all public policy as it clearly contributes to the achievement of greater social cohesion.

An aspect of great interest is to know how the research on spatial equity in geography has been oriented, in particular from what criteria is measured as a first step for the proposal of strategic improvement actions. Spatial equity is the key concept that lies at the base of the location models of economic activities. These models which have been developed since the 1950s try to find an optimal location to achieve maximum profitability of the offer, for example public services, however, the reality is sometimes much more complex than the one considered by them. Political factors associated with local decision-making or with very different public priorities, explain the creation of a supply network of the main well-being services (health, education and social services) that does not always respond to this optimal location, objective of the classic models in search of spatial equity.

Since the 70s, the measurement of equity has been carried out with more emphasis based on accessibility (Garner 1971; Domanski 1979). The main research question in this topic was how to achieve greater spatial equity without necessarily implying a reduction in economic efficiency. On multiple occasions, accessibility has been the basis of the models and explanations that try to shed some light on the implications of locating public services in the territory. Different types of models have been proposed, from very centralist ones to those that favour extreme dispersion, from the most theoretical to the most applied, but almost all with the common characteristic of maximising the amount of population served by those services, equipment, programmes or public actions that are offered by the government. One way to achieve this goal is to improve accessibility through public transport, so very soon, studies on public and private transport networks multiplied.

The location of economic activities, particularly that of the supply of public and private services, is not unrelated to the structure of the territory, both from the physical point of view (transport network, equipment, etc.) and social (location of the population, average income, location of workplaces and residences, etc.), which places it at the centre of the interest in geography. However, the analyses carried out clearly differ according to the level of work, and, as we will see later, the role of geographic technologies, particularly GIS, will be much more decisive on the local scale, that of applied geography, territorial strategic planning.

Inequality exists at all levels. Throughout history, human beings have created a network of tangible and intangible socio-economic relations based on unequal exchanges. For years economic geography has been explaining, from different theories, such as unequal development or the centre–periphery among others, the current global spatial structure as a consequence of a process, or set of processes, that have led us to conformation of the global world at present, with its fundamental geographical characteristic that is inequality.

The scale of global analysis has led to studies on equity which is not considered as such, although they are the fundamental idea in their background. Many of the authors who currently work on the issue of justice take up the critical conception from the 1970s, especially from the current crisis, and relate the spatial injustice to the different forms of oppression generated by the capitalist system (Brennetot 2011). In the context of globalisation, there are several issues that are directly related to locational aspects, and one of them has to do with the options of locating different services to companies, but also to the consumer. New forms of marginality and polarisation appear in this global environment. According to Sassen (1991), 'the evidence, for the case of the United States, Western Europe and Japan, suggests that government action and policy will be necessary to reduce new forms of spatial and social inequality.' (p. 8). The concept of justice and spatial equity acquires an enormous pluralism and is clearly linked to postmodernism from an epistemological and theoretical point of view.

As Beder (2000) points out, the main ethical principle behind sustainable development is equity. According to this author, 'equity means that there should be a minimum level of income and environmental quality below which nobody falls. Within a community it usually also means that everyone should have equal access to community resources and opportunities, and that no individuals or groups of people should be asked to carry a greater environmental burden than the rest of the community as a result of government actions. It is generally agreed that equity implies a need for fairness (not necessarily equality) in the distribution of gains and losses, and the entitlement of everyone to an acceptable quality and standard of living' (p. 227). Thus, social, environmental and economic inequalities exist internationally and, in order to achieve sustainable development for all, the fight against poverty and inequality is essential at the global level. Like other sciences, geography incorporates the concept of equity in the broader sustainable development to analyse inequality on a global scale.

Although spatial equity is probably only a small part of sustainability, it is a solid part, with concrete proposals for action and that at local and regional level has had, and will continue to have, concrete impacts (Zuindeau 2006; Dempsey et al. 2011; Pitarch-Garrido 2017). In this concept, spatial equity intersects sustainability and geography, presenting great potential for scientific and political development. Spatial equity has the great advantage of incorporating aspects not only of enormous interest for the real life of people, and therefore clearly influencing their quality of life, but it also has a clear practical interest in the sense that these variables are quantifiable and, therefore, help to delimit the concept of social sustainability as well as to put it into practice. These are relatively simple variables to measure, even more so with current computer techniques and the existence of very complete information sources (official statistics, big data, etc.). This leads directly to the change from global to local level. In recent decades, geography has made its main contributions on the local level.

Currently, the use of the concept of spatial justice is understood from different perspectives or approaches to geography, as well as from different scales (Gervais-Lambony and Dufaux 2009). Most of the research that expressly incorporates the term spatial equity is at the local level, that is, it is case studies that allow the use of new techniques and lead to the definition of new analysis methodologies. The standard tool for measuring equity has traditionally been the rate of variation of demand inputs (for example, students per teacher, doctors per thousand inhabitants, etc.); However, this measure has little to do with accessibility measures, which clearly contribute to measuring efficiency and equity in the location of public services. The balance between two factors, which we can call size and distance, helps to delimit equity in the access to the service and the efficiency in its use to be able to serve a certain demand. The issue is especially relevant in urban and metropolitan areas with a high concentration of population in certain spaces and a notable dispersion in others.

In this regard, it should be noted that the so-called intelligent urban growth considers sustainability as the basis for urban planning, and although its main orientation is towards the management of growth taking into account environmental aspects, the problems of social equity and the quality of life of people are no less important. In this sense, the closeness to the supply of public services is consolidated as one of the aspects that is most valued and that best guarantees the sustainability of the territory and, therefore, spatial equity (Dempsey et al. 2011).

The various current processes related to increased mobility of people, the suburbanisation of jobs and rapid real estate growth have led to a change in regional and urban planning. The governance of the territory must adapt to its complexity in order to be more effective and more adequately respond to the new problems and realities that emanate from it.

Current studies are more oriented to the practice for decision-making help. The idea of spatial justice, according to Soja (2010), is not based only on external processes such as globalisation (Harvey 2003), but also develops from endogenous decision-making processes at the local level. One of the ways that this author proposes to reflect on the spatial aspects of injustice is based on geographical studies on inequality and social welfare.

To try to achieve a fairer distribution over space, geographers continue to work on the development or improvement of localisation models that incorporate criteria such as public utility (number of people using the service), travel costs and means of transportation (Moreno Jiménez 2015; Geurs et al. 2016; Saghapour et al. 2016; El-Geneidy et al. 2016; Farber and Fu 2017; Ruiz et al. 2017). The current reality is that new technologies have powerfully contributed to favour the development of spatial models as tools for planning.

10.3 The Role of Geographic Information Systems in the Renewal of the Geography of the Twenty-First Century

The postmodern society is characterised by being the information society. Like all sciences, geography has sought to improve the knowledge of previous stages in a constant advance to better understand the territorial problems and, with them, the social, economic and environmental ones. This objective has been constant throughout the history of geography, what has varied has been the technical means to achieve it. Technological advances are the basis of new ways of thinking about geographical reality, of interpreting it.

It is necessary to continue with geography's commitment to the usefulness of its knowledge, that is to say, a geography committed to the time and the society in which it is developed. It is an old idea that was already developed in the time of Hettner in his work *Die Geographie, ihre Geschichte, ihr Wesenundihre Methoden* (1927) and which has been reflected by later authors, among others in the work of Unwin, *The Place of Geography* (1992). The geographer must be able to analyse the territorial reality and propose alternatives and priorities to clearly contribute to the improvement of the quality of life of people. This is possible, or at least more effective, based on good training in applied subjects and new techniques, including computer technology, which has become part of the central structure that underpins the new geography in recent years.

Territorial issues have acquired great social relevance. The reality is constantly changing and geography is currently experiencing a process of renewal that, according to Marchand (2001), is based on three factors: historical heritage, social culture and technological progress. Of them, we now focus on the role of third parties.

The incorporation of computer technology has developed the practical application of geography, facilitating the application of spatial planning processes more than in other historical moments, in particular, as we will see, of local environments, which have been able to take advantage of technological advantages more quickly and in a better way for the study of territorial problems (Taylor and Lange 2016).

But before continuing with this, it should be noted from a more theoretical point of view that on occasion, studies based on the application of computer techniques have been accused of excessive instrumentalists. The interest for the establishment of a technical control over the environment is understood as such. Given that it is the result that matters, the theory loses its relevance and it is the methods (based on advanced technologies) that gain prominence to make the appropriate predictions from the observable data. It is a philosophy of science that was already developed in the quantitative revolution (1960s and 1970s of the twentieth century), and now seems to be taking centre stage before the generalisation of methodologies based on the new contributions of the GIS and the big data, among others. However, while for some it seems to be a criticism, for others it is nothing more than the verification of being on the right track and the advantages in terms of application of the geographical technologies developed since the late twentieth century and now widespread in the studies of both geographers as well as other related sciences whose goal is to be useful to society.

Since the end of the 1990s, the interest that the role of computer technology and other advances linked to the generalisation of the internet in geographical studies has aroused is reflected in the appearance of monographs on the subject in large prestigious geographical journals, such as *Geojournal*. Number 45 of this journal in 1998 was entitled 'The Globalization of Geography', *Environment and Planning, B*, number 28, in 2001 on 'Cyber Geography', *Urban Studies*, number 38, in 2002, entitled 'The knowledge Based City', among other journals that have increasingly incorporated articles focused on the use of GIS and other technologies in geography, such as *Cartographica*, with its number 39 of 2004 practically being a monograph on GIS from critical geography. In addition, an increasing number of specific journals on this subject have been consolidated in the scientific panorama, among which we can highlight *International Journal of Geographical Information Science*, *Transaction in GIS*, *Cartography and Geographical Information Science*, *Geofocus*, among others.

All this interest in technological applications has been developed along with the evolution of GIS and other communication technologies and cartographic representation. In the last decade, in-depth analyses have multiplied on the intrinsic nature of GIS, its ability to analyse physical and social reality, its place at the centre of geography as a discipline or just as a technique applicable to various objects of study in the social sciences, etc. The controversy is still seen in different contributions from different methodological and epistemological approaches. However, in what seems to be more or less explicit agreement is to consider the technological advances associated with information technology, especially GIS, and the revolution in communications, particularly the Internet and, with it, the so-called digital geography, as an undeniable advance for the professional and practical projection of geography. The most important impact has been on cartography, which, thanks to the incorporation of information technology, has faced new challenges and opportunities for the representation of geographical reality and, above all, has become widespread among scientists and popularised among the general population. The technological applications in geography have made the cooperation between different disciplines possible (inside and outside of it), which has contributed to an enrichment of the most traditional approaches (Crampton 2001). According to Chuvieco et al. (2005) GIS have meant an epistemological split not only in the field of geographic communication (through maps), but also in the visualisation of information on the spatial relationships between the various factors that make up the territories. The reality is that the application of GIS to the more traditional problems addressed by geography and that until now had not had techniques that facilitated analysis with high precision, has been and is a usual and highly successful practice in applied geography. This has allowed us to deal with very varied territorial problems and open up new work possibilities for geographers.

In the same way that the spatial turn of the social sciences has been pointed out before, it should be noted that geography also talks about other turns: the political turn, the cultural turn and the digital or technological turn. In reality, all of them are related and do nothing but show that as a science, geography is in a good stage of production and, above all, of contribution to society. Without entering into the discussion about whether or not geotechnology is a nuclear or peripheral part of geography, what is evident from the above and from the evidence regarding production capacity is that technology has marked a new era of modern geography. The technological turn has been very profound (Ash et al. 2018). Digital geographies are discussed in order to include everything that has contributed to technological development under this umbrella, from digital cartography to geo-positioning websites. More than considering digital as something extraneous, or as a different subdiscipline, Ash et al. (2018) propose the consideration that digital covers all the action areas of geography and that it clearly contributes to changing and improving the production of geographic knowledge. These authors point out in their conclusion: ‘As the proliferation, commercialization and popularisation of geolocation technologies are itself engendering the flourishing of spatial ontologies and epistemologies, we encourage geographers to adopt and embrace an epistemological, ontological, and methodological openness in their engagements with the digital.' (p. 38).

Part of this new phase of the history of geography is the so-called GIS-2, which was already referred to in the 1990s. It is a term that emerged in the conference entitled 'GIS and Society', organised by the NCGIA[2] (National Center for Geographic Information and Analysis) of the University of California in 1996. The GIS itself became an object of study of geography, and still remains one today. When considering what it is for and what its limits are, geographers wanted to grant it a greater entity than mere cartographic representation. GIS-2 is an environment which generates knowledge and increases the emphasis on participation for the creation of information, incorporates the equitable representation of the different ways of understanding the world, it can redefine its parameters to adapt to the standards and objectives of the participants (incorporates subjectivity), it is able to incorporate the time variable and is able to manage all the components of a theoretical or applied research. In short, it supposes a proposal for growth for the GIS, on the way by which to develop, overcoming an only technological definition and incorporating greater creativity and adaptation to real problems for which it may be necessary to have the participation of citizens, their individual or collective narratives, new methods of analysis, etc.

Years later, geographers still need to address the development of GIS (Sieber 2004; Miller 2006; O'Sullivan 2006; Radil and Anderson 2018). GIS is a powerful tool and a body of knowledge which, oddly enough, includes both characteristics that have been evolving towards online geospatial applications that, for some, are the beginning of a democratic GIS, which favours the incorporation of diverse social groups, non-profit organisations, etc., despite accessibility problems for certain groups or sectors of the population linked to the interests of large private companies. The demand for a free, equitable and democratic GIS-2 or 3 is still alive today.

In this context, it arises in the concept of neogeography, which responds to the above, and even delves into the concept of geography as a social phenomenon that implies a new relationship with territories and with freedom as its main characteristic. Following Turner (2006), 'Neogeography means ‹new geography› and consists of a set of techniques and tools that fall outside the realm of traditional GIS, Geographic Information Systems. Where historically a professional cartographer might use ArcGIS, talk of Mercator versus Mollweide projections, and resolve land area disputes, a neogeographer uses a mapping API like Google Maps, talks about GPX versus KML, and geotags his photos to make a map of his summer vacation' (p. 2).

The separation between scientific and popular contribution, between the expert and the volunteer, has traditionally been made to bring complex scientific concepts to the non-expert population. However, in the case of geography, it may suppose some recently developed problems such as the lack of rigour over the information processed and generated. However, GPS, web and open-source GIS have reduced the cost of entry to geographic knowledge, at least in the mind of neogeographers

[2] http://www.ncgia.ucsb.edu/; http://www.ncgia.ucsb.edu/research/initiatives.html.

(Goodchild 2007, 2008). Without entering into an argument, it is interesting to note the weight of technology not only in the production of scientific or pseudoscientific knowledge, but in the greater proximity of geography to society, which deals with cartographic knowledge, at least, with greater familiarity than in the last century.

In conclusion, the contribution of geotechnology to the improvement of scientific and applied analyses carried out by geographers, and also by other specialists has meant a clear improvement in obtaining more realistic and useful results for society. The future is more open than ever and changes are happening faster than in previous years. The education of our young geographers must change in line with the new reality, as well as the ongoing training of the older ones. The knowledge that we are able to contribute, explain and translate into current communication formats (maps, applications, websites, etc.) should not be isolated in academia, but applied to the real problems of people to improve the global society and the place where we live. As we indicated in the title of this chapter, they are new solutions to old problems that still exist and can be improved, when not solvable. Geography, which is a science as old as human beings who have knowledge about where they are and about the territory in which they inhabit as one of their main desires, still has much to contribute, and technology clearly contributes to it.

10.4 Geographic Information Systems and Spatial Equity in the Twenty-First Century

Up to this point, the importance of geography studies in the twenty-first century with the idea of a search fund for spatial equity on different scales have been expressed, above all, on the most direct and effective level of public action: the local level. Therefore, there is no doubt that equity and/or spatial justice is still a subject of interest for geographers and that they are immersed in a global world in which technology is part of our lives and, therefore, of the research methodologies. They have substantially advanced towards more precise forms of measurement and more accurate analysis, capable of considering a greater number of variables, responding to territorially complex situations.

10.4.1 Methodology

In order to identify the most recent research on the issues of spatial equity made by geographers, a bibliometric analysis of geography journals indexed in the Scopus database has been carried out. The selected articles are those published since 2000, although reference will be made to others within the same theme published prior to this date (see Annex).

A search has been carried out using the following combined terms that may be present in the title, abstract or keywords: ‘spatial equity’ and ‘GIS’, ‘spatial justice’ and ‘GIS’, ‘spatial’ and ‘equity’ and ‘GIS’, ‘spatial’ and ‘equity’. Starting with these last two terms searched as separate words, 249 documents appear since 1978. The years with the most articles are 2016, with 34 documents, and 2017, with 45 documents that meet this criterion. As it is evident, both terms ‘spatial’ and ‘equity’ do not appear in this first search related to computer technologies. It is interesting to know the enormous amount of articles on this subject, which increases as the century progresses. The most important journals are *Journal of Transport Geography*, with 12 articles in which both terms appear, *International Journal for Equity and Health*, with 10 articles, and *Landscape and Urban Planning*, with 8 articles. The spatial equity linked to transport turns out to be one of the aspects that geographers are most interested in.

However, when we incorporate the term ‘GIS’ into the previous search, the number of documents is drastically reduced. Only 34 meet that triple condition. The years 2014 and 2016 have the most articles, with 6 each. The most important journals are *Journal of Transport Geography*, as in the previous case, with 5 articles, *Cities*, with 4 and *Sustainability (Switzerland)* with 2.

The most precise combination of the terms ‘spatial equity’, jointly, and ‘GIS’ results in 24 documents, of which 3 correspond to conference proceedings and 1 to a revision of a book, therefore, in reality, it is about 20 scientific articles to be precise. 2014 includes more articles with these terms, with a total of 4, while 2016 and 2017 add 3 more each. In this case, the journal that leads the publications on the subject is *Cities*, with 4 articles, followed by *Journal of Transport Geography*, with 3 articles.

In the same way, the terms ‘spatial justice’ and ‘GIS’ add up to a total of 6 articles, all of them included in the previous search.

A search in other scientific journal databases results in a greater number of articles, and a broader search incorporate topics that are not directly related to what geography understands as spatial equity. Therefore, and to be specific, we will focus on the 20 scientific articles that, from geography, have entered into the study of spatial equity through GIS in the twenty-first century. It is worth noting that all of them have been published in English, except 2, 1 in Japanese (in the *Geographical Review of Japan* journal) and 1 in Spanish (in the journal *Investigaciones Geográficas*) which is the only 1 in open access.

10.4.2 Results

From the analysis of the selected articles, a first overview of the specific topics analysed can be offered. First, it should be noted that the objective of most of the research published in the journals indicated is to measure equity based on the location of different types of public services: parks or urban green areas, hospitals, family doctors, educational centres, social services, children’s recreational services, services for the elderly, etc. From their location, the different authors develop either accessibility models (with or without restrictions) or demand indices to measure the consumption capacity of said services by social groups with different economic characteristics.

Not all selected articles have been produced by geographers. Of the 20, there is only an author assigned to a clearly denominated department of geography in 7. This does not mean that other authors linked to departments such as Earth Sciences, Geoinformatics and Engineering, are not geographers, however, it gives us a clear idea of the current interdisciplinarity of the science and, also, of the interest from other disciplines on the subject of spatial equity and geographical analysis.

The most widely used technique is spatial statistics with results mapped through the GIS. Most articles use the analysis of accessibility to assess the degree of equity in a specific territory. This is related to multiple issues such as decisions on the allocation of resources, the location of the service or activity, information and even the quality of it. In short, it is the 'ease' with which the user can get the service they need, for which physical accessibility is important, but so is the measure of it in time. Travel time contributes enormously to the perception that citizens have about the quality of the supply of public services and, therefore, about the quality of life. Time is a measurement that links activities and places (May and Thrift 2001; Davouidi 2009).

The most widely used measurement of spatial equity has been accessibility to public services. To this end, interesting studies on public transport have been carried out since the 1990s, with very reliable results, despite not having the exact location of the demand (the population). This was compensated, in some way, with the correct location of the service offering centre. Currently, the use of GIS has made it easier for the real-time accessibility indicator to get closer to reality in complex areas such as urban and metropolitan areas, being able to reach conclusions that were not possible with a less precise technique.

From the establishment of different limits (in time of access), it is possible to characterise the different areas and municipalities according to their greater or lesser equity. The establishment of these limits is an important aspect when drawing up public policies at the local and regional level.

Another recurring theme for the analysis of spatial equity is transportation: public bus lines, toll roads, high-speed train, etc. Evidently, the structure of the public transport network determines the results of equity. The improvement of the transport network and/or the creation of new networks is fundamental today to integrate and order urban and metropolitan areas, in which dispersion and urban complexity is inevitable. The so-called intelligent urban growth considers sustainability as the basis for urban planning, however, its orientation towards the management of growth and environmental aspects seems to leave aside the problems of social equity. In the articles analysed, studies on transport are the only ones that go beyond the urban scope, focusing on the intermediate scale, the regional one.

On the other hand, it is worth noting the interest of a significant amount of research to characterise the population susceptible to demand public services from the socio-economic point of view. On the one hand, the study of the socio-economic and demographic characteristics of the resident population in the spaces with the lowest level of accessibility serves to delve into the real impact of spatial equity. On the other hand, if we consider the characteristics of the population without linking it to their place of residence, it is possible to know the social implications of equity in the territory analysed as a whole. The GIS allows both types of analysis as evidenced in the articles presented.

Another feature common to research published on spatial equity is its local approach. The spaces analysed are, above all, cities such as: Changting (China), Palma de Mallorca (Spain), Hamadan (Iran), Zahedan (Iran), Cape Town (South Africa), Madrid (Spain), Edinburgh (United Kingdom), Tehran (Iran), Beijing (China), Tainan (Taiwan), Toronto (Canada), Chicago (USA) and Edmonton (Canada). And, a few regions such as Sundarbans (India) and England (United Kingdom), or countries such as Israel and Spain.

The city is the place where justice and equity are more clearly defined and where they can best be analysed. Both from the global point of view (its role in the international economy) and from a local perspective (centre of services provided to its own hinterland), the city is the most appropriate space to define the processes of improvement in equity and therefore, in the achievement of greater spatial justice at all levels. This explains the geographers' interest in using the case study as an analysis methodology and for this case to be a city.

A common element in almost all the analysed contributions, closely related to the previously described idea, is the explicit interest of the authors for their research to have a practical application in spatial or local politics. The public action can be twofold: on the location or relocation of the centres offering services, but also on the public transport network. An optimisation of the former and a broadening or territorial expansion of the latter in order to reach a greater part of the territory would considerably improve equity in a territory.

The future possibilities of geographic technologies, in particular GIS, are many and varied. One of the most interesting ones is to perform simulations to measure the consequences of new locations or closures, aspects so relevant in times of crisis. Possible closures of service supply centres (part of the public decision-making policy) do not have to be negative if the service is not reduced and its localisation is carried out effectively and, above all, taking into account territorial equity, even being able to improve it. Applied geography seems to be more relevant than ever in the twenty-first century, and in the old issue of fairness or spatial justice, it can still bring many surprises.

10.5 Conclusions

The impact of technology on geography as a science is indisputable. The emergence of new ways of doing geography has led to pioneering research, better communication of results, availability of material to contribute to decision-making in spatial planning processes at different scales, especially on a spatially local scale, etc. All of which has also generated challenges for future generations of geographers such as a greater need to acquire new technical skills, improve continuous training, interact with other disciplines more closely, consider the use of other languages to communicate the results to a greater extent, such as audiovisual language, to address practical problems for the proposal of solutions to real situations, etc. The biggest challenge for geographers is to be able to show the importance of spatial analysis and the interaction of the human being with the environment (natural and artificial) on all scales, knowledge that we share with colleagues from other disciplines, without losing the essence that defines geographic knowledge and maintaining its usefulness.

Regarding the issue at hand, it should be noted that spatial equity and its analysis (and proposals) based on the incorporation of geotechnologies is not an exhausted issue, despite having been studied since the mid-twentieth century. The perspective has not changed much since then, which has meant that the use of GIS is a remarkable qualitative improvement. In recent years, and perhaps due to the variety and breadth of new topics for geography (some of them linked to new technological realities), and with its political implications, equity is of less interest. It remains a clear theme (it appears as a keyword) in countries such as China, Iran and Spain with a recent interest by their geographers to publish their results in international journals in English, thus becoming more visible, which does not mean that these older subjects have not traditionally been addressed in these countries. In addition, it is necessary to consider that the research developed by geography is not always classified with the basic keywords, but that related topics can lead to true applied analyses on the phenomenon of spatial equity, without being referred to in that way.

In any case, in this chapter, we have tried to give a general view of the technological applications for the proposal of actions that seek greater social and territorial equity based on an adequate location of public services and transport management. The future opens up many possibilities of work in this field, always associated with new technological developments and communication, some of them already present in the most advanced societies. The technical improvement of GIS, associated with the better qualification of future geographers, opens up new possibilities. The availability of a large amount of geolocated data, and in particular big data, opens a window of opportunity for more and more specific and reliable analyses. To this, we must add the enormous possibilities presented by the internet and social networks to gather qualitative information, that is, opinions, assessments, perceptions regarding public policies that affect citizens as a whole, quality of services, conservation status of equipment, etc. When all this is managed and screened, it can provide even more rigour than just quantitative information. In addition, networking with multidisciplinary teams and experts from many parts of the world will become much more common than today. GIS and other geoinformatic applications will undoubtedly contribute to facilitating the exchange of ideas and an increase in the understanding of territorial and social diversity. The realisation of proposals that can be applied with the aim of improving the quality of life of all people will remain in the hands of geographers and other scientists.

Annex

Title	Authors Affiliation	Journal	Keywords
A spatially accurate method for evaluating distributional effects of ecosystem services	Aliza Fleischer[a] Daniel Felsenstein[b] Micha Lichter[b] [a]Department of Environmental Economics and Management, The Centre for Agricultural Economics Research, Hebrew University of Jerusalem, Israel [b]Department of Geography, Hebrew University of Jerusalem, Israel	*Ecological Economics* Volume 145, March 2018, Pages 451–460	Ecosystem services Equity Welfare distribution Synthetic spatial microdata
Spatial equity measure on urban ecological space layout based on accessibility of socially vulnerable groups—a case study of Changting, China	Yanhua Yuan[1,2] Jiangang Xu[3,*] Zhenbo Wang[4,5,*] [1]School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, China [2]Nanjing Engineering Consulting Center, Nanjing, China [3]School of Architecture and Urban Planning, Nanjing University, Nanjing, China [4]Key Laboratory of Regional Sustainable Development Modeling, Chinese Academy of Sciences, Beijing, China [5]Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China	*Sustainability* 2017, *9*(9), 1552	National famous historical and cultural cities Public parks GIS spatial analysis Accessibility Spatial equity Socially vulnerable groups Mountainous city

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Title	Authors Affiliation	Journal	Keywords
Improving bus service levels and social equity through bus frequency modelling	Maurici Ruiz[a] Joana Maria Segui-Pons[b] Jaume Mateu-LLadó[b] [a]GIS and Remote Sensing Service, University of the Balearic Islands, Palma de Mallorca, Spain [b]Geography Department, University of the Balearic Islands, Palma de Mallorca, Spain	*Journal of Transport Geography* Volume 58, January 2017, Pages 220–233	Public transport Bus headways optimization Social equity Spatial equity Simulation GIS-T
Measuring spatial equity and access to maternal health services using enhanced two step floating catchment area method (E2SFCA)—a case study of the Indian Sundarbans	LalithaVadrevu Barun Kanjilal IIHMR University, Sanganer, Jaipur, Rajasthan, India	*International Journal for Equity in Health*, 2016, 15:87	Maternal health Enhanced two step floating catchment area method Geographic information system Sundarbans Equity
Is inequality in the distribution of urban facilities inequitable? Exploring a method for identifying spatial inequity in an Iranian city	Hashem Dadashpoor[a] Faramarz Rostami[b] Bahram Alizadeh[c] [a]Department of Urban and Regional Planning Tarbiat Modares University, Tehran, Iran [b]Researcher of Urban and Regional Planning, Tehran, Iran [c]Tabriz Islamic Art University, Tabriz, Iran	*Cities* Volume 52, March 2016, Pages 159–172	Inequality Spatial inequity measurement Public facility distribution Enjoyment Hamadan city Iran

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Title	Authors Affiliation	Journal	Keywords
Distributional planning of educational places in developing cities with case studies	Abdol Aziz Shahraki[a] Issa Ebrahimzadeh[b] Diman Kashefidoost[b] [a]Royal Institute of Technology, The School of Architecture and the Built Environment, Department of Regional Studies, Stockholm, Sweden [b]University of Sistan and Baluchestan, Department of Urban planning and Geography, Zahedan, Iran	*Habitat International* Volume 51, February 2016, Pages 168–177	Iran Land use policy Educational spaces Distribution pattern Optimal distribution
Toward spatial justice: The spatial equity effects of a toll road in Cape Town, South Africa	Justin van Dijk Stephan Krygsman Stellenbosch Tom de Jong University Stellenbosch Utrecht University	*Journal of Transport and Land Use* Vol. 8, No. 3, 2015	Accessibility Toll road Spatial equity GIS South Africa
Designing a socio-spatial need indicator for urban social services analysis and decision-making. A case study [Diseño de un indicador de necesidad socio-espacial para el análisis y la formación de decisiones sobre servicios sociales urbanos. Un estudio de caso]	Jiménez, A.M. Universidad Autónoma de Madrid, Departamento de Geografía, Madrid, Spain	*Investigaciones Geográficas* Open Access Volume 87, 2015, Pages 102–117	GIS Local public policies Social indicator Social needs Social services
Accessibility modelling: Predicting the impact of planned transport infrastructure on accessibility patterns in Edinburgh, UK	Karou, S. Hull, A. School of the Built Environment, Heriot-Watt University, Edinburgh, United Kingdom	*Journal of Transport Geography* Volume 35, February 2014, Pages 1–11	Accessibility Edimbourg Tram GIS Spatial equity Transport Planning

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Title	Authors Affiliation	Journal	Keywords
An integrated framework to evaluate the equity of urban public facilities using spatial multi-criteria analysis	Taleai, M.[a], Sliuzas, R.[b], Flacke, J.[b] [a]Center of Excellence for Geomatics Information Technology, Geomatics Faculty, K.N. Toosi University of Technology, Tehran, Iran [b]Faculty of Geo-Information Science and Earth Observation, University of Twente, Netherlands	*Cities* Volume 40, Issue PA, October 2014, Pages 56–69	GIS Linkage among land uses Multicriteria evaluation Multifunctional land uses Spatial equity
Using connectivity for measuring equity in transit provision	Kaplan, S.[a], Popoks, D.[a], Prato, C.G.[a], Ceder, A.[b] [a]Department of Transport, Technical University of Denmark, Bygningstorvet 116B, 2800 Kgs. Lyngby, Denmark [b]Department of Civil and Environmental Engineering, University of Auckland, 20 Symonds Street, 1010 Auckland, New Zealand	*Journal of Transport Geography* Volume 37, May 2014, Pages 82–92	Geographical Information Systems Intergenerational equity Spatial equity Transit connectivity Vertical equity
Assessing the location of public-and-community facilities for the elderly in Beijing, China	Zhou, S., Cheng, Y. Xiao, M. Bao, X. Beijing Normal University, Beijing, China	*GeoJournal* Volume 78, Issue 3, June 2013, Pages 539–551	Beijing Public-and-community facilities Spatial analysis Spatial equity The elderly

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Title	Authors Affiliation	Journal	Keywords
Efficiency and spatial equity impacts of high-speed rail extensions in urban areas	Monzón, A. Ortega, E., López, E. TRANS y T-UPM Centro de Investigación del Transporte, Universidad Politécnica de Madrid, ETSI, Madrid, Spain	*Cities* Volume 30, Issue 1, February 2013, Pages 18–30	Accessibility indicators Efficiency impacts High-speed rail (HSR) Spatial Equity Urban areas
Estimating secondary school catchment areas and the spatial equity of access	Singleton, A.D.[a], Longley, P.A.[b] Allen, R.[c], O'Brien, O.[b] [a]Department of Civic Design, University of Liverpool, United Kingdom [b]Department of Geography and CASA, University College London, United Kingdom [c]Department of Quantitative Social Science, Institute of Education University of London, United Kingdom	*Computers, Environment and Urban Systems* Volume 35, Issue 3, May 2011, Pages 241–249	Catchment analysis Decision support system Education GIS Percent volume contour School
Exploring an integrated method for measuring the relative spatial equity in public facilities in the context of urban parks	Chang, H.-S. Liao, C.-H. Department of Urban Planning, National Cheng-Kung University, Taiwan	*Cities* Volume 28, Issue 5, October 2011, Pages 361–371	Accessibility Mobility Spatial equity Urban public facilities
Immigration, ethnicity, and accessibility to culturally diverse family physicians	Wang, L. Department of Geography, Ryerson University, Toronto, Canada	*Health and Place* Volume 13, Issue 3, September 2007, Pages 656–671	Accessibility Chinese immigrants Ethnicity Family physician

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Title	Authors Affiliation	Journal	Keywords
Spatial equity in facilities providing low- or no-fee screening mammography in Chicago neighbourhoods	Zenk, S.N.[a] Tarlov, E.[b], Sun, J.[c] [a]Program in Cancer Control and Population Sciences, University of Illinois at Chicago, United States [b]Midwest Center for Health Services and Policy Research, Hines VA Hospital, United States [c]Department of Sociology and Criminal Justice, Texas A and M University-Commerce, United States	*Journal of Urban Health* Volume 83, Issue 2, March 2006, Pages 195–210	African-american GIS Health care access Mammography Neighbourhood Poverty Urban health
An accessibility-based integrated measure of relative spatial equity in urban public facilities	Tsou, K.-W. Hung, Y.-T. Chang, Y.-L. Department of Urban Planning, National Cheng-Kung University, Taiwan	*Cities* Volume 22, Issue 6, December 2005, Pages 424–435	Geographical Information Systems Integrated equity indices Spatial analysis models
Trends and issues in accessibility studies in the GIS Era	Tanaka, K. Faculty of Integrated Arts/Sciences, University of Tokushima, Tokushima, Japan	*Geographical Review of Japan* Volume 77, Issue 14, December 2004, Pages 977–996	Accessibility GIS Space-time measure
Spatial accessibility and equity of playgrounds in Edmonton, Canada	Smoyer-Tomic, K.E. Hewko, J.N. Hodgson, M.J. Department of Earth/Atmospheric Sci., University of Alberta, Canada	*Canadian Geographer* Volume 48, Issue 3, September 2004, Pages 287–302	Accessibility GIS Amenity Equity Spatial distribution Urban area

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Chapter 11
Changing River Courses and Border Determination Challenges: The Case of the Slovenian–Croatian Border

Drago Perko, Matija Zorn, Rok Ciglič and Mateja Breg Valjavec

Abstract After the independence of Slovenia and Croatia in 1991, the former internal Yugoslav border between the two countries became an international border (today a Schengen border), of which over two-fifths follows rivers (the Drava, Sotla, Kolpa, Dragonja, and others). Rivers are natural geographical dividers whose shifting courses hamper permanent administrative demarcation, especially in flat areas exposed to frequent flooding and meandering. Thus, rivers as borders may cause problems because they are not static. Moreover, they are very dynamic and tend to change their courses; for example, one country may claim that the "old" course is the border and the other that the "new" course is the border. Practically, all rivers and streams on the Slovenian–Croatian border are such examples. Applied geography and geospatial technologies, especially geographic information systems, have played an important role in the preparation of geographical bases for the arbitration procedure to determine the Slovenian–Croatian border. The final decision, which was announced on June 29, 2017 by The Hague-based Permanent Court of Arbitration, will affect the lives of many people along the border. To analyze the dynamics of changing river courses along the Slovenian–Croatian border, we used geographic information systems and multitemporal analysis of cartographic and other pictorial sources: historical maps, historical aerial images, satellite images, and precise digital elevation models (LiDAR).

Keywords Political geography · Applied geography · GIS
Historical cartography · LiDAR · Border rivers · Arbitration · Slovenia · Croatia

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11.1 Introduction

After the independence of Slovenia and Croatia in 1991, the former internal Yugoslav border became an international border (today a Schengen border). Because this border was never precisely mapped and marked with border stones during Yugoslav times, since 1991, it has been a contentious issue between the two countries. To put an end to this dispute, both countries agreed on an arbitration process by the Permanent Court of Arbitration in The Hague (in the Netherlands). The final decision, which was announced by the court on June 29, 2017, will affect the lives of many people along the border.

Over two-fifths of this border follows rivers (the Drava, Sotla, Kolpa, Dragonja, and others). Rivers are natural geographical dividers whose shifting courses hamper permanent administrative demarcation, especially in flat areas exposed to frequent flooding. Thus, rivers as borders may cause problems because they are not static. Moreover, they are very dynamic and tend to change their courses; for example, one country may claim that the "old" course is the border and the other that the "new" course is the border. Practically all rivers and streams on the Slovenian–Croatian border are such examples.

Through much of human history, borders were not exact lines but an area—a borderland. "During the Middle Ages, there is some evidence that the feudal system was more concerned with the control of cities and territories, which, rather than having clear boundaries, had somewhat vague borderlands" (Brunet-Jailly 2010, 1). In this regard, changes in river courses did not pose a problem. "Thanks to geographers, however, mapping technology allowed rulers to have a spatial view of their possessions; thus, what was originally borderland or border regions progressively became boundaries" (Brunet-Jailly 2010, 1). Thus, when maps became a reference for international agreements, especially with the Treaty of Paris after the First World War (Brunet-Jailly 2010), static lines were put on maps as borders. With these, changes in river courses became a problem if rivers were defined as the borderline.

The main categories of morphological classification of political borders are:

(1) Anthropogeographic or geometric usually following straight lines (e.g., a parallel or meridian); and
(2) Physiographic following some notable natural geographic element in the area, such as orographic lines, ridges, or watercourses (Boundary… 2018).

The last are often called natural boundaries, even though virtually all political borders, including those based on natural features, are the result of human activity and as such purely artificial.

Border rivers can have very different dimensions. They may be large (e.g., the Danube) and a very important landscape feature (e.g., the Rio de la Plata between Argentina and Uruguay) or they can be rather small (unimportant) landscape features, but in some cases, they are a long-standing divide—if not between countries, then between neighboring ethnic groups, such as the 18 km Čabranka River between the Slovenians and Croats, which now also runs between Slovenia and Croatia.

In this chapter, we show how border rivers have been changing their courses over the last two centuries compared to today's border and the Slovenian land cadaster. We especially focus on the historical sources used and the GIS methodology applied.

11.2 Slovenian–Croatian Border Determination Challenges

Following a series of unsuccessful bilateral attempts to resolve the dispute over their land and maritime boundary, Slovenia and Croatia, with the facilitation of the European Commission, signed an arbitration agreement on November 4th, 2009 (Arbitration… 2009) establishing an arbitration tribunal tasked to determine:

- The course of the maritime and land boundary between Slovenia and Croatia;
- Slovenia's junction to the high sea; and
- The regime for the use of the relevant maritime areas.

According to Article 4 of the Agreement (Arbitration… 2009), in its deliberations concerning the junction and the regime, the arbitration tribunal must apply the rules and principles of international law, as well as equity and the principle of good neighborly relations in order to achieve a fair and just result. Furthermore, it must take into account all of the relevant circumstances.

The final decision was announced on June 29, 2017 by The Hague-based Permanent Court of Arbitration.

In 2011, the Slovenian Ministry of Foreign Affairs ordered the preparation of geographical material for the arbitration procedure to determine the Slovenian–Croatian border. In 2012, we prepared extensive material entitled "Geography of the Slovenian–Croatian Border" (Perko 2012). Geographic information systems and other geospatial tools played an important role in the preparation of this material. The results show how important applied geography can be in resolving border disputes.

11.3 A Brief Geography of the Slovenian–Croatian Border

At its regional conference in Prague in 1994, the International Geographical Union placed Slovenia among central European countries and Croatia among southeastern European countries. Slovenia is located at the contact of four major European geographical units: the Alps, the Dinaric Alps, the Pannonian Basin, and the Mediterranean, and Croatia is at the contact of the Dinaric Alps, the Pannonian Basin, and the Mediterranean. Their borders from northeast to southwest run first along the edge of the central European Pannonian Basin, then cross the northwestern part of the Balkan Dinaric Alps, and finally reach the northern edge of the Mediterranean and continue to the Adriatic Sea. The Slovenian–Croatian border represents 49% of the entire Slovenian border and 28% of the entire Croatian border (Statistični… 2013) on land.

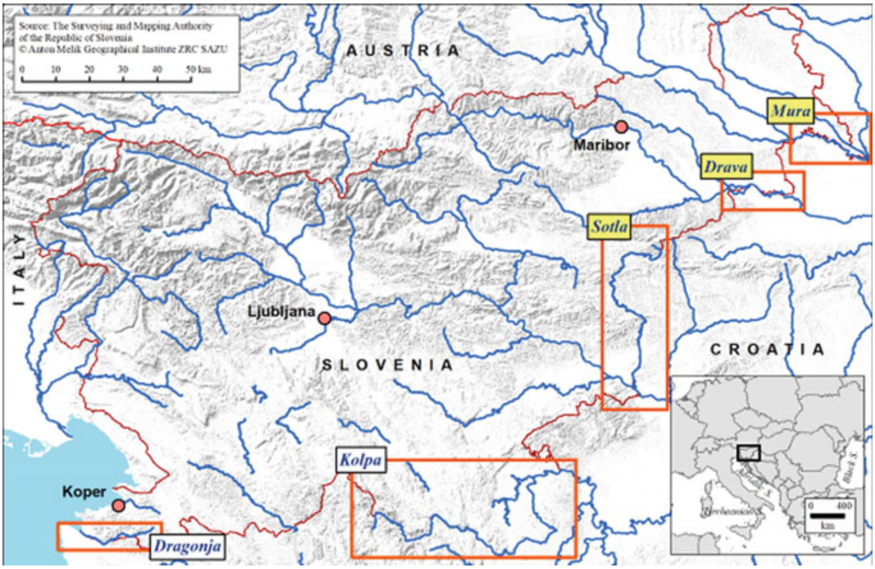

Fig. 11.1 Border rivers between Slovenia and Croatia (rivers discussed in the text are highlighted in yellow)

Along its entire length of 654 km, the border is mostly adapted to natural conditions. The natural borders are the most favorable from the perspective of defense strategy, and partly also from the economic point of view (Bognar 2001). The historical and geographical development of the Slovenian–Croatian border area shows that the borders between the historical provinces and other political units were already based on natural boundaries in the past, such as the border between Austria and Hungary within the Habsburg Monarchy. In sections that rely on natural elements, the border between today's independent countries of Slovenia and Croatia has generally remained unchanged since the late Middle Ages (Bognar 2001).

In total, almost exactly four-fifths of the boundary passes along rivers and streams (a hydrographic border) and follows hill ridges (an orographic border).

There are 57 border crossings between Slovenia and Croatia: 49 road and 8 railway crossings. This means that, on average, one border crossing is located every 11.5 km of the border. Twenty-five border crossings are international (including all 8 railway crossings), ten crossings are binational, and the remaining 22 are local.

The area along the Slovenian–Croatian border can be divided into four parts (Fig. 11.1): the Mura Basin, the Drava Basin, the Sava Basin (with the Sotla Basin and the Kolpa Basin), and the Adriatic Sea catchment (with the Dragonja Basin).

The first three basins are part of the Black Sea catchment.

In the Mura Basin, the border mostly runs along the Mura River, which often floods, and divides the flatter Slovenian part from the hilly Croatian part. Both sides are densely populated and farmed.

In the Drava Basin, the border mostly flows through hills with numerous vineyards, and partly across the plain along the Drava River, which is dammed for hydroelectric power stations in some places.

In the Sava Basin, the border runs mostly along the Sotla River and the Kolpa River. The landscape along the northern Sotla is mostly hilly, whereas the landscape along the southern Sotla is flat. The landscape near the Kolpa is mainly karst: in the west, there are sparsely populated plateaus, and in the east there is a low corrosion plain.

In the Adriatic Sea catchment, there are two very different landscapes. In the east, the border mostly runs on high karst plateaus, which are almost uninhabited, and in the west the border runs along the Dragonja River, which penetrates through flysch hills, reaching the highly populated coast of the Adriatic Sea.

11.4 Cartographic Sources

Modern technologies, remote sensing data, and digitalized historical maps make it possible to study the dynamics of river courses over a long timespan. Several sources that can be used to study the dynamics of river courses in the last two centuries exist for Slovenian territory (Table 11.1).

We traced the changes in river courses over the last two centuries. The cartographic sources from this period can be used for multitemporal analysis because they were

Table 11.1 List of cartographic sources and spatial data for Slovenian territory that make it possible to study the dynamics of river courses

Source name	Accuracy or scale	Online source	Remarks
Habsburg military survey maps	1:28,800 (first and second survey) 1:25,000 (third survey)	http://mapire.eu/en/	Eighteenth- and nineteenth-century military map viewer of Habsburg Monarchy territory
Franciscan cadaster	1:2,880	http://giskd6s.situla.org/giskd/	Georeferenced tiles of a Franciscan cadaster viewer for part of Slovenian territory
Satellite images	30 m and more	http://earthexplorer.usgs.gov http://glovis.usgs.gov http://landsatlook.usgs.gov	Complete world satellite images
Light detection and ranging; digital elevation model	1 m	http://evode.arso.gov.si/indexd022.html?q=node/12	Light detection and ranging images for Slovenian territory

created at an adequate scale and with proper geodetic means. We used historical maps, historical aerial images, satellite images, and precise digital elevation models (LiDAR).

Errors may occur when processing historical data and may originate with the source itself because precision decreases with greater age. Errors can also be generated while digitalizing or scanning the material because the original cartographic material may be deformed due to twisting, shrinkage, or wrinkling. Last but not least, errors can occur also during georeferencing.

11.4.1 Historical Maps

Among the historical maps are three Habsburg military land surveys. The first survey was carried out between 1784 and 1787 (Rajšp 1996; Zorn 2007), the second one between 1806 and 1869 (Timár 2009), and the third one between 1869 and 1887 (Molnár et al. 2009). Due to their scale (1:28,880 for the first two and 1:25,000 for the third), the military surveys are suitable for studying changes in the courses of larger rivers. Errors, which are sometimes greater than the actual changes, prevent the study of smaller watercourses (Skaloš et al. 2011); the first and second survey have errors up to several hundred meters (Podobnikar 2009; Timár 2009; Štular 2010). However, the surveys became better over time: the first survey was not based on detailed geodetic measurement or a special cartographic projection, but the second one was already based on good geodetic measurements (Zimova et al. 2006); nonetheless, the third, most accurate survey also had errors up to 220 m in some places (Molnár et al. 2009).

Figure 11.2 shows changes in the course of the Drava River from the second half of the eighteenth century to the second half of the nineteenth century in today's border area between Slovenia and Croatia.

In addition to military purposes, cartographic data in Habsburg Monarchy were also gathered for the land cadaster to catalog properties for tax purposes (Ribnikar 1982; Golec 2010). The Franciscan cadaster was used for all of Slovenian territory between 1818 and 1828 (Dobernik 2002; Golec 2010), and its updated (revised) version between 1869 and 1887 (Seručnik 2009), both at a scale of 1:2,880. In addition to the scale, the omission of surface relief data differentiates them from military maps. River courses are shown as "polygons"; that is, a river is drawn as a light blue parcel or group of parcels. River names are included.

11.4.2 Historical Aerial Images

We used historical aerial photographs of Slovenian territory that were taken from the Second World War until 1972 by the Military Geography Institute in Belgrade, which carried out surveys primarily for defense purposes and partly also for major civil engineering projects (e.g., freeways). In 1972, these surveys became a civil domain

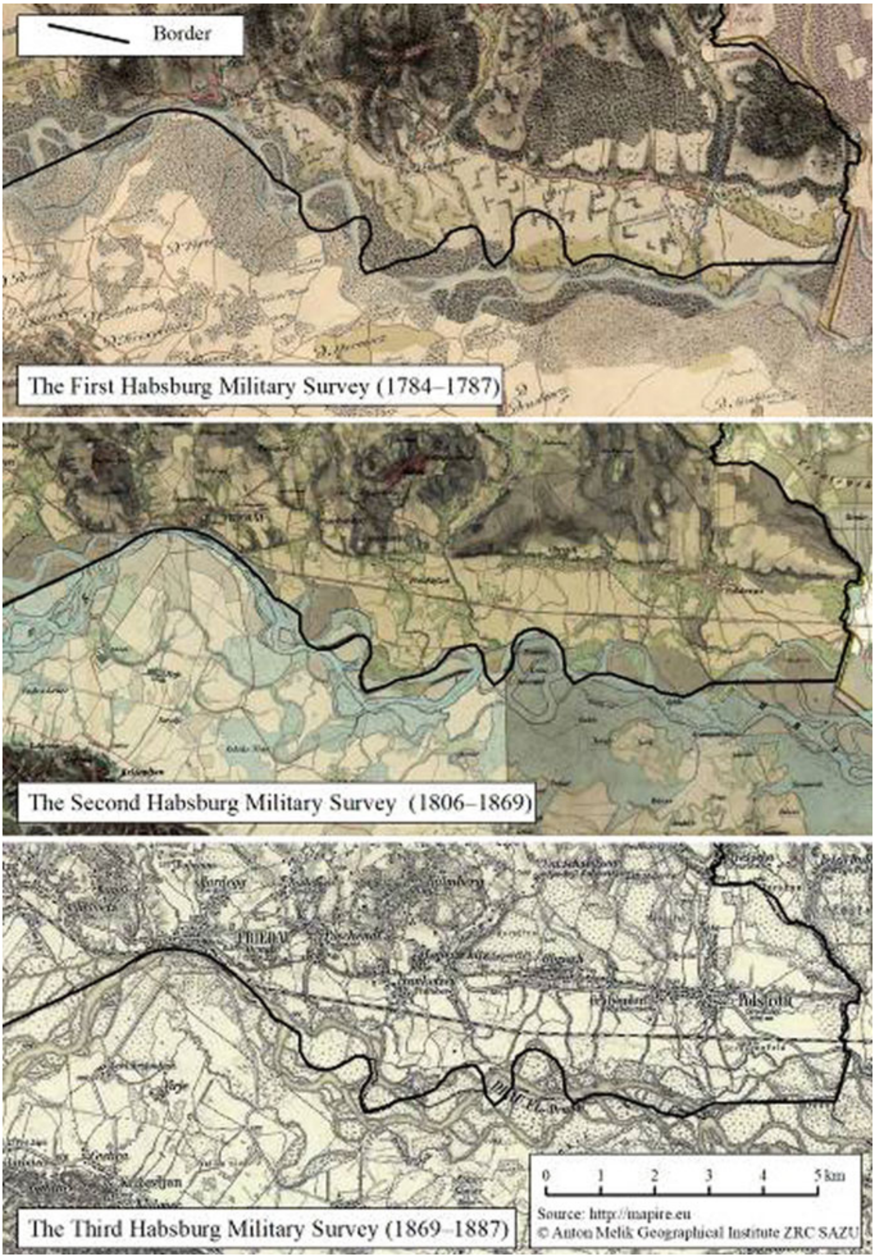

Fig. 11.2 Changes in the course of the Drava River between the first, second, and third Habsburg military surveys and today's border between Slovenia (north) and Croatia (south and east)

managed by the Geodetic Survey of the Socialist Republic of Slovenia. Slovenia was first fully photographed in 1975. This was the beginning of the Cyclical Aerial Photogrammetric Measurements of Slovenia (Lipej 1992), carried out up until the present. Slovenia was photographed at a 1:17,500 scale. The first images were black and white, and color images were created in the 1980s. Many smaller areas were already photographed immediately after the Second World War (Breg Valjavec and Ribeiro 2014).

The collection of postwar aerial photographs includes mainly metric photographs that make possible photogrammetric stereoimage processing and generation of historical DEMs. Postwar aerial photographs are well preserved and largely accessible to the public from the Archives of Aerial Photos (maintained by Geodetic Institute of Slovenia). Some of the photographs taken before 1972 are still kept exclusively at the Military Geography Institute in Belgrade.

11.4.3 Satellite Images

Alongside the advances in technology, remote sensing methods have been advancing as well, including satellite remote sensing. There are a large number of free and for-pay satellite images available on the market. The free ones—for example, Landsat images, Moderate Resolution Imaging Spectroradiometer (MODIS), and Sentinel—have low resolution (10 m or several 100 m) and are only appropriate for analyzing larger areas. The for-pay ones have better resolution (even smaller than 1 m; e.g., GeoEye and WorldView). In addition to good spatial resolution, radiometric resolution is also important because it indicates how many different values a sensor can detect for a shape, and time resolution, which indicates how many images of a particular area a sensor can make in a certain time period. For example, Landsat satellites create an image of the same area every sixteen days, whereas MODIS satellites create an image of the same area every day. For our research, we used Landsat images.

The problem when using satellite images is limited resolution, which is usually not good enough to monitor landscape changes (including rivers) in detail (Huziu et al. 2012).

11.4.4 Digital Elevation Models

Digital elevation models are used for viewing surface relief. This includes river meandering, which reflects past river dynamics.

Topographic data are the most accessible data (Mücher et al. 2003), which is also the case in Slovenia. The Surveying and Mapping Authority of the Republic of Slovenia has published several digital elevation models with various resolutions. DEM with a resolution of 25, 12.5, and 5 m are the most frequently used ones. A large step forward was made by using Light Detection and Ranging (LiDAR) technology (Triglav Čekada et al. 2012), which has a high resolution (e.g., 1 m). Laser scanning of the entire territory of Slovenia was carried out between 2011 and 2015.

11.5 Spatial Data Collection

Using historical maps in GIS requires appropriate preparation of raw data, commonly in three phases: digitization, georeferencing, and vectorization. The first phase is the transformation of cartographic material into digital form, usually through optical scanning to obtain a raster image. With georeferencing, a cartographic source is aligned with a selected coordinate system using computer software (Jenny et al. 2009; Petek and Fridl 2010). The last phase is digitizing of selected elements (rivers, borders, etc.) of scanned raster images into vectors, which makes it possible to carry out spatial analyses.

First, the analog maps were digitized into tif format using an optical scanner (300–600 dpi). Georeferencing was performed by preparing a reference background, which was used to integrate the non-georeferenced map into real-world coordinates. The reference background was constructed with modern topographic maps at various scales (between 1:25,000 and 1:50,000). By comparing referenced points identified on old and modern maps, we embedded old maps into a coordinate system. Five to ten reference points were used for each map sheet. The scanned maps of various ages were put into the Slovenian national coordinate system D48.

Roof ridges and corners of churches and other buildings in urban settlements were used as reference points on the Franciscan cadaster sheets. Bordering points between two, three, or more parcels were also very useful. Less appropriate, but still useful as reference points, were road intersections, which often have not changed except for their width.

Integration of the coordinate system was followed by vectorization. Watercourses were drawn using vector polygons and lines, which were then merged and compared to the same watercourses throughout the period studied.

11.5.1 Historical Aerial Images

Aerial images also need to be georeferenced to be used in a GIS environment. This was done similarly to historical maps by comparing reference points, or triangulation was used when stereophotographs were available. We used ArcGIS Desktop software for this.

11.5.2 Satellite Images

In addition to spatial, radiometric, and time resolution, we focused on the duration of the data collection. Therefore, we chose Landsat satellite mission images, which have a long-term record starting in 1973. Based on images recorded by Thematic Mapper (TM) sensors on the Landsat 5 satellite and Operational Land Imager (OLI) on the Landsat 8 satellite, we investigated the dynamics of the Drava River's course (Fig. 11.3). By comparing images from different spectral belts, the infrared spectrum turned out to be the most suitable for investigating water areas due to absorption of infrared light by water and its consequent lower reflection values than soil, vegetation, or built-up land (Frazier and Page 2000).

Choosing images from the infrared spectral belt is an advantage in viewing water bodies compared to images from the visual spectral belt. We used this method to study annual river courses using ArcGIS Desktop software.

11.5.3 Digital Elevation Models

The data acquired by the Light Detection and Ranging (LiDAR) for Slovenia were provided by the Slovenian Environment Agency. Compared to older DEM images (12.5 m or 5 m resolution), the LiDAR dataset has better resolution, which makes it possible to create very detailed DEMs (1 m) and consequently more precise analysis of the surface morphology (Fig. 11.4). Compared to aerial images, LiDAR's advantage is also voided vegetation features from elevation data.

Analytical relief shading is the most straightforward presentation of surface relief (Burrough and McDonell 1998), but more specialized indicators can also be used; for example, sky-view factor (Zakšek et al. 2011). These tools help us recognize surface morphology. For this study, we used shaded relief and visually analyzed wider areas of watercourses. Using EzLAS software, the original point cloud was converted from zlas format into las format, which was imported into ArcGIS Desktop software to construct shaded relief. The point cloud was used for elevation interpolation to obtain a complete digital elevation model, upon which the shaded relief was constructed. We used this to observe traces of previous watercourses.

11.6 Shifting Rivers and the National Border: Some Examples

The Permanent Court of Arbitration determined that the cadastral boundaries should become the border between Slovenia and Croatia on land. Such a decision could negatively affect many inhabitants along the border, especially farmers. Most problems are connected with the course of the border along rivers.

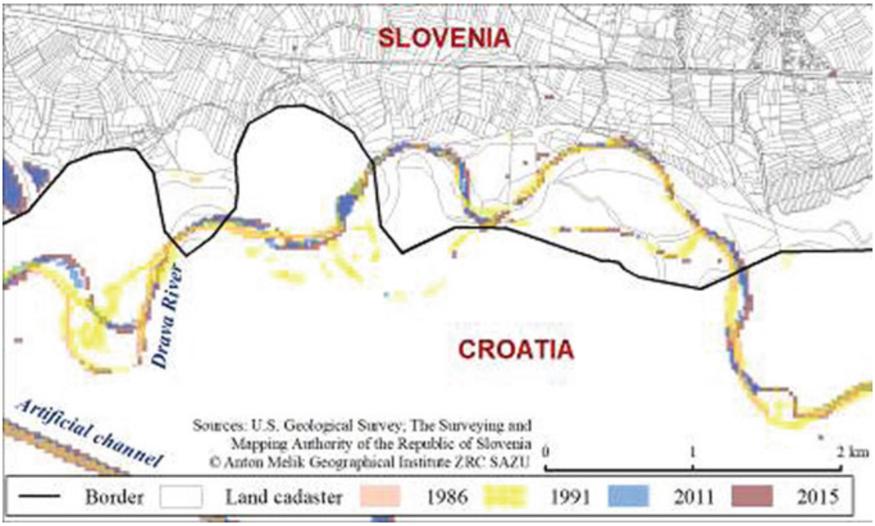

Fig. 11.3 The changing course of the Drava River at Ormož in the last thirty years based on satellite images

At the time of the formation of the land cadaster, the cadastral boundaries were determined by the courses of the rivers at that time. Due to the movement and changing of river courses, the gap between the cadastral boundaries and the current river courses has increased greatly over the centuries. Thus, numerous "pockets" of the cadastral territories of both countries emerged on the opposite banks of the river. These small areas can be described as hard-to-reach places.

The complexity of these problems is clearly represented by three examples, selected for short sections of the Drava, Mura, and Sotla rivers (Figs. 11.5, 11.6 and 11.7).

For example, in some places, the Mura flows up to two kilometers south of the former riverbed. The result is that about 800 ha of Croatian cadastral parcels lie on the Slovenian left bank, and about 260 ha of Slovenian cadastral parcels lie on the Croatian right bank (Fig. 11.6).

All of the analog and digital sources mentioned in Sects. 11.4 and 11.5 were analyzed for the entire area along the Slovenian–Croatian border. The final results also include thematic maps showing the change in river courses along the border in the last two centuries.

Final thematic maps were created by overlapping partial maps of individual cartographic and digital data sources.

For example, the map section as shown in Fig. 11.3 was created by comparing the classification of the infrared spectral band of satellite images for 1986 and 2015, which detects water bodies such as rivers and lakes very well. Possible classification errors were checked in the field and other sources. Figure 11.3 shows how great the changes were that occurred in the riverbed of the Drava in only 30 years.

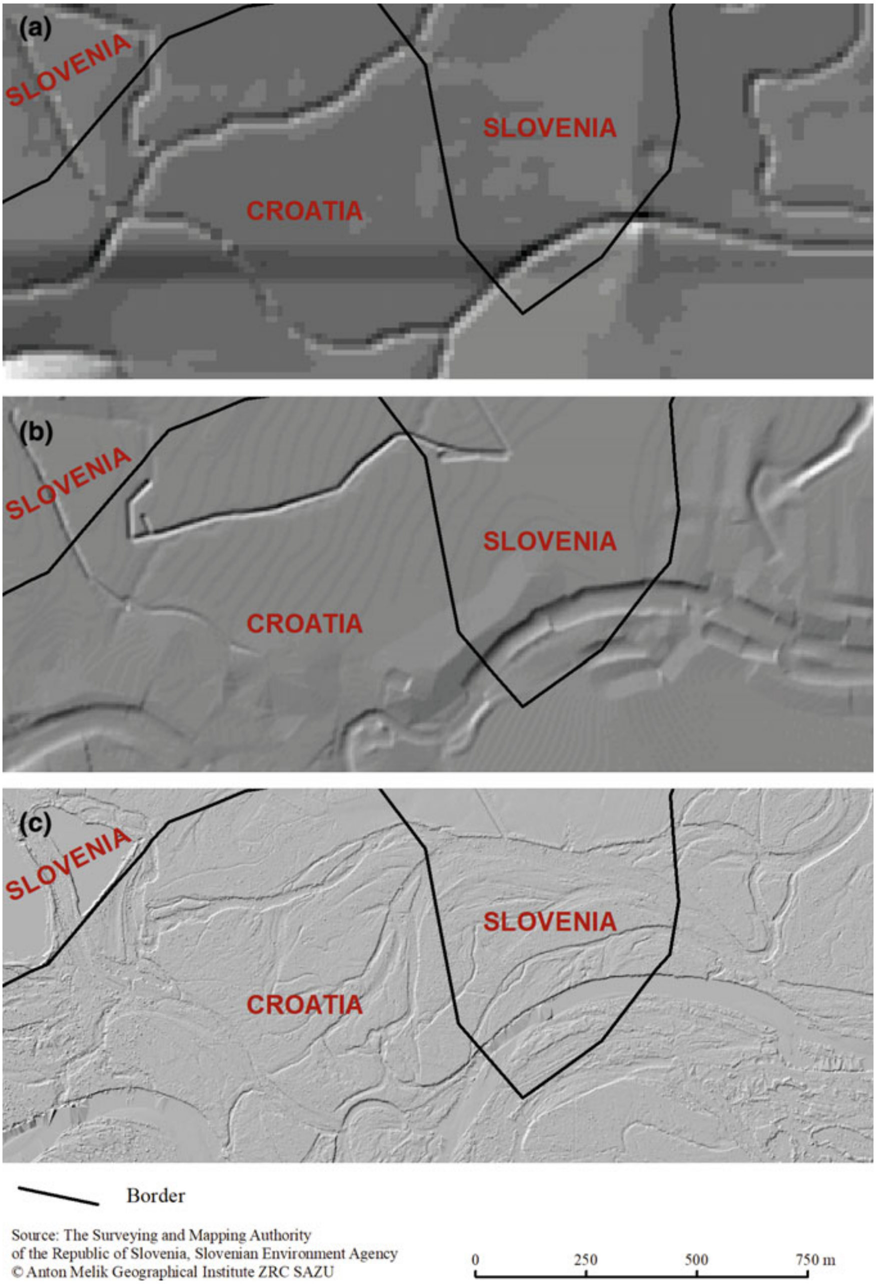

Fig. 11.4 Comparison of shaded relief with a resolution of 12.5 m (**a**), 5 m (**b**), and 1 m (**c**) along the Drava River at Ormož

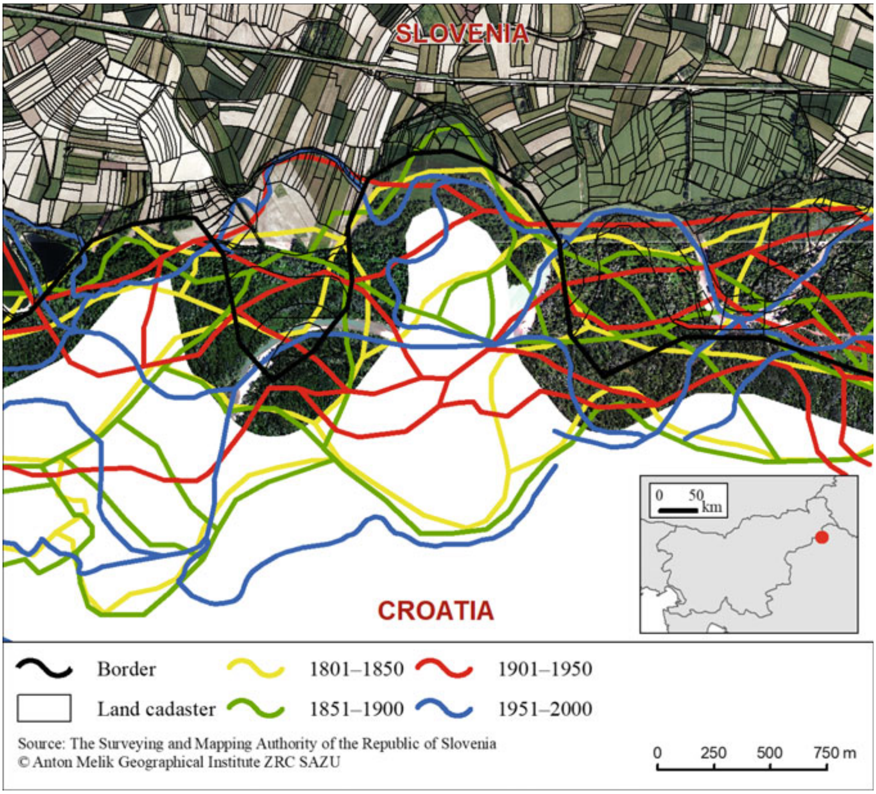

Fig. 11.5 The changing course of the Drava River at Ormož in the last 200 years based on cartographic sources

The second example is the use of digital elevation models and shaded reliefs (Fig. 11.4). Of course, the most useful is the digital elevation model with a resolution of 1 m or LiDAR DEM. Figure 11.4 shows traces of the Drava River's meanders. Due to the absorption of rays, laser scanning in the water area does not make it possible to obtain information about the surface, and so the water area has no data and looks completely flat. The surface area of the former watercourses that are now dry is also visible. Because laser scanning penetrates through vegetation (unlike aerial and satellite optical imagery), the shadow relief clearly shows the shape of the surface. In Fig. 11.4c, the recent Drava riverbed and many paleoriverbeds can be recognized.

The final three maps show all of the changes on short sections of the Drava, Mura, and Sotla rivers in the last two centuries that have been identified with the help of the aforementioned analog and digital sources (Figs. 11.5, 11.6 and 11.7).

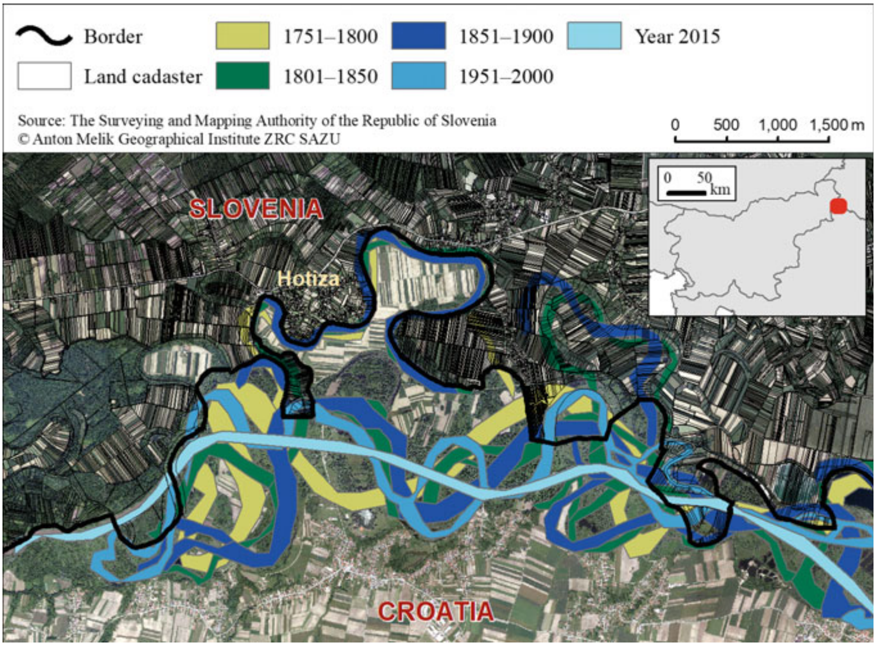

Fig. 11.6 The changing course of the Mura River at Hotiza in the last 200 years based on cartographic sources

11.7 Conclusions

"… 'Common sense' ideas about border rivers imply that the river bed and boundary usually match. However, in actual landscape and cartographic representations, the differences between these elements can be significant. […] Due to meandering and erosion, a river does not 'stick' to the river bed as 'captured' by cartographers or geodesists at a certain historical moment…" (Zajc 2017).

Natural geographical conditions are often overlooked in political decision-making (including delimitation). However, if one uses a natural geographical feature as border (e.g., rivers), these may also cause problems because they are not static. Even though changes in "small" watercourses that are characteristic for the border between Slovenia and Croatia are less distinct, under exceptional circumstances (such as flooding) their courses can also change. It is precisely because of these shifts in their courses that rivers, especially in flat areas, can be problematic for political demarcation.

Historical cartographic sources at an adequate scale and using proper geodetic means can help in reconstructing river courses for the last approximately two hundred years. Unfortunately, on even older maps the errors are too large for these kinds of studies. Today with the help of LiDAR, one can see all of the historical dynamics of rivers, but the problem is that these dynamics cannot also be followed temporally.

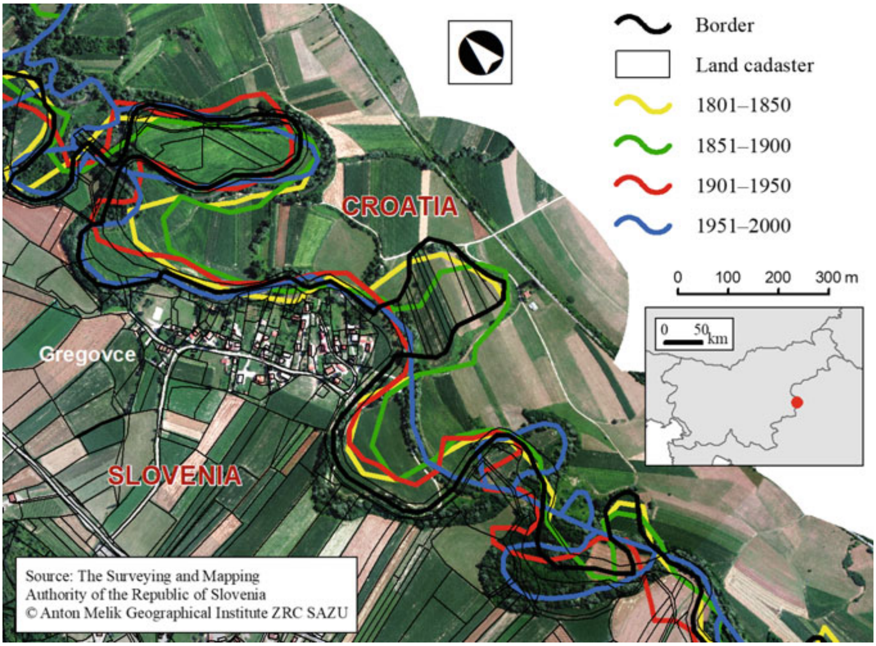

Fig. 11.7 The changing course of the Sotla River at Gregovce in the last 200 years based on cartographic sources

In the history of determining the border, Croatia favored the cadastral border, whereas Slovenia wanted to adjust the border in some sections to concrete natural conditions in order to facilitate the lives of people along the border, in particular farmers, and to make possible effective measures against natural disasters, especially floods.

The final determination of the national border along the existing cadastral borders was the easiest for the Permanent Court of Arbitration. This is why many illogical and unusual courses of the border have been preserved (Fig. 11.8). However, Slovenia and Croatia still have the option to change the course of the border independently in difficult sections and by agreement, if necessary. With the new (arbitration) border, Slovenia lost 2.9 km^2 of its land territory and gained some territorial sea.

Our research in this chapter is only a small part of the extensive material that we prepared for the Slovenian government and that was included in the arbitration procedure. The chapter does not deal with the history of negotiations to determine the border between Slovenia and Croatia, nor does it deal with the arbitration procedure and the final arbitration decision, let alone with their evaluation, but merely demonstrates the usefulness of geoinformation tools and geospatial technology for analyzing river dynamics, which have further increased the applicability of geography. For the time being, Slovenia and Croatia have not taken advantage of the opportunities offered by applied geography.

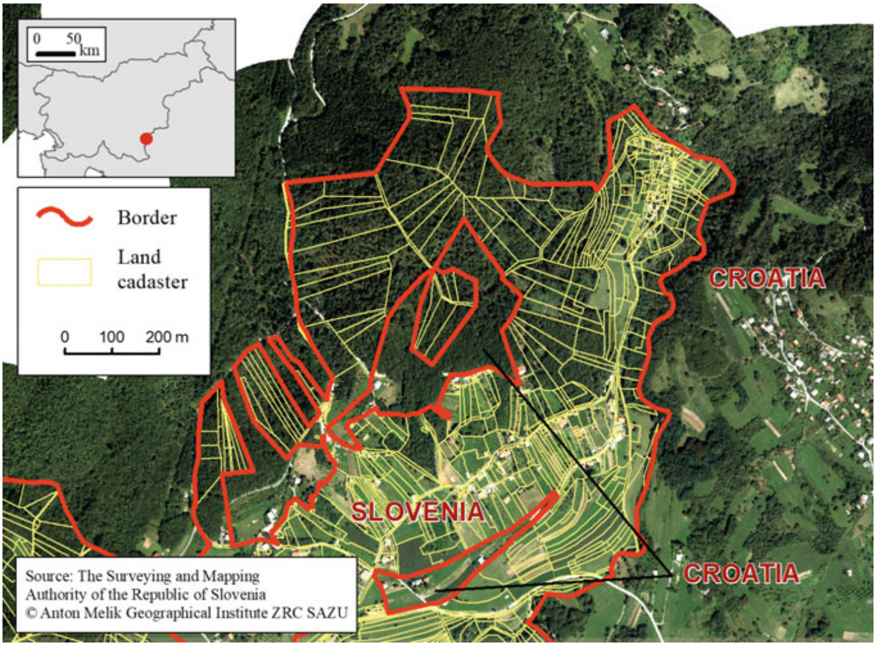

Fig. 11.8 The unusual course of the Slovenian–Croatian border in the Kolpa Basin

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Chapter 12
Cultural Heritage and Collective Knowledge

Teresa Amodio

Abstract This research deals with the analysis of cultural heritage through innovative technologies and presents, in detail, a project which proved fully in line with the “smart city” model, in specie created for the promotion of the old neighborhoods downtown Salerno. The initiative, named “Salerno in Particular. Cultural Heritage and Innovation”, raised from the creativity of several students in the University of Salerno, who—within institutional cooperation—developed a cultural alternative to the extant ones, focused on the systematization of a wide range of knowledge and skills, both humanistic and scientific. Through a wide-ranging performance of activities and events—carried out in different and prestigious venues throughout the city—the historic district’s downtown Salerno (a geographical context characterized by a distributed presence of historical, artistic, and archeological relics) have been interpreted and proposed so to retrace the past with an eye to modernity. From a methodological point of view, the named actions have greatly benefited from the geographic-based contribution; in particular, they have allowed the deepening of aspects related to localization and contextualization of cultural heritage and made possible the elaboration of detailed maps (even geo-referenced and interactive, independently proposed, and others) as a starting point for the various involvements of the project).

Keywords Cultural heritage · Innovative technologies
Historical downtown of Salerno

12.1 Introduction and Project Presentation

The locution “Smart City” defines “*a city model that through the help of new technologies is able to implement a transparent and participatory governance policy*

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aimed at improving the quality of life of its citizens and pursuing sustainable development goals" (Giffinger 2007).

This concept, which has lately found ample interest in political agendas and in scientific studies, refers to "*a territory that*, *in defining its growth and competitiveness strategies*, *adopts a creative*, *digital approach focused on e-governance*, *activating*, *respectively*, *the internal envelope of human*, *technological and institutional factors*" (Caragliu et al. 2011).

This perspective include urban policy guidelines, aimed at enhancing territorial distinguishing characteristics, and at creating new opportunities for economic growth through the development of different local cultural heritages.

In this regard, it is to be said that, after the period when the debates on ancient relics were focused on the need to include the majority of the territorial resources in the conceptual category, the expression of the identity of places has moved to a phase in which has emerged the need, first, to consider cultural heritages within their contexts (so as to include them in a systemic network configuration) and second, to focus the attention on their public fruition. In such developmental logic, it should be considered that the value attributed to ancient relics depends not only on their identification and intrinsic importance, but also on the ability to publicize their presence and to improve their attractiveness by facilitating their enjoyment by a vast majority of the populace.

As a result, the territories do require the use of expertise and resources for the creation of cultural exhibits with a specific content, but—at the same time—with suitable forms of communication and ways of fruition. Such activities should be joined by using techniques, technologies, and innovative tools that can integrate more traditional organizational patterns and enjoyment (Bonacini 2011).

From this point of view, over the last 20 years, new technologies have made a major contribution through solutions that redefine space and timing of data transmission, that emphasize perceptual aspects (through images that aim to facilitate understanding and clarify aspects of complexity), and that are able to actively engage users in content exploration.

Among other aspects, the radical renewal of the design of digital dialog systems has facilitated some characteristics of cultural heritage, in developing new forms of "democratization" of knowledge.

The cultural property sector was also able to take advantage of the opportunity displaying simple and interactive (virtual) reconstructions and virtual tours,[1] increased reality integration[2] (with multi-touch monitors), and user-friendly applications based on tactile systems. Moreover, some dynamic sites[3] and portals have been set up as well as social networks entries.

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[1]Virtual tours recreate virtual spaces within which the user can navigate between different parking points, observing 360°, interacting with the environment, activating points of depth with tabs with textual and multimedia content.

[2]Increased reality allows you to read additional information about the scene, using a QR code that initiates HTML tabs, movies, and audio files.

[3]Dynamic sites, such as social networks, allow continuous interaction from commented or uploaded users.

An example is the project "Salerno in Particular. Cultural Heritage and Innovation", carried out by the Department of Cultural Heritage Sciences of the University of Salerno, in the framework of the activities promoted by the DATABENC.[4]

The nature of the project was of a bottom up type, promoted by the University, in the context of a full collaboration with the competent territorial institutions such as the Municipal Administration, the Superintendence Archeology of Fine Arts and Landscape for the Province of Salerno and Avellino, the State Archives, the Provincial Library, the archiepiscopal Curia.

The project aimed at capitalizing the research results that is knowledge promotion on local cultural heritage, as well as, the restoration in terms of public benefit of a significant system of monuments, tradition, and memories.

To this end, the project intended to contribute to the cultural progress of Salerno, whose stakeholders are engaged since more than a decade in the implementation of a vast urban redevelopment program. This latter has heavily focused on the tourist vocation of the city, resulting in a new cultural gravity of the historical center, and rich in cultural heritage dating back to different historical periods (Roman, Lombard, Norman-Swabian, and Angevin, Aragonese).

As a matter of fact, the area represents a multilayered system that gathers the historical, political, and cultural identity of the city. Therefore, the interventions carried on are based on humanistic and scientific knowledge synergy in order to implement an integrated plan of knowledge, conservation, management, valorization, and communication of such historical and monumental heritage.

As part of the project, a series of geo-referenced thematic maps were drawn up in order to acquire and make available information on the rich monumental heritage existing in the city.

Through the various initiatives of the project, the digital technologies utilized a strategic role in enhancing the fruition of geographical and cartographic contents, as enabled a more rapid and effective dissemination of such enormous flow of information. A result that is particularly relevant when considering the global society we live in, where data and communication take place through endless networks and nodes that are impossible to reach with standard tools.

12.2 The Reference Area

The Municipality of Salerno, with an extension of 59.75 sq. km^2 and a population of 135,261 (2016 data), has a peculiar geographical configuration which has characterized its development path and urban growth.

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[4]Italian acronym for Distretto ad Alta TecnologiA per i BENi Culturali, i.e. High Technology Consortium for Cultural Heritage, private Company which uses modern technologies applied to the cultural heritages.It is a Consortium where the Universities of Naples Federico II and Salerno converge, the CNR, Small and Medium Enterprise Research Entities, created to develop a strategic programming action on cultural assets, Environmental heritage and tourism.

Fig. 12.1 Historic center of Salerno. *Source* Own elaboration

The historic core (Fig. 12.1)—edged by the natural boundaries of the background hills, which have in Mt Bonadies the highest peak, by the sea, and in the West, by the orographic features of the Amalfi Coast—have had the possibility to expand its south side only eastward.

This expansion, affected by an intensive urbanization, eventually reached the Municipality of Pontecagnano, with which presently the city of Salerno is a complete conurbation.

The urban expansion, driven by demographic growth and by new public housing programs (aimed to relieve the damages caused by the 1954 flood), led to the establishment of new neighborhoods in the South East direction and to the related progressive desertion of the Old Downtown, at first by middle-class traders and small craftsmen and then by poorer classes workers. This flow left back many empty houses, often illegally occupied by non-EU immigrants expelled from the countryside or attracted by prospects to improve their quality of life.

The outpouring from the Old Downtown was exacerbated by all the persons displaced from their houses due to the 1990 earthquake that struck the entire Campania Region.

This led again to a gradual urban degradation, an economic devolution, a widespread sentiment of disaffection, and a loss of places' identity. Nevertheless, at the end of the 1980s, some circumstances—such as the revivification of the scientific debate about the recovery and enhancement of historic downtowns, the appreciation of the financial opportunities offered by the European Union, and the determination of the local politicians—reversed the trend that until then had been recorded.

Since then, Salerno has been affected by a significant urban and socioeconomic transformation, still in progress, that has enhanced the touristic potential of the city and established a central reference for both its large provincial territory (to name only the Amalfi Coast, the Capaccio-Paestum Magna-Graecia archeological area, and the Cilento coastal district) and other linked regional areas such as the Royal Palace of Caserta, the Roman City of Pompei, or the islands in the Gulf of Naples.

The main course of action has involved the improvement of the touristic functions related to ships and seafaring activities through an immense infrastructure along the south coast, completely renovated and equipped with facilities for sailing crafts, powerboats, and cruise ships, with a new harbor, and with mooring spaces for leisure boats.

Cultural happenings have also multiplied, partly due to tourism development goals and partly to the city people itself with its demand for inclusive and collective growth. Those activities have originated a wide range of initiatives.[5]

Last but not least, many actions aimed at improving the quality of life for local communities have been launched, such as the recovery of urban design and security, the restoration of ancient monuments and churches, the opening of public parks and gardens, the arrangement of streets and squares, and the creation of spaces for artistic, cultural, and recreational activities.

In this multifaceted process—since the 1990s (the beginning of the urban transformation of Salerno)[6]—the historic downtown has been the object of a substantial structural redevelopment work, which had as a direct consequence the progressive restoration of residential functions and then of economic and cultural assets, with a priority given to the services sector. In addition, it must be credited an unwritten desire to return to the ancient city nucleus, with its historical, artistic, and archeological evidences of great wealth, to represent the role of the territorial center for renewal, and to support those cultural initiatives that could, in various ways, contribute to reinforce the already defined urban strategy.

[5] Among which Luci d'Artista, Linea d'Ombra, Literature Festival, and Premio Charlot.

[6] Actions funded by the Urban and Urban II Initiatives.

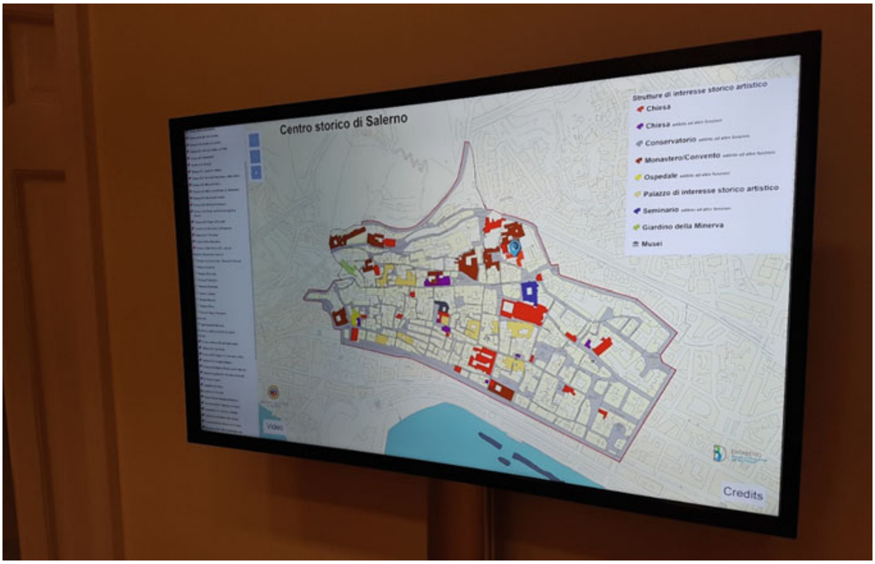

Fig. 12.2 Touch screen for geo-referenced interactive mapping. *Source* Own photo

Table 12.1 Monument with historical and artistic relevance in the historic center of Salerno

Typology	Number of structure
Church	30
Palace with historical relevance	9
Historic garden	1
Monastery and convent	10
Conservatory	1
Ancient hospital	1
Religious seminar	1
Museum	2

Source Data processed based on the ABAP Superintendence for the city of Salerno and Avellino

12.3 "Salerno in Particular—Cultural Heritage and Innovation"

The initiative,[7] dedicated to the historic downtown of Salerno, has been a composite engagement based on the integration of both humanistic and scientific knowledge for the development of an integrated plan of analysis, promotion, and outward advertisement of the existent precious monumental heritage.

[7] http://www.databenc.it/wp/prodotti/.

The project benefited from an in-depth work of specialists that made possible to outline the reference database, conceived to include both the geographic context, as a whole, and the aggregate of cultural heritage sites (museums, churches, aristocratic residences, and archeological discoveries, as well as minor elements rendering ancient ways of life and civilization, such as isolated courtyards or smaller streets).

This phase was followed up by the identification of innovative means of exploiting the cultural heritage with the support of new technologies, aiming to enable citizens, as well as tourists, to learn more in detail about the eminent system of monuments, traditions, and memory from which the current city configuration is stemmed.

The outcome has been the arrangement of an articulated network of activities consisting of an interactive mapping of monumental heritage, an application for the historic downtown as a whole, a dedicated footage, a Digital Versatile Disk (DVD) that recreates city monuments, history, and culture. Moreover, it has been staged a public information campaign consisting of conversations addressed to the citizens, several multimedia installations, a city knowledge atlas and a specialized application, the "Guide to the Sarcophagi of the Salerno Cathedral".

These activities have been located and presented in various strategic loci around the city, appropriately identified and set up to exhibit the desired system of cultural offerings and to offer a chance to appreciate such prestigious locations for a period of about three months (November 2016–February 2017).

The first step was the development of a geo-referenced, interactive mapping (Fig. 12.2).

The map was created to represent the monumental assets located in the historical center, in relation to the reference contest (Table 12.1), surveyed trough on-the-spot inspections and the support of the Superintendence of Archeology, Fine Arts, and Landscape for the city of Salerno.

During the first stage of the map, elaboration was carried out a survey on the fabric of the city (buildings, streets, squares, courtyards, as well as other architectural elements such as pedestrian arches, which are a linked between structures above the road plan), through the specific analysis of both urban and topographic elements; reported on cartographic bases.[8]

The representation of the urban fabric, shaped with reference to topographic elements, have facilitated the identification and naming of buildings of historical interest as well as the determination of the correct names of streets and squares.

Subsequently, the identified assets were geo-localized and the historical and artistic structures represented on a series of large-scale maps (1:5000), indicating the related chronology (Fig. 12.3), the ownership, the original as well as the current functions.

Applied cartography, when accessible through a touch screen, will provide the designation of every single city monumental heritage site, classified by typology

[8]Digital georeferenced orthophotos of Campania (orthophotos dated 2004 on a scale of 1:5000 and dated 2011 on a scale of 1:10,000); topographic map OSM (OpenStreetMaps); open source topographic maps available online.

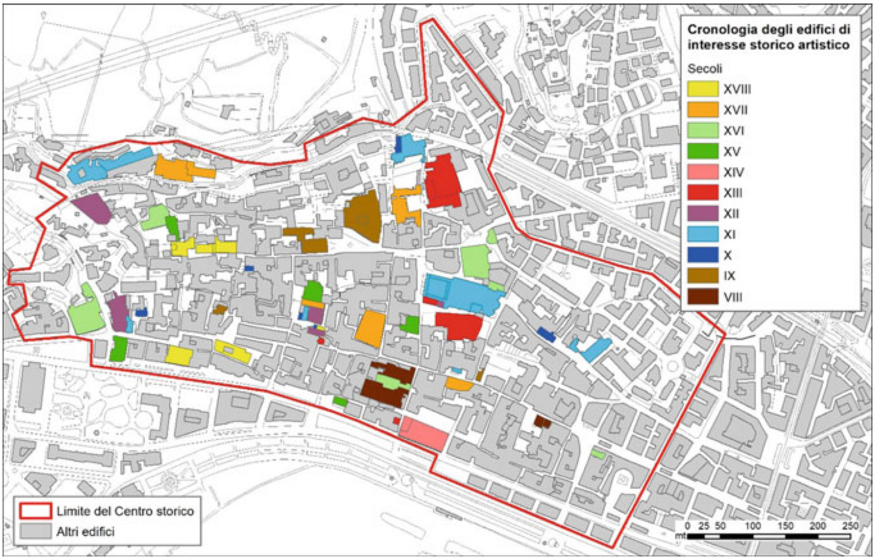

Fig. 12.3 Information level relating to the buildings chronology. *Source* Data processed based on the superintendence for the city of Salerno and Avellino

(churches, monasteries, mansions, palaces, etc.), the display of related comments, and some photographic images, specially made.

12.4 Additional Application of Cartography and Computer Applications

The same cartography, printed in a large-scale format (7.0 by 3.5 m), was also a reference for the "Salerno" exhibition—in particular "Pictures of the Old Town"—to highlight the complexity and richness of the cultural heritage of the city context (Fig. 12.4). The cartography, has been realized in a multilevel PDF format, including open layers in EPS format (compatible with Adobe Photoshop).

The huge size of the cartographic representation, characterized by the precise location of the spots therein, was complemented by several detailed views taken during a photographic campaign by the author, which while portraying paintings, sculptures, and other architectural elements, revealed new small details known as "urban landscape" (such as pavements, portals, arches, windows, etc.).

Photographic images on the main map have been accompanied with QR code for supplemental information labels, which could be viewed by device-equipped visitors.

Fig. 12.4 Image of the large cartography exposed during the show. *Source* Own photo

At the same time, a photographic contest was launched among high school students, to promote the consideration of the valuable and stratified cultural heritage of the ancient center of Salerno and interpretations of the city's image.

The initiative was greatly appreciated by the participants and provided another recognition of some of the details represented in the shoots exhibited during the show. Indeed, it brought forth the identification of their exact position by GPS and the acquisition of several new pictures, related to one or more specific features, with reference to their specific context.

During the exhibition period, it was also staged a cycle of conversations titled "La bellezza dei secoli in Salerno" ("The Beauty of Centuries in Salerno") which, moving through the history and the artifacts of the city from ancient to contemporary times, was an occasion to introduce the rich heritage, still perceptible today in museums, in palaces, in churches, and in the urban fabric of the Old Town.

In the same venue of the show, as well as in other parts of the city, the project of the "Cross through Salerno" was set up so that—with reference to the history, the monuments, the traditions, and the suggestive glimpses of the historic downtown—it was able to offer a reconstruction of the close link between the most significant religious places in the city and the active memory transmitted by its historical and monumental heritage.

The combination of geographic elements, ancient relics, and new technologies has also been implemented with the organization of a laboratory, located in Palazzo Fruscione, which has allowed its visitors to experiment some technological applications presented through multimedia and interactive installations.

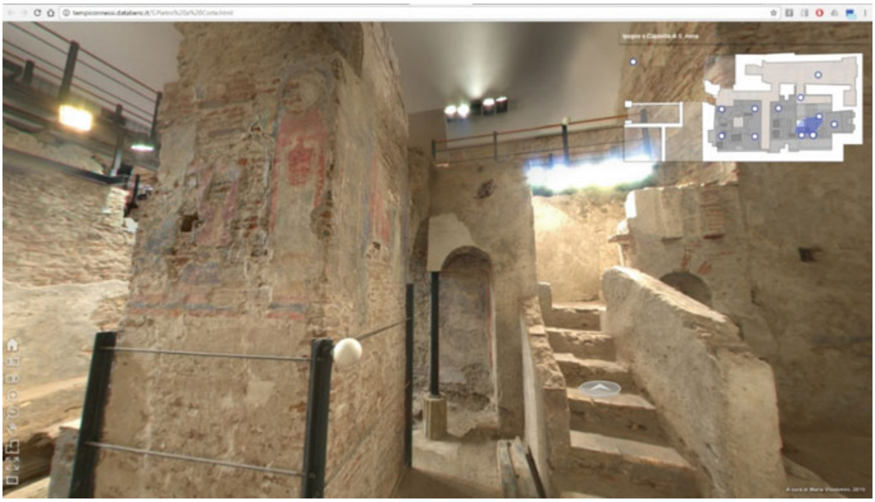

Fig. 12.5 Framework of the installation "Videostoria di San Pietro a Corte". *Source* Own elaboration

The first involved—named "The Line of Time" and dedicated to the Monastery Compound of St Peter a Corte—was meant to provide a vision of the monument history in relation to the political, social, and cultural transformations of Salerno. The application highlighted the historical and artistic stratifications characterizing the monument, enabled it to be enjoyed even by less educated users (with virtual navigation through time, divided into six different phases), and presented finds or discoveries of different works of art, with the related bibliographic sources. An ancient status quo of St Peter's a Corte church has been inserted in the virtual 3D reconstruction of the monumental Roman phase (Fig. 12.5).

This is the scenario in which takes place a computer game named "Hippocratica Civitas".[9] The game, envisaged for collaborative action,[10] stages a journey to different archeological themes, the overcoming of which allows you to virtually visit the various structures in the simulated reconstruction of the ancient compound.

In order to promote the rediscovery of this portion of the millennial life of Salerno, the multimedia exhibition "Video Story of St Peter a Corte" has been performed inside the monastery. It is a journey through life from Roman times to the present, under the guidance of a narrator's voice that illustrates the stratification of phases and cultures with the aid of light effects, of images projections, and of 3D pictures mapping techniques.

[9]"Hippocratica Civitas" (Latin for "Hippocratic Town") is the motto on Salerno's Coat of Arms.

[10]The use of virtual reconstructions is presented through multi-platform and multi-device cooperative activities that allow groups of users to navigate within the same reconstructed environment, using a combination of immersive reality (3d viewers, Oculus Rift), 3d reality (With autostereoscopic screens) and collaborative interaction through appropriate sensor (Kinect).

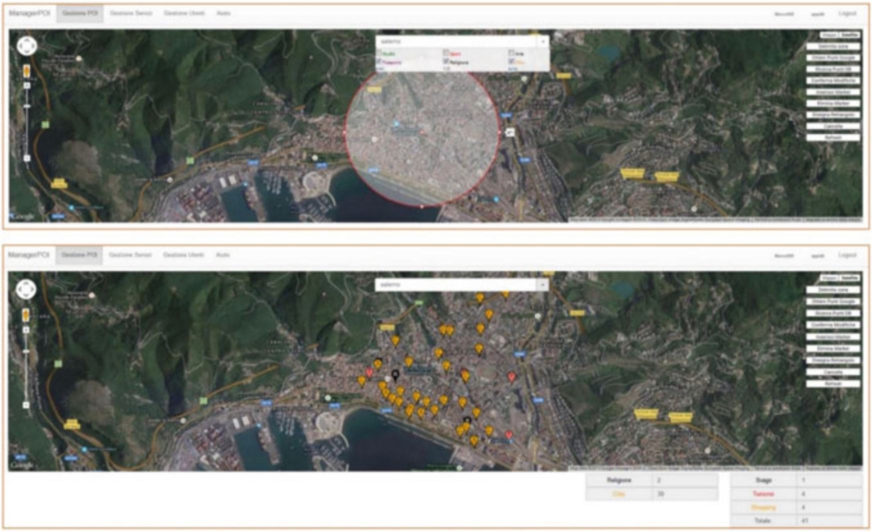

Fig. 12.6 Salerno SmartApp framework. *Source* Own elaboration

Starting with the objective of gathering knowledge and a careful acquisition of cultural heritage, has been, finally, developed a territorial database called the "Atlas of Knowledge".

This data collection has been designed with the aim of assembling and making available online information about a wide range of cultural assets (e.g., archeological and monumental heritage, fine arts, architectural structures, landscapes, etc.) in a geo-referenced and integrated way.

The geo-referenced map has been used in the implementation of other project activities, including the configuration of the SmartApp "Salerno", developed for mobile devices as a guide to the city main points of interest (Fig. 12.6).

A second application, in double version—for standard sight and non-sighted people (this latter developed in collaboration with the Italian Blind and Visually Impaired Union)—is available for a visit to the Roman Sarcophagi, reused in medieval times, which are arranged in the quadriportico of St Matthew's Cathedral.

As a consequence, an articulated system of knowledge is currently available, aimed to facilitate the management of the cultural heritage of Salerno's historic downtown in the processes of urban planning, protection, and conservation, and of improvement of cultural assets.

As an added value, it is also accessible the provision of expert opinions in cases of archeological risk determination. In the "Atlas" the context of the Old Town was also

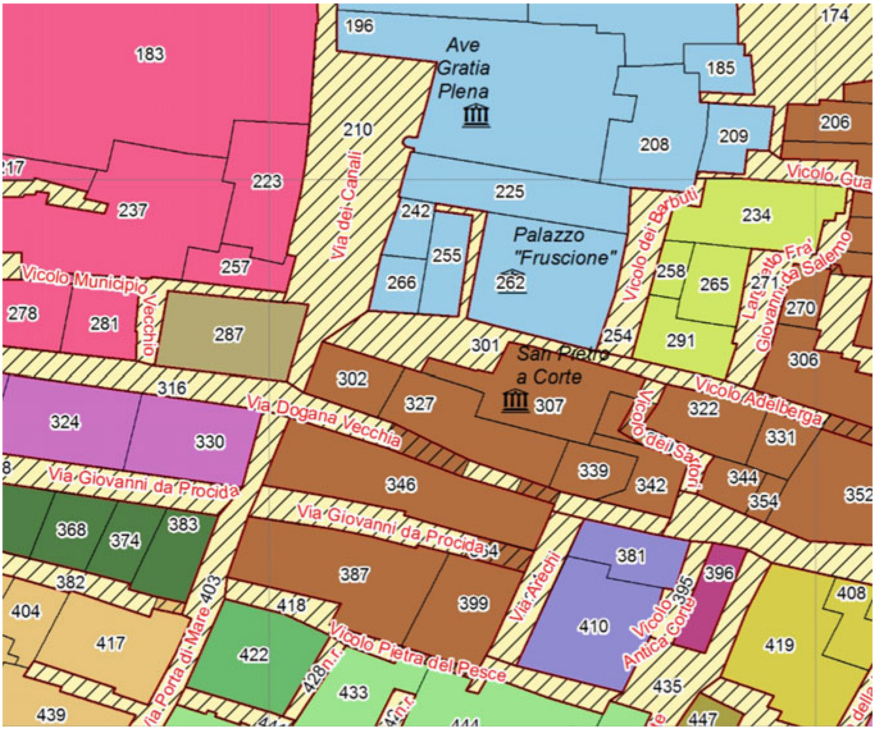

Fig. 12.7 Detail of cartography for UTU/EU representation. *Source* Data processing on surveying archeology, fine arts and landscape for the provinces of Salerno and Avellino

presented through an Archeological Urban System, characterized by the division of the territory into Topographic Urban Intervention Units (TUIU).[11]

A TUIU defines the spatial-temporal dimension and represents the logical framework of the information system. It corresponds to a container and, at the same time, a "historical landscape" unity.

It is the geographical areas where converge cultural, topographic and archeological information of both past and future, as well as the transversal data and photo archive (database) of the archeological, cultural, and environmental heritage having historical and tourism importance.

These were realized by adapting the current urban structure to the historical one, derived from the cadastral maps and verified on a periodic basis through the perimeters and typology of the urban elements (Fig. 12.7).

This configuration adds another step to EU defined level (Urban Entity), created as an UTU grouping in larger aggregates, in order not to split the cross-sectional

[11] The TUIU is a logical scaffolding of the information system, defined by the space-time dimension, in which cultural, ancestral, topographic, archaeological, or archaeological, cultural, environmental, and tourist information can be combined.

elements that were affected by multiple UTUs such as the facades of historic buildings or porticoes running through multiple buildings.[12]

In the final version, the database includes the following fields:

- the ID of the UTU;
- cartographic coordinates "*x*" and "*y*" of the UTU central point in decimal degrees (GCS—Geographic Coordinate System *ETRS* 1989/UTM Zone 33N);
- unit category (buildings or streets and squares);
- ID of the category that can include several UTU;
- description of the UTU (for the categories building is used an alphanumeric abbreviation, streets, or squares instead were referred to with the place names);
- perimeter dimension of the UTU expressed in meters while the area measure is in m^2;
- EU identification code; cartographic coordinates "*x*" and "*y*" of the central point of the EU in decimal degrees (*ETRS* system 1989/UTM Zone 33N).

The final cartography, in addition to the UTU/EU level, includes other overlapping levels such as streets and squares toponymy; main points of interest in the historic center of Salerno (POI); the ESRI basic topographic map; a selection of the Numeric Regional Technical Paper of the Campania Region (CTRN 98), which contains only those information consistent with the involved research; an excerpt from the cadastral map of Salerno.

12.5 Research Results

In general terms, the initiative was considered praiseworthy for having told the historic center with details and minutiae not always known and visible.

Thanks to all the other events organized, there has been a rediscovery of the city, just as the photographic competition represented a further enrichment for the young students who had the opportunity to discover and appreciate further its territory. Using modern tools and languages, in fact, they were able to "dialogue" with the past of which there is still traces in our alleys and in our palaces.

Considering all the proposed events, the project received a huge appreciation in terms of visitors and users (including students and people with disabilities), about 15,000 in 3 months, who commented positively the initiatives, especially with regards to existing fruition tools.

So, with reference to the effects of the project, in view of usefulness for the city, it should be borne in mind that the activities put in place have had local communities as their destination, especially as regards the youth component, so as to strengthen the awareness of the value of resources located in the territories to which they belong, but also tourists.

[12]The TUIU spatial contiguity is used for EU detection.

The appreciation for the initiative was witnessed by the turnout and significant success that the project as a whole has received not only among the Salerno, but also among visitors from other regions of Italy and abroad. The initiatives implemented have allowed to make known and appreciate the important and often unknown artistic and cultural heritage of the city, returning the collective dimension, which belongs to the city and to research.

Overall, the exhibition “Salerno in particular—Images of the historic center” was visited by about 1500 people; while at Palazzo Fruscione and San Pietro a Corte, where multimedia installations are set up, around 9000 visitors were registered.

The Virtual Museum of the Salernitan Medical School has hosted around 1100 people.

The turnout was high especially during the Christmas period, thanks to the concomitance with “Luci d’Artista[13]”; the peak of presences was on January 1.

The exhibition has been appreciated by many students and by over five hundred visitors, mostly residents in the municipality of Salerno, although there have been users from other regions (mainly from Lombardy, Emilia Romagna, and Lazio) and some foreign countries. Many students who also participated, with interest and enthusiasm, always at Palazzo Ruggi d’Aragona, to the cycle of conversations entitled “The Beauty of the centuries in Salerno” that has retraced the history and art of the city, from the age ancient to contemporary”.

But particularly appreciated was the ability to involve young people in initiatives related to cultural heritage, directly related to the type of instruments adopted. In the case presented, for example, the decision to set up a photographic competition concerning some of the cultural heritage of the city of Salerno was a particularly appreciated and effective choice.

Sixteen classes of nine schools in Salerno and the province participated in the photo competition, which engaged in the study and recognition of the rich and stratified cultural heritage of the historic center. The young students have been called to photographically recontextualize some little-known details or for different reasons even “invisible” of the ancient city having as a trace the 100 details of portals, floors, and windows immortalized in a “metaphysical” by the photographer Ciro Fundarò and exposed in the exhibition “Salerno in particular—Images of the historic center” realized at Palazzo Ruggi d’Aragona by DiSPaC, in collaboration with the Superintendence.

The pupils had to draw inspiration from the shots made for the exhibition and aimed to bring to light the extraordinary beauty of the urban landscape.

Through the “like”, the boys have “challenged” on Facebook, while the best shots were chosen and then evaluated by a special commission that, based on the quality of the photos, has rewarded the winners with certificates of participation in the Competition, a copy of the exhibition catalog “Salerno in particular. Images of

[13]The initiative consists of the installation of luminous art works, created by internationally renowned artists, scattered throughout the main streets and in the most attractive corners of the Historic Center.

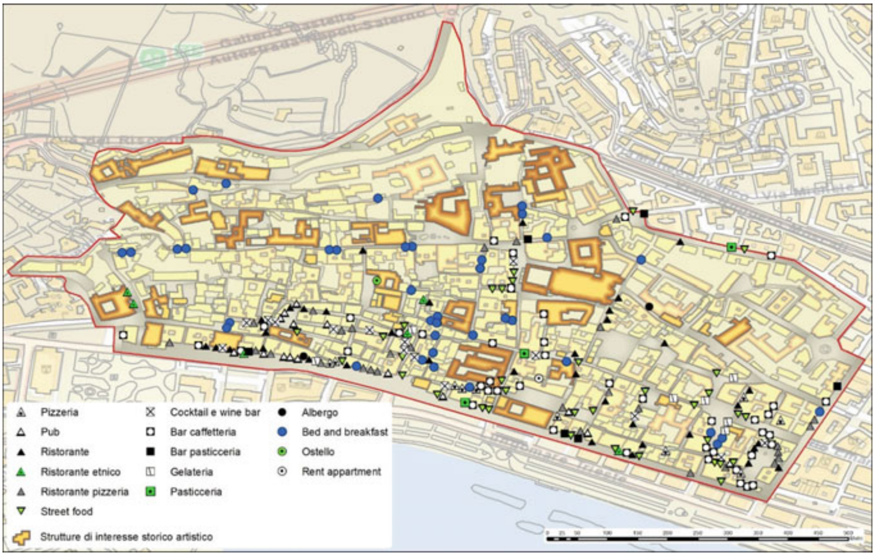

Fig. 12.8 The receptive and restaurant activities. *Source* Data elaboration made available by chamber of commerce, industry, agriculture, and craft

the historic center" and the printing of the winning photos in large format that can be exhibited in the premises of the school of origin.

Therefore, the shared synergy with the local institutions that if on one hand can support the initiatives themselves, and at the same time, benefit from cultural activities made available to the territory in an optic both of strengthening the overall cultural offer and of collective involvement.

As far as the real lack of explanation on how this project has contributed to some local decision-making process, in particular urban planning, it should be noted that the municipal administration asked for a GIS implementation with additional levels of information, to be associated with geo-referenced maps and connected with tourism services.

In a first phase, the request concerned the realization of a tool able to enhance a greater knowledge about tertiary touristic activities, to be located in different points of the city, through dedicated installations.

To this regard, geography and its tools represented to proper discipline, as it made possible to further support the tourism development of the geographical context. It was, therefore, realized a first informative level, concerning accommodation and restaurant segments, connected with the presence, consistency, and location of hotel and extra hotel in the historic center of Salerno (Fig. 12.8).

The activity involved information retrieval and a database implementation relating the commercial functions performed in the historical center, the area delimitation, on-the-spot investigations aiming at obtaining the geographic coordinates of the areas statistically surveyed and coordinates synchronization through the geo-mapping services. Finally, was developed a geo-referenced cartography concerning the selected activities, that were already classified (Fig. 12.8).

The data have been provided by the Chamber of Commerce of Salerno which has made available the lists of all the activities listed above, attributable to the entire municipal territory, containing, for each activity, a series of very detailed information on names, activities, tax codes, VAT numbers, ATECO codes, addresses, and years of construction.

Extracting just the data related to the historical center first identified the presence, consistency, and exact location of the present activities, and consequently was developed a consistent database containing the relevant information.

All the data concerning the registered structures were verified and geo-referenced through a survey using a professional GPS device with Geotag Photo function, and they were integrated with detailed data,[14] acquired with direct surveys, and photographic campaign.

During the cartographic representation phase, in order to simplify the information reading and to guarantee a direct access user service having in mind the tourism purposes, the accommodation and restaurant activities have been divided into different categories (Hotel, Bed and Breakfast, Hostel, Rent Apartment, Cocktail bar, Cafeteria bar, Pastry bar, Ice-cream parlor, Confectioner's shop, Wine bar, Pizzeria, Pub, Restaurant, Ethnic restaurant, Pizzeria restaurant, and Street food).

With reference to the historical Center, a geo-referenced synthesis cartography was realized, gathering 278 accommodation and catering facilities, identified within the involved territorial area, where were then added the structures with historical and artistic relevance.

12.6 Conclusions

Assuming that improving the knowledge of places can be created added value, changes, and innovation, it is possible to carry out some synthesis reflections aimed at highlighting the role of cartography in smart growth processes, connected with the local cultural asset.

On the whole, the initiative has been a model (a prototype) of factual design and actualization inspired by the smart city principles, both for the purpose of promoting cultural heritages, supported by innovative technologies, and in relation to the "Social Inclusion" criterion.

First, it must be said that initiatives aimed at disseminating knowledge of cultural heritage cannot be separated from a start-up phase characterized by the setting up of interdisciplinary humanistic and specialist competences. In the specific case, experts in the history of art, archeology, or epigraphy have provided the knowledge of the

[14] Per ciascuna struttura, schede contenenti la denominazione dell'attività, le fasce orarie di apertura e chiusura, i giorni di chiusura, ma anche i recapiti telefonici, gli indirizzi e-mail e web site, nonché il numero di tavoli o di stanze, a seconda che si trattasse di attività di ristorazione o ricettiva.

sectorial type related to the territorial endowment on which it is acted to activate local development processes.

These territorial connotations were then deepened by the geographical study that allowed both to contextualize the presence of cultural heritage, and to carry out cartographic elaborations, at different scales, through a GIS.

In this regard, it should be emphasized that the geographical research, in the specific case, has contributed to the overall realization of the project in various capacities, through the realization of territorial studies as well as the elaboration of numerous cartographic representations, some of which geo-referenced and interactive.

The activities carried out and the relative research products were aimed at realizing cognitive frameworks and cartographies to be inserted in the computing platforms in order to convey the project contents through social networks.

In this regard, it should be said that the set of cartographic contents and tools have been made available and processed by experts in innovative technologies so as to be able to design effective ways of disseminating and disseminating knowledge, based on some principles, some of which respond to the logic of facilitation and attraction.

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Chapter 13
Geoweb Methods for Public Participation in Urban Planning: Selected Cases from Poland

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Abstract This chapter presents Public Participation GIS (PPGIS) methods and tools based on open data, public input and Web 2 technologies, employed in participatory urban planning processes. The recent focus on sustainable urban development and livability has increased the demand for new data sourcing techniques to capture expe-

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riences, preferences and values of urban dwellers. At the same time, developments of geospatial technologies and social media have enabled new types of user-generated geographic information and spatially explicit online communication that is place-specific and often content-rich. As a result, new methods for engaging large groups of individuals that supplement, and sometimes, supplant traditional methods (e.g. public meetings) have emerged. Despite different application domains (e.g. land use and zoning, transportation, urban revitalization, green infrastructure and landscape audit), many participatory planning processes have shared common steps, in which PPGIS/Geoweb methods have been applied including (1) collection of values and preferences to inform the creation of plan draft and (2) discussion and feedback from participants on the plan draft. This chapter presents two methods and the corresponding tools that have been used by the authors in a number of participatory planning cases between 2014 and 2017. The cases concerning various planning problem and scales have been situated in two metropolitan areas of Poland.

Keywords Geospatial technologies · Public participation · Poland · GIS

13.1 Introduction

Public participation in urban planning has been theorized about and practiced since the 1960s. Various planning theories including transactive, negotiative and communicative provided conceptual, ethical and pragmatic arguments for opening technocratic and expert-driven planning processes to public input. The emergence of alternative (to rational planning) theories accompanied the critiques of public participation including the influential Arnstein's (1969) Ladder of Citizen Participation. They spurred the proliferation of public participation methods such as public meetings, planning and design charrettes, citizen juries, citizen panels, focus groups, deliberative polling and citizen advisory committees, among others. Despite the variety of public participation methods, the predominant method in urban planning has been public meeting offering an open format, an opportunity for face-to-face interaction, a real-time setting for an argumentative discourse and an opportunity to create social bonds and trust. Its inherent limitations have been well known including the requirement of physical presence in fixed time and place setting; an environment that can be intimidating for those who are uncomfortable with public speaking due to low education, socio-economic status, gender or other reasons; and low social, demographic and geographical scalability (Nyerges and Aguirre 2011; Jankowski et al. 2017).

The emergence and quick proliferation of information and communication technologies relying on the internet and W3 coupled with developments in Geographic Information Systems, GPS, mobile data platforms and digital geographic data, spurred the interest in new methods of public participation in urban planning. The overarching motivation for these methods has been the desire to democratize public participation by broadening the base and scaling it up and out to include broader groups of participants from geographically wider areas, and to harness local knowledge for the benefit of both participating and non-participating public.

Public participation methods and tools based on geodata, interoperable interfaces, Web 2 software services and public input have been increasingly employed in participatory urban planning within the last decade, and are often holistically referred to as Geoweb (Sieber et al. 2016). A widely spread policy focus of many governments and civic society organizations on sustainable urban development and liveability has increased the demand for new data sourcing techniques to capture experiential knowledge, preferences and values of urban dwellers. At the same time, developments in geospatial technologies and social media have enabled new types of user-generated geographic information and spatially explicit online communication that is place-specific and often content-rich (Goodchild 2007; Senaratne et al. 2017). As a result, Geoweb methods for engaging large groups of individuals that supplement, and sometimes supplant traditional methods (e.g. public meetings) have emerged. Despite different application domains (e.g. land use and zoning, transportation, urban revitalization, green infrastructure and landscape audit), many participatory planning processes share common steps including:

– collection of values and preferences to inform the creation of draft plan, and
– discussion and feedback from participants on the draft plan.

This makes it possible to develop generic methods supporting public participation that can be applied across different application domains. This chapter presents two such methods and the corresponding Geoweb applications that have been developed by the authors and subsequently applied in a number of participatory planning cases in Poland between 2014 and 2017. The cases representing various planning problem and spatial scales have been situated in two metropolitan areas: Poznań (population 542,500) and Łódź (population 701,000). The methods called *geo-questionnaire* (Jankowski et al. 2016; Czepkiewicz et al. 2017) and *geo-discussion* (Jankowski et al. 2017), have been developed to support (1) geographically informed collection of individual preferences that can be instrumental in the creation of draft plan, and (2) structured online discussion of draft plan, respectively. The tool that implements geo-questionnaire method enables capturing and storing participants' responses and analysing them with spatial analysis GIS functions. The tool implementing geo-discussion is a web application comprised of a structured discussion forum coupled with an interactive map, allowing sketching on the map geometric objects (point, line and area entities) and linking them with discussion contributions. Following the description of geo-questionnaire and geo-discussion methods, the chapter presents selected application cases focusing on the assessment of participation level and demographic characteristics of participants. The chapter closes with a discussion of issues affecting the use of geo-questionnaire and geo-discussion in planning applications.

13.2 Methods

The roots of the methods discussed in this section can be traced at least to early 1990s and the work on GIS-supported group decision-making involving interactive map sketching and annotating to capture spatial manifestations of stakeholder preferences concerning environmental management plans (Faber et al. 1994, 1995). The precursor of geo-questionnaire has been a method of soliciting and collecting public input on land use and development preferences. The method dubbed *softGIS*, used in the context of urban planning and environmental psychology (Kahila and Kyttä 2009; Kahila-Tani et al. 2016), is based on the concept of online questionnaire integrated with a map that opens up for the user a possibility of responding to questions by marking locations on a map. The precursors of geo-discussion include *argumentation maps*—a concept of asynchronous online discussion forum coupled with a map and database for storing georeferenced discussion contributions (Rinner 2001), and a parallel concept of *map-chatting* in the form of map-linked text messaging facilitating a dialogue over issues of relevance to local community (Hall et al. 2010).

13.2.1 Geo-questionnaire

Geo-questionnaire combines a web-based questionnaire with a sketchable map, making it possible to respond to spatially explicit questions by marking a point location, delineating a linear feature or drawing a polygon on the map (Jankowski et al. 2016; Czepkiewicz et al. 2017). A map accompanying the questionnaire can also facilitate nested questions by linking text with map, thus allowing a geo-questionnaire administrator to set-up a mechanism triggering additional questions in response to drawing on or selecting a feature from the map (Fig. 13.1).

In the example of geo-questionnaire functionality depicted in Fig. 13.1, a respondent sketched a polygon on the plan map to delineate commercial and retail designation (red rectangle), and in response, the geo-questionnaire tool displayed two questions concerning the minimum and the maximum number of floors for the delineated area. Such level of detail, often required in planning decisions, can be informed by (1) local knowledge of planning area and (2) specific location visible on the map and contextualized by thematic information afforded by the map and by the respondent's knowledge of the area. The difference between non-spatial online questionnaire and geo-questionnaire is an additional layer of information made available to the respondent—a map of the relevant area.

A typical geo-questionnaire is comprised of multiple pages with some questions without spatially explicit references and others linked with a map. The interactive map offers simple navigation tools such as zoom in, zoom out, and pan functions, as well as selection of base map layers (e.g. an Open Street Map layer, a satellite image or an orthophoto of the pertinent area). The responses to single- and multiple-choice questions, open-ended questions, slide bars capturing interval-scale expressions of

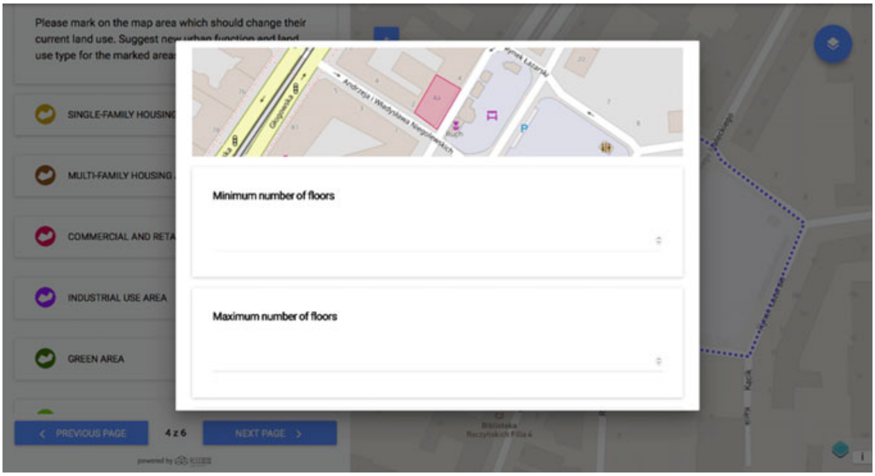

Fig. 13.1 An example of geo-questionnaire functionality showing questions in a pop-up window frame

respondent's preferences and map markings/sketches, can be stored in a database (e.g. a PostgreSQL) enabling easy access to collected data. The data can be subsequently analysed by aggregating location-specific land use preferences pertaining to the plan area using spatial analysis functions in GIS software such as map overlay, rasterization of vector features, kernel density, spatial autocorrelation measures and with qualitative text analysis (Jankowski et al. 2016).

Respondents to surveys do not need training on how to use geo-questionnaire, and the only prerequisites are basic familiarity with document browsing and map reading. An average web user familiar with browser functions including different field types, forms, buttons and basic map navigation functions (zoom in, zoom out, sketch point, lines and polygons) will be able to effectively respond to an online geo-questionnaire. The geo-questionnaires discussed in Sect. 13.3 were available for participants via standard web browsers and did not require additional software. That said, geo-questionnaire may be found difficult to respond to by those who are unfamiliar with Web technology (e.g. some seniors) and/or have not used online mapping applications before.

13.2.2 Geo-discussion

Geo-discussion combines a discussion forum with an interactive map, allowing the participant to select map objects (e.g. parcels) and/or mark/sketch geometric objects (point, line and area) on the map, and link them with discussion posts (Jankowski et al. 2017). The discussion forum offers several standard functions such as adding a new thread, commenting on threads added by other participants, subscribing to posts and threads, adding attachments, sorting, searching posts and reacting to posts by selecting like or dislike button. The map interface of geo-discussion offers basic tools to measure distances and surfaces, search by address, toggle between map layers, filter objects from a selected area and retrieve attribute information about the selected map object (Fig. 13.2).

The screen copy of geo-discussion application in local land use planning shows the plan area subdivided into colour coded and selectable parcels. Participants can read parcel descriptions and intended use prescribed by the discussed draft plan. They can select a parcel(s) of interest and post an opinion, agreement or disagreement with the intended land use designation. They can also quickly find out the overall sentiment in regard to a particular post, statement, or discussion argument. Additionally, they can mark specific locations within the study plan in reference to a discussion post. Unlike geo-questionnaire that serves the purpose of collecting public responses to both non-spatial and spatially explicit (linked to geographical location) questions and hence, facilitates one-way communication only (from respondent to database server), geo-discussion enables communication between all participants. All geo-discussion posts and map markings can be freely queried, read and responded to by anybody who is logged into a geo-discussion application through any Internet-connected device.

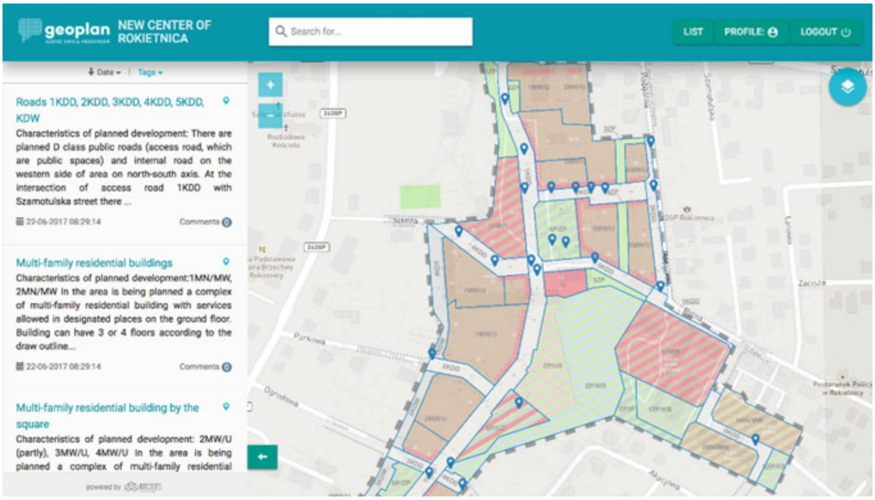

Fig. 13.2 An example of geo-discussion interface showing the discussion panel and the map panel

13.3 Application Cases

The applications of geo-questionnaire and geo-discussion presented in this section have been situated in two metropolitan areas (Poznań and Łódź) and ranged in scale from city to suburban municipality. The geo-questionnaires were used to collect urban development preferences of residents, whereas geo-discussions gave local residents and urban planners an opportunity to discuss preliminary drafts of:

– local spatial development plan, and
– local transportation infrastructure plan.

Given that all presented here applications are from Poland and deal with spatial planning issues, the section opens with a brief overview of the current spatial planning system in Poland.

13.3.1 The Spatial Planning System in Poland and Forms of Public Participation

The currently binding Polish Act on spatial planning and development of 27 March 2003 defines three tiers of the spatial planning system: national, regional and local (at municipality level), each developing spatial planning documentation differing in scope and character. These are as follows:

– at the local level: study of the conditions and directions of spatial development of a municipality and a local spatial development plan,
– at the regional level: spatial development plan of the region (i.e. province in Poland), inclusive of the spatial development plan of the metropolitan area, which primarily focuses on the province centre and its impact zone,
– at the national level: overall concept of spatial planning in the country.

Spatial planning at the national level is primarily analytical and informative. Coordination functions increase at the regional level, while at a local scale, the study of the conditions and directions of spatial development meets the following functions: analytical, coordinating and informative. The cornerstone of the system of legal acts related to physical planning in Poland is the local development plan. As an instrument of law issued by a municipality government, it is a commonly binding decision which concerns a whole range of issues, including but not limited to the division and functions to be met by a given area, constraints on investment, aesthetic qualities of development and architectural order as well as landscaping. The currently binding planning system is strongly devolved and the responsibility of the municipality for physical planning has become one of the pillars of local policy (Gawroński et al. 2010).

The procedure of drafting and adopting planning documents in Poland integrates elements which are important from the point of view of democracy instruments safeguarding the interests of private owners, public accessibility to and public participation in the plan development activities. The legal regulations concerning the participation of local communities in the procedure of drafting planning documents are defined in the Act of 27 March 2003 on spatial planning and development. The principal planning rules as set out in Art. 1 Section 2 of the above law are defined as follows:

– assurance of public participation in the study of the conditions and directions of spatial development of a municipality, local spatial development plan and the province spatial development plan, including by electronic communications means,
– assurance of public participation in and transparency of the planning procedures.

Pursuant to the Act on spatial planning and development, participation of the general public in drafting both local spatial development plans and studies of the conditions and directions of spatial development is assured in three fundamental areas:

– filing motions related to the draft spatial planning documents at the preliminary stage,
– participation in public debate when the draft document is made available to the general public for consultations,
– submitting comments to the draft after it is no longer made publicly available.

The provisions of the relevant law, on the one hand, assure to members of the general public the minimum participation standards, which arise from the above elements of the planning procedure being obligatory, yet on the other hand, are seriously flawed. First of all, the instrument through which members of the general public can practically influence the content of the planning document, i.e. submitting comments to the draft, appears relatively late in the procedure, after the issuance of the necessary opinions and consents by external institutions. Furthermore, the introduction of the amendments postulated in the comments—in the case of the draft local development plan—requires the resumption of the formal components of the procedure. Due to the deficiencies of the statutory forms of social participation in the planning process, some Polish cities and municipalities have in the past few years introduced additional, optional methods of extending social participation in the drafting of spatial planning documents. This is based on social consultations with the residents still before the draft plan is made available for the public. This offers an opportunity to exchange views with designers of the plan and often helps eliminate or limit social conflict related to changes in spatial development.

13.3.2 Geo-questionnaire Applications

There were five applications of geo-questionnaire during 2015–2016, of which three P1–P3 took place in Poznań agglomeration and two L1–L2 in Łódź (Table 13.1).

Table 13.1 Specification of geo-questionnaires implemented in Poznań and Łódź agglomerations in 2015–2016 (according to Bąkowska et al. 2016)

Case	Poznań agglomeration			Łódź agglomeration	
	P1: Rynek Łazarski	P2: Map of Local Needs	P3: New Centre of Rokietnica	L1: Regulating advertisement placement	L2: Public transportation plan
Spatial range	Rynek Łazarski in Poznań	Poznań Inner City	Rokietnica Centre	Łódź City	
Study area	0.58 ha	1680 ha	16 ha	29,325 ha	
Purpose of public participation	Design of Rynek Łazarski public space	Preparation of a Map of Local Needs	Plan of local urban development	Preparation of Legal Act on Landscape Protection	Development of a Model of Sustainable Public Transportation
Number of inhabitants	Św. Łazarz District: 32,000 Poznań: 542,500	Poznań Centre: 122,500 Poznań: 542,500	Rokietnica: 5500 Rokietnica Commune: 15,500	Łódź: 701,000	
Recipient of geo-questionnaire results	Municipal Authorities of Poznań, Łazarz Neighbourhood Council	Municipal Authorities of Poznań Centre, Neighbourhood Councils	Rokietnica Commune Authorities, local urban planning unit	Municipal Authorities of Łódź	

In all cases, the geo-questionnaire content was developed by the authors in close cooperation with local planning authorities interested in the implementation of public participation in spatial planning.

The cases presented in Table 13.1 differ from each other in terms of location, type of spatial planning project, purpose of public consultations and spatial scale. With the exception of Rokietnica case (P3), all other applications were related to urban areas. Only in one case study (P3), the purpose of geo-questionnaire application was to solicit public input for the local spatial development plan. The motivation for seeking public input was the Act on Spatial Planning and Management of 2003 requiring public participation in local planning. Other cases in Table 13.1 are related to urban design for an open-air marketplace (P1), neighbourhood-scale infrastructure improvements (P2), development of rules for the use of public spaces (city-owned land) for placing billboard advertisements (L1) and city transportation plan (L2). The Poznań agglomeration cases dealt with localized areas—market square (P1), inner city (P2) and suburb/village centre (P3), while those in Łódź covered the entire city (L1, L2).

In total, there were 4054 respondents who participated in 5 geo-questionnaire applications (Table 13.2). The number of respondents was the highest in case P3, where public consultation process was the longest and where postal invitations to participate were delivered to all households in the village, in addition to other recruitment methods including social media and public spaces (library, school, gym, etc.) advertisements. The high number of Rokietnica village residents who responded to the geo-questionnaire was also the result of the already established practice of public consultations in locally important issues.

The duration of geo-questionnaire consultations varied in all cases from 2 to 4 weeks. The respondents were recruited using social media (the highest effectiveness), Internet information portals, city hall/commune websites, postal invitations (only in P3) and traditional media (posters, radio and local TV ads). The geo-questionnaires ranged in length from five to seven pages where each page contained between two and four questions. Some questions pertaining to personal data and questionnaire evaluation were exclusively text-based while the other questions leveraged text with a map by focusing on evaluative and perceptual aspects of proposed land use and infrastructure changes.

The age structure of geo-questionnaire respondents (Figs. 13.3 and 13.4) shows the over-representation of people in the age cohorts 20–39 in Poznań and 15–39 in Łódź, respectively, which is the reverse to the age structure of respondents who participated in public consultations performed by traditional methods, i.e. face-to-face meetings (Kaczmarek and Wójcicki 2015). This result suggests that the geo-questionnaire method cannot fully replace the traditional consultation methods and should be complementary to public meetings, which are still favoured by older population groups. The Geoweb consultation methods such as geo-questionnaire have shown a demographic bias in that the participants tend to be younger and technologically savvier than those who attend public meetings.

The analysis of respondents' educational attainment level reveals that by far, the most numerous group (59.9% of all respondents) was comprised of people with a college level education, followed by those with a high school education (32.0% of all respondents), a vocational education (3.3% of all respondents) and a primary education (4.8% of all respondents). The educational structure of the geo-questionnaire respondents represents a significant over-representation of people with higher education (22.3% of Polish society) in comparison to those with lower education levels including secondary (33.4% of Polish society), vocational (24.4%) and primary (19.9%). Given that a similar educational structure can be observed in traditional methods, geo-questionnaire does not bridge the educational gap observed in public meetings; in both methods, the percentage of participants with higher education was much higher than in the general population.

The experience with the use of geo-questionnaire in collecting public preferences relevant to land use and transportation planning underscores the versatility of the method and reveals socio-demographic characteristic of its users. Moreover, it indicates that further development of this application should concentrate on extending its availability to persons of different age and educational backgrounds. Geo-questionnaire as a method of public consultations has been well received by both the

Table 13.2 Specification of geo-questionnaires implemented in the Poznań and Łódź agglomerations in 2015–2016 (according Bąkowska et al. 2016)

Case	Poznań agglomeration			Łódź agglomeration	
	P1: Rynek Łazarski	P2: Map of Local Needs	P3: New Centre of Rokietnica	L1: Regulating advertisement placement	L2: Public transportation plan
Access time	3–16.12.2015	14–31.03.2016	14.12.2015–17.01.2016	27.11–7.12.2015	28.02–14.03.2016
Number of respondents	386	709	435	137	2387
Percentage of inhabitants (%)	0.9	0.58	7.91	0.02	0.34
Recruitment methods and their effectiveness in terms of percentage of respondents recruited with a given method	Social media (51.6%) Internet portals (18.2%) City Hall website (5.4%)	Social media (58.7%) Internet portals (9.7%) City Hall website (4.2%)	Social media (31.9%) Commune website (19.2%) Postal invitations (8.7%) Internet portal (7.5%) Traditional media (6.3%)	No data	
Geo-questionnaire content	(1) personal data (2) hitherto forms of the space use (3) directions of modernisation of Rynek Łazarski (4) expected urban development in Rynek Łazarski (5) questionnaire evaluation	(1) personal data (2) sites visited in Poznań city centre (3) mobility (4) evaluation of dwelling conditions (5) evaluation of the quality of space (6) questionnaire evaluation	(1) personal data (2) sites visited and perception of space (3) directions of urban development (4) public transportation system (5) service infrastructure (6) area development potential (7) questionnaire evaluation	(1) personal data (2) preferred forms of advertisements (3) landscape protection zones (4) evaluation of space in the context of advertisements placement (5) questionnaire evaluation	(1) personal data (2) use of public transportation (3) evaluation of public transportation effectiveness (4) expected improvements in public transportation (5) questionnaire evaluation

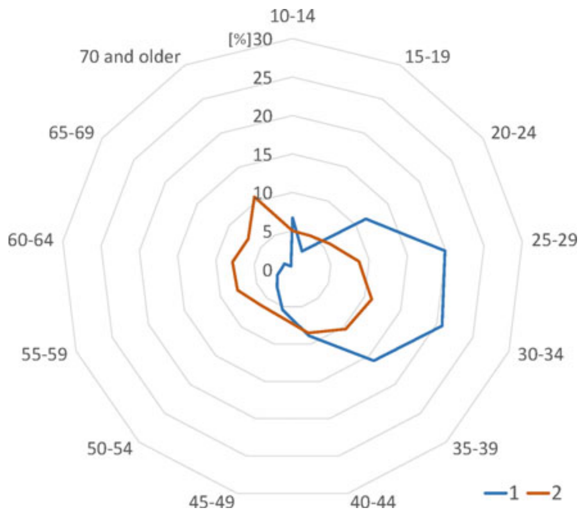

Fig. 13.3 Age structure of geo-questionnaire respondents in Poznań Agglomeration in comparison to the city age structure: 1—respondents, 2—Poznań residents (data source for Poznań residents: Central Statistical Office)

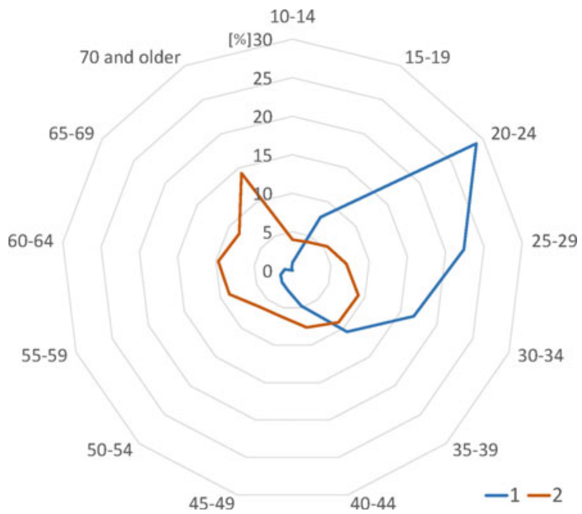

Fig. 13.4 Age structure of geo-questionnaires respondents in Łódź in comparison to the city age structure: 1—respondents, 2—Łódź residents data source for Łódź residents: Central Statistical Office)

respondents and recipients (planners and local decision makers) of collected data, who had a direct input into the geo-questionnaire content. This underscores the need for involving data recipients in the design of geo-questionnaires.

13.3.3 Geo-discussion Applications

The geo-discussion method and tool were used in 2017 in Poznań and Łódź agglomerations, and in two cases, D1 and D2 (Table 13.3) were applied as a second step of

Table 13.3 Overview of the geo-discussion implementations in Poznań and Łódź agglomerations in 2017

Case	D1: Rokietnica	D2: Łódź	D3: Jeżyce
Spatial extent	Poznań Agglomeration	City of Łódź	District in Poznań
Area concerned	16 ha	29,325 ha	198 ha
Topic of the consultation	Developing a land use plan for the future village centre	Performance of public transportation system	Introduction of district-wide traffic calming plan
Aim of the consultation	Present and consult draft land use plan for the considered area	Collect feedback on the performance of the new model of public transportation	Present and consult the draft concept of traffic calming on network level
Number of inhabitants	Rokietnica village: 5,500 Rokietnica Commune: 15,500	City of Łódź: 701,000	Jeżyce district: 24,000 City of Poznań: 542,500
Recipient of results	Communal Authority of Rokietnica Local urban planning unit	Municipal Authority of Łódź	Municipal Road Administration, designer of the traffic calming plan, Jeżyce council

the participatory process, in which a draft plan developed with public input collected via a geo-questionnaire was discussed and commented on using geo-discussion.

The first implementation (D1) was carried out in Rokietnica (Poznań agglomeration) as the second step of land use planning process involving the future centre of growing suburban village. The aim of geo-discussion was to consult with the Rokietnica residents a draft plan for the new village centre. The plan was prepared by a private firm contracted by the village administration and was intended to present a design transforming an undeveloped plot of land, located near the geographical centre of the village, into an urban and densely built-up public space. The geo-discussion forum was open for 4 weeks between 15th of May and 11th of June 2017.

The second implementation (D2), carried out in Łódź—Poland's third most populous city, aimed at collecting feedback on the performance of public transportation system, following its significant alteration 6 months earlier, when the Model of Sustainable Public Transportation for Łódź was introduced. Unlike the other two cases (D1 and D3), where the geo-discussion was used to consult a draft plan, the geo-discussion in Łódź was carried out after the implementation of a plan and was used as a tool for collecting public feedback on the implementation results. The discussion was open during a 12-day period between 9th and 20th of October 2017.

The third implementation (D3) was carried out in Jeżyce, one of Poznań's 42 neighbourhoods (self-governing city districts). The geo-discussion was implemented during the second phase of consultations concerning the neighbourhood-wide plan of traffic calming, commissioned by the neighbourhood council and the Municipal Road

Administration, and carried out by a private company. The aim of geo-discussion was to collect opinions and suggestions of residents for preliminary traffic calming variants, and subsequently, pass them on to traffic planners for a consideration during the next phase of plan development. The draft plan in two variants, as well as supporting materials, were made available for the geo-discussion during a 2-week period from October 13 through 27, 2017.

The described geo-discussion implementations differed not only in application domain (land use planning, public transportation planning, traffic calming), but also in spatial extent (from city-wide to city district), and step in the planning procedure (consultation of a draft concept, consultation of a fully developed plan, collecting feedback during implementation phase). The overview of described geo-discussion implementations is presented in Table 13.3.

In addition to the already mentioned differences, the cases also differed in the configuration of the geo-discussion tool. In the Rokietnica land use planning case (D1), the participants were presented with an interactive visualization of the proposed land use plan, and were only allowed to attach their comments to geographical objects selected from a predefined set of land parcels comprising the plan area (Fig. 13.5). This restriction in selecting the geographical location corresponding to the object of discussion stood in contrast with the other two cases (D2 and D3) and was introduced by the application designers to satisfy the information needs of geo-discussion recipient (Rokietnica Village Authority). It is worth noting here that the presented case is representative of the top-down deployment of Geoweb tools for public participation, in which the application design follows a specification of the information recipient, i.e. a local or regional governmental authority responsible for a plan under consideration.

In the Łódź public transportation case (D2), the users were presented only with a base map of the area in question and the possibility to express their opinion by sketching a point, a line or a polygon on the map and describing the sketched features using open-ended questions, selecting from eight thematic categories related to public transit (e.g. meeting the posted departure and arrival times, frequency of service and the adequacy of transit routes in terms of meeting the demand), and assigning the number of public transit lines relevant to a sketched feature. An exemplary screen copy of the application is presented in Fig. 13.6.

In the Jeżyce traffic calming case (D3), the participants were able to freely choose the geographic location corresponding to the expressed opinion. In addition, they were also presented with two different variants of the traffic calming plan, morning and afternoon traffic conditions on the street network, and computer simulations of traffic volume (Fig. 13.7). Moreover, during the whole period of discussion, the representatives of local council, the project responsible planner and road authority representatives had access to special moderator accounts to facilitate the discussion. The role of moderator in this and in other cases was to answer questions from participants related to geo-discussion content and in isolated cases (e.g. inappropriate language) to remove discussion posts. The role of moderator was filled by geo-discussion conveners (i.e. researchers and local planers).

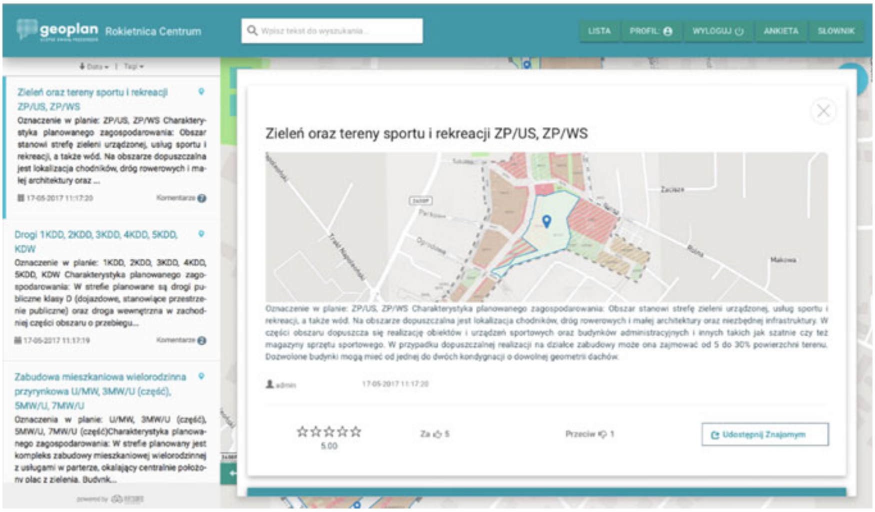

Fig. 13.5 A screen copy of the geo-discussion application used in Rokietnica land use plan case (D1). The left discussion panel contains the descriptions of land zoning codes pertinent to the plan area. The right panel shows the map of study area with a user-selected parcel and its description

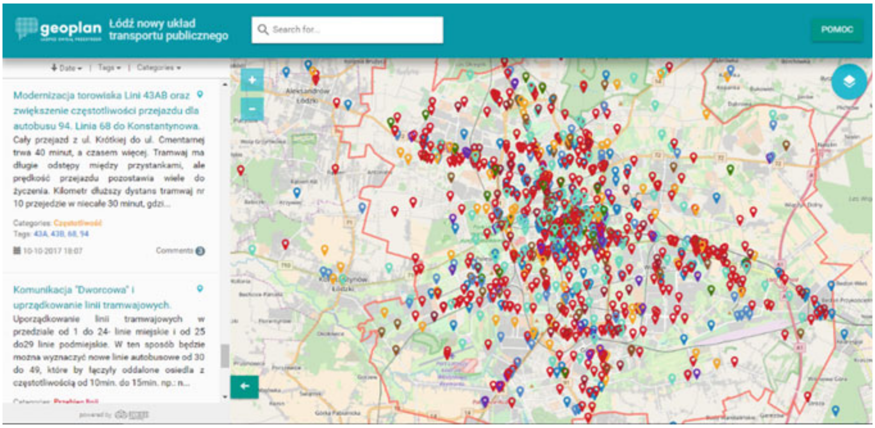

Fig. 13.6 A screen copy of the application used in the Łódź public transportation case (D2) showing point locations marked on the base map corresponding to discussion contributions. The point markers are colour coded in reference to thematic classification categories. For example, red markers denote streetcar lines, blue refer to schedule, cyan to traffic organization

Depending on the size of the case area and the public resonance of the case, the pilot implementations resulted in varying levels of usage (Table 13.4).

The most highly subscribed geo-discussion took place in Łódź (D2). This was likely due to the scale of the case (city-wide) and its resonance among the public (city public transportation system). Less popular were the geo-discussions held in

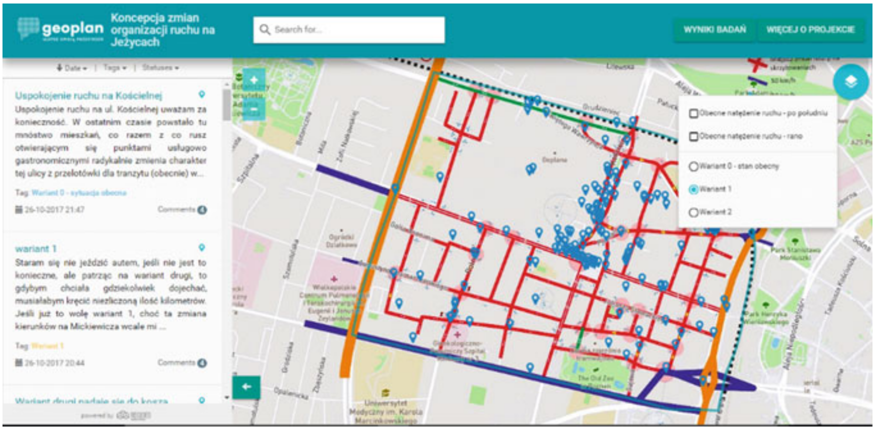

Fig. 13.7 A screen copy of the geo-discussion application used for traffic calming case (D3) in Jeżyce (Poznań). In the right top corner, there are radio buttons for switching between the maps layers representing traffic calming variants

Table 13.4 Summary of geo-discussion outcomes in Poznań and Łódź agglomerations in 2017

Case	D1: Rokietnica	D2: Łódź	D3: Jeżyce
Access time	15.05–11.06.2017	09–20.10.2017	13–27.10.2017
Number of participants	66	1390	234
Percentage of inhabitants (%)	1.2	0.2	1.0
Number of discussion threads	48	1222	160
Number of comments	131	1696	308
Percentage of threads containing a comment (%)	48.0	50.0	62.5
Percentage of returning users* (%)	52.0	56.0	39.6
Methods of recruitment	1. Link published in posters and flyers 2. Link published in social media 3. Press release	1. Link published in social media 2. Link published on websites 3. Local media	1. Link published in social media 2. Link published on websites 3. Local media

*If someone visited geo-discussion from the same device more than one time, they were marked as a Returning Visitor

Rokietnica (D1) and Jeżyce (D3). The difference in participant activity levels is most likely the result of varying target populations (from 5500 to 701,000) and, to lesser degree, areas concerned (from 16 to 29,325 ha).

The number of registered users, which varied from 66 in Rokietnica (D1), through 234 in Jeżyce (D3) to 1390 in Łódź (D2), constituted respectively 1.2, 1.0 and 0.2% of the target populations. Approximately, the half of discussion thread contained at least one comment. The percentage of such threads varied from 48% in Rokietnica (D1) through 50% in Łódź (D2) to 62.5% in Jeżyce (D3). Additionally, the percentage of returning users varied from 39.6% in Jeżyce to 56% in Łódź, which means that approximately, half of users logged into the discussion more than once.

Although the available data does not allow to draw any generalizable conclusions, there are three possible explanations for the levels of participant activity:

- the absolute values of indicators measuring participation in geo-discussion (i.e. the number of users, threads and comments) may be positively correlated with the size of target population and/or the size of area concerned,
- the relative number of participants can be inversely correlated with the size of the target population (the smaller the target population, the higher the percentage of the population taking part in the discussion),
- the percentage of returning users and the percentage of threads containing at least one comment do not bear a relationship with the size of target population or the area concerned.

13.4 Discussion

The applications of two Geoweb methods: geo-questionnaire and geo-discussion, presented in the chapter, covered various topics and geographical scales, and were set in distinct phases of decision-making processes. A wider adoption of the methods and their usefulness for the planning practice depends on the quality of their outcomes and their value for planners, decision makers and the public. The chapter presents one aspect on such quality evaluation, related to the representativeness of participants and the level of their involvement.

The analysed case studies were biased towards the over-representation of young and technologically savvy segments of the population. This stresses the need for complementing Public Participation Geographical Information Systems (PPGIS) with more traditional participatory methods such as public meetings or workshops. Furthermore, the samples over-represent people with higher education, similarly to other methods of public participation (e.g. Jankowski et al. 2017). This, in turn, points out to the need for further development of participatory methods and its context-sensitive application, particularly to facilitate the participation of those with less education or otherwise marginalized, even excluded.

The case studies attracted a relatively high number of participants, from 66 in the Rokietnica geo-discussion to 2387 in the geo-questionnaire on public transportation plan for Łódź. Both methods provided rich data sets with potentially high usability for planning practice. A simple measure of the number of returning visitors ranging from 40 to 56% points out to a relatively high engagement level. On the other hand, the percentage of threads containing at least one comment (from 48 to 62%) suggests that to a large extent the geo-discussion was used to express individual points of view, rather than to get involved in debates with other participants. It may not be possible to draw any generalizable conclusions based on the observations gathered from the cases discussed here, but they open up several avenues for future studies. For instance, future studies could look at relationships between tool design, problem domain or characteristics of target population and study area (e.g. size, socio-demographic structure) and measures of participant activity (e.g. number of users, threads or comments and response rate) or participant interaction (e.g. comment-to-thread ratio).

Further challenges related to Geoweb methods and PPGIS applications in planning refer to the influence of the methods on the quality of public debate regarding urban planning. One positive aspect that is already evident from the data is the sheer number of geo-questionnaire respondents and geo-discussion participants. The numbers are unprecedented in Polish planning practice where public participation has been so far largely limited to sparsely attended public meetings. The Geoweb methods have thus likely enticed and enabled many previously uninvolved individuals. Further assessment of Geoweb and PPGIS influence on the quality of planning debates would require a deeper analysis of both the content contributed by participants and broader discourse surrounding the planning topics at hand. Another challenge refers to how the Geoweb methods improve and expand the body of knowledge available to planners by introducing public input, and whether such new knowledge is valued by practitioners. These questions would need to be addressed by future assessments of public-volunteered data conducted from planners' perspective.

Finally, it is worthwhile to reflect on how the methods discussed in the chapter fit into the fabric of smart cities. Geo-questionnaire and geo-discussion—just like virtually all Geoweb methods, both generate and consume geospatial data. In that sense, they contribute to the already large volume of data generated by various sensors and other systematic data collection activities undertaken passively or actively in a smart city. At the same time, they also rely on authoritative geospatial data to collect public input in the form of volunteered data. Such data can in turn be used to enrich the authoritative data and become the bases for decision-making in planning providing the quality of volunteered data meets the needs of intended users. One can argue that high-quality volunteered geospatial data contributes to a smart city by making its functioning more sustainable through, for example, more sustainable planning decisions. Still, the challenge lies in establishing what constitutes *high-quality* volunteered geospatial data as this qualification clearly goes beyond simple positional and attribute data accuracy.

13.5 Conclusion

Participatory methods of public involvement in urban planning, advocated for by proponents of communicative turn in planning (Horelli 2002; Innes and Booher 2005), have been developing in step with information and communication technologies

(Sieber et al. 2016). A rational for these methods, primarily enabling virtual (online) forms of participation, derives from scaling public participation to include larger, demographically more diverse and geographically wider groups of urban residents than what has been afforded by the traditional form of public participation in urban planning—town hall meeting (Jankowski et al. 2017). Moreover, a rational has been the need to address the limitations of town hall meetings including the requirement of physical presence, favouring experienced and highly motivated individuals over the inexperienced ones and creating an intimidating environment for those who are uncomfortable with public speaking. Methods of participation in urban planning such as online participatory mapping have been offered to circumvent some of these limitations, based on the assumption that the asynchronous and distributed character of online participatory processes may offer a path to public engagement to those who typically do not participate (Nyerges and Aguirre 2011). Another argument in favour of using Geoweb methods includes the recognition that different members of the public are willing to participate at different levels of mental and time effort required to engage in public participation. Following this argument, one would expect that improving the convenience and comfort of participation will promote the inclusion of those who are willing to participate, but only from the comfort of their homes and at the time of their choosing (Halvorsen 2001). Still another argument has been that online participation employing interactive and visual forms of communicating information may be more effective than the forms of conveying information used in town hall meetings.

Yet, despite numerous potential benefits, Geoweb methods still raise some questions concerning their viability and usefulness for aiding participatory democracy and decision-making processes at a local level—common to application domains discussed in this chapter. One concern has been the digital divide, which limits access to online participation to those who are not connected to or simply lack skills for using Internet tools. Using Geoweb methods such as participatory mapping also requires basic map literacy skills, which may further limit the pool of potential participants. Another concern has been the lack of trust among planners and decision makers in data quality generated by public participation (Brown 2015). Still, other concerns include the lack of evidence on whether or not Geoweb methods supporting participatory processes contribute to sustainable planning decisions, and whether such methods are capable of facilitating a two-way communication between urban planners and the participating public. These concerns pose valid questions that must be answered if Geoweb methods are to be trusted as a mainstream approach to supporting public participation in local decision-making processes.

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Chapter 14
Quest to Define the Knowledge and Skills Needed by Geospatial Professionals

Ann Johnson

Abstract In 1988–89, the National Center for Geographic Information and Analysis (NCGIA) made the first attempt to develop a Core Curriculum for programs focused on preparing professionals engaged in Geographic Information Science and Related Technology (GIS&T) including geographic information science (GIS). By 1995, NCGIA had distributed copies of its Core Curriculum to 70 countries. This quest continues with efforts by organizations in academia, industry, and government to identify the GIS&T knowledge and skills needed by the workforce. The expanded use of GIS&T across almost all workforce domains, new technologies and analysis techniques, and the ability to access big data in real time have made this quest even more complex and important. Early efforts also included work to support recognition of GIS&T as a distinct profession and not just as a tool used by professionals. This effort has been generally successful as evidenced by multiple opportunities for individuals to become certified as GIS&T professionals, but the expanded use and simplification of GIS&T applications has again questioned who should be considered a GIS&T professional and what skill sets should be included. Should knowledge and skills in computer science (programming) and remote sensing be integral to a GIS&T professional, or are they part of other professional qualifications? This chapter will follow the history of efforts to codify the knowledge and skills needed by professionals and develop a comprehensive competency model. It will also include how these resources are being used by educators to develop curriculum, organizations to develop certification processes and by industry and government to identify individuals qualified to be hired as GIS&T professionals.

Keywords Geospatial technologies · Professional skills · Curriculum · GIS

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14.1 Defining the Quest

A quest according to the online Cambridge Dictionary is: "a long search for something that is difficult to find." The *Quest to Define the Knowledge and Skills Needed by Geospatial Professionals* is one that has proven difficult. This quest began more than 50 years ago, first with the need to recognize geospatial technology as an industry made up of geospatial professionals, and second to define the specific knowledge and skills needed by those professionals. This quest continues today by individuals and multinational collaborations interested in the expanding use of computerized mapping, analysis, and visualization.

There was no consensus on either its status as a profession or what terms should be used for the profession. Many people felt the technology was "just a tool" needed by other professions or that it was a subset of skills in computer science or surveying rather than a distinct, separate profession. Resolving the status as a profession with a recognized name became more pressing as government and industry adopted the technology and needed a way to evaluate and hire competent individuals. Educators and academic institutions wishing to create programs to educate geospatial professionals had few guidelines or resources to determine what to call their program, what the curriculum should include or assess if their program matched workforce needs. Government and industry had few guidelines in assessing the knowledge, skills, or competencies, and it needed for a geospatial project or assessing if individuals they hired had the requisite skills. The quest continues to see if it is possible to determine those knowledge, skills, and competencies that geospatial professionals must possess to compete in such a diverse, international geospatial workplace. If it is not possible, is it possible to at least identify the core knowledge, skills, and competencies needed by most geospatial professionals?

This chapter will present a brief overview of these efforts both to recognize it as a profession and to define the knowledge and skills needed by an expanding professional workforce. It will also investigate if it would be valuable to identify those core knowledge, skills, and competencies as an aid for geospatial professionals, the industry, and academic institutions focused on the use of geospatial technology.

14.2 Historical Perspective

In the early 1960s, Roger Tomlinson, while leading the Canadian Land Inventory program that developed the first computerized GIS, is credited with coining the term Geographic Information System (GIS) (URISA 2004). Tomlinson, in his introduction to the use of electronic computerized GIS, provided evidence of the value of using layers of digital data in a system for analytical purposes and outlined many of the techniques that are still important skills for GIS users today (Tomlinson 1962). Not long after the start of using the acronym of GIS, questions were raised as to the meaning of the "S" in GIS. Should it be system, systems or should it be broader than just technology and be Science? Should GIS be narrowly defined as digital mapping or did it include related topics such as remote sensing, programming, or surveying? Goodchild, in his Forward to *Teaching Geographic Information Science and Technology* uses the terms GIScience and refers to the terms GIScience and Technology (GIS&T) (Goodchild 2012). He also questions who the audience is for GIS&T education—is it the future GIS&T scientists, professionals in applications using GIS&T or well-educated citizens? More terms have come into common use such as geomatics, geoinfomatics and geospatial, and simply geospatial. By 2003, the USA Department of Labor Education and Training Agency (DoLETA) began funding organizations to help create a definition for the geospatial industry leading to a Geospatial Technology Competency Model (GTCM). In 2009, it established six new occupation titles for the profession (DiBiase et al. 2010). While there continues to be a debate as to what to call the profession, used here, the term geospatial shall include all aspects of GIS, remote sensing, and imagery, Global Navigation Satellite Systems (GNSS), and other related software, hardware, and web-based technologies.

14.2.1 Defining the Knowledge, Skills, and Competencies Needed by Geospatial Professionals

Why has this quest been so difficult? There are many factors, but some are related to Goodchild's comment about defining the audience for geospatial education. With expansion of the technology into so many fields and disciplines and the levels of complexity for different types of geospatial applications, it is important to understand what skills and competencies the different audiences might need. Can a common set of skills and competencies or core be defined that, as a minimum, should be known to all geospatial professionals? Figure 14.1 compares different levels of Geospatial Users and the depth of their geospatial and non-geospatial knowledge. The Depth of Knowledge scale on the left and the Geospatial Users listed in the center pyramid illustrate the relationship between different skill levels and types of users progressing from those of Virtual Consumers having little geospatial knowledge to GIScientist having the most in-depth geospatial knowledge. Few geospatial professionals restrict their knowledge to purely geospatial technology. Most practitioners also have a discipline or occupation where they apply their geospatial knowledge. The triangle on the right suggests that their knowledge levels increase and include Geospatial Skills and Competencies, Core geospatial skills and domain knowledge in an occupation (NonSpatial Knowledge). The Core region on the pyramid on the right suggests that all users share a **core set of geospatial knowledge** common to all professional users and even to some of the ancillary users such as those who collect data about a topic and visualize their data using a browser-based application like Google Earth.

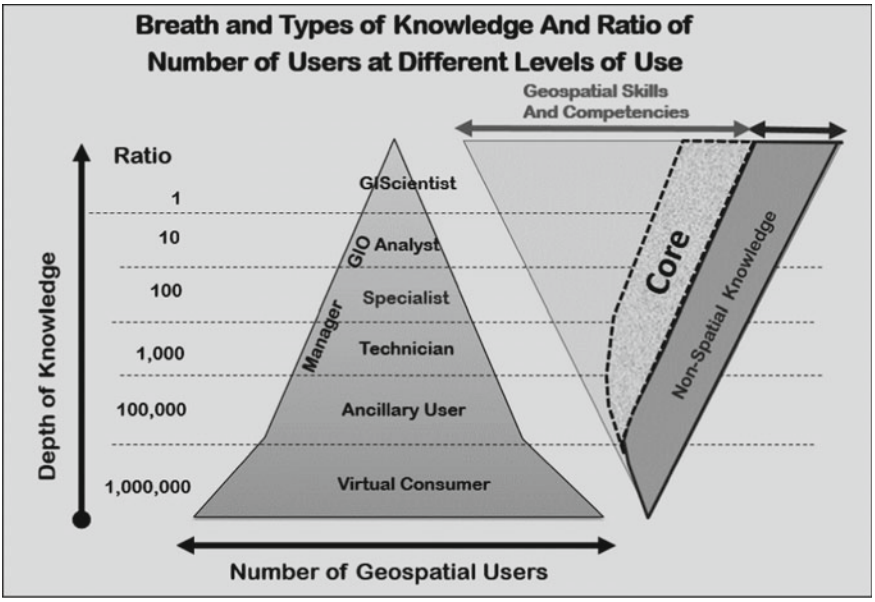

Fig. 14.1 Geospatial users and their knowledge levels

14.3 Factors Affecting GIS Education and the Growth of a GIS Profession

What factors, perspectives, and methods have been used to try and define what knowledge, skills, and competencies are needed by geospatial professionals? Ken Foote provided an overview of the challenges and opportunities in GIS&T education up to 2012 (Foote et al. 2012). These challenges and opportunities continue even with advances in technology, data access, and the abundance of teaching resources. Programs that is used to be restricted to graduate-level courses at major research universities due to the need for complex, command-driven software, and costly hardware can now be offered to students in K-12 using little more than browser-based applications and Internet access.

As a member of the Esri Education Team from 1997 and continuing for 13 years, my focus was on supporting GIS education and the use of Esri's software in the USA and internationally. The most common question I heard from faculty wanting to start a GIS program was: "What should I teach?" While many factors came together to help spread the use of geospatial technology, it is also important to understand how this evolution of the technology has affected the answer to the question of "What should I teach?" A summary of those factors includes:

14.3.1 Lower Cost, More Robust, and Easier to Use Hardware and Software

Progress from having to use mainframe computers and command-line software to the ability to use a browser-based web application on a tablet or smartphone has changed who can use geospatial technology and who might be considered as a geospatial professional.

14.3.2 Data—Access and Sharing

Initially, data creation accounted for 80% of the cost of a GIS project and many agencies, industries, and countries restricted or denied access to their data. Remote sensing imagery was out of the reach to all but a few specialized university programs due to the difficulty of accessing and analyzing the large amounts of data as well as the cost to acquire imagery. Today, data are readily available as many entities share their data via the internet in formats that can be incorporated in different geospatial applications. The cost of imagery has come down and includes free access to moderate resolution imagery while hardware and software able to access and analyze data is also less complex and costly. Large data sets, *Big Data* feeds, and data sharing have created new problems for programs with the need for methods (Spatial Data Infrastructure) and costly hardware to effectively use and share data.

14.3.3 Resources for Teaching GIS&T

Initially, there were few resources to aid teaching GIS except a few user guides for early software. Karen Kemp states that the first textbook was published in 1986… (Kemp 2012a). From this meager start, the next two decades experienced an expansion of resources for teaching GIS&T and use of the technology. By 1996, more resources (hardware, software, and teaching resources) existed for upper division and graduate-level education, but few resources were available to lower division programs where cost of hardware, software, and faculty expertise impeded the development of courses. The lack of lower division programs was reflected in the finding that only eight community college level GIS programs were identified by Morgan's survey of GIS courses and programs in the *1996 Directory of Academic GIS Education* (Morgan et al. 1996).

14.3.4 Internet and Web Applications

Advances in Internet and web technology in tandem with the advances in GIS&T have allowed faculty and students to access, store, and share projects more easily. Geospatial Web applications such as Google Earth and ArcGIS Online have spread the use of GIS&T to individuals who need little to no formal education to use basic GIS&T data and visualization. Location awareness has increased too via the common use of in-car navigational systems using Global Navigation Satellite Systems (GNSS), with detailed maps and routing that include information about services based on a user's current location with the push of a few buttons.

14.3.5 Innovations in Teaching

Initially, students were told where the software user guides were located and to learn on their own. Often, faculty had little formal training and relied on students to learn how to use the programs and help them carry out research. GIS went from a few programs in the early 1990s to 1000s of programs globally by 2000 (Phoenix 2012). Along with the increasing number of programs, better methods (pedagogy) to effective educate students were being investigated. GIS&T was well suited to innovations such as Active Learning pedagogy that enabled students at any level of education use real-world data to investigate problems spatially with GIS technology. Curriculum advanced to a combination of formats including self-education, face to face, online, and hybrid programs.

14.3.6 Spread of Use Across Fields and Disciplines and Globally

Initially, programs were mainly housed in geography and land use planning departments in the USA, EU, and Australia. As more disciplines and fields became aware of the importance of location and spatial analysis and software and hardware decreased in cost, and became easier in varying levels of expertise and needs incorporating desktop, server, and browser-based applications. The issues that continue for academic and industry users include the cost of keeping the hardware, software, and level of user's expertise up to date.

14.3.7 Certification

Until the last couple of decades, certification was not popular to use, GIS&T spread to many other disciplines. In industry, GIS was initially carried out by a few designated individuals who had access to hardware, software, and expertise. More often today, GIS is no longer isolated in a single entity, but has spread across many departments with users has with many in the GIS workforce or academic programs. As more industries adopted the use of the technology, more calls for ways to judge the expertise of individuals were heard. Several geospatially related organizations began investigating certification options. Currently, several organizations provide certification of individuals through portfolios and exams. This includes the American Society for Photogrammetry and Remote Sensing (ASPRS), the GIS Certification Institute (GISCI), and the United States Geospatial Intelligence Foundation (USGIF) GEOINT Certification Program (Kemp 2016). Some USA federal government-related agencies are now requiring employees or consultants to be certified.

14.4 Overview of Efforts to Define Geospatial Knowledge, Skills, and Competencies

The quest to clearly define the needed GIS&T knowledge, skills, and competencies for professionals has been a global quest with simultaneous initiatives taking place as collaborations between educators from multiple countries or as efforts supported by governments and industry focused on the specific needs of its geospatial workforce. This quest has taken on importance as certification programs have become more common and require individuals to pass an examination testing their knowledge of concepts as part of the path to certification. A summary of some of these efforts will be presented below, including efforts carried out in the USA, Australia, Europe, and Japan. My apologies to the many important efforts that is not included in this summary. Each has moved the process forward and should be recognized, but including all of them, unfortunately, is beyond the scope of this chapter.

14.4.1 Different Perspectives, Methodologies, and Outcomes

At least, three different perspectives were employed to tackle this quest. Perspective of the primary developing entity along with the needs of its primary audience dictated the content and format of its outcomes. The efforts have been separated into three different methodologies to:

a. Define the specific skills and competencies that should be in an academic program based on the needs of the workforce (currently or the near term);
b. Define the roles, tasks, and outputs or competencies for a specific occupation; or
c. Define the complete domain knowledge of GIS&T.

While the efforts are separated into three methodologies, most have some overlap or similarities in that they focus on GIS&T. Each has valuable content useful for its primary audience and may be used by different audiences—academia, government or industry. Several of the efforts were started at about the same time in the late 1990s—one by a USA government program through grants from the National Aeronautics and Space Administration (NASA); one by University Consortium for Geographic Information Science (UCGIS); and one in Australia as part of its National Training Authority, the National Spatial Information Services Industry Competency Standards.

14.4.2 Methodology One: Define the Specific Skills and Competencies that Should Be in an Academic Program Based on the Needs of the Workforce (Currently or the Near Term)

14.4.2.1 NCGIA Core Curriculum

While Karen Kemp points out that there were many early efforts to create resources to aid GIS education, the work by the National Center for Geographic Information and Analysis (NCGIA) produced the widely used resource called the *Core Curriculum* in 1990 (Kemp 2012a). NCGIA was funded by the National Science Foundation in 1988 through a grant to the three-university consortium (University of California Santa Barbara, State University of New York at Buffalo and University of Maine) with the specific task to focus on the development and dissemination of a standardized curriculum for teaching the basics of Geographic Information Analysis (GIA) (Kemp 2012b). The *Core Curriculum* began as a collaborative effort by the 3 universities to create 75 lecture topics organized into 3 courses. Faculty at 35 academic intuitions in the USA and internationally were asked to contribute notes for specific topics. The combined notes for topics were edited and formatted into a draft version that was sent out to 100 institutions for review and revision. The edited topics were then finalized into the 1990 version of the *Core Curriculum*. The simple format of grouping the topics into three courses, the input and revisions based on feedback from numerous educators, and the lack of copyright or other restrictions on its use resulted in a resource that helped faculty develop their own courses and also helped them fill in gaps in their personal knowledge of GIS&T. Some negative comments about the *Core Curriculum* were voiced, including the fact that it was not a real curriculum, but just a list of lecture notes, that there were many important topics that were not addressed and there were issues of depth and balance of the 75 topics. Nevertheless, the *Core Curriculum* was distributed to and used by 100s of educators globally and can still be found on the Internet.

14.4.2.2 Australian National Training Authority, the National Spatial Information Services Industry Competency Standards

Australia in the 1990s recognized that multiple provinces were defining competencies for workers and creating a curriculum to meet those needs. To standardize the process based on industry-defined competencies, they set up the Australian National Training Authority (ANTA). ANTA developed a framework to identify the needs of industry with competency standards and assessment for vocational education and training. The process included surveys of industry needs to create a Skills Profile for geospatial technology and a 1996 Training Needs Assessment report (Australian 1996). In 2006, a National Spatial Information Services Industry Competency Standard was published outlining the competencies in a structure that organized competencies in a hierarchal structure with the highest level called a Stream broken down into Units including a definition. Units are broken down to Elements with one or more Performance Criteria. The Australia Government, under its Department of Education and Training has undergone major changes under the Higher Education Standards Framework with a 2015–16 update to Surveys and Spatial Scientists Occupational Summary. Additional revisions and updates are being undertaken with a date for release in mid-to-late 2017.

14.4.2.3 Japan—National Spatial Data Infrastructure Act and Developing GIS Expertise Projects and Agencies Working on Curriculum and Standards

Japan also has had a long-term effort to promote teaching and use of geospatial technology. Morishige Ota stated in a presentation at the European GIS Education Seminar (EUGISES) in 2014 that one factor that influenced the need to promote geospatial technology was the 1995 Great Hanshin Earthquake (Ota 2014). The damage severely impacted the ability to share information and map the area of devastation. The Central Government of Japan held a meeting of ministries to share geospatial data and set up the NSDI Promoting Association. By 1997, the efforts were underway to work with international associations to share data. In 2007, the Basic Act on the Advancement of Utilizing Geospatial Information was set out in the Development of Human Resources (Article 13). Over the next few years, the Ministry of Education, Culture, Sports, Science, and Technology funded work to use the GIS&T Body of Knowledge and set up a Japanese Body of Knowledge and GISc Standard Curricula.

14.4.2.4 Western Balkans Academic Education Evolution and Professional's Sustainable Training for Spatial Data Infrastructure (BESTSDI)

The BESTSDI project was funded by ERASMUS +KA2 Capacity Building in Higher Education for three years starting in 2016. The focus is on increasing knowledge and skills in using Spatial Data Infrastructure (SDI) and E-Government at partner universities serving students in geospatial (geodesy) programs or in ancillary disciplines that should have a firm foundation in SDI. The work stresses that data management and data sharing are important topics and the understanding of SDI and standards is essential for future students and industry. The objectives of the grant are to increase capacity by improving curricula (aligned with workforce needs), create resources for learning and teaching, and working with other disciplines to increase their understanding and use of SDI.

14.4.2.5 Advanced Placement GIS&T Course Development

A recent project has been to create an Advanced Placement GIS&T Course (AP GIST) for students in USA high schools. While not directly related to the needed competencies for working professionals, it is the first step into a career in geospatial technology for students. In 2015, the College Board requested that the Geography Education National Implementation Project (GENIP) propose an AP GIS&T course. Advanced Placement courses in other disciplines have been created that provide methods for high school students to request that postsecondary (college or university) programs accept credit for a course completed successfully in high school. The American Association of Geographers (AAG) was funded by GENIP to create the AP GIS&T course that will introduce high school students to GIS&T if the course is accepted into the AP program. The steps to create an AP course are to document the need for such a course, create the content of such a course, define assessment criteria for the course, and then seek approval to offer the course. Faculty at high schools will also need training and education to successfully offer the course. The AAG has created a recommended list of course topics organized into six knowledge areas that were determined from an analysis of multiple college syllabi and crosswalked using the BoK Knowledge Areas (Alqvist 2016). See a complete summary of the proposal and progress of the work at the AP GIS&T Course proposal website (http://gistcourseproposal.org).

14.4.3 Methodology Two: Define the Roles, Tasks, and Outputs or Competencies for a for Specific Occupation

14.4.3.1 National Workforce Development Education and Training Initiative

Some government agencies in the USA recognized that there needed to be a better understanding of what skills and competencies the workforce really required. One effort begun in 1997 was funded by NASA Stennis, was the National Workforce Development Education and Training Initiative hosted by the University of Southern Mississippi. By 2001, the work continued as part of the Geospatial Workforce Development Center at the university. The initiative took a slightly different approach from earlier work and instead of creating curriculum or listing a set of topics or skills and competencies, it focused on "roles" that included competencies to accomplish a job or function and produce a specified outcome. It also defined 12 distinct roles with details for each role (Gaudet et al. 2003). The initiative also arranged broadly defined skills and competencies into four distinct competency categories: Technical, Business, Analytical, and Interpersonal Competencies. This outcome led to a draft version of the USA Department of Labor Employment and Training Agency (DoLETA) Geospatial Technology Competency Model (GTCM) defining the competencies for the geospatial workforce as a matrix of roles and competencies. A finalized version of the GTCM was approved by the DoLETA in 2009 as an outcome of work funded by the USA National Science Foundation to the National Geospatial Technology Center of Excellence (see Methodology Sect. 14.4.3.2).

14.4.3.2 National Geospatial Technology Center of Excellence (GeoTech Center) MetaDACUM, Program Content Tool, and Finalized GTCM

In 2003, the USA Department of Labor, through its High Growth Initiative highlighted the need for more qualified geospatial workers. At the same time, more lower division (first 2 years of a 4-year degree) programs at community (2-year) colleges began teaching geospatial programs. By 2007, a USA NSF-funded project was undertaken to research the need for an organization to oversee geospatial technology education from a community college perspective (Sullivan et al. 2008). The outcome of this project led to a proposal in 2008 to the NSF Advanced Technology Education (ATE) program for a National Geospatial Center of Excellence (GeoTech Center, geotechcenter.org) to support geospatial education at community colleges. The perspective of this effort was to support community college geospatial programs and its students with a curriculum that would prepare students for entry-level geospatial careers. To accomplish this goal, the GeoTech Center undertook efforts to identify the skills and competencies needed by entry-level geospatial professionals and creates tools and curriculum resources to help create, expand and assess community college programs. The GeoTech Center used the **D**eveloping **a C**urriculu**m** (DACUM) process to identify what entry-level (Technician) geospatial workers needed to know. A DACUM process brings together 8–12 current workers led by a facilitator for two days to identify what they do, how they do it and what they need to know to carry out their duties and tasks for a specific occupation. A DACUM Chart is created that lists those Duties and Tasks as well as listing Knowledge and Abilities for the occupation. Academic disciples and industries use this process, but some negatives of the process are that it is time, place, and occupation specific. The GeoTech Center facilitator, John Johnson, undertook a detailed analysis of multiple DACUM outcomes from different places, times, and occupations relating to geospatial technology to create a very detailed, combined MetaDACUM Chart. The details of the analysis are described more fully by Johnson in an article in a special issue of the URISA journal (Johnson 2010). The content of the MetaDACUM was used to create a Program Content Tool as an Excel Spreadsheet, listing the competencies that should be covered at some depth in an entry-level certificate program. Educators and others interested in geospatial education attended multiple events to determine what courses should be included in a Certificate and suggest the depth of coverage for each competency in the courses. Competencies listed in the Program Content Tool were also crosswalked with competencies in the UCGIS BoK. The Tool was updated in 2014 and additional updates are anticipated in 2018.

In 2009, the GeoTech Center undertook an effort (led by David DiBiase) to finalize the USA Department of Labor Employment and Training Agency (DoLATE) Geospatial Technology Competency Model (GTCM). DiBiase brought together a panel of geospatial professionals to review the draft GTCM and recommend changes to its content. Figure 14.2 is the finalized GTCM pyramid approved by the DoLETA built with multiple Tiers made up of Blocks representing different exemplary skills and competence needs for professionals, terminating in the highest block with the title of the specific geospatial workforce role.

Each Block is linked to more information online. Much of the information for the GTCM is based on the content of the 2006 UCGIS Body of Knowledge. In 2014, the GeoTech Center undertook a review of the GTCM which was approved by the DoLETA and anticipates updating it again in fall 2018. The GTCM can be found online at Competency Model Clearing House on the Career One Stop website with more than 12 other industry Competency Models (see www.careeonestop.org). Additional use of the Center's resources supports individuals preparing to take a certification exam. The Center has a Self-Assessment tool and is working on creating practice exams and other resources for individuals interested in assessing their readiness to enter the field or in becoming certified.

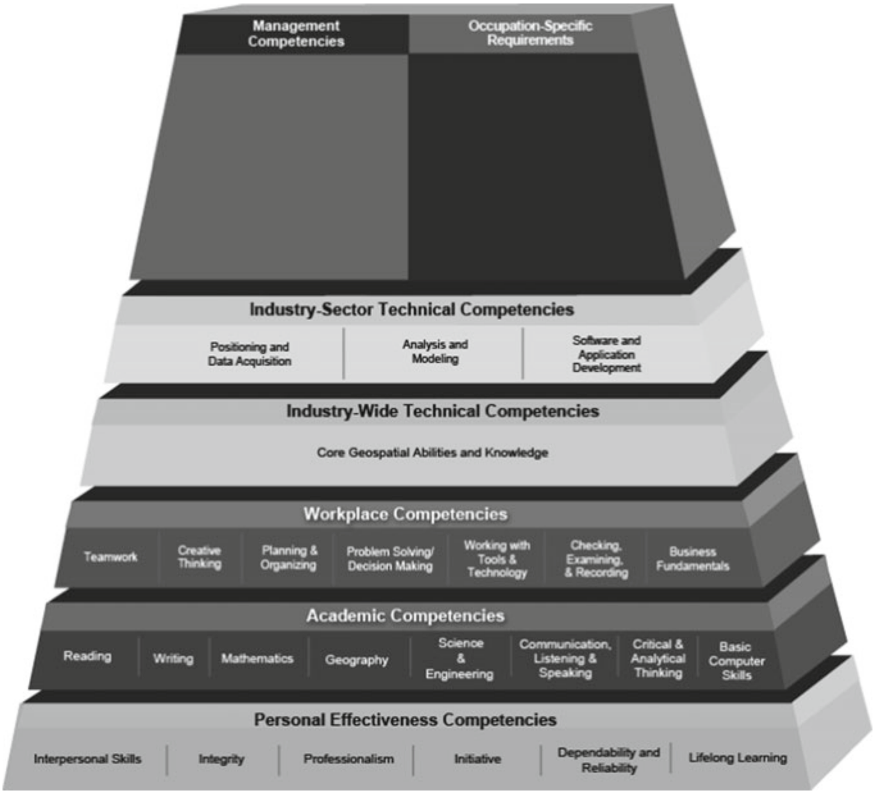

Fig. 14.2 Geospatial technology competency model

14.4.4 Methodology Three: Define the Complete Domain Knowledge Needed for the GIS&T

14.4.4.1 UCGIS Body of Knowledge

David DiBiase in Chapter II of the *Geographic Information Science and Technology Body of Knowledge* highlights the factors that led to the development of the GIS&T Body of Knowledge (BoK) by the University Consortium for GIScience (UCGIS) (DiBiase et al. 2006). One factor was the significant gap between the number of well-qualified students graduating with the needed expertise and the number of workers needed by a rapidly expanding geospatial industry. This gap had occurred despite the huge increase in the number of institutions offering GIS programs (Phoenix 2012). DiBiase suggested that this gap might stem from the fact that there were no regulations or measurements on which to build a program or assess if a program included the curriculum needed to prepare students to enter the workforce. Other concerns expressed by Duane Marble were that programs did not have the rigor needed in GIScience and that students no longer received a This group called on numerous volunteers to help create the content of the first edition of the BoK in 2006. As first proposed, the BoK included 12 Knowledge Areas (KA). The DiBiase effort combined the 12 into background in programming but learned how to use commercial software rather than advance the technology (DiBiase et al. 2006). The initial project undertaken by UCGIS and led by Duane Marble included creating resources that would provide curricula and career pathways for different geospatial disciplines. Due to lack of funding and other factors, the effort was simplified. DiBiase, as Chair of the UCGIS Education Committee, was able to acquire funding to support a working group for a 1-year long initiative focusing on identifying the skills and competencies for the GIS&T domain in a structured format.

10 Knowledge Areas. The 10 KAs were broken down into 73 Units, with 329 Topic and 1660 Learning Objectives, and identified the Core KA Units by color coding them on the cover of the document. The original edition was published as a paperback book by the American Association of Geographers in 2006 and PDF version made available later from the UCGIS. While it was a very valuable resource, it was difficult to search effectively, use to create a subset of competencies or update as the profession and technology evolved. The editors believed that this first edition would soon be revised and updated, but it was almost 10 years later that a new, digital online version of the BoK has been undertaken by the UCGIS.

This new version is an interactive, digital version available from UCGIS (gistbok.ucgis.org) website. The titles for the KAs have been updated or combined and a new template of required content for each topic. One of the objectives for this new format is that it will be easier to revise and update, while archiving previous versions. The community of users is being sought to act as authors to help build and revise the content. This is a work in process that will take some length of time to complete as more authors are sought and submissions go through various states of peer review. It will also not be a static document, but be editable by the community of users through a process of peer review and approval.

14.4.4.2 European Union GI-Need to Know (GI-N2K) Project

European Union GI-Need to Know (GI-N2K) project was funded in 2013 for 3 years by the EU Erasmus Lifelong Learn Program with 31 partners from 25 countries participating in the project. GI-N2 K focused on foundational research to improve the curriculum and access to demand-driven and flexible geospatial education based on the needs of the European geospatial workforce (Salvemini 2016). In 2014, Frans Rip summarized the initial research findings from a survey focused on the Demand for and Supply of Geospatial Education and Training at the European Union GIS Education Seminar (EUGISES). The work surveyed the Demand Side (industry and students) and the Supply Side (GI Teaching) and compared what each side felt were the needed skills and competencies. The work also compared those identified skills and competencies to those in the UCGIS BoK. While the GI-N2K started with the content of the BoK, the project focused on identifying the competencies that were lacking or were needed from a European Perspective. Workshops were held by project partners to help identify topics that were needed as well as develop educational resources to support program development (Vandenbroucke 2016). The GI-N2K project developed an innovative dynamic online platform called the Virtual Laboratory for the Bok (VirLaBok). Figure 14.3 is a grayscale version of the interactive graphic linking color coded Knowledge Areas (KA) with connecting lines indicating relationships between concepts (GI-N2K Newsletter #5, 2016 http://www.gi-n2k.eu/publications/).

While the grant funding ended in 2016 the work continues, and new funding opportunities are anticipated to support the project.

14.4.4.3 GEOINT Essential Body of Knowledge

The United States Geospatial Intelligence Foundation (USGIF) is made up of government, industry, academia, professional organizations and individuals interested in the application of geospatial intelligence (GEOINT) focused on natural security objectives. One of the objectives of the USGIF has been to accredit programs at academic institutions that offer GEOINT-focused programs. Requirements were developed with program content recommendations, but it was felt that a more GEOINT-specific set of knowledge and skills was needed. To accomplish this goal, the USGIF undertook the creation of the GEOINT Essential Body of Knowledge (EBK). The EBK was produced by the USGIF after conducting in-depth reviews with members of the GEOINT workforce. The EBK is made up of four Universal GEOINT Essential Competency Areas (ECA) including Competency I: GIS & Analysis Tools; Competency II: Remote Sensing & Imagery; Competency III: Geospatial Data Management; and Competency IV: Data Visualization. Each ECA lists and defines concepts that are related to the specific ECA. The EBK also includes three cross-functional knowledge and skills competency areas (Syntheses, Reporting, and Collaboration) including soft

Fig. 14.3 VirLaBoK online interactive graph

skills and other competency needs for GEOINT workers. The EBK is a relatively short document that generally uses language that members of the geospatial workforce can easily understand and is available from the USGIF website (usgif.org). It also serves as a resource for the USGIF Certification efforts and as a tool in its Accreditation of GEOINT Academic Programs. This document is currently undergoing review and an updated version is anticipated in fall 2018.

14.5 Conclusions and Recommendations

Many resources from many different types of efforts now exist to help define the skills and competencies that are important to some of the geospatial workforce domains. Which of the resources from these diverse efforts can be used in the quest to define the specific needs of a broadly defined geospatial workforce? The answer may be that there is no single effort or outcome that meets all the specific needs of all audiences. For example, the skills and competency needs are very different for an audience of an awareness course introducing spatial thinking compared to an audience addressing a specific workforce tradecraft such as GEOINT professionals. The skills and competency content of a lower division certificate program at a 2-year community college compared to a graduate-level certificate program at a major research university might include many of the same competencies but will likely require students to have a more advanced background in scientific or mathematical knowledge for the university program. Different user audiences for the resources may require the list of skills and competencies to be written at a simpler, more easily understood level or in a different format. A Human Resources recruiter deciding on who to hire, a student wishing to enter a geospatial career, a professional preparing for a certification exam, or faculty member developing a graduate-level certificate program will have very different resource needs.

In 2018, the Geospatial Technology Competency Model (GTCM) from the USA Department of Labor was reviewed by more than 300 geospatial professionals and updated. The UCGIS Body of Knowledge is now online and topics are being updated and expanded. Other organizations (such as the GISCI) are also updating resources for use by geospatial professionals and academic institutions. It appears that the quest to define the knowledge, skills, and competencies does not have a singular conclusion. Different efforts have created useful resources for their own audiences, but there is not a ***one size fits all*** list. Figure 14.1 graphically presents the idea that a common **Core** of geospatial skills and knowledge is foundational to all levels of the geospatial workforce. One effort that could be undertaken would be to determine what should be included in that Core. This process could be carried out by doing a crosswalk of all the competencies identified by the different organizations mentioned above. A possible starting point for this effort might include the GIS&T Review Syllabi that was created by the AAG as part of the proposal to create and Advanced Placement (AP) GIS&T course for high school students. Any list would then need to be vetted by professional geospatial organizations including certification programs, academia, government, and industry to verify it is the Core. The format for such a list should be easy for users to access and understand with terms and topics clearly defined to suit the needs of a broad user community. Once again, it would also need to be updatable as geospatial technology evolves. An Internet-based format with a peer review process similar to current efforts would be beneficial, but to be done in a timely manner, would need to be funded rather than done on a voluntary basis. The creation of a Core is not a simple task but would provide a way to define a connection between different geospatial communities and workforce domains and help insure that those working in any discipline or domain have the requisite knowledge at least at in the common core competencies.

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Chapter 15
Uncertainty Challenge in Geospatial Analysis: An Approximation from the Land Use Cover Change Modelling Perspective

David García-Álvarez, Hedwig Van Delden, María Teresa Camacho Olmedo and Martin Paegelow

Abstract All data and geospatial analyses come with uncertainty. Although its importance has been widely recognized, uncertainty issues are still not correctly addressed in most of the current geospatial research. This chapter aims to provide an overview of the concepts, sources and tools to manage the uncertainty in geospatial analysis. To this end, we intend to increase the awareness about the importance of uncertainty for all geospatial data and analyses. Due to time and chapter length considerations, we address this topic from the Land Use Cover Change Modelling perspective.

Keywords Geospatial technologies · Uncertainty · Land cover · Modelling Land Use

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15.1 Introduction

Geospatial data and analyses have been gaining an increasing importance in the last decades, achieving a prominent position in the study, management and solution of many of the problems that our society copes with. Geospatial analysis is used to study many current and future challenges of our society, such as climate change, urban sprawl and environmental degradation. However, there are still unresolved questions about the limits of those studies and, specifically, about the uncertainty that their conclusions convey.

Although uncertainty has always been present in any type of geographical research, it is more relevant nowadays because of the wider use of geospatial technologies and the false idea of precision that this quantitative branch of geography embraces. Geography is about synthesis, being the maps the main language through which geographical knowledge is spread. They, as an abstraction of the real world, always come with uncertainty. We can therefore trace this uncertainty back to the beginning of mapping and geography as a knowledge of synthesis. Every study and analysis, even the manually ones made before the emergence of geospatial technologies, is therefore equally uncertain.

Despite the importance of uncertainty in any geospatial research, especially after the advent of geospatial technologies, little attention has been paid to all sources of uncertainty that particular geospatial studies convey. They are important and affect the meaningfulness of the results user and audience get.

Users are still not aware of the uncertainties associated with the use of geospatial tools and methods and how their decisions affect those. Neither is the audience nor the agents, for whom uncertainty acts as a barrier for the adoption of the conclusions from any geospatial analysis in their decisions. That is why more and better information about uncertainty is needed. In this regard, Goodchild (1991) and Hunter (2005) laid out an uncertainty research agenda to achieve better methods for uncertainty management and hence a better understanding of the problem. This agenda has not been met yet. In addition, despite the increasing awareness and research about uncertainty, the uncertainty recognition is not widely spread across most of the geospatial studies and analyses. Accordingly, we present here the uncertainty issue as one of the key geospatial challenges of the twenty-first century.

To remark the importance of this topic and make users aware of the extent of the issue, this chapter gives a general overview of concepts, sources and methods to deal with uncertainty in geospatial analysis. We address this topic from a Land Use Cover Change Modelling (LUCCM) perspective. LUCCM integrates many geospatial tools, processes and data in just one wide analysis. Accordingly, this perspective covers most of the uncertainty issues that any user can face.

15.2 What Does Uncertainty Mean?

There are many definitions of uncertainty, which range from generic approaches to those that focus on specific fields of knowledge. In general, all authors agree in referring to the difference between the perfect representation of any feature or process and how it is really addressed through data and geospatial tools when talking about uncertainty. Given this difference, authors talk about doubt, reliability, lack of knowledge, degree of distrust, etc. to define uncertainty as for the user perception about how that difference affects their studies. In other cases, uncertainty also refers to the confidence that an agent has when using geospatial data to make decisions. All in all, in simple terms, uncertainty can be defined as the lack or the degree of certainty about any data or geospatial analysis due to the difference between reality and its representation through geospatial data or tools.

Many concepts arise when talking about uncertainty, like ignorance, error, accuracy, vagueness or ambiguity. They refer to specific aspects of uncertainty or issues that this term does not cover. Their definition is therefore essential to clarify the conceptual framework of uncertainty, which we propose in Fig. 15.1.

Whereas uncertainty implies that the user is aware of the limitation of his knowledge, ignorance exists when there is no such awareness. It is therefore related to the unknown unknowns, that is, those aspects that we do not even know we do not know (Recker 2015).

Error is objective and, hence, quantitative. It is a measure of the distance between reality and our representation. Accordingly, it just refers to those features which can be measured and quantified. For land cover data, as a forest density map, error could

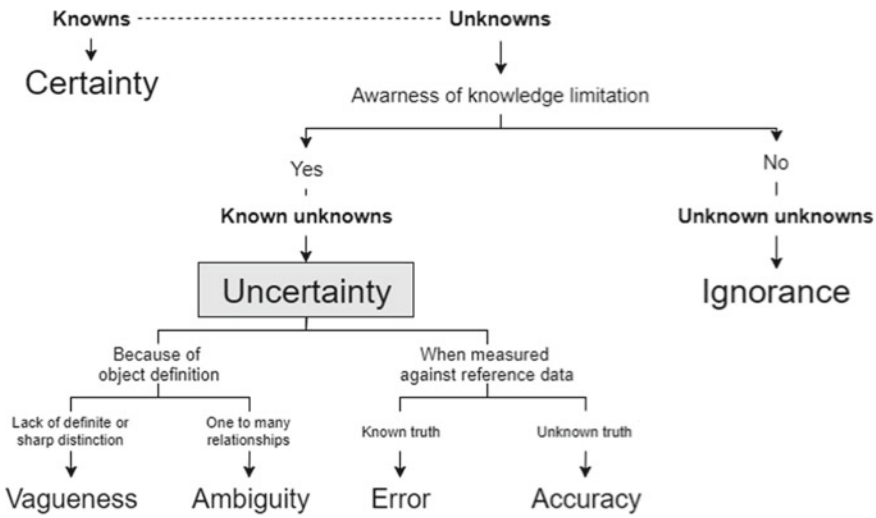

Fig. 15.1 Conceptual chart of uncertainty and related concepts. *Source* Partially based on Klir and Wierman (1999) and Gómez Delgado and Barredo (2006)

be measured from the difference between the forest density in a pixel and the real forest density measured on the ground. Accuracy is the closeness of observations to the truth (Kemp 2008). As an ideal, complete truth is usually unachievable. The data that we consider the truth comes with uncertainty, which the accuracy assessment, unlike the uncertainty analysis, does not consider. When assessing a simulated map to a reference map for the same area, we are checking the accuracy of our simulation. That reference map is not completely certain and, therefore, contains some uncertainty that also transfers to the accuracy assessment analysis.

On the other hand, vagueness and ambiguity are qualitative types of uncertainty. They refer to the certainty at which objects or phenomena are delimited. Vagueness refers to the poor or precise definition of classes or objects, whereas ambiguity arises when the same object can be classified as part of different groups or assets. The former is more about the object definition and ambiguity about the object classification. For land use data, vagueness arises when we are not completely sure about what the label of a class, as urban, covers. Is a village where most of the land is dedicated to agricultural uses urban or not? On the other hand, when upscaling a land use map, ambiguity arises when we are not sure if a landscape previously classified as several patches of cropland and tree cover is then agroforestry or any other category.

15.3 The Three Dimensions of Uncertainty

Following the proposal made by Refsgaard et al. (2013), we differentiate three dimensions of uncertainty as follows: source, level and nature (Fig. 15.2).

- The source is the dimension which gives information where the uncertainty manifests itself. Several studies have proposed a generic classification of sources of uncertainty for modelling environments (Van Asselt 2000; Walker et al. 2003; Refsgaard et al. 2007, 2013; Klein Goldewijk and Verburg 2013; Uusitalo et al. 2015) or even for categorical maps (Aspinall and Pearson 1995) and spatial data obtained through remote sensing analysis (Congalton et al. 1991; Chuvieco 2016).
- The level of uncertainty is the degree of doubt, reliability or lack of knowledge. It moves from complete knowledge and, consequently, absence of uncertainty, to total ignorance.
- The nature of uncertainty is the type of uncertainty we are working with. Literature usually distinguishes to this end between uncertainty due to imperfect knowledge and uncertainty because of natural phenomena variability, being the last one identified as knowledge or epistemic uncertainty and the first one as aleatory, stochastic or ontic uncertainty. Ascough et al. (2008) distinguish different components of the epistemic uncertainty: natural, human, institutional and technological, depending on the source of the variability.

  Uusitalo et al. (2015) added to the previous two the linguistic uncertainty, which arises from language issues. Refsgaard et al. (2013) considered the ambiguity as

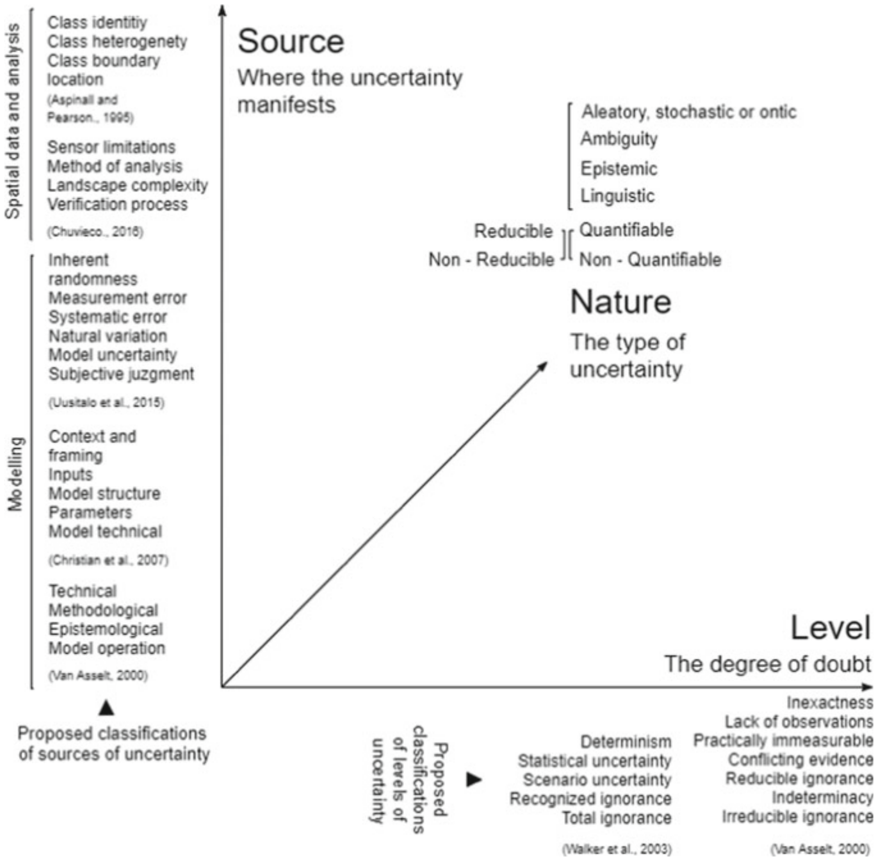

Fig. 15.2 The three dimensions of uncertainty. *Source* Based on Walker et al. (2003)

the third nature of uncertainty. It refers to the different possible understanding of the same system.

Finally, other distinctions exist that differentiate between reducible and non-reducible uncertainties and those measurable and, therefore, quantifiable, and those which are not.

15.4 Sources of Uncertainty in Geospatial Analysis: An Approximation from the Land Use Cover Change Modelling Perspective

Many sources of uncertainty can be pointed out when studying uncertainty in LUCCM or any geospatial analysis. Accordingly, several papers have tried to propose a classification, as pointed out in the previous section and reviewed by Matott et al. (2009). However, those classifications, as the one proposed here (Fig. 15.3), are just theoretical frameworks aiding in the comprehension and management of uncertainty. The user must be aware of the complex interactions between all sources of uncertainty and the difficulty of individualizing any of them. All together, they are known as output uncertainty (Refsgaard et al. 2007) or the uncertainty cascade (Refsgaard et al. 2013), that is, the combination of all uncertainties that the results from a geospatial analysis convey.

15.4.1 Problem Conceptualization

The problem conceptualization can be considered as one of the most important sources of uncertainty, since it comes from the very initial decisions of any analysis, which will shape the study to be carried out. Geospatial data and analysis, as LUCCM, means simplifying the real world and phenomena. When doing this, the user conceptualizes them. The coherence of that conceptualization and how it fits with the problem to be studied or resolved determine the goodness of the managed concepts and the level of uncertainty that the study conveys.

The very first decision comes from the selection of the problem to be studied. Problems are usually complex and related to other processes. Accordingly, their selection is usually difficult and, often, not very well reasoned. There are no widespread methods to deal with this issue, though Dunn (2001) proposed a context validation framework which can serve as a basis to this end. For modelling environments, several papers have addressed, as part of general guides for setting up models, these conceptual questions, pointing out, among other recommendations, the need of engaging agents and final users in those decisions (Van Delden et al. 2011; Elsawah et al. 2017).

Once the problem to be analysed is chosen, it is necessary to define its boundaries. These are not usually real, given the continuation of the earth processes and features. Choosing different temporal or spatial extents (Fig. 15.4) for the same problem may result in different outputs, as shown by papers studying the impact of spatial (extent) (Verburg and Veldkamp 2004) and temporal scale (Pontius and Spencer 2005; Rosa et al. 2015) in LUCCM.

Regarding the temporal extent, the further the time horizon the LUCCM simulation has, the higher the uncertainty becomes, given the unknown variability of real-world processes (epistemic uncertainty). As most LUCC models rely on historical data for their calibration, the temporal resolution of these data as well as the temporal extent of the calibration period also affects the obtained results (Burnicki et al. 2010). The duration of the calibration period must be long enough to avoid noise and the influence of one-off events in the process comprehension. However, as the aim of the calibration is to simulate future land use developments, it is important to focus on processes that are relevant for simulating future dynamics, as not all past developments would be relevant for this. In some cases, more recent development

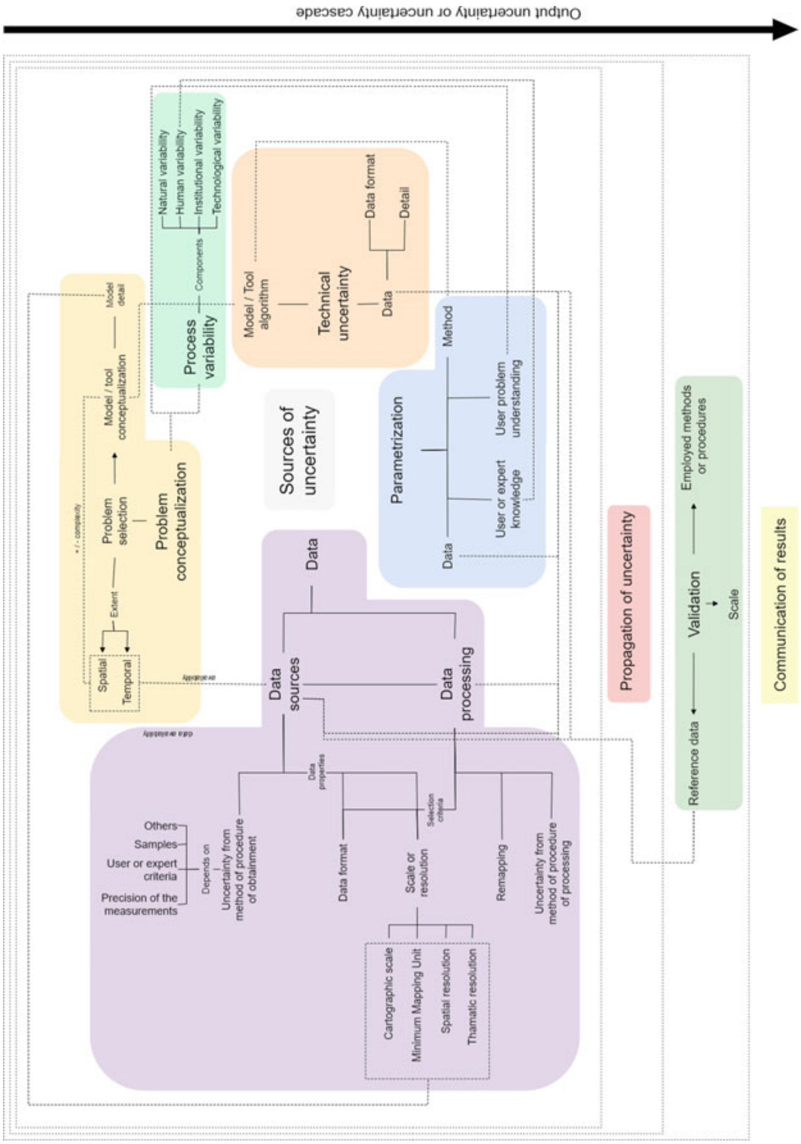

Fig. 15.3 Author's proposal of sources of uncertainty in geospatial analysis from a LUCCM perspective. It represents the main sources of uncertainty as well as the interactions between them (dotted lines)

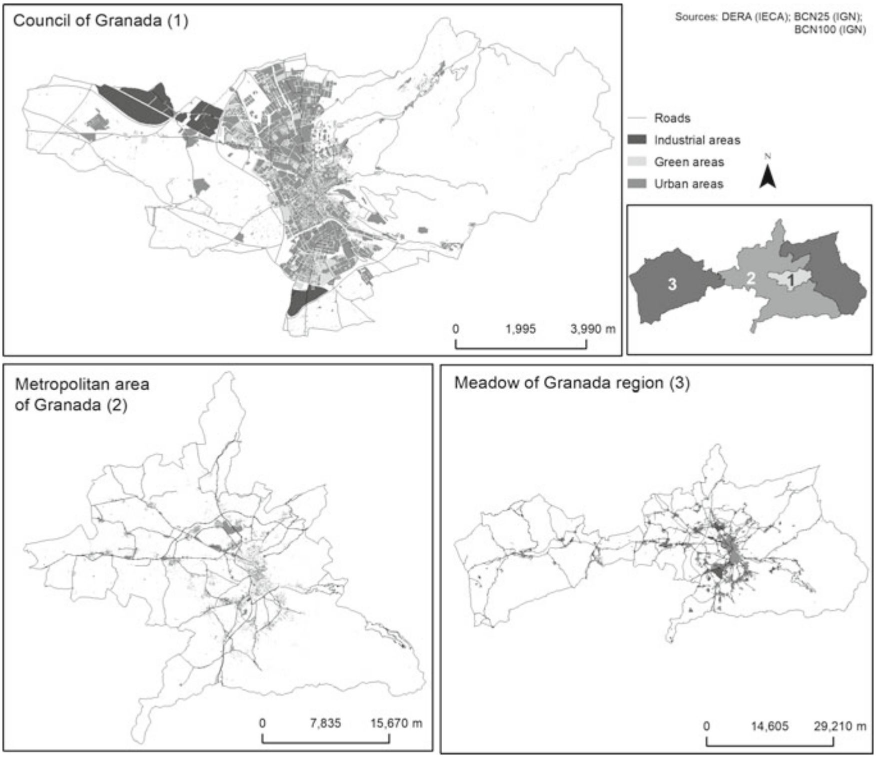

Fig. 15.4 Different spatial extents and approaches for the study of the Granada area (Spain). Every extent matches with a specific level of spatial and thematic detail. The extents refer to different types of boundaries (political, planning and agricultural management)

might be more representative than a long historic period. Analysing and understanding the processes and dynamics of the area under study and placing them in context are therefore essential.

Regarding the spatial extent, every spatial extent must be linked to a conceptualization level of the system under study: when working at continental scale, the system's conceptualization should not be as detailed as a national or regional scales. Therefore, thematic, temporal or spatial resolutions, that is, model detail, should be chosen considering these criteria.

The model conceptualization is then, for LUCCM, the critical step in the problem definition. Model conceptualization means the simplification of the system to be modelled into terms that are understandable, as simple as possible and, especially, possible to be implemented through a software. That conceptualization will be affected by the modeller experience and preferences (Klein Goldewijk and Verburg 2013), but also by the data available and the feasibility of its implementation in a specific algorithm. Accordingly, there is a close link between problem conceptualization uncertainty and the one arising from data and technical issues.

When conceptualizing the model, one must consider that more complexity does not always mean less uncertainty, but can also lead to the opposite (Van Asselt 2000). Complex models are not easy to understand, making the engagement of agents and final users difficult. Complex models also require many parameters and complex algorithms, making the technical and parameter uncertainties very high.

As previously stated, when managing the complexity, the user must keep in mind the thematic, temporal and spatial resolution of the data and the model, since they are the main source of model detail. Finally, the model conceptualization must ensure that all processes and interactions of interest are in the model, that is, the model completeness.

15.4.2 Data Sources and Processing

A big part of the uncertainty of any analysis comes from data. The utility of the analysis will rely on the uncertainties of these data and how data are used. In addition, depending on the study purpose, data uncertainties will play a major or minor role. LUCCM usually relies on data to set up the starting conditions of the model and to parametrize (calibrate) and validate it. Accordingly, data plays a key role in the obtained results. The importance of the availability and quality of the data will increase with the dependence of the model on data, and therefore will be particularly relevant for data-driven models.

We differentiate between those uncertainties that data comes with, which are unavoidable, and those caused by data processing. Altogether, for LUCCM, they are also known as the input uncertainty (Refsgaard et al. 2007).

15.4.2.1 Data Sources

All data comes with uncertainty, even in the case of raw data obtained by measurement or surveys. Because it is unavoidable, the user needs to have as much information as possible about it; ergo, they can understand the limits that these data put on their analysis. Sometimes, accuracy or uncertainty reports are attached to the data. However, this information is uncertain as well, because of the uncertainty of the validation process.

For categorical data, as Land Use Land Cover (LULC) maps, we can broadly distinguish between two main sources of uncertainty: the categorical or thematic uncertainty that comes from the attribute definition, and the positional uncertainty, which comes from the object position (Castilla and Hay 2007). Numerous causes explain for every case the extent and importance of these sources of uncertainty. Expert knowledge is one main reason in the case of data obtained by photointerpretation. The data format (raster vs. vector) is another factor determining the accuracy of data, especially regarding the position of elements. However, the scale or detail of data is maybe the key element explaining the uncertainty. The smaller or coarser the

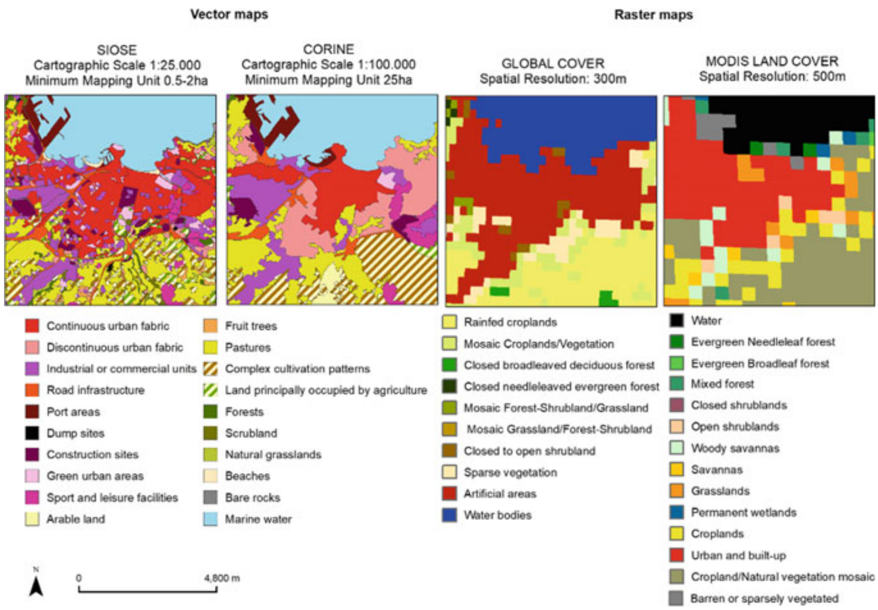

Fig. 15.5 Comparison of different LULC datasets with different formats and at different spatial and thematic resolutions for a test area (Gijón, Spain) in 2005

scale, the bigger the abstraction and, therefore, the larger the uncertainty. Notwithstanding, at finer scales, the definition of elements must be more detailed, making the chance of error larger. Including much detail can also make the analysis too complex. The comparison of several datasets at different scales for the same study area (Fig. 15.5) has proven the influence of scale in data uncertainty (Waser and Schwarz 2006; García Martínez et al. 2015).

The main input of LUCC models is LULC maps, from which modellers analyse LULC change. Changes often represent a small portion of the maps, which usually have an overall accuracy around 80% (Pontius and Lippitt 2006). Consequently, identified changes can be affected by large uncertainties. These uncertainties can propagate to the quantity of change estimation or the model parametrization. Therefore, providing information about the uncertainty of the measured changes would be very relevant (Pontius and Lippitt 2006), including the distinction between technical and real changes (Verburg et al. 2011), which is between those changes that really happened and those ones that are caused by atmospheric or radiance noise in the case of data obtained by remote sensing classification techniques or by variable photointerpretation criteria in case of data obtained by photointerpretation.

According to Grinblat et al. (2016), maps obtained through remote sensing classification techniques are far from the requirements of LUCCM, because of the uncertainty of the classification methods. Traditional photointerpretation provides better results, with the uncertainty dependent on the knowledge of the expert. In both cases, it is difficult to find consistent temporal series of maps without technical changes that allow the user an adequate analysis and comprehension of LULC changes (Verburg et al. 2011). The recent changes in the method used in the production of CORINE for some countries (García-Álvarez and Camacho Olmedo 2017) are, in this regard, a perfect example of those difficulties.

In addition, most data are usually produced for specific purposes, so their use for other aims, as LUCCM, can introduce new uncertainties. All in all, it would be extremely useful to increase efforts in the uncertainty analysis of data. For LUCCM, there is still a great need of sources suitable to the needs and requirements of this type of analysis.

15.4.3 Data Processing

For complex geospatial analysis, as LUCCM, there are strong data requirements, not just in terms of quantity of data, but also in terms of format or resolution. In consequence, it is usually necessary to perform data treatments to fit those data with the characteristics required by the employed tool. As any geospatial analysis, these transformations introduce new sources of uncertainty, which must be considered.

Among the usual transformations performed, we can mention vector to raster and raster to vector conversions (Fig. 15.6) (Congalton 1997) or raster resampling techniques (Fig. 15.7) (Dendoncker et al. 2008). Scale issues, as the thematic (Aldwaik et al. 2015) or spatial resolution (Díaz-Pacheco et al. 2018), and the minimum mapping unit (García-Álvarez 2018), are also key decisions that introduce great variations in data. Regarding the thematic resolution, for LUCCM, some classes, as construction sites, might need to be remapped to fit with the model conceptualization. The way this treatment is made also introduces new sources of uncertainty.

Although this processing can be seen as a new source of uncertainty, it also provides a way of dealing with data; hence, it becomes more suitable for the intended analysis purpose, aiding in the management of the parameter uncertainty. To this end, several studies have addressed the scale influence in LUCCM (Ménard and Marceau 2005; Conway 2009) or the general effects that data transformations, in the case of driving forces, have in LUCCM (Houet et al. 2015).

15.4.4 Technical Uncertainty

It refers to the uncertainty that arises from the computer implementation of tools and data, that is, from the translation of concepts to computer entities and tools. It is therefore related to the problem of conceptualization uncertainty, since the possibilities of addressing a problem will be given by the technical limits of the computer.

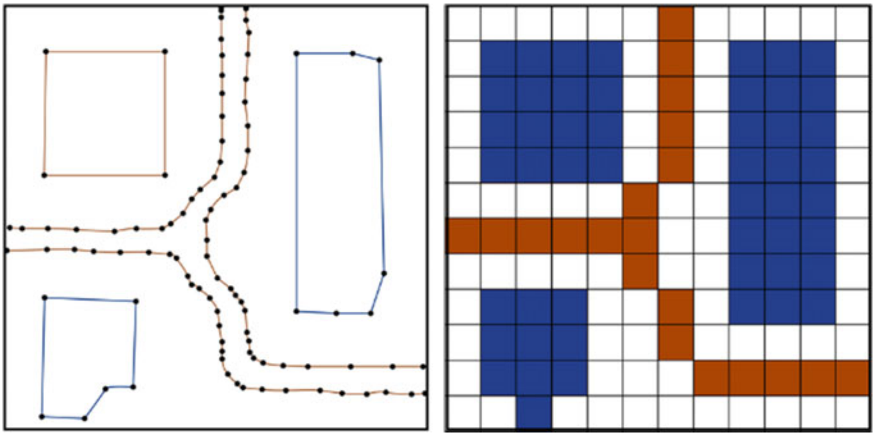

Fig. 15.6 Differences in the representation of the same features under vector (right) and raster (left) formats. *Source* Taken from Olaya (2014)

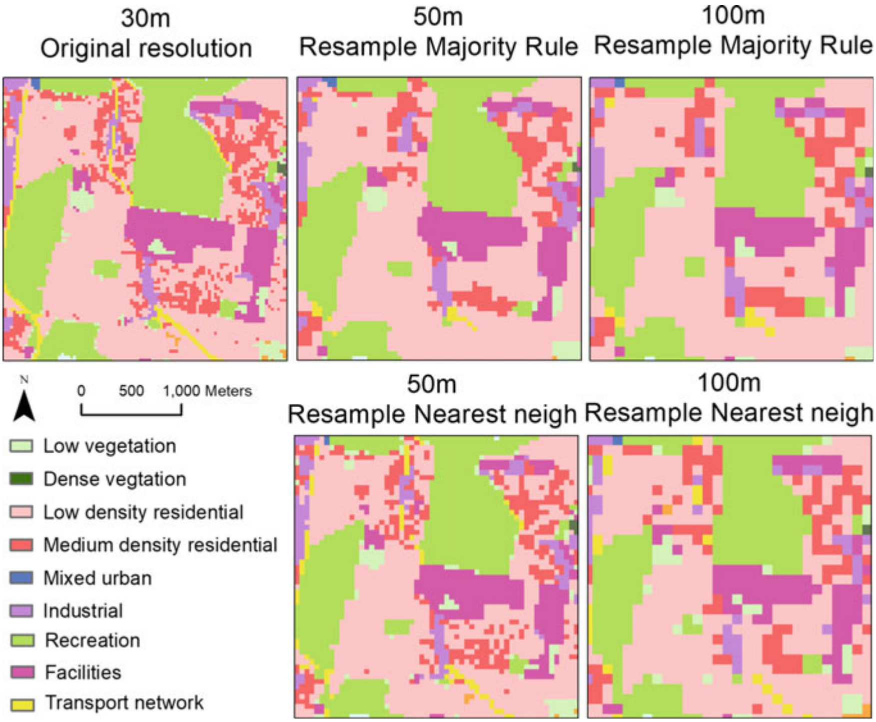

Fig. 15.7 Influence of different resampling methods and spatial resolutions in the pattern and proportions of an LULC map for the Kensington suburb (Sydney)

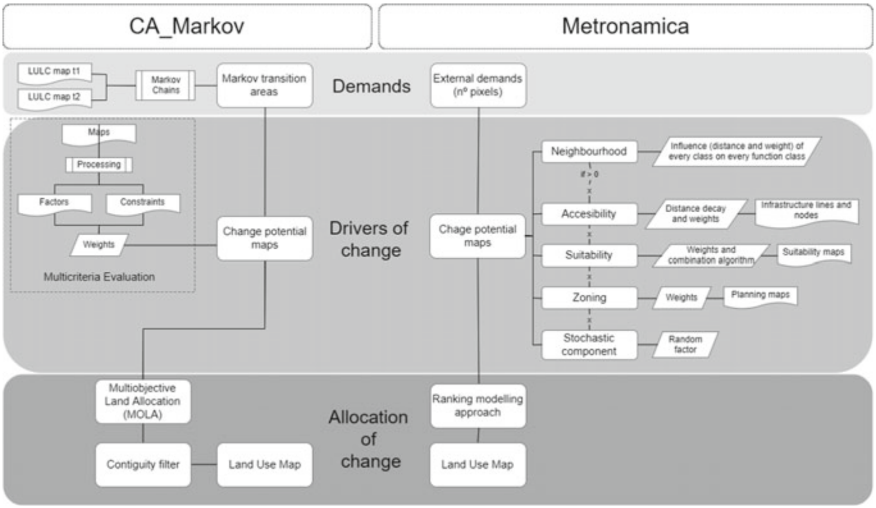

Fig. 15.8 Comparison of the structure of two common LUCCM approaches: CA_Markov and Metronamica

Regarding data, this uncertainty comes from the format and data detail, taking part in the data uncertainty (Sect. 15.4.2). There is ample information about pros and cons of different data formats in most GIS manuals, as well as about scale and resolution issues (Quattrochi and Goodchild 1997; Lloyd 2014). For LUCCM, technical uncertainty mostly comes from the model algorithm.

Some model approaches are designed for specific applications, whereas general approaches, as CA_Markov or Metronamica (Fig. 15.8), can be applied to a wide range of problems (Torrens 2011). Whereas the first group provides an adjusted solution for a particular problem, allowing the reduction of the technical uncertainty to the minimum, the second group allows more research about their limits and disadvantages, and about the uncertainty that they convey. That is why some authors appeal to put the effort in the improvement of these general models (Hewitt et al. 2014).

When selecting or developing a computer model, one must consider the desired complexity. Following Lee (1973), the user must strike a balance between model complexity and data. That is, the model must not be more complex than the data on which it is based. Neither should the complexity avoid agent engagement or user comprehension.

Several model approaches can be distinguished (Yeh and Li 2003; National Research Council 2014), which go from data-driven to knowledge-driven models. Data-driven models incorporate statistical or automatic methods for finding the relation between the dependent and independent variables, that is, to determine the model parameters. In the case of expert-driven approaches, these parameters are decided by expert judgment. Each method introduces a different type of uncertainty in the model parametrization, as we will see in the next section.

15.4.5 Parametrization

The way a geospatial tool, as an LUCC model, is parametrized (i.e. calibrated) determines the utility of the results. Poor parametrizations end in meaningless conclusions. Accordingly, attention must be paid to the uncertainties of this process.

Parameter uncertainty is affected by model structure (technical uncertainty) and data, but also by the problem conceptualization and the user understanding of all the analyses and concepts. Open or poorly defined systems are more complex to understand and, ergo, more difficult to parametrize. User knowledge and understanding of the system (real and conceptualized) is vital to get a correct parametrization. Notwithstanding, the importance of user knowledge in the parameter uncertainty will depend on the role that they play in the model (technical uncertainty).

In statistical or automatic approaches, most of the uncertainty comes from the method used. Some of them are described as black boxes. The user cannot understand how they find the relation between drivers and changes, which makes the obtained result very uncertain. These approaches are also affected by methodological issues such as multicollinearity, autocorrelation, the modifiable areal unit problem, the ecological fallacy problem or the category aggregation problem (Pontius and Spencer 2005). In addition, if the method needs to be technically parametrized through modeller criteria, uncertainty can be also introduced because of human subjectivity (Jafarnezhad et al. 2012).

In knowledge-driven approaches, uncertainty mostly comes from the user understanding of both the process and the conceptual model. Some authors stated that user knowledge is case-specific and, therefore, uncertain (Botterweg 1995). Statistical or automatic procedures guarantee repeatability over study cases, which is not possible under knowledge-driven approaches. However, practical experience of the authors showed that, when working with a meaningful group of agents, there is a common consensus and, therefore, a way of repeatability.

In both approaches, data uncertainty plays a decisive role. Most parametrizations, at least for LUCCM, are based on historical data and, therefore, they will be as certain as the data are (Batisani and Yarnal 2009). Notwithstanding, whereas data uncertainties can be dealt with through user intervention, this is not possible if the method is completely statistical or automatic.

Scale and resolution can be used as tools to reduce the uncertainty of the parametrization. By changing the temporal (Bolliger et al. 2017), spatial (Ménard and Marceau 2005) or thematic resolution (Conway 2009), the user can discard information which he or she cannot explain and, therefore, for which parameters are uncertain. Finer resolutions, that is, more complexity, do not necessarily mean less uncertainty. Thus, complexity must be decided according to the parameters and issues that can be explained by knowledge or data.

15.4.6 Validation and Propagation of Uncertainty

Once the analysis is performed, we usually validate the obtained results. These come with an additional uncertainty to those referred to previously: the one that arises from the propagation of the other uncertainties when data and processes, and their uncertainties, interact. Because of the origin of this uncertainty, it is very difficult to study and usually takes part in the called unknown unknowns, as we are not usually aware of their existence and extent. That is why its study has been pointed out as an important research need (Gómez Delgado and Bosque Sendra 2004; Hunter 2005).

The larger the amount of data and components, the more important the propagation of uncertainty, being especially meaningful for integrated modelling (Van Delden et al. 2011). Where possible the user should avoid data or methods which introduce great sources of uncertainty, trying to keep an equilibrium between all sources of uncertainty that will take part in the analysis. Important drivers can, however, not be discarded and when they come with high uncertainty, solutions (participatory approaches, exploratory scenarios, etc.) need to be sought to deal with them.

Several studies have tried to quantify the propagation of uncertainty (Tayyebi et al. 2014; Ferchichi et al. 2017). From a conceptual point of view, Yeh and Li (2006) tried to study this topic for a cellular automata model.

The validation of the analysis results, including the abovementioned source of uncertainty, is usually performed against reference data. However, there is a great deal of methods and tools to perform this validation, which come with different sources of uncertainty as well. When using reference data, the uncertainty that they convey also affects the uncertainty of the validation.

When validating data, as LULC maps, the sample strategy in case of field validation data or the reference data uncertainty in the case of data comparison validation are important sources of uncertainty. Regarding the methods, there is a vast amount of literature about validation tools and techniques acknowledging their limits. For LUCCM, there are noticeable the critics to the kappa statistics (Pontius and Millones 2011) (Fig. 15.9), which have been answered by the development of new kappa measures that account for the LULC changes (Van Vliet et al. 2011). Different concepts and methods as the null resolution, fuzzy similarity or integrated validation tools have been proposed in the research about the validation uncertainties and limits (Hagen 2003; Pontius et al. 2004; Bradley et al. 2016).

In many cases, uncertainty or accuracy measures are provided for the whole dataset or analysis. However, these uncertainties can be different depending on the area or component considered. For data, uncertainties are usually contrasted between areas or, in the case of categorical data, between classes (Castilla and Hay 2007). Therefore, scale also plays a key role in the study of those uncertainties. For specific analysis, as LUCCM, some of the components can gather most of the uncertainty.

While there is a large number of methods available for the validation of those aspects of the analysis which are quantifiable or more evident (Paegelow et al. 2014), as the final results, there is less research about those qualitative uncertainties, regarding the problem conceptualization (Van Asselt 2000) or the role played by the user's

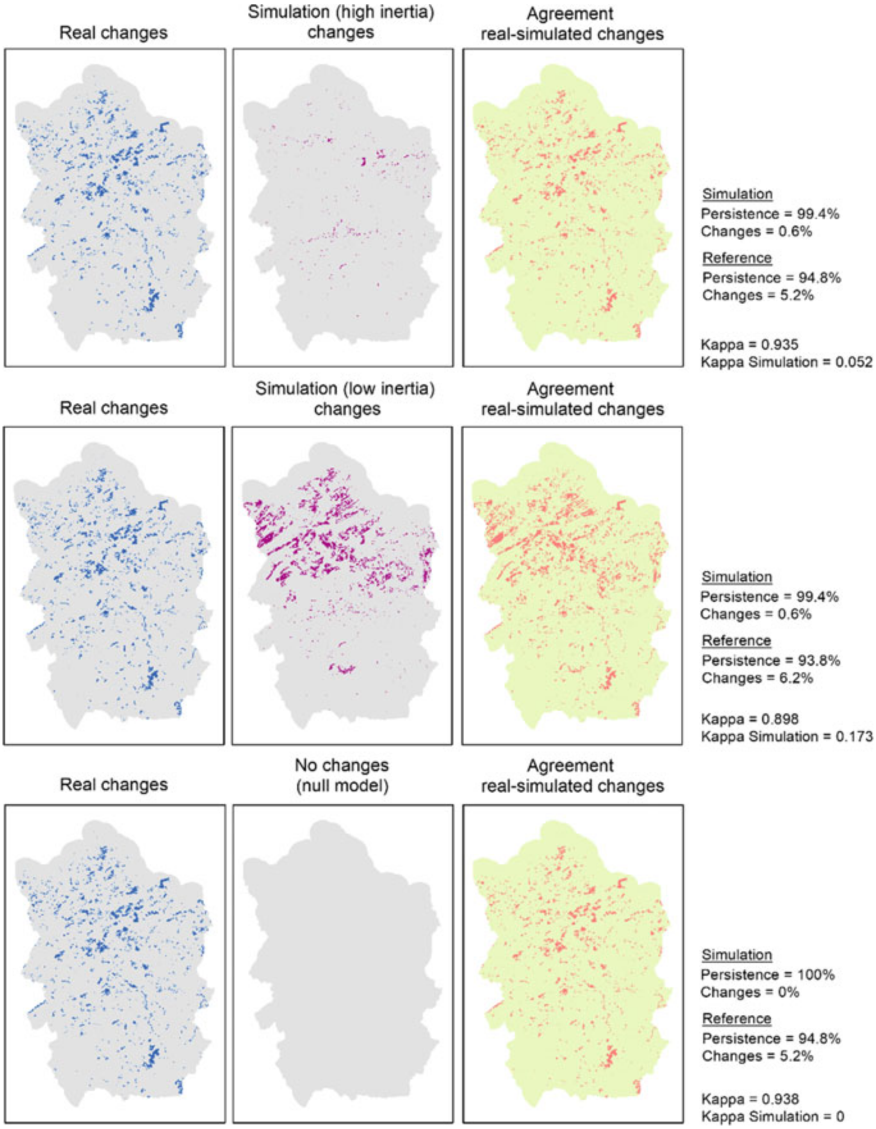

Fig. 15.9 Uncertainties of the kappa validation measures. Kappa accounts well for persistence, but not for change. Conversely, Kappa simulation accounts well for change, but not for persistence. The null model only accounts for persistence, serving as reference

knowledge and perspectives (Brown 2004). Nevertheless, when validating, the user must acknowledge that perfect validation is usually a utopia, especially for some analysis, as LUCCM, due to the inherent uncertainty of the complex systems which LUCC models try to replicate (Van Asselt 2000).

15.4.7 Process Variability and Communication of Results

Regarding the epistemic uncertainty, we cannot know how the system or processes studied will evolve in the future (Fig. 15.10). This evolution will depend on a wide variety of factors, as environmental, socioeconomic or political ones, whose behaviour we cannot know with certainty in advance.

Accounting for this uncertainty is one of the main challenges, since we are not aware of all the possibilities of change that the analysed system can experience. In this regard, it is useful referring to the known unknowns and the unknown unknowns, that is, those issues that we know that we cannot know, but also those ones that we do not even know that we do not know (Recker 2015). Keeping in mind these ideas helps in the dealing and recognition of this uncertainty.

When communicating the results of an LUCC model, accounting for those possible system evolutions is essential to transmit the audience one of the main uncertainties that the results of our analysis convey. In this regard, how we communicate these also introduces important uncertainties that must be conveniently addressed.

In the same manner, we simplify the real world to represent it through data and geospatial tools; when we communicate the results of our analysis, we also simplify the outputs. If our analysis is stochastic, we must communicate how this stochasticity has affected the results (Fig. 15.11). In a similar vein, if the obtained maps are too detailed to be represented without any modifications, information about differences between maps showed and maps actually obtained should be provided.

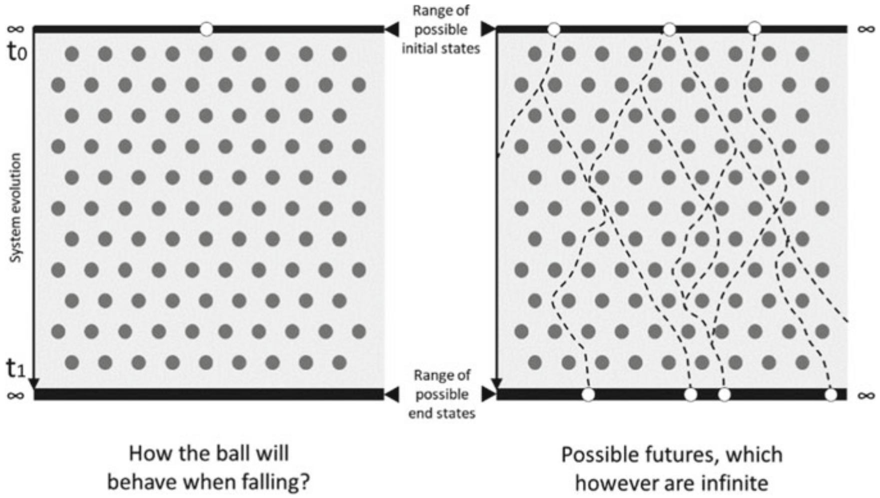

Fig. 15.10 Authors' view on the different ways a system can evolve in the future. Like a ball when falling through a labyrinth, we cannot be sure about the circumstances that the process will face. The end state of the system will depend on those, but also on its initial state, as the ball in our example

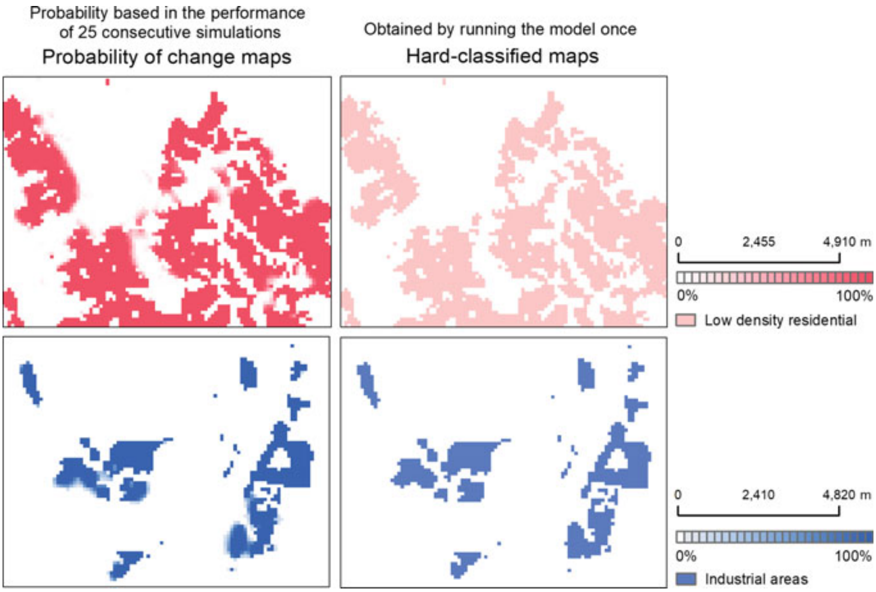

Fig. 15.11 Two different ways of communicating LUCCM results, which are especially contrasted in the case of high stochastic models, unlike the example included here. It shows part of the results of a model for the Great Sydney Area

15.5 How to Deal with Uncertainty?

When dealing with uncertainty one must be aware that it is unavoidable. Accordingly, the user can just act to reduce it and to provide as much information as possible about it. To do so, the user must first locate and determine the extent of the uncertainty.

15.5.1 Transparency and Communication

Every analysis contains uncertainty and, consequently, all the achieved conclusions are uncertain as well. The utility of those conclusions and studies will depend on their level of uncertainty and on the users understanding of this uncertainty as well as on the limitations that it imposes.

To help in the understanding of the uncertainty, providing as much information as possible about it is an essential step. As every decision that we take, from the very selection of the problem to be studied, comes with uncertainty, providing information about uncertainty means spreading all the information and details of the analysis carried out, that is, all the decisions taken and their justification. For LUCCM, problem, level of detail (spatial, temporal and thematic resolution) and software choices are important decisions impacting on the uncertainty of the analysis. Therefore, appropriate justification must be given. Thus, transparency of the way the study has been carried out is a required step for communicating uncertainty.

In addition to transparency, we must provide reports and measures about uncertainties but always warn about the limitations and uncertainties of this information. In this regard, scale issues must always be considered when communicating this information, since uncertainty will be different depending on the area, class or component considered.

According to the public for which the analysis is intended, the language used in the communication of the uncertainty will be different, but always transparent, i.e. clear and concise. This avoids confusion, misinterpretation and lack of understanding, that is, the translational uncertainties (Van Asselt 2000). Moreover, when delivering the information, it must be clearly hierarchized in order to get the audience's interest. A summary of the most important uncertainties should first be presented, going from there into the details. This strategy, which has been called 'progressive disclosure of information' (Kloprogge et al. 2007), favours the audience attention and, ergo, the audience awareness.

According to the previous ideas, when delivering conclusions that will form a base for decision-making, giving information about the uncertainty of the possible decisions that will be taken is important as well. That is, providing the trust interval over which the results and conclusions could be used to take decisions. In this regard, Openshaw (1989) stated that, instead of mere estimations of error, what is really needed is the certainty that decisions could be taken from the results of geospatial analysis. In a similar vein, Brown (2004) talks about educating uncertainty in the decision-making process and Hunter (2005) points out the need of knowing the uncertainty of data and analysis from a legal point of view.

15.5.2 Methods and Strategies

Different strategies have been laid out for dealing with uncertainty. They come from different perspectives in the uncertainty management, which go from positivism (uncertainty can be studied objectively) to constructivism (uncertainty always depends on the context in which the analysis has been carried out, including an important subjectivity) (Wardekker et al. 2008). The positivist perspective has dominated most of the uncertainty research over the last decades. Main attention has focused on the quantification and reduction of uncertainty. In fact, Klir and Wierman (1999) stated that for three centuries uncertainty analysis was interpreted as probability theory.

The research community admits today the existence of qualitative and quantitative uncertainties (Warmink et al. 2010), which ergo are studied by qualitative or quantitative approaches (Van Asselt 2000). There is not a single method that can analyse all types of uncertainty and, therefore, different approaches are needed for its complete study. Nevertheless, even in that case, a whole inventory and analysis of uncertainties is not possible. That is why every uncertainty analysis is at the same

Table 15.1 Common procedures for uncertainty analysis in modelling environments

Method	Description	Studied uncertainties
Expert elicitation (QN/QL)	Collection of expert opinions through an established method about one of several aspects of the performed analysis to account for the analysis uncertainty	Very flexible approach. Most of the uncertainties
Model comparison (QN)	Comparison of the same application over several model structures to evaluate the influence of the model structure on the achieved results	Problem conceptualization and technical uncertainties
Monte Carlo analysis (QN)	It gives output statistics from the repetition of the same analysis under random variations of input data and parameters	Data and parameter uncertainty
NUSAP (QN/QL)	It is a method that provides a comprehensive assessment of uncertainty for policy purposes. It characterizes the uncertainty according to five categories: numeral, unit, spread (QN), assessment and pedigree (QL)	Data and parameter uncertainties
Participatory approaches (QL)	Accounting for the opinion of stakeholders or policymakers (practical knowledge) to study the parameters and assumptions made	Very flexible approach. Most of the uncertainties
Scenario analysis (QN/QL)	It explores the possible future states of the studied system through the consideration of different assumptions about its evolution, which translates in changes in the parameters (QN) or trajectories (QL)	Process variability
Sensitivity analysis (QN)	It studies how changes in the parameters or the initial values of the analysis affect the outcomes	Data and parameter uncertainties
Uncertainty matrix (QL)	Identification of types and location of the analysis uncertainties	Identification of all sources of uncertainty
Validation techniques (QN/QL)	Evaluation of the agreement between the model outcome and reference data. It can comprise quantitative methods, but also expert assessment and participatory approaches	Output uncertainty

Quantitative (QN) and qualitative (QL) approaches

LOCATION		LEVEL			NATURE	
		Statistical uncertainty	Scenario uncertainty	Recognized ignorance	Epistemic uncertainty	Stochastic uncertainty
Context	Natural, technological, economic, social and political					
Model	Model structure					
	Technical					
Inputs	Driving forces					
	System data					
Parameters						
Outputs						

Fig. 15.12 The uncertainty matrix. *Source* Based on Walker et al. (2003)

time uncertain. Thus, the study of uncertainty just offers an overview of the limitations of our analysis, arising the awareness about the possible interpretations of its conclusions.

Refsgaard et al. (2007), Li and Wu (2006), Klir and Wierman (1999), Matott et al. (2009), Uusitalo et al. (2015) and Van Asselt (2000) give an overview of different methods and strategies for the management of uncertainty. We summarize some of the most common ones in Table 15.1.

Although the quantitative approaches are common, we want to stress here the importance of qualitative ones. One of the main objectives of LUCCM is assessing the possible future states of a system under different management policies. Scenario analysis provides to this end a consistent tool to deal with the future system variability. Scenarios can act as qualitative tools, as an image or representation of possible future narratives (storylines) or as quantitative ones, when those narratives are translated to parameters. Some research has gone in depth in this translation (Van Delden and Hagen-Zanker 2009). In addition, Mahmoud et al. (2009) provide a framework for the development of scenarios in environmental decision-making.

The uncertainty matrix proposed by Walker et al. (2003) offers a simple and easily understandable approach for uncertainty identification. It locates the different uncertainties of an analysis, giving information about their level and nature (Fig. 15.12). It is therefore a good tool for transmitting directly and in a summarized way all the uncertainties that an analysis conveys. The main problem of this method comes from the difficulty of individualizing every source of uncertainty, given the complex interactions between them. Warmink et al. (2010) have proposed a guideline to solve this issue, so every source of uncertainty can be classified in the matrix just once.

Finally, participatory approaches, both from experts and agents, provide a useful and easy way of accounting for most of the uncertainties at the same time that the user makes the audience aware of the limitations and problems of the analysis. For LUCCM, the study developed by Hewitt et al. (2014) can be used as reference. Moreover, Reed et al. (2017) and Van Delden et al. (2011) give some useful tips and frameworks for the inclusion of participation in the analysis.

15.6 Concluding Remarks

Uncertainty, as an unavoidable attribute of any geospatial data or analysis, is a complex issue which deserves special attention in order to increase the reliability of our studies. This can be meaningful as well in the search for the daily applicability of our analysis and theories in policy processes.

Although substantial research has been done in this field, there are still plenty of unresolved issues which need to be addressed. It is especially important to focus on the analysis and management of qualitative uncertainties, which greatly determine the achieved results and whose communication is still a pending matter. How uncertainties are communicated is, at the same time, another key point that has not received much attention. Efforts should be put in the increment of uncertainty communication awareness among the research community. Many studies are still presented today without proper information and justification of key decisions, as resolution or extent. Just by changing this common practise, we can really account for the uncertainty problem and translate those practices to the practical works delivered by the same community.

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Chapter 16
The Pervasive Challenge of Error and Uncertainty in Geospatial Data

Suzanne Perlitsh Wechsler, Hyowon Ban and Linna Li

"…human knowledge is personal and responsible, an unending adventure at the edge of uncertainty."
Bronowski (1974, p. 367).

Abstract Understanding, quantifying and communicating uncertainty in spatial data, and its propagation through geospatial analyses have been a challenge long recognized in the geospatial community. Over the decades, extensive research has contributed to our understanding of geospatial uncertainty. However, consistent agreed upon methods for addressing, managing, and communicating uncertainty have not been integrated into common geospatial practice. Understanding and accepting the challenge that uncertainty presents to practitioners in the twenty-first century is a step forward in ensuring results of spatial analyses are communicated with greater accuracy and validity for responsible geospatial practice. The mission of this chapter is to provide readers with an appreciation of the varied nature of uncertainty in spatial data, its sources, propagation, and communication.

Keywords Geospatial technologies · Uncertainty · Data · Error

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16.1 Introduction

Uncertainty refers to an overall lack of confidence in the quality of scientific data, analyses, and the decisions upon which these are based (Brown 2010). Understanding, quantifying, and communicating uncertainty in *spatial data,* and its propagation through geospatial analyses, have been challenges long recognized in the geospatial community. However, consistent agreed upon methods for addressing, managing, and communicating uncertainty in the results of geospatial analyses have not been integrated into common geospatial practice. *If results of spatial analyses are unaccompanied by measures of certainty, how can we ensure that users of spatial data and associated analyses are provided with the requisite information for responsible data use and decision-making?*

Identifying and utilizing mechanisms for addressing uncertainty and integrating these approaches into common geospatial practice remain challenges for geospatial researchers and practitioners. Over the decades, extensive research has contributed to our understanding of geospatial uncertainty (see for example (Couclelis 2003; Fisher 1999, 2006; Heuvelink and Burrough 2002; Hunsaker et al. 2013; Li et al. 2018). The intent of this chapter is to present: (1) generally agreed upon concepts of uncertainty and (2) provide examples of types of approaches to address uncertainty that can be applied to specific spatial datasets.

We begin this chapter with definitions of terms and associated concepts. This first section provides an overview of the complexities of uncertainty in geospatial science. The next sections expand on this background with examples of how methods of confronting uncertainty can be integrated to address uncertainty into geospatial practice.

16.2 Uncertainty Fundamentals

> Understanding the error in spatial databases is necessary to ensure appropriate application of GIS and to ensure progress in theory and tool development. (Chrisman 1991, p. 167)

The largest contributing factor to spatial data uncertainty is *error*. Error is defined as the departure of a measure from its true value. Our lack of knowledge of the extent and expression of errors in spatial datasets, and their propagation through analyses, results in uncertainty. In applying scientific principles, we have been taught that errors are "bad" and with enough practice and attention to detail, error can be eliminated. However, error abounds in spatial data. No matter how sophisticated mapping technologies become, spatial representations of map features are still generalizations from limited samples of reality. Positions of features represented on a map are subject to displacement and associated attributes are subject to inconsistencies in description and ontological representation. Even at our present level of technological capacity, distortions are an inherent component of maps and their digital representation, and a concomitant component of spatial data. All geospatial data are likely to contain errors, which leads to uncertainty in measurement and in visualization of analytic results (Chrisman 1991; Goodchild and Gopal 1989).

16.2.1 Error As a Consequence of Scale

In what ways are errors introduced into geospatial data? Let us begin with recognizing the major sources of geospatial data. Geographic Information Systems (GISs) enable exploration of patterns in spatial data in order to understand natural, physical, and anthropogenic processes. These latter phenomena all have variations in their spatial and temporal scale. However, spatial data used to represent them are generated at fixed scales in space and time. This difference results in a major source of error in GIS data: varying spatial and temporal scale are discrepant from obtained GIS data. GISs are incorrectly assumed to be scale independent, because we are able to zoom in and out of data layers. This assumption is untrue and problematic. All map features are *only* representations of reality and are thus distorted through the cartographic process. Projections displace features in area, size, distance, and direction, while datums determine where features are placed. Additionally, all map features are generalized based on the spatial scale of representation. For example, the twists and turns of a stream represented cartographically at a map with a scale of 1:24,000 will be more detailed than the same stream represented at a scale of 1:100,000. In thematic maps, boundaries of features are represented as discrete and mutually exclusive (Woodcock and Gopal 2000). However, due to positional errors and spatial scale, boundaries are imprecise and can be indeterminate. Furthermore, spatial analyses that include soil boundaries may misrepresent results when Boolean logical operations are used. For example, soil polygons are represented with discrete boundaries. In a query that only includes binary selections of discrete objects such as "is" soil_type_A and "is not" soil_type_A, areas that may contain some components of soil_type_A will be missed.

> It is clear that scale is a problematic issue in many sciences, notably those that study phenomena embedded in space and time. (Goodchild 2011, p. 5)

Error due to spatial scale can be minimized by improved precision of measurement that results in greater accuracy. The terms precision and accuracy cannot be used interchangeably. *Precision* refers to the exactness of a measurement. In spatial data, precision can be attained, for example, using high-quality receivers embedded in a global positioning system (GPS) that enable more exact measures of horizontal and vertical positions. In a raster GIS, precision is achieved through more closely spaced measurements as represented by higher resolution grid cells. *Accuracy* is defined as the closeness of a measure to its "true" value (Chrisman 1991). Accuracy is quantified by comparing measurements in a dataset with co-located values deemed "higher accuracy."

While there are many versions of accuracy statistics (Chow and Kar 2017), the accuracy of geospatial data is most commonly quantified using the Root Mean Square Error (RMSE, Eq. 16.1). This global statistic requires access to a higher accuracy measurement, which is not always attainable. As a parametric measure, it is based on the assumption that errors are both normally distributed and representative of the dataset, both of which are not always the case. Nonetheless, the RMSE is the most standard accuracy statistic and has been integrated in common practice as an accepted measure of data quality. The RMSE is expressed as

$$\sqrt{\frac{\sum_{i=1}^{N}(y_i - yt_i)^2}{N-1}} \tag{16.1}$$

where y_i refers to the ith map value, yt_i refers to the ith known or measured or higher accuracy sample point, and N is the number of sample points.

A consequence of imprecision in spatial data representation is that sampling may occur at a spacing that does not match the underlying frequency of the process we are trying to represent, thus missing the natural scale of a process. Data representation misses the complexity of the natural environment. This is referred to as *aliasing* and results in *bias* in representation. Landscape studies are particularly susceptible to this mismatch between spatial and temporal scales. For example, satellites such as MODIS collect fire signatures on the landscape at a high temporal resolution, but on 1-km^2 grid cells. These signatures are difficult to match to other satellite data such as Landsat where land cover is represented using a high spatial resolution (30 m^2) but a comparably coarse temporal resolution. Matching fire patterns with landscape patterns are therefore problematic (Laris et al. 2016).

Another example of uncertainty that is contributed by error occurs when the spatial scales and boundaries imposed by scale do not match the processes we are trying to understand. This is known as the *modifiable aerial unit problem* (MAUP) (Openshaw 1984). Gerrymandering is an example of an outcome of MAUP in practice. Where we place census boundaries influences the decisions that are made about communities, and can be based on different spatial representations of underlying demographic attributes. Political outcomes can be manipulated by the spatial scales that are employed. Aggregating from census block group to census tract to zip code each changes the outcome of demographic spatial analyses. Similarly, the extent to which geographic boundaries deviate from behavioral context, for example, within and between neighborhoods, has recently been differentiated from MAUP and referred to as the Uncertain Geographic Context Problem—UGCoP (Kwan 2012). Another offshoot of MAUP is the Modifiable Conceptual Unit Problem (MCUP) whereby how we conceptualize spatial processes through the models we develop to represent them may lead to different model predictions (Miller 2016). MAUP and its derivative concepts are unavoidable.

So far we have discussed how spatial and temporal scalings result in uncertainty. In the next section, we explore uncertainty that is due to the lack of precision of language and the choices of words we use to describe spatial phenomena.

16.2.2 Semantic Uncertainty

> When I use a word," Humpty Dumpty said in rather a scornful tone, "it means just what I choose it to mean — neither more nor less."…"The question is," said Alice, "whether you can make words mean so many different things. (Carroll 2002, p. 185)

As Humpty Dumpty asserts, words should be used consistently, without altering their underlying definition (Chisholm 2012). Often, however, descriptive information of map features are inconsistent and have multiple definitions. The resulting uncertainty is referred to as *semantic uncertainty* and arises from "*vague*" and "*ambiguous*" definitions of geospatial representations. Vagueness refers to a lack of unique distinction between objects and classes such as the boundary of a mountain that is continuous and fuzzy rather than crisp. Ambiguity occurs when there are more than two different definitions for a term (Fisher 1999).

Spatial data are developed by people, and as such are affected by variations in human judgment (Shi et al. 2003). For example, it is not uncommon to have two soil experts disagree on a classified type of soil at a particular position. Meanings are attached to geographic features using categories, tags, or descriptive text that are usually loosely defined. For example, two land cover classification systems—the National Land Cover Dataset (NLCD) 1992 and NLCD 2001—provide different definitions for the same land cover classes (Ahlqvist 2008). Similarly, various land cover products can have different thematic accuracies. A land use term such as "area not taken up by agricultural activities" may overlap with a range of various land cover types (Devos and Milenov 2015). The uncertainty that arises from discrepancies in meanings that are applied to spatial data is referred to as *semantic uncertainty*.

16.2.3 Semantic Uncertainty in Web-Based Geographic Data

Increasingly, GIS services reside in the cloud and are transmitted over the Internet. Collaboration between distant GISs using the Internet requires interoperability among the GISs so that databases and applications can be shared. However, semantic uncertainty can occur between web-based GISs. For example, if a user of a web-based GIS "*A*" requests data that is only provided by GIS "*B*", the request and the response between "*A*" and "*B*" should be understood correctly for successful transfer of the data. This communication between different GISs requires a variety of protocols related to the data request such as visualization of the requested data, format of data, and queries used to request and extract the data. Successful interoperability requires structuring the GIS in terms of the data model and applying agreed upon semantics, using sets of rules and constraints of object class definitions in the GIS (Bishr 1998).

16.2.4 Semantic Uncertainty in Crowdsourced Geographic Data

In the previous sections, we discussed different types of uncertainty and various ways in which they are introduced into geographic information. Numerous methods have been created to quantify and visualize geographic data uncertainty, many of which are based on comparing a dataset with a mathematical model or a dataset with higher accuracy. These techniques are very helpful for understanding and quantifying uncertainty, but they may not be appropriate for a new and promising type of data that have increasingly become an important and complementary source of geographic information: crowdsourced geographic data or volunteered geographic information (VGI). Crowdsourcing refers to the process of soliciting information, ideas, or services from the crowds who are largely untrained volunteers. For example, many projects have taken place to collect various data from general citizens, including the Audubon Christmas Bird Count project and OpenStreetMap (OSM). This popular type of data source has raised new and unique challenges for assessing, measuring, and communicating data uncertainty (Goodchild 2007).

Semantic uncertainty may be hard to measure and characterize in crowdsourced geographic data. While mapping professionals may disagree on what class to assign to a particular pixel, the information that may be associated with any piece of crowdsourced information is wide open; people may disagree about everything associated with a crowdsourced feature. For instance, when a road is the subject for a dataset, attributes for a road feature may include the road name, highway, other tags, and length. But the specific information assigned to each of these attributes is provided solely at the discretion of a volunteer. Comparisons between crowdsourced datasets and non-crowdsourced data (i.e., authoritative data) reveal that crowdsourced data are inconsistent, with different classification systems, loose definitions, and inconsistent naming.

In a comparison between authoritative and crowdsourced bike path data, for example, the underlying meaning of the attributes must first be determined and agreed upon to establish semantic correspondences between the two datasets (Li and Valdovinos 2018). In a specific example, the Open Street Model (OSM) is a crowdsourced dataset. Volunteers may choose different tags to attach to the same type of feature due to a lack of strict definitions. A bikeway may have a tag "track," "lane," "designated bicycle," etc. in various attribute columns. Another example of semantic uncertainty can be observed when assessing categorized messages on the Ushahidi platform in the 2010 Haiti Earthquake. Camponovo and Freundschuh (2014) found that 50% of the messages were mis-categorized by volunteers for major categories, and 73% of the messages were misinterpreted at the subcategory level. This level of uncertainty raises serious concerns over the legitimacy of using crowdsourced data for emergency responses and other similar critical situations. In another study, expert volunteers were better at identifying land cover types than nonexpert volunteers using the data from the Geo-Wiki crowdsourcing tool (See et al. 2013). This argues for the potential usefulness of training volunteers and the necessity for establishing standards for data gathering and observing as part of the VGI process.

In authoritative (i.e., non-crowdsourced) datasets, it is the responsibility of data producers to provide data quality metadata. According to the Content Standard for Digital Geospatial Metadata created by the United States Federal Geographic Data Committee (FGDC 1998), data quality information is an essential part of metadata in geographic datasets and the FGDC has set forth basic standards for data quality. For example, metadata should include a general assessment of attribute accuracy, positional accuracy, logical consistency, completeness, and lineage.

Traditional geographic datasets are typically created using consistent and verified data collection methods (e.g., surveying, remote sensing imagery) and evaluated using agreed upon quality control standards such as the RMSE. Traditional quality control procedures usually involve a selection of a sample from a dataset and measurement of average uncertainty associated with the selected features. Such results are recorded as a general assessment of data quality.

Lack of quality control and data quality documentation is common in crowdsourced data. These aspects of quality information are not present in most crowdsourced datasets for a variety of reasons:

(1) Crowdsourced data are contributed by various volunteers with a wide range of data collection skills, mapping experience, and familiarity with geospatial technologies.
(2) In the volunteer world, volunteers may not have the necessary skills or guidance required to systematically measure and communicate uncertainty.
(3) Selection of a representative sample for quality evaluation is not available in crowdsourced data.
(4) Definitions of objects under investigation are inconsistent.
(5) Inherent observer bias is introduced into the dataset.
(6) Uncertainty may not be consistent even within the same dataset, which makes it challenging for experts to evaluate the quality of VGI dataset.

The result of such absence of standards is that there are various levels of uncertainty even within the same dataset. This makes it impossible to use a single measurement to describe the uncertainty associated with a whole geographic dataset.

An example of how positional uncertainty and completeness vary significantly from area to area is a comparison between the crowdsourced OSM and the authoritative dataset provided by the Ordnance Survey of Great Britain (Haklay 2010). Similarly, in a study using geotagged Flickr photos of places in France, peoples' perceptions showed that positional uncertainty associated with these photos varied from a few meters to 78,200 m (Li and Goodchild 2012). This suggests that feature-level accuracy is required if uncertainty is to be represented accurately in VGI. However, a major value of crowdsourcing is its rapid production of geographic data that are not available from traditional sources. Comparison of every piece of VGI-generated geographic information using a "gold standard" for data accuracy is impractical (Goodchild and Li 2012). New uncertainty evaluation methods need to be developed for crowdsourced data that are acceptable for their intended use. For example, there may be a higher standard required for datasets that are used to provide information to emergency responders in search and rescue operations.

16.2.5 Sampling Bias in Crowdsourced Data

Crowdsourced geographic datasets can be massive having millions of geographic features. For example, Wikimapia, an open-content mapping project completely contributed by volunteers, had just under 28,000,000 objects as of January 2018 (Wikimapia 2018). Large-sized datasets known as big geodata does not guarantee that they are complete or representative. Volume and types of geographic features in a particular area are largely dependent on the interests of volunteers. As people tend to contribute data in their familiar areas, population density plays a large role in data availability. Populous metropolitan areas are more likely to have a more complete dataset compared to rural areas (Estima et al. 2014). Omission of important features may be difficult to detect. This further confirms that the quality of a crowdsourced dataset may be very uneven within the same source due to different samples, different methods, and mixed populations with a lack of specificity about the mixed population.

People are optimistic about the ever-growing field of big data because it allows us to record large volumes of objects and events nearly in real-time using advanced geospatial technologies. However, large quantities of data do not equal greater quality and we need to always be aware of the limitations of the accuracy crowdsourced data. Twitter, for example, has been a popular data source in many applications across different fields because of its convenience to obtain. Yang and Mu (2015) studied geographic patterns of psychological depression using georeferenced tweets. Widener and Li (2014) used geolocated tweets to describe the distribution of healthy and unhealthy food across the contiguous United States. In all these studies, although the total number of investigated tweets is impressive, the limitations are also obvious. Twitter users and particularly a small percentage of heavy users cannot be representative of specific populations. As demonstrated by Li et al. (2013), the spatial and temporal distribution of tweets is uneven from place to place, and the variation is often correlated with socioeconomic characteristics of places. If we look further, a long tail effect is present in any Twitter dataset: a large percentage of tweets is dominated by a small percent of users. Sociology places high value in carefully selected samples that effectively represent a larger population. However, when a data source like Twitter is used, identifying a specific population is uncertain. Addressing error due to the limits of the sampled population and associated inherent biases continues to pose a challenge in working with this rich geospatial data source. It is incumbent upon data analysts to qualifying the data based on the way it was gathered and any evidence of the nature of the bias.

16.2.6 Using Fuzzy Sets to Visualize Semantic Uncertainty

Errors due to semantic uncertainty result from incomplete knowledge of spatial phenomena. Traditionally, in a cartographic map, boundaries are treated as discrete and mutually exclusive (Woodcock and Gopal 2000). Positional errors are not incorporated in the representations map features. The true location of a boundary is unknowable and subject to positional and semantic error. Researchers have explored the use of fuzzy set theory (Zadeh 1965) to visualize semantic uncertainty (Ban and Ahlqvist 2009; Bishr 1998; Li et al. 2018; McBratney 1992). Fuzzy set theory assumes all boundaries are fuzzy. Fuzzy logic specifically addresses situations when the boundaries between classes are not clear. Unlike crisp sets, fuzzy logic is not a matter of "in" or "out" of the class; it defines how likely it is that the phenomenon is a member of a set.

Specific mathematical membership classes are used to classify the likelihood of membership in a class (Zadeh 1978). For example, an area that is definitely classified as, for example, being a specific soil type, is given a membership value of 1. An area that is definitely not part of that specific soil type is given a membership class with a value of 0. Anything in between is assigned a value ranging from 0 to 1, based on a membership curve. Various membership curves have been developed to represent the nature of the fuzzy relationship. These membership classes can be used to represent semantic similarity metrics for evaluation of different classifications—or definitions—of the same concept (Ahlqvist 2008). Semantic uncertainty can be reduced by developing and applying these types of measures of semantic membership.

16.2.7 Summary of Variables and Concepts of Data Uncertainty

Figure 16.1 provides various representations of spatial data uncertainty by building on the framework of Foote and Huebner (2000) and Chrisman's (1991) taxonomy of error (Chrisman 1991; Foote and Huebner 2000). These ideas are further expanded to include issues of vagueness and ambiguity that contribute to semantic uncertainty. The various sources of error that contribute to spatial data uncertainty can be encapsulated under the framework of spatial, temporal, and observational scales. Our understanding of processes, achieved through spatial datasets and geospatial analyses, is derived through this lens.

16.3 Approaches to Error and Confronting Uncertainty

> Once a model of error is developed, what good does it do? (Chrisman 1991, p. 173)

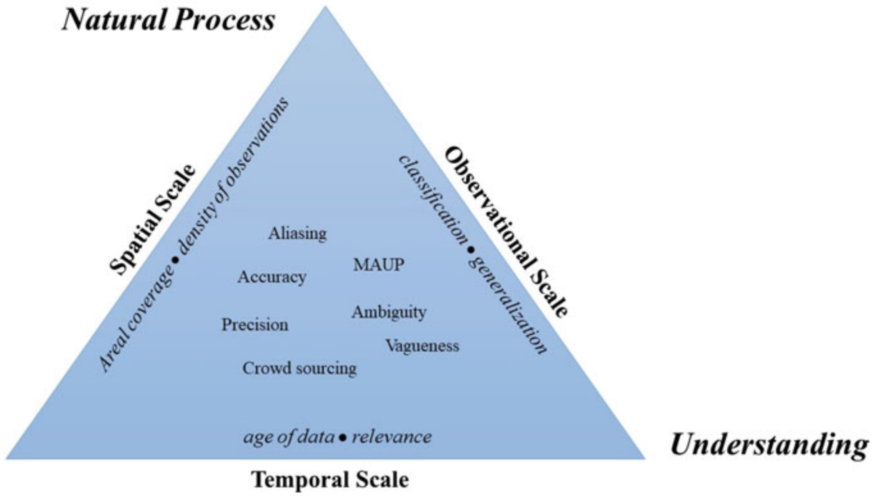

Fig. 16.1 Components of spatial data uncertainty

The previous section broadly contextualizes sources of error that contribute to uncertainty in spatial data. In this section, we discuss how our understanding of these errors can be used to address uncertainty. We provide two examples of how error can be modeled. The first example provides an example of approaching uncertainty in a raster elevation dataset. The second example demonstrates an approach to visualizing semantic uncertainty in census tract data using fuzzy set theory.

16.3.1 An Example: Modeling Error to Address Uncertainty Using Monte Carlo Simulation

Measures of error, such as the RMSE, provide mechanisms for quantifying uncertainty. Assuming that the estimator of elevation is unbiased, the RMSE provides an estimate of the variance of the error estimation. The RMSE can be used as springboard for generating random error fields. For example, in a digital elevation model (DEM), elevations are represented as continuous fields using a raster grid cell structure. Assuming that error can be approximated by the RMSE, each elevation value has the possibility of being the stated value, or any other value in a normal distribution with a mean of 0 and a standard deviation equal to the RMSE.

Numerous studies have applied Monte Carlo simulation techniques to evaluate uncertainty, specifically in digital elevation models (DEM) where elevations are represented as continuous fields using a raster grid cell structure (Ehlschlaeger et al. 1997; Hunter and Goodchild 1997; Wechsler 2000, 2006, 2007). Random error fields can be generated where each cell represents a value within the distribution of the

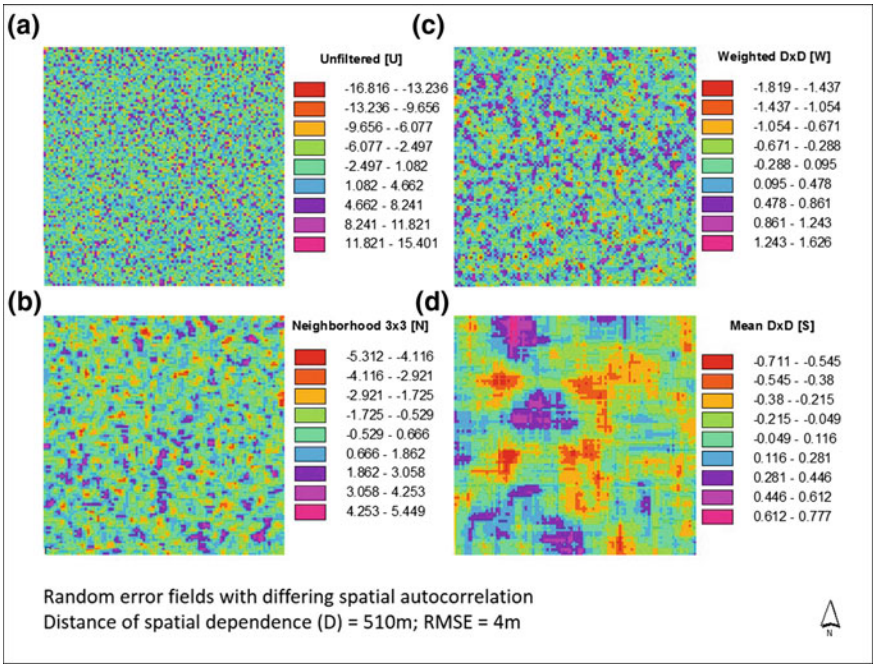

Fig. 16.2 Examples of variations of random error fields with various levels of spatial autocorrelation and based on an RMSE of 4 m. Autocorrelation is derived from a semivariogram of the distribution of randomly selected ($N = 1000$) elevation values. The sill of the semivariogram represents the distance of spatial dependence (510 m). Each error field, when added to a DEM, provides a realization of the elevation surface. **a** $U =$ unfiltered random field with no spatial autocorrelation, **b** $N =$ random field filtered using a 3×3 neighborhood, **c** $W =$ random values filtered based on the distance of spatial dependence with less weight given to cells farther away, **d** $S =$ random values filtered based on the distance of spatial dependence

RMSE. When added to the original elevation dataset, a possible realization of the elevation, under uncertainty, is achieved. Hundreds or thousands of these equally viable realizations of the elevation surface can be generated. When overlaid upon each other, and using a Monte Carlo simulation approach, statistical distributions of uncertainty, on a per-cell-basis, can be generated.

In analyzing data to determine error fields, the goal is to spatially represent the underlying potential nature of error, which as previously established are unknowable. However, in accordance with Tobler's First Law of Geography (Tobler 1970), adapted from Neprash (1934), map features, including error are more similar the closer they are in proximity (Neprash 1934; Tobler 1970). Thus, errors are spatially autocorrelated. Varying the spatial autocorrelation of random fields allows the data user to visualize and quantify error present in their data. Figure 16.2 provides an example of four random error fields with varied representation of spatial autocorrelation. When added to surfaces, each error field represents the surface under uncertain conditions.

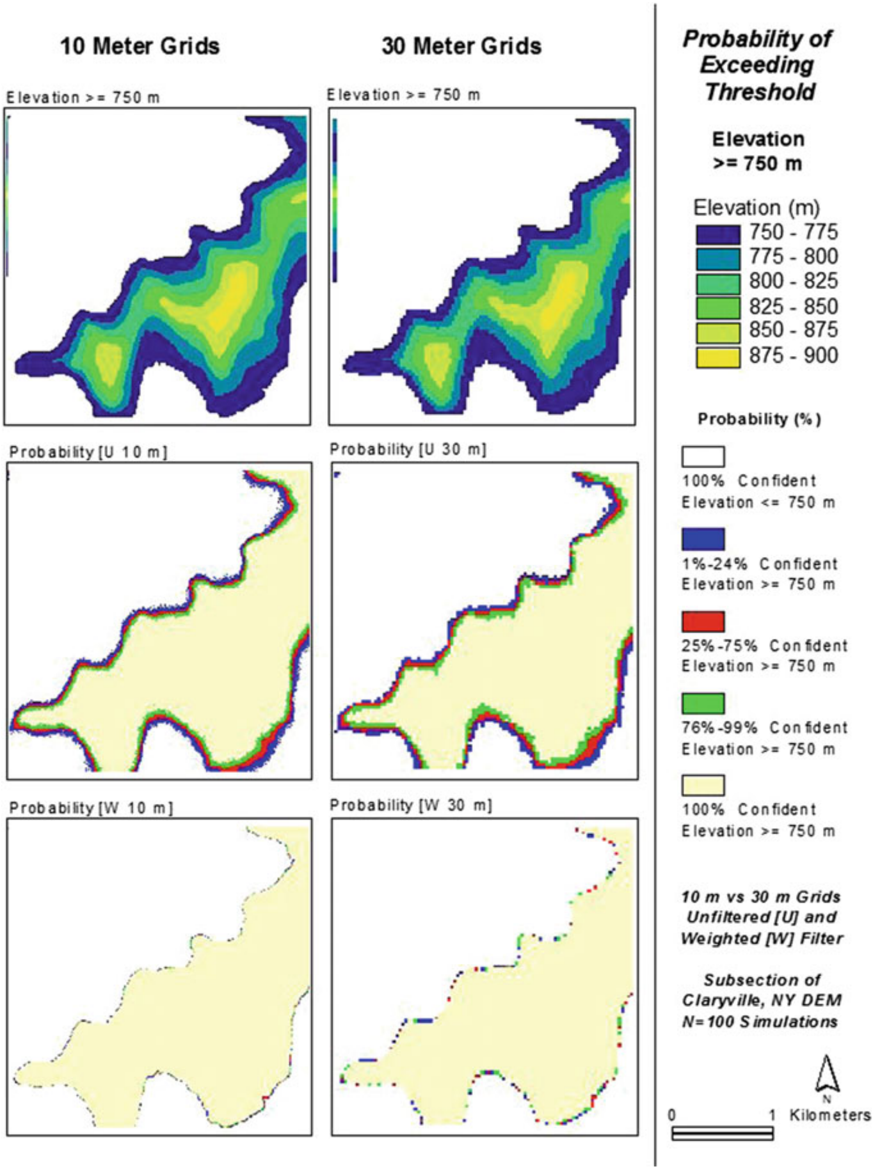

Fig. 16.3 Results of a Monte Carlo simulation demonstrating the probability that an elevation value will be = 750 m, **a** elevation values >=750 m in a 10–30 m^2 DEM, **b** probability of elevation >=750 using uncorrelated random fields, **c** probability of elevation >=750 using spatially autocorrelated random fields

Using Monte Carlo simulation techniques, these grids are analyzed to provide statistical estimations of uncertainty (Fig. 16.2). Such surface realizations can be used to derive per-cell uncertainty estimators and probability surfaces that can better inform decision-makers about the variability of outcomes (Fig. 16.3). This increased understanding of the data can enable decision-makers to consider how much error and what types of error can be tolerated in predicting events.

16.3.2 An Example: Semantic Uncertainty of the Exurbanization Concept

Exurbanization refers to the demarcation between urban and suburban areas. Here, we provide an example where fuzzy set theory is applied to address semantic uncertainty, using exurbanization as an example. The exurbanization boundary has been a subject of research in over eighteen studies; however, there is no agreement in these studies on the definition of exurbanization. This subject therefore is an excellent example of semantic uncertainty (Berube et al. 2006). For instance, exurbanization can be defined by various characteristics of a region such as population density, distance, and household lot size (Ban and Ahlqvist 2009). The same exurban area, therefore, may be represented differently based on the definition used. For example, Daniels (1999) defined the exurban areas as "10–50 miles away from a major urban center of at least 500,000 people," "5–30 miles from a city of at least 50,000 people," "generally within 25-min commuting distance," and/or "the population density is generally less than 500 people per square mile" (Daniels 1999). These four definitions are each different, resulting in semantic uncertainty.

A fuzzy set approach can be used to visualize the boundaries of the exurban areas given semantic uncertainty. In this example, we use population density for the exurban definition given by Daniels (1999) where exurban areas include "less than 500 people/mi^2." The fuzzy set membership function assigns each spatial object a membership value ranging between zero—e.g., not exurbanized at all—and one—e.g., entirely exurbanized. In addition, a membership value of 0.5 is the breakpoint of the definition—e.g., either exurban or non-exurban (Li et al. 2018). Using this function within a GIS, boundaries can be represented by their likelihood of membership and given fuzzy boundaries.

Figures 16.4 and 16.5 demonstrate how fuzzy set membership functions can be developed for a chosen exurban definition using a fuzzy set approach. According to the numerical expression of the attribute, the population density values of "500 people/mi^2" serve as the breakpoint in this fuzzy set membership function in determining whether a location is more exurban or not.

The areas between 0 people/mi^2 and 500 people/mi^2 represent fuzziness in our understanding of what constitutes exurban with high degrees. These areas are assigned a membership value between 1 and 0.5 in the fuzzy set membership function. A membership value of 0.5 is assigned to areas of the breakpoints—exactly

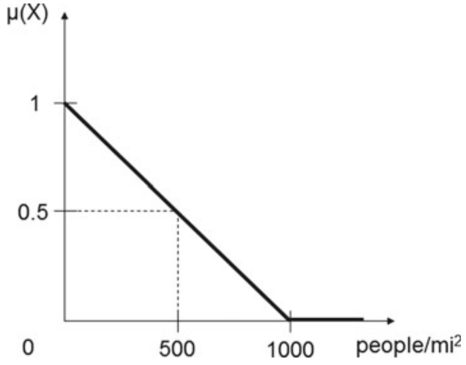

Fig. 16.4 Example fuzzy set membership functions of one of the exurbanization definitions in Daniels (1999) focusing on a population attribute. Redrawn from Ban and Ahlqvist (2009). Representing and negotiating uncertain geospatial concepts—where are the exurban areas? computers, environment, and urban systems. 33(4), 233–246, Table 1

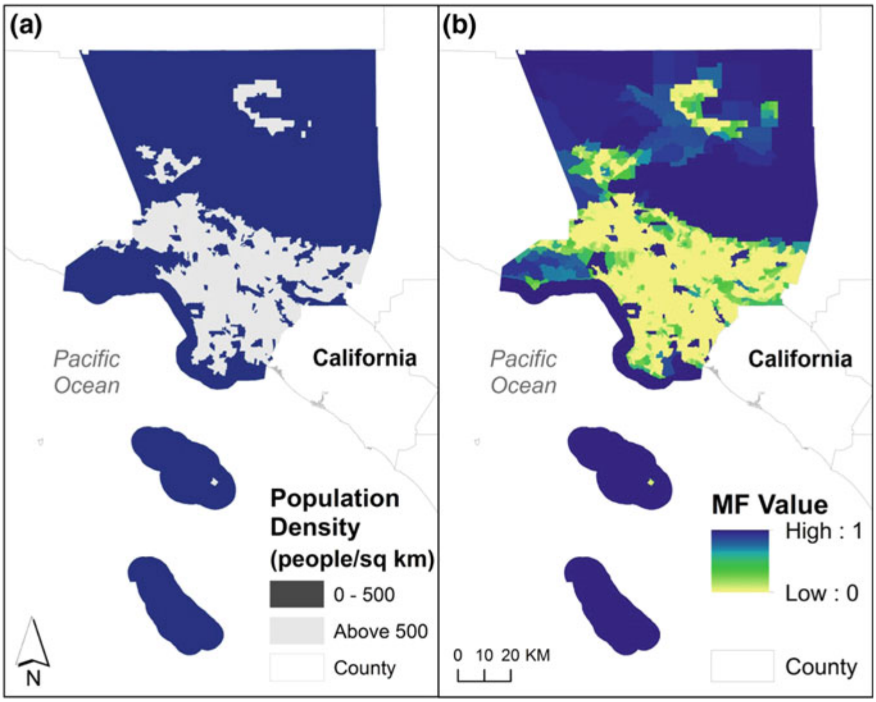

Fig. 16.5 Visualization of the degree of exurbanization of Los Angeles County, CA, U.S.A. based on the **a** crisp, non-fuzzy membership and **b** the fuzzy set membership using empirical GIS data (Census 2010)

500 people/mi^2. A full fuzzy set membership value of 1 is assigned to areas with a population density value of 0 people/mi^2, since these areas are definitely exurban. A membership value of 0 is assigned to all areas with population density values greater than 1000 people/mi^2 since these areas definitely satisfy our conceptualization of this area as non exurban (Fig. 16.4).

Following Ban and Ahlqvist (2009), a set of membership functions for population density using the membership function (mf) expressed in Fig. 16.4 can be developed as follows in Eq. 16.2:

$$\begin{aligned} &\text{mf: } -\frac{1}{1000}\cdot X + 1 \text{ for } (X \leq 1000), \text{ and} \\ &\text{mf: } 0 \text{ for } (X > 1000) \end{aligned} \tag{16.2}$$

where mf refers to the membership function and X = population density.

When Eq. 16.2 is applied to census block data, results can be visualized cartographically (Fig. 16.5). Figure 16.5b illustrates the uncertain spatial boundaries based on the exurban definition from Daniels (1999) spatially measured using Eq. 16.2 and population density in Los Angeles County in California, USA. The continuous and fuzzy scale values in Fig. 16.5b represent the heterogeneous degrees of exurbanization in the study areas that crisp Boolean-style boundaries may miss (Fig. 16.5a). Darker blue colors represent higher degrees of exurbanization.

The use of a fuzzy set approach to address semantic uncertainty is presented using the case of the exurbanization concept. The usefulness of this approach to represent uncertainty in spatial boundaries is demonstrated and serves as an example of how this information can be applied to visually represent datasets with semantic inconsistencies.

16.4 Decision-Making Under Uncertainty

Error is an inevitable component of all scientific endeavors. Error in geospatial datasets is introduced into and propagated in all spatial analyses. As described in this chapter, approaches to addressing and communicating the level of error and associated uncertainty are unique and specific to each spatial analysis and associated datasets.

The decision-maker is obligated to take into consideration *all* aspects of spatial analyses, including error. The utilization of the analyses is at the discretion of the decision-maker, who takes into account the context and nature of risks and benefits of the unique applications of the analyses. It is the responsibility of the geospatial analyst to provide a decision-maker with the data necessary to assist in determining the level of uncertainty and associated risk that are acceptable and appropriate. In fact, geospatial practitioners who become certified geospatial professionals (GISPs) must adhere to a GIS Code of Ethics and Rules of Conduct to "*…do the best work possible…provide full, clear, and accurate information…*" (GISCI Code of Ethics

2018) and "*…acknowledge…errors and…not distort or alter the facts…*" (GISCI Rules of Conduct 2018).

Academics and researchers must continue to develop accessible approaches for quantification and visualization of such error propagation, and prepare students to understand and accept such approaches. Software vendors must seamlessly integrate such measures so that they are available to practitioners who at a minimum acknowledge and communicate the limitations of the datasets that have been incorporated into analyses. Utilization of error by practitioners is a separate and complex area of study that merits extended examination and review.

16.5 Conclusions

Uncertainty in geospatial data results from error. We have identified various sources of error as summarized in Fig. 16.1. The following are examples of sources of error. (1) technological limitations affect the precision of measurements. (2) The imposition of scale in a spatial and temporal context inevitably results in discrepancies between measurement and ground truth. (3) Vague concepts, ambiguous boundaries, and contentious classifications all introduce uncertainty into geographic representation. (4) Unknown and unknowable samples and sampling procedures are the inherent sources of error in crowdsourced data.

Why should we care about geospatial uncertainty and why is this a persistent challenge of geospatial practice? The goal of geospatial information is to provide a deeper understanding of the world. Deriving understanding from information is essential for knowledge building. Common geospatial practice does not consistently include representations of uncertainty as an essential and expected component of results. The intent of this chapter was to provide a general review of "uncertainty basics." An improved understanding and acceptance of uncertainty will lead to more effective and responsible geospatial practice.

We assert that all spatial analyses should include appropriate statements of qualifications related to error. These should be sufficient to enable a user to take error into consideration in decision-making. Addressing uncertainty requires a recalibration of our perspective related to error, moving from aversion to acceptance to integration. To manage uncertainty requires acknowledging how errors are introduced into spatial data and how errors are measured. Error should be minimized to the best of our ability and then quantified to the extent possible. Uncertainty measures should be developed and applied *routinely* as a part of spatial analyses and communication of results. These tools are essential to capture the complexity in geospatial analyses and in turn used for improved application and knowledge building.

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Part III
Geospatial Challenges and Geographical Knowledge

Chapter 17
Navigational Strategies in Transition from Initial Route

Margarita Zaleshina, Alexander Zaleshin and Adriana Galvani

Abstract Here, we present a study of navigation strategies in transition from initial route with the help of geographic information system technologies. Navigation behavior is usually based on an internal plan of the route, which is compared with external data of multiple types, including (I) the results of perception of the environment, especially visual information about external objects and surface textures; (II) points, lines, and regions of interest; and (III) sets of natural landmarks or artificial signposts which make it possible to determine the current location and estimate distances to the following waypoints. In this paper, we considered how navigation algorithms may be changed if deviations and transitions from the route are possible. Here, the features of spatial orientation in two cases are discussed. The first case is explored using tracks of homing pigeons as example. With large displacements from the primary positions, the trajectory of the pigeons varies in direction, but birds are still able to find familiar sites. The second case is considered using biking tours as example. Bicyclists can take a route with considerable deviations, similar to how pigeons do it in survey flights. In both cases, spatial data was analyzed using the geographical information system QGIS.

Keywords Navigational strategies · Spatial orientation · Routing · GIS

17.1 Introduction

A navigation strategy can be defined as a complex of behavioral algorithms which are used to make decisions on the route, depending on the surroundings and the set

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of available plans and resources, based on knowledge of the environment in which the motion occurs.

A navigation strategy makes it possible to change algorithms of movement and to change intermediate points and endpoints of the route. Moreover, the task of navigation consists of drawing up navigation maps and creating plans (schedules) of routes, some of which refer to time, with instructions on modes of movement.

Montello and Freundschuh (2004), Montello (2005), defined "navigation" as goal-directed movement through the environment by organisms or intelligent machines, which may be understood to consist of the two broad components of locomotion and wayfinding: locomotion is body movement coordinated to the local surrounds; and wayfinding is planning and decision-making coordinated to the distal as well as local surrounds.

But navigation strategies also can be used by people and animals to deal with unknown or ambiguous information, including situations with changed or missing waypoints. This is a more complicated task than scheduling a route on a previously defined road graph in transport logistics. Strickrodt et al. (2015) presented two experiments investigating how navigators deal with ambiguous landmark information when learning unfamiliar routes. The authors changed reference objects along a route to study how informative single landmarks were about the navigators' location and the action navigators had to take at that location. The results suggest that route knowledge is more complex than simple stimulus–response associations and that neighboring places are tightly linked.

The paper discusses the features of spatial orientation in cases of deviations and transitions from the route. Common types of behavior are analyzed in this paper using two examples: (I) trajectories of pigeons and (II) trajectories of bicyclists. The first case is explored using homing pigeon tracks as an example. With large displacements from the primary positions, the trajectory of the pigeons varies in direction, but birds are still able to find familiar sites. We show the influence of visual properties of the landscape on the pigeon's navigational behavior, including the effects of line landmarks such as roads or rivers. The second case is considered using the cycling routes in directional trips or in sightseeing tours as an example.

In this paper, we investigate how navigation strategies may be changed if deviations from the route are possible. The spatial data were analyzed using the geographical information system QGIS (http://qgis.org). All primary materials and results of spatial data processing are presented as groups of layers in QGIS.

17.2 Spatial Orientation

17.2.1 Perception of the Environment

Apelt et al. (2007) described the basic principles of wayfinding system creation and importance of external factors in orientation. Such systems should provide information for users about how to orient themselves in open countryside or within a building, and should calculate intermediate points in an individual journey and identify the destination on arrival.

Significant external factors which influence the selection of navigation algorithms by a subject are

- Perceived background environment,
- Spatial landmarks which can help to correlate the current position with known information about the location (with a map, verbal description, or own memories),
- Objects of interest that can change the route and become an intermediate or final goal of the route, and
- External factors causing deviation from the route or forcing a change in the route (such as obstacles on the road or wind).

17.2.2 Landmarks and Attributes

Spatial landmarks help to correlate the current position of the subject with known information about the location (with map, with verbal description, and with own memories). Such landmarks include not only point objects but also areal objects and textures.

Chan et al. (2012) argued that extended surfaces or boundaries can act as landmarks by providing a frame of reference for encoding spatial information. According to Chan et al. (2012), single environmental object can function as navigational beacons, or act as associative or orientation cues. Several useful concepts have been introduced (Boccia et al. 2017; Siegel and Sheldon 1975): «Landmark representation», «Route representation», and «Survey representation». Landmark representation focuses on "beacons"—salient objects within the vista space. Route representation focuses on the path, with the sequence of landmarks, directions, and distances along the path connecting the starting point and the goal. Survey representation relies on the internal frame of reference to restructure the "route" knowledge about a given environment.

Duckham et al. (2010) presented the main approaches used to identify landmarks from spatial datasets, to select appropriate landmarks from a set for a specific route, and to incorporate landmarks into routing instructions. However, these approaches rely on detailed information about specific landmarks, which may be unavailable on certain occasions.

If reference points are selected together, then individual elements can be not taken into account or relationships between these elements can be distorted, but new elements can be added. The result may differ significantly from the originally perceived source data.

A set of landmarks may be changed gradually or, by contrast, significant changes in the landmarks set can be made at once. Abrupt changes lead to a revaluation of the data and to the occurrence of new landmarks.

Use of different external data sets causes the existing pool of landmarks to rearrange. Combining new and previously known signs and landmarks allow to evaluate the route from varied points of view and to expand the range of possible choices.

Adding new sets of data can lead to the construction of distinct routes for the same departure and destination points. For example, in the context of digital mapping, it is possible to build alternative routes in QGIS with using the online routing mapper module (https://cbsuygulama.wordpress.com/online-routing-mapper-en), based on data from altering sources (Google Directions, Here, MapBox, YourNavigation, OSRM, etc.).

17.2.3 Routing Network and Transition from the Route

The transition from the route can occur with or without changing in navigation strategy (Fig. 17.1).

Mainly, bicyclists ride along existing roads or bicycle paths with different options for movement. In one case, the transition is represented as a change of one way to another within common network of roads. In another case, the transition appears due to "walking with bike" between waypoints of distinct networks and this trip may be of various lengths. Sometimes, it is necessary to cut a path through steep terrain, cross a creek, or take a train to go to new railway station. This may result in a complete change in navigation behavior—as in the case if the bicyclist used the train to reach a remote point of the route.

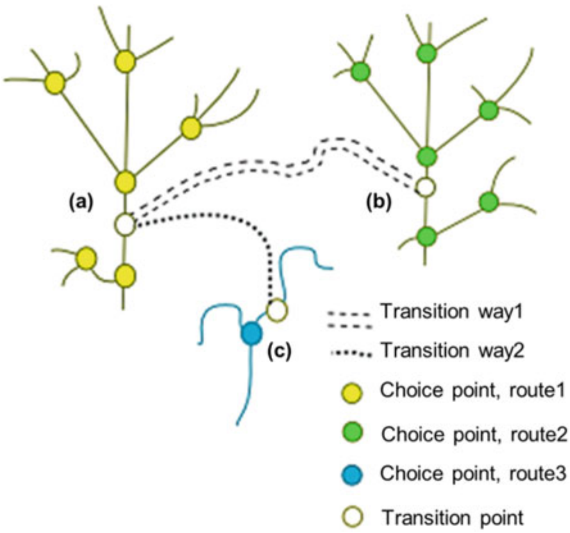

Fig. 17.1 Path trees with transitions. Transition way 1 passes from route **a** to similar route **b**, along which one can move further without changing the navigation algorithm. Transition way 2 passes from route **a** to another route **c** with new algorithm of movement

Table 17.1 Main navigational modes

Mode	Description
Planning and predicting	Accumulation of information about route, identification of key points, determination of applicable way parameters, referencing to the schedule, assumption of deviating factors
Environment perception and extraction of navigational objects	Defining of significant navigational parameters (attributes or the context for searching). Environment data perception (by a set of already defined parameters). Selection and formation of navigational objects from the background, including intermediate waypoints
Wayfinding	Decision-making coordinated to navigational objects in surrounds, including such process as searching, choice in uncertainly, etc.
Control of deviations	Comparison of expected and observed data. Time control
Choice of alternate routes in decision-making processes	Decision-making on strategy change, on the basis of deviating factors or on the basis of additional objects of interest
Postprocessing	Record information about the completed route

17.2.4 Navigation Algorithm

Table 17.1 shows the main modes that can be distinguished in the preparation and implementation of navigation strategies in the route.

17.3 Changes in the Route

17.3.1 Events on the Route

The route change can be continuous transition in which the same route attributes are kept for a long time, or it can be abrupt transition with quick transformation of a set of attributes or modification of their values. When a continuous transition occurs, the recent history of route changes can be monitored and coming changes along the route can be predicted.

Various events along the route can lead to the deviation, and may cause a complete change in the prescheduled route, for example,

– Obstacles on the road preventing movement (road repair, accident, landslide);
– Adverse weather phenomena, such as rain, a thunderstorm, and strong wind; and
– Discrepancy between the observed surrounding area and expected landmarks indicated on the map or in the description of the territory.

The existence of another route in the accessible area can lead to accidental or intentional transition to this route (Fig. 17.2). Movement along another route will be

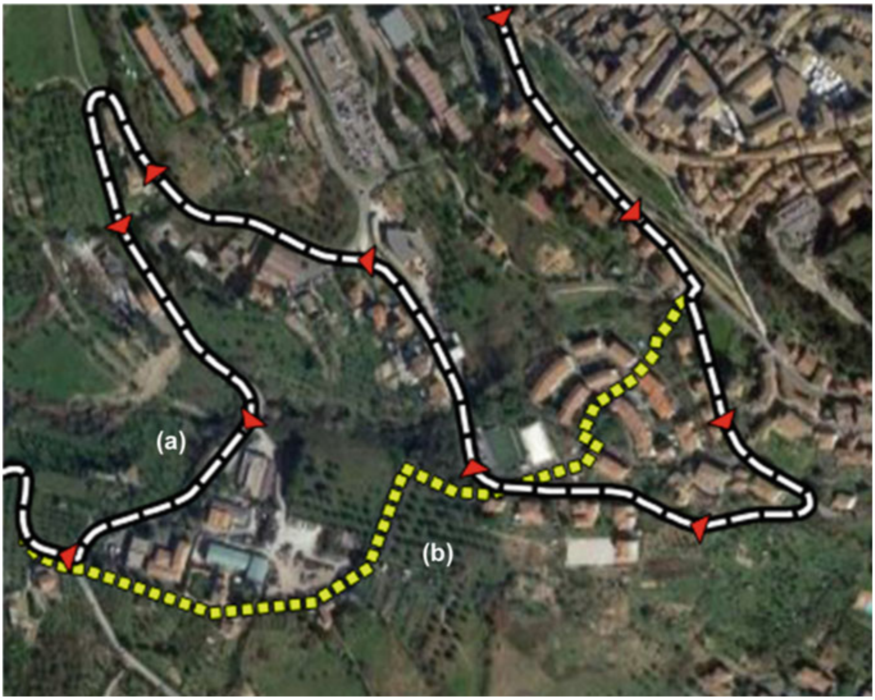

Fig. 17.2 Main and alternative routes. The dashed line **a** represents the main route offered by the mobile navigator, the dotted line **b** represents the alternative route on the site. Choice of the alternative route is possible if additional information about the road is available—or if the subject accidentally takes a wrong turn

sustainable if the route has the necessary characteristics. A change in the route can occur either along the path itself (with the choice of a certain fork in the road) or between the paths.

17.3.2 Appearance of New Landmarks

The change of route can be influenced by the specific characteristics of physical perception or by the appearance of an obstacle on the road. Vyssotski et al. (2009) presented data on the influence of visibility on the pigeon flight trajectory. As a result of a path displacement or due to a change in route parameters, the intermediate points and, possibly, the endpoints may also be changed, or may be added new points of changing route reference to additional landmarks. A change in algorithm of a pigeon flight provides such example the formation of new control points. Figure 17.3 shows the diagram of pigeon flight. This figure shows how the route change point appears during the pigeon flight in conditions of good and poor visibility when the pigeon is

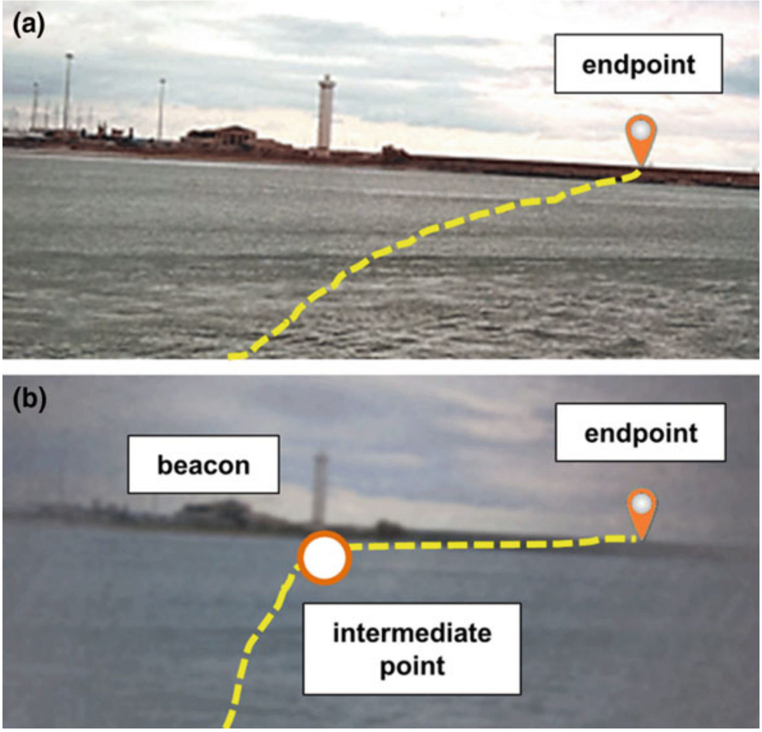

Fig. 17.3 The pigeon flight from the sea to the shore: **a** in good visibility, the pigeon flies directly to the endpoint, **b** in poor visibility it tries to use the landmarks (beacon). The dotted line shows the trajectory of flight for a pigeon in both cases

flying from the sea to the shore. In good visibility (a), the pigeon flies in the chosen direction to the endpoint along a straight line. In bad visibility (b), the pigeon does not fly straight to the goal, but to the most visible landmark (beacon), from which it continues the flight using ground reference points.

17.3.3 Displacement of Landmarks and Moving Landmarks

Zhao and Warren (2015) describe how people combine their sense of direction with their use of visual landmarks during navigation. This paper reports on a homing task, in which participants followed successive cues to walk from the starting location to home, to an intermediate point, and to the end of path, where they were then asked to return to the now unmarked home location without assistance. When landmarks were shifted, homing could be based on path integration alone, landmarks alone, or a combination of these. Similarly, Foo et al. (2005) present that humans have at least two distinct navigational strategies available to them and can switch adaptively between them. Participants generally rely on accurate landmark-based navigation, but can fall back on survey knowledge derived from path integration if landmarks are absent or perceived as unreliable.

Not only stable landmarks, but also moving entities, play a role in the production of turn-by-turn route directions. Baltaretu et al. (2017) show that moving objects as well as non-moving objects can attract attention. In this paper, it is shown that moving entities are a relevant type of information available only in the here-and-now (e.g., bicyclists, pedestrians). The results suggest that movement detected in the nearby environment can be informative in a landmark selection task.

17.4 Choice and Decision-Making

17.4.1 Navigational Map

A navigation map is produced based on previously studied data about the existing spatial objects, presented in a form allowing estimation of the relative landmark positions. For the creation of movement algorithms, an additional "navigation tip" such as a spatial representation of the route ("map") or a verbal procedural description of the route ("turn left after the crossroads") is often used as a supporting element. The "navigation tip" stored in the memory may be inaccurate: when routes are repeated, memories of previous trips will be used that may be vague or incorrect.

Navigation mental maps can be created by animals as well. Mann et al. (2014) show that pigeons have long served as a model for the study of avian navigation, and they can make use of some form of navigational map, combined with time-compensated solar compass information, to orient homeward from distant unfamiliar places. Blaser et al. (2013) investigated whether homing pigeons use a mental map: the birds knew their geographical position in relation to the targets and chose a flight direction according to their needs—clearly the essence of a cognitive navigational map.

The ability to solve spatial problems depends on the "area of perception" and the scale of the space relative to the observer. Of course, the "area of perception" varies depending on the location of the observer: a pigeon in flight sees things that are invisible to it on earth, and a bicyclist on a hill can view the area and decide which direction to move in. Wolbers and Wiener (2014) emphasized that spatial information such as direction or distance can be coded egocentrically (relative to an observer) or allocentrically (in a reference frame independent from the observer). Montello (1993) suggests that the ways in which individuals differ in their abilities to solve spatial problems may be distinct at different spatial scales. The author's terminology reflects a concern for the size of a space relative to a person, and more precisely, to a person's body and action (e.g., looking, walking). Scale is important in tasks such as navigation or landmark location. The scale of a map and methods used to describe distances usually vary and are correlated to the average travel speed (hours of walking, days of driving, etc.), which is primarily determined by the area of perception. The schedule of movement can be drawn on the base of the map.

17.4.2 Uncertainty and Ambiguity in Navigation

Jonietz and Kiefer (2017) proposed a conceptual framework for modeling uncertainty in wayfinding using reference system transformations. The authors state that uncertainty in wayfinding is always related to a spatial reference system. They distinguish three types of uncertainty: egocentric (path choice), allocentric (current location), and survey (wayfinder's location on a map).

In navigation, it is often necessary to make a choice in conditions of lack or excess of information. It is difficult to choose one of two ways (excess of options) without knowing which one is better and easier (lack of knowledge).

When information about a route is lacking, individuals may try to repeat patterns of behavior, which may no longer work. When a person appears in a new place, one will try to use a previously tested set of patterns of behavior. But, to use them, a reference context which can be used for the implementation of well-known algorithms is necessary. Route repetition in conditions in which information is lacking may be an attempt to associate a route with a previously known context. But this does not always account for the possibility that the context could change or disappear after time, and that previous sets of behavior patterns may be not applicable.

Often, when selecting intermediate waypoints under conditions of uncertainty, the objects are selected by their significant parameters or set of parameters (the most convenient highway, the picturesque lake, the most famous museum, etc.).

17.4.3 Choice on the Routes

The route can be represented as several segments, within each of which motion has a slight radial deviation, without changing the main parameters of the route. It should be noted that a turn in the road is not necessarily the point at which navigation behavior changes. For example, if a bicyclist is following the road, there is no need to make a choice when the road turns—he will simply follow its movement. Route selection may occur at the fork in the road.

At the point at which navigation behavior changes, the subject can make a choice of multiple sets of behaviors that define the transition to an altered route.

In the example shown in Fig. 17.4, the subject chooses between two possible routes, one of which involves a longer travel distance. To arrive at endpoint 1, it may be enough to reach endpoint 2 and walk with the bike along a footpath between buildings.

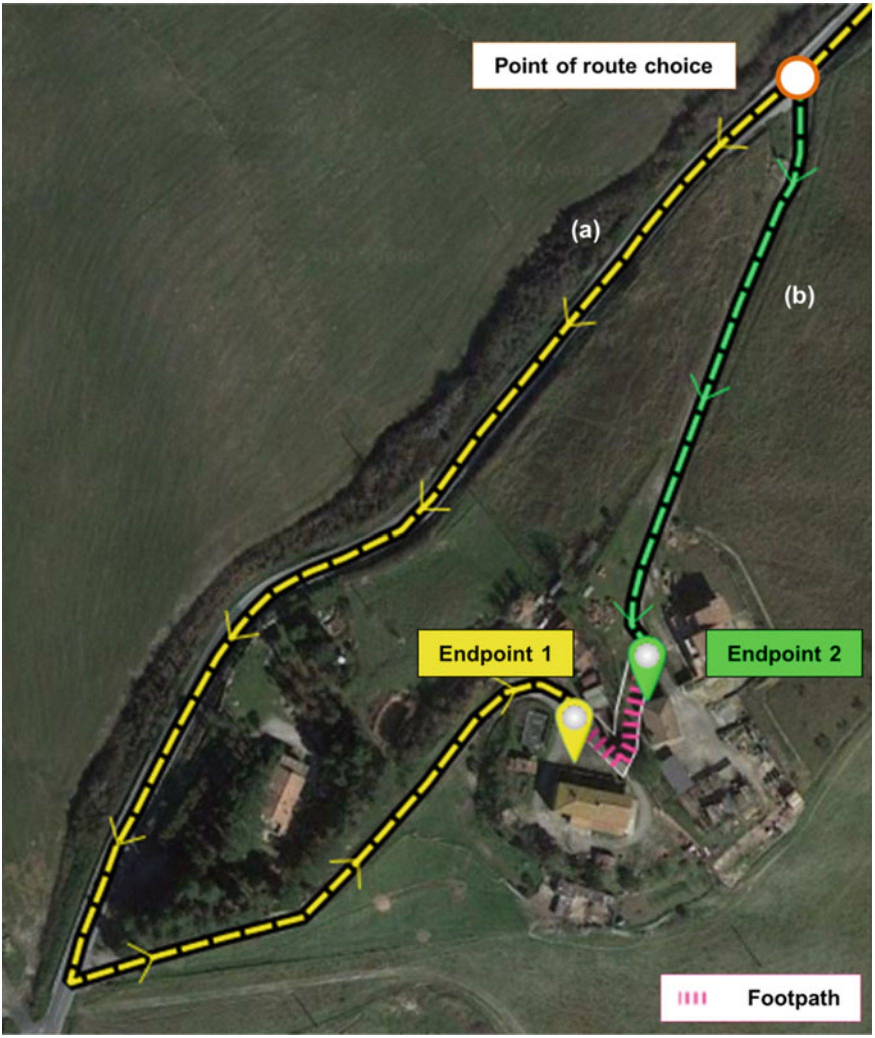

Fig. 17.4 A point of route choice for bicyclists and two alternative routes involving multiple sets of behaviors. Long dashed lines **a** and **b** indicate first and second alternative routes, short perpendicular dashed line indicates the footpath between Endpoint 1 and Endpoint 2

17.4.4 Predicting Navigation in Motion and Route Planning

Predicting navigation in motion is considered in (Grübel et al. 2017), where, on the basis of experiments performed on people's behavior in virtual reality, it was shown that a dynamic task (i.e., intercepting a moving object) is capable of predicting navigation performance in a familiar virtual environment better than several categories of static tasks.

A route planning problem is a special case of an algorithm for selection of a navigation strategy. In route planning as part of transport logistics, it is usually specified that the route should be optimized for some of the parameters (e.g., average speed, elevation, turnover of cars, or minimum time of transportation by public transport). In such a case, the external environment is the road graph; the calculated routes have a start and end point, and perhaps a set of intermediate points.

Virtually, all modern GIS systems have applications for route creation if information about the road network is available, as can be seen in the example at http://planet.qgis.org/planet/tag/routing. An overview of the transport geography tasks and possible application of GIS technologies to them is given by Weisbrod in (2011). A detailed review of Advanced Route Planning in Transportation Networks is given by Geisberger in the thesis (2011), with discussion of how route planning takes points of interest (POI) and node optimization into account.

GIS technologies can be used to study not only the behavior of individuals but also joint strategies for moving in a group. In this case, it is necessary to take into account the fact that movement is guided not only by the objects of the external world but also other members of the group.

17.5 The Application of GIS Technologies in the Study of Navigation Behavior

17.5.1 General Context

In this section, two different cases for the selection of a navigation behavior are studied. First, pigeon flights are discussed. This is characterized by free movement along the earth's surface, and the choice of route is made based on natural landmarks between start and the endpoint and the training level of the pigeon.

Next, trips of bicyclists are considered in which the choice of movement route is generally associated with the road network.

17.6 Open Spatial Datasets and QGIS Plugins

In this study, open remote sensing data were applied. The source data layers were added using the OpenLayers plugin in QGIS, which allows to obtain Google Maps, Bing Maps, and other open layers. The original coordinate system is WGS 84/Pseudo-Mercator (EPSG:3857).

The data were processed using the Open Source Geographic Information System QGIS (http://qgis.org), including additional analysis plugins: GDAL/OGR, QGIS geoalgorithms, SAGA, GRASS, and external QGIS plugins (Table 17.2).

Table 17.2 External QGIS plugins

Plugin	Description
OpenLayers plugin https://github.com/sourcepole/qgis-openlayers-plugin	QGIS plugin embeds OpenLayers (http://openlayers.org) functionality. It uses WebKit to render web-based map services using their official Javascript API
Points2One http://plugins.qgis.org/plugins/points2one	Create lines and polygons from vertices. Connects points in a layer to form lines and polygons
Online routing mapper https://cbsuygulama.wordpress.com/online-routing-mapper-en	Generate routes by using online services (Google Directions, Here, MapBox, YourNavigation, OSRM, etc.)
The QGIS line direction histogram plugin http://arken.nmbu.no/~havatv/gis/qgisplugins/LineDirectionHistogram	Create a histogram (rose diagram) of line directions Visualize the distribution of line segment directions as a rose diagram (weighted using the line segment lengths)
AutoFields http://geotux.tuxfamily.org/index.php/en/geo-blogs/item/333-autofields-plugin-for-qgis	This plugin allows to configure vector fields to be automatically calculated when digitizing new features or modifying existing ones
Statist https://github.com/alexbruy/statist	Calculate and show statistics for a field

We used QGIS applications to identify typical deviations from the pigeon track for different cases. Analysis of a set of directions for a sequence of node points along the route was used to detect sharp deviations from the routes. At the coincidence of the initial and final points, the direction trends calculated for these routes may be different. This statement is correct for various scales and lengths of routes.

17.6.1 Case 1. Pigeons

Here, we consider typical pigeons' tracks. In this example, documentation of pigeon's flights from the Dryad Digital Repository (http://datadryad.org) was used. Pettit et al. (2012) used GPS tracking to examine the ability of pigeons to learn a homing route and the shapes of these routes. Data on her work are available from http://datadryad.org/resource/doi:10.5061/dryad.53f4b. All flights were monitored using micro-GPS data loggers, and the GPS track data consist of a set of points in CSV format. The pigeons started at various times in similar weather conditions and flew about 12 km.

The direction of movement of pigeons in their initial flights reflects the characteristics of the area in which they moved. The route along which the pigeons flew had deviations both to the left and to the right relative to the straight line connecting the start and endpoints of the route.

Figure 17.5 shows typical set of initial pigeons' flights. The deviation from a straight line and other changes of direction presumably can be explained by tenden-

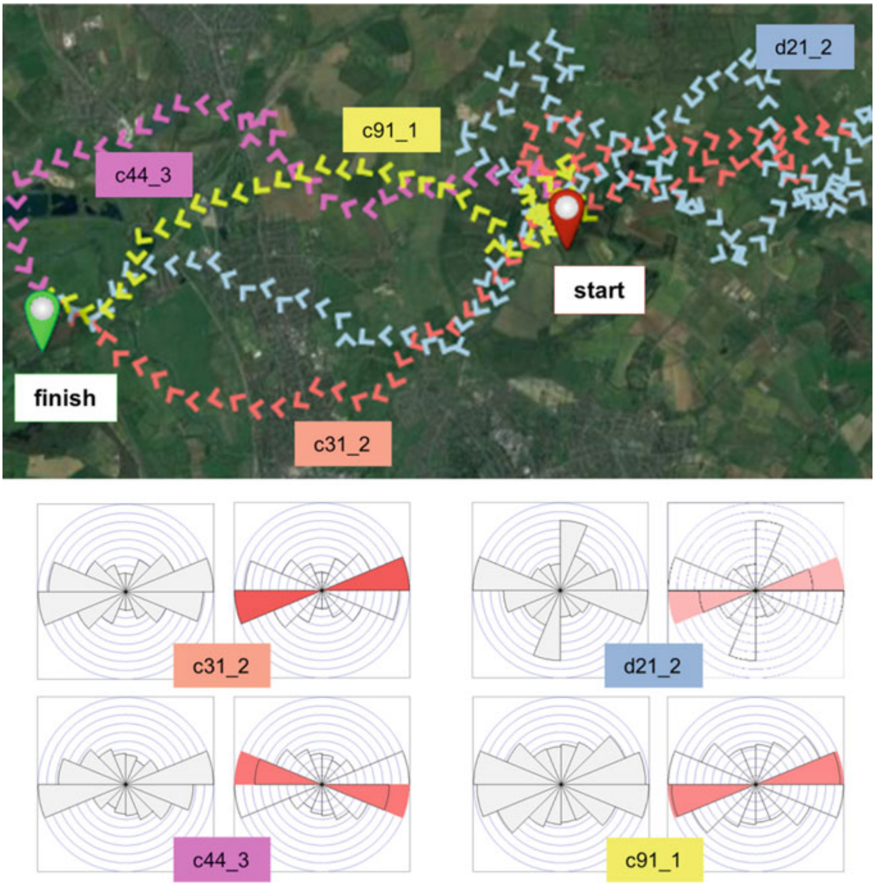

Fig. 17.5 Initial deviation of the pigeon tracks in their initial flights. Summarized line direction histograms of pigeons' movement are shown below the map with appropriate flights' numbers. Rose diagrams are shown to the left and trend direction diagrams are shown to the right for each flight case

cies for the pigeons to fly toward a high object (one pigeon with number c44_3) or along long linear objects (three pigeons with numbers c31_2, d21_2, and c91_1). The sets of directions are various for each of the pigeons, but the general trend line differs only for the pigeon c44_3. It should be noted that these pigeons did not fly together.

As can be seen in Fig. 17.6, deviation is reduced in the process of training. To explore the effect of teaching on deviation, the center and zone of the flight route were calculated for trained and untrained pigeons with SAGA's analysis tools.

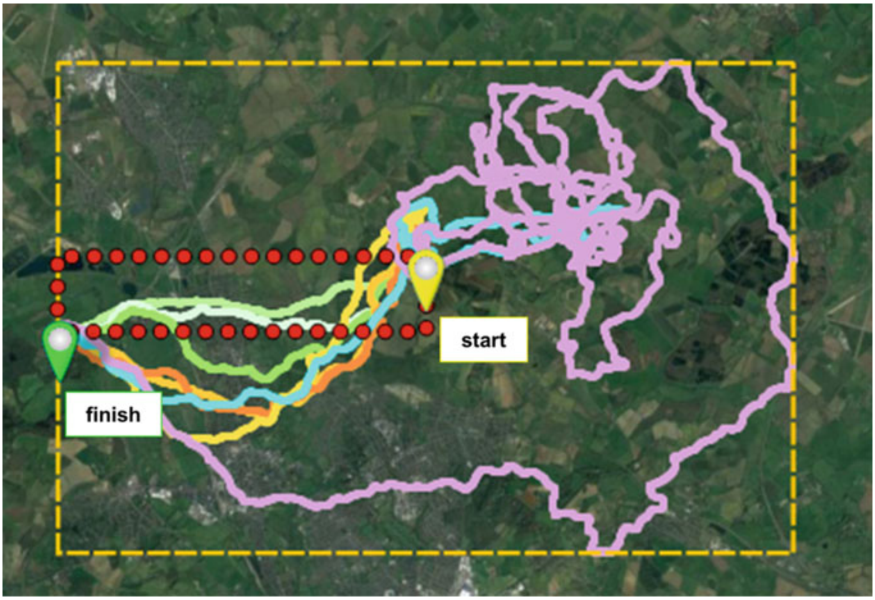

Fig. 17.6 Reduction of deviation after training. Flight paths of trained and untrained pigeons from start to finish. Dashed line indicates variation in deviation for untrained pigeons, dotted line—in deviation for trained pigeons

The following sets of deviations can be identified based on the analysis of pigeon trajectories: (i) deviation at the start and at the finish—at the start, deviations are larger; (ii) deviation to newly emerging points of interest; and (iii) deviations associated with linear landmarks. All these cases are shown in Fig. 17.7.

17.6.2 Case 2. Bicyclists

In the second case, bicyclist trips are discussed, with reference to data on the actual bike rides. We obtained records of cycling tracks from the site https://www.bikemap.net. Bicyclists moved both along bike paths and along the highway.

Over short distances, bicyclists can ride to directional trips or to sightseeing tours. It should be noted that bicyclists can take a route with considerable deviations, similar to how pigeons do it in survey flights over the terrain (route 1c in Fig. 17.8).

In traveling over longer distances, bicyclists can choose different routes and to find transition points between these routes if it is required (Fig. 17.9).

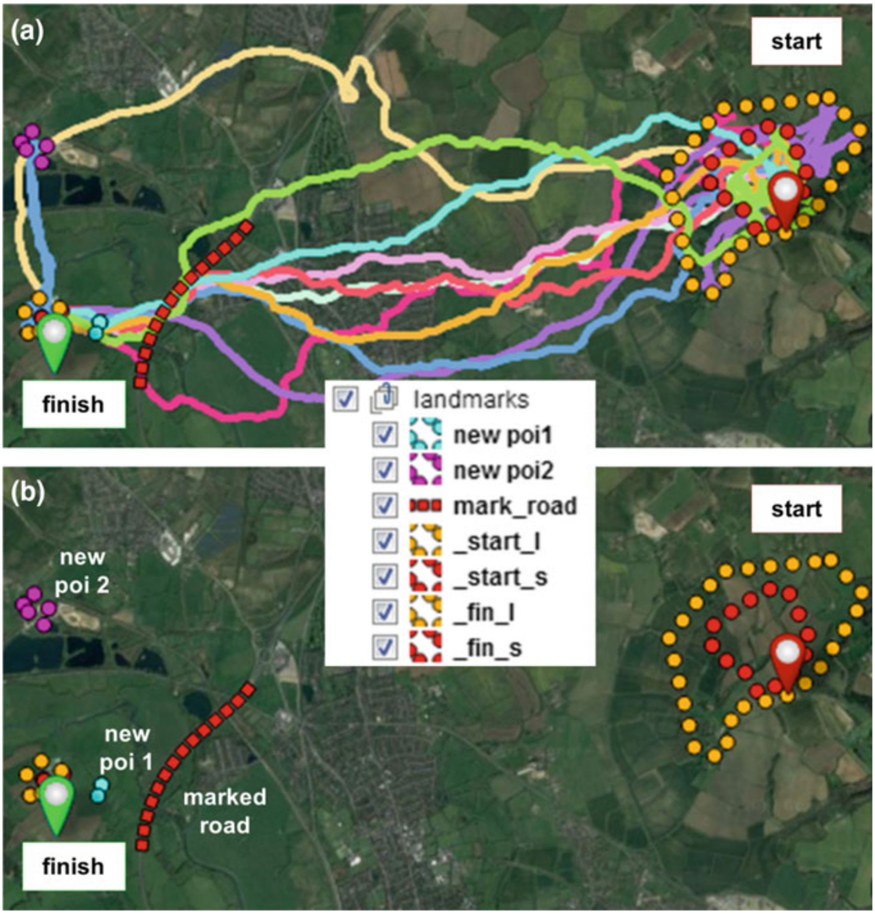

Fig. 17.7 Main sets of deviations. Basic sets of deviations: **a** deviation areas and landmarks are shown together with the trajectories of pigeons, **b** deviation areas and landmarks are shown without pigeons' tracks. Colored dots show the main area of regions of interest (ROI) at the start, in flight, and at the finish. The dashed line marked road as the line of interest (LOI). "New poi 1" and "new poi 2" refer to new points of interest, which was discovered by pigeons

17.7 Conclusion

Human and animal brains maintain all spatial knowledge about the Earth for many generations, especially when this is correlated with features of the natural world. This is shown by animal migrations, which always follow the same paths, guided by natural characteristics. Ancient people were able to find the right path without any navigation devices. Nowadays, researcher's goal could be to restore these inherent skills and combine them with the new digital tools. Special education could merge the knowledge of the natural world with the opportunities provided by new media.

Fig. 17.8 Deviation in a short-distance trip. The summarized direction of movement of bicyclists reflecting characteristics of the area through which they moved. Rose diagrams of the general direction trend for different parts of the route are shown on the right: **a** on the road to Viareggio, two bicyclists go straight along the cycling road, along the sea, and along the path with bends, approaching closer to the mountains or moving away from them, with regular increases and decreases in altitude and **b** on the road from Viareggio, two bicyclists follow different roads: the first traveling along the cycling road, along the sea, and the second traveling—closer to the mountains, with slight changes in altitude and direction of movement

In 2014, the Nobel Prize in Physiology or Medicine was shared, with half of the prize awarded to John O'Keefe, and the other half awarded jointly to May-Britt Moser and Edvard Moser "for their discoveries of cells that constitute a positioning system in the brain" (http://www.nobelprize.org/nobel_prizes/medicine/laureates/2014). Bor-

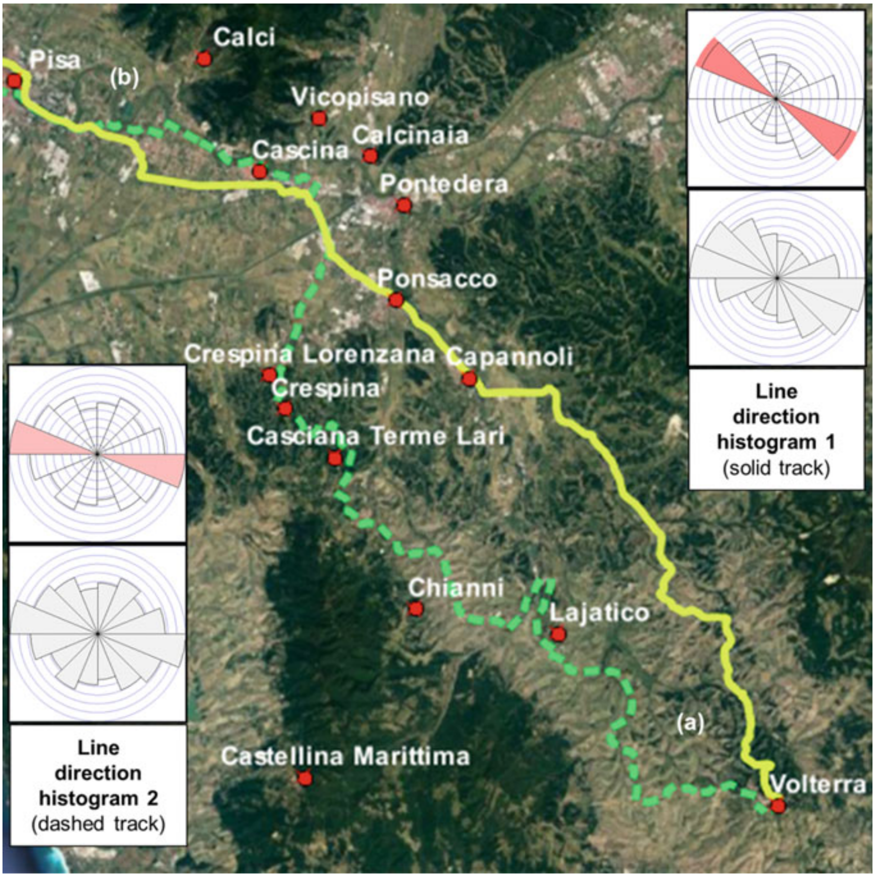

Fig. 17.9 Deviation in a long-distance trip. Each trajectory of bicyclist reflects characteristics of the area where bike ride took place: **a** on the road from Volterra to Pontedera, two bicyclists follow directly along the different paths, which do not intersect, but there is a large distance from one bike route to another. It is difficult to imagine a situation in which, if one track is under repair, the bicyclist can go into another bike path without much effort and **b** on the road from Pontedera to Pisa, two bicyclists follow directly along the different paths which do not intersect, but are located a small distance from one bike route to another. So, if one bike path is under repair, the bicyclist can go into another bike path without much effort. In both cases, two bicyclists follow their own bike paths with slight changes in altitude and direction of movement

der cells, grid cells, and head direction cells constitute the elements of a spatial representation in mental map, and are likely used when an animal navigates through its environment. During spatial survey, pathways are permanently stored in the brain, so that animals can restore previous experiences and retrace an already completed route. All this has been demonstrated in mice and is supposed to exist also in humans, for whom the experiments are more challenging. It is certainly reasonable to suppose that the same capacities are present in humans, since many animal species have a spatial memory, inherited from ancestral times, and even from the first appearance of those species on Earth.

As a confirmation, we can give the example of birds, being these among the oldest living species. They are surely the best able to organize their scheduled trips along thousands of kilometers, even if other species are more mobile. To do this, they use an innate sense of direction in relation to the relative positions of the sun and stars.

While animals maintain navigational capacities, people prefer to improve technological skills, developing the application of GIS and navigation technologies. The process of digitization of maps is a cultural revolution that is as crucial as the emergence and development of language. Unfortunately, at a time when technological processes facilitate new skills, there is a risk that innate skills will disappear.

We think that new navigational abilities can advance further, if scientists are able to coordinate biological research with medical, engineering, geophysical, and geographical investigation.

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Chapter 18
Perspectives About the Meaning of Space

Mairie Doufexopoulou

Abstract The second part of the twentieth century established extended changes in many fields of life. The impact of geospatial technology and informatics introduced a configuration of new goals in science and engineering or has extended the perspectives about traditional issues on the complex use of the Earth's surface. New learning topics and needs of expertise with technological tools were introduced to handle an abundance of new types of data, their management, processing and use for many goals. Space—or space-time in relativistic physics—is a foundation entity either as variable or parameter for the description or a solution of many professional problems in a perspective of geographers or of other professional users. The forms of its representation (i.e. mapping forms) as well as its qualification features (i.e. physical, properties, human-based activities) are means for a geospatial representation of geographical "objects". Thus, geospatial technology provides also a paradigm of how two foundation meanings about (a) "space" and (b) "geographical objects" (or geo-information) are merged in the complex use of technological "tools" as Global Positioning System and Geographical Information Systems.

Keywords Geospatial technologies · Space · GPS · GIS

18.1 Introduction

Geospatial and Information Technology developed during the second part of the twentieth century in course of Space Exploration and Communications and initiated the establishment of four technological branches: (i) Remote Sensing/Satellite Imaging (ii) Geographical Information Systems (GIS) (iii) Global Positioning Systems (GPS) and (iv) Internet Mapping Technologies. In context of these branches, there are various disciplines in which the diverse objectives in context of applications use commonly "space" as an entity receiving particular meanings.

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At “first glance” the contribution of these technologies enlarged and extended the use and the representation approaches of geographical and physical “space” (or space-time in relativistic Physics) on and around the Earth. Through “space” one may establish a conceptual and mathematical interconnection between the various types and forms of data, which are acquired either (i) to describe (map) parts of “space” or determine (ii) “places” of *imaging* geospatial “objects” or various human activities and physical processes. The contribution initiated also: (i) *various new learning subjects* and a *continuous need to upgrade practical expertise and skills* for handling the associated technological “tools” (i.e. complex measuring systems, hardware, software, data platforms) (ii) a necessity to improve a mutual understanding on the associated meanings about “space”, followed among professionals (e.g. engineers, developers, town planners, geographers, sociologists, Earth scientists). In fact “space” is a variable entity for a description of Nature and also for a description of human activities or physical processes within “space”. Also, the impact of “space” upon measures for its description or upon geo-referenced “objects” is an object of study in the context of geography. Hence the role of “space” in forming/solving problems may receive various qualifying perspectives for its description.

The involvement of physical “space” for mapping or monitoring geo-referenced and/or time-varying geographical “objects” at “places”, is classified in the various disciplines (professional uses) with respect to an associated meaning according only to two main groups: (i) disciplines *related to spatial mapping* (ii) disciplines commonly using *the impact of “space”* (or space-time) upon physical or human-related processes. The first group includes all professional objectives to map the “space”, “objects” and “places” within it, while in the second one the “space” beyond its mapped form may *receive qualifications* which are associated to the illustrated “objects” or its physical properties (in case of data processing, or other reductions) at “places”. Hence, “space” is a dual physical/conceptual entity, used to “place” various sorts of “objects” and/or interconnect its impact upon mapped “objects” (geo-referencing information). A trivial example is the combined use of **GPS**, satellite imaging, **GIS** platforms and Internet Mapping Technology for everyday needs (e.g. mobile phone guidance maps).

Several professionals or experts of technologies do not have a clear perception *about the role and the varying importance of the contribution* of “space” in forming or solving actual problems. In practice, this importance relates to standards of *required resolution and accuracy of mapped “places” or of recorded “objects”* in particular problems. These mathematical measures can vary depending on the impact of the spatial contribution either when “space” is only *a variable* to describe or simply when “space” is *a parameter* with impact upon the spatial variation of geographical “objects”. For mapping/positioning, the space is represented by forms based on mathematical rationality (models of space) through a type of “geometry”. For geo-referencing “objects”, the perspective about “space” includes other qualifications according to user-selected properties, which depend on the type of mapped “objects”.

Thus, the *thematic spaces* of Geography are characterized by relative importance of the mapping form of “space” as in the Geographical perspective the (geographical) scale keeps a significant role. For physical “objects”/entities the terms "space"/"place" keep equal importance in the context of their mapping. For "objects" of cultural meaning or representing human activities (e.g. social, economic and cultural processes) the mapping of "space" is less important than the mapping of "objects". A rigorous description about how various professions in science, engineering, environmental or geographical issues, meteorology, etc., profited of the geospatial technology is an exciting, challenging but difficult task.

This work attempts to classify the variety of followed perspectives in the use of physical "space" and data acquiring systems either for (i) mapping/positioning or (ii) monitoring the variation of geographical "objects", according only two main orientations: (i) The *professional*, which includes all mapping/positioning disciplines and disciplines in context of using the geographical space or planning in it. (ii) The *philosophical*, which introduces the *mental way* to consider the Nature for its description either as conception or as perception and human/cultural activities within "space" in the context of existing ideologies.

Thus, in the context of a general modeling of "space" two professional orientations are combined: a representation (mapping) form and the perspective of an entity having an impact and interrelating various geographical "objects". For simple mapping only, a description about "space"/"place" is used but in geography or other parametric contributions of "space", the standards relate to its use and include user-defined properties. The professional users of geographical "objects" meet this *duality* as (a) a representation form (a mapped product of space) (b) a conceived or perceived entity for interrelating "places" of "objects" which may be qualified in various perspectives. All mapping forms (from the old printed maps to digital/electronic on real-line imaging) of "space" may include the consideration of a *mental evolution* in a geographical perspective (phenomena, economy, town and regional planners, managers, social users, decision makers). Such a perspective reflects the "history" of "space" and/or the impact of social structures in it. Some of these features are not subjected to rationalism; hence a perspective of *postmodernism* may be considered e.g. Knox and Marston (2007).

Professional experts on Geospatial Technology develop and use applications of remote sensing techniques, satellite imaging (Mapping professions, engineering applications, other geo-sciences, oceanography, climatology, hazards). All these "products" (hardware, software, measuring systems) support various sectors for providing answers on (i) *where* (ii) *what/how* much (iii) *when* for all types of georeferenced "objects". The priority among *where, what, when* varies in disciplines. The terms "space"/"place" (i) describe, monitor, support diverse problems or processes in Nature and engineering and (ii) contribute to methods to acquire various data types by different technologies for various professions.

A goal of this chapter is to diffuse the idea that all mapping forms of "space" beyond the determination of "places" may include inhered social/political, cultural and physical perspectives in geographical/cultural/physical "space". There is an entire class of perspectives about "space" in using Geographical Information Systems. A mapped region is a result of a rational process but in mapping cultural issues the impact of "space" *becomes an intellectual process* in the context of the thematic character.

18.2 Professional Perspectives About Space

A basic difference between professional perspectives (in context of particular disciplines) in using “space” is according to its use either as (i) geospatial mapping disciplines where “space” is an “object” to represent or (ii) Geography and all other professional or Engineering issues in which “space”/“places” are “means” to interrelate various sorts of “objects” (geo-information) or the impact of “space” upon physical phenomena. A conceptual difference between the two perspectives is that for geospatial mapping (i) the priority is for a rigorous description either of a conceived or a perceived form of “space” (called a *model space*). For Geography or other professional uses (ii) the priority is given to a *mapping of geo-referenced “objects”* and the impact of “space” through “places”.

Geospatial, technology emerged the Geographical perspective in many Environmental, Engineering applications and complex decision-making issues. For only the mapping “space” disciplines the meaning of “space” kept the *objective perspective* to describe “space”, which is *founded upon the impact of human senses about a perceived local geometry* (e.g. the direction of natural height coordinate along plumb-line, the 3D Euclidean perception of space, the dependence of spatial mapping geometry on the Earth’s shape). In view of Geography as a field of science for studying lands, their features, human activities and diverse phenomena of the Earth, “space” reveals the real meaning of this branch—as the term Geography in Greek means *to describe the Earth* (*Γαια-γραφω*). Geography is *an encompassing discipline* for understanding of the Earth and its *human* or *natural* complexities.

In this description, any mapping form of physical “space” is only a part.

There are three main ways to view Nature:

(1) As a way of looking after *place, space, scale*.
(2) Through domains of synthesis between represented “objects” and physical environment.
(3) As spatial common representation forms of places/“objects” as visual, verbal, mathematic, digital, cognitive approaches.

The third way illustrates the best how geospatial technology penetrated for the Nature’s description and how all Mapping disciplines contributed to the Geographical scale. The connection of two, distinguished in past, professional perspectives in context of “space”/“place” is illustrated well by the GIS (Geographical Information Systems) platforms, which provide answer to “*where*” about any geographical “object” and many presentations of how geo-referenced “objects” interrelate, changed or come to be. Geography is a *thematic discipline*, characterized after the type of illustrated geographical “objects” and the *history of the thematic space*. Another perspective of Geography may follow its main research branches: (i) spatial analyses of natural/human phenomena (ii) area studies of places and regions, (iii) studies of human–land relationships (iv) earth Science (website-1).

Finally, in professional terms of human and physical geography, Geography is a study of people, communities, cultures, economies and interactions with Environment by investigating their relations with and across space/place. Geography includes both foundation perspectives about geographical “space”: (i) a study of processes and patterns in natural environment (atmosphere, hydrosphere, biosphere, geo-sphere) (ii) the study of human processes placed in a representation form of “space”. Hence any formal meaning of “place” is a restricted viewpoint of positioning in context of a particular representation form of “space”. All perspectives about “space” include “objective” representations associated to a given structure of rational models of space and “subjective” views associated to particular professional users.

The relationship between objective and subjective views of the geographical space may be illustrated by adopting Lefebvre’s principal work (Lefebvre 1992) in which he provides an *ideological basis* about a connection between objective and subjective perspectives. That work expresses how the conceived (modeled) or the perceived (sensed or measured) manifestations of space can interact. He had introduced some important implications for an analysis of space on an ideological base. In contrary, the professional branches having as main objective or simply using any mapped form of space/geo-referenced “objects”, give priority of importance to a rigorous description of space/“objects”. Such descriptions are quantified by *resolution and accuracy* of the mapped space or by the represented values of spatial elements (=differentials of the unit descriptive form of “space”) or of the represented “objects”. These Mathematical measures qualify the accuracy and/or precision of these mappings. Such a mapping either of “space” or “objects” in it, starts from a particular *conceived* or *perceived* model of “space” and/of mapped “objects” at “places” through a coordinate frame. If the mapped “object” is only a “place”, its mapping is in context of Mathematical/Physical background, which is based on a *geometric structure* among points, lines, areas, volumes by *using different geometries* for the rigorous representation form of the differential element **ds** of a spatial “distance” or of a volume **dv**, using thus various systems of coordinates.

Analog or digital mappings describe only a Mathematical differentiation *in theory*, resulting variations in the resolving capability of a model space or to analog, digital or image-based representation forms. However, in practice, there are physical variables in space or instrumental impacts that should be used upon acquired measures coming from complex measuring systems of Geospatial technology. Their use aims to eliminate irrelevant physical and instrumental effects and provide the conversion of measurements into “geometric” entities for the description of spatial coordinates. Such physical variables include—among other impacts—physical fields of the Earth’s system (gravity, electric, magnetic), or meteorological measures (air pressure, wind force) and other geographical natural variables such as oceans, streams or the *terrain relief*.

In fact, fields of Geospatial Technology *initiated models with complex description about the Earth, the geo-referenced space and the Earth’s system*. The technological “products” (measuring systems, hardware and software entities) assisted greatly to determine unique places in a Universal positioning system **GPS** (Global Positioning System). The raw geometry perspective of the simplest description of this system starts from a *pure simple Riemann geometry* (ellipsoidal geometry) and a homogenous Earth’s ellipsoid. However, several physical features in atmosphere, ionosphere as well as the impact of the time upon the trajectories of satellites are involved in

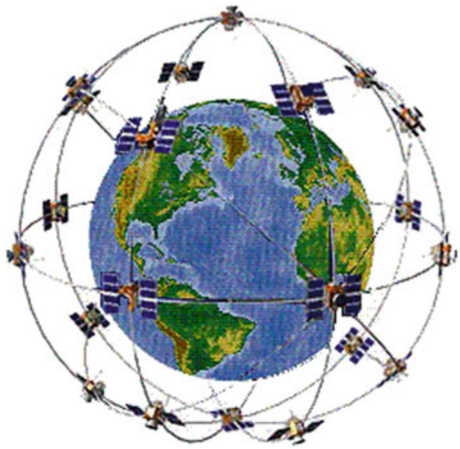

Fig. 18.1 The constellation of GPS satellites around the Earth for positioning (from https://www.pdhonline.com/courses/l116/l116content.htm)

processing radar measurements between satellites and a place for the optimal determination of a junction point of distances given by its geographical coordinates, which describe GPS coordinates. Naturally, the impact of the Earth's gravity field upon trajectories of several positioning satellites had been a crucial professional issue to consider in technological research, before the release of many types commercial GPS receivers, which presently are in everyday practice. The background of Geospatial technology involves deeply relativistic Physics (Fig. 18.1).

18.3 Spatial Mapping and Geographical Space—The Ideology Link

The meaning of "place" expresses a restricted consideration of positioning in any representation form of "space" in *absolute* or in *relative* scale. For Geography and several professional uses, the *scale, place* and *space* determine a way to look at the World (here as a synonym to Nature). Geospatial technology founded on the dual Mathematical/Physical consideration of physical "space", involves a structural "space" as a basis to determine "places" through various mapping models. These models differ only in their mathematical structure (through geometry) and the system of coordinates. Any type of structured basic "space" (model space) can be used to add perspectives of thematic meanings on any particular professional use and represented "objects". For Geography, a mapped form of "space" is a necessity for any further spatial representation form (visual, verbal, mathematical, digital) of the thematic variables/parameters in context of any particular professional use.

For Geographers or other professionals, *the meaning of space is dual* having a *modern* and a *postmodern* perspective. The modern perspective is represented by the rational mapping model and a description of "places", while the *postmodern* is involved through the *possibility to consider and involve any type of thinking stream* of *not rational meaning* about the use or an interpretation of using the "space" (cultural, political, economic, public services, etc.).

The duality in context of modern and postmodern perspective caused during the past three decades extended controversies between scientists and philosophers. (However, this duality introduced *an ideological perspective* to consider all human-based activities in the World in context of existing forms of available mapping models of "space"). All mapping forms follow modern approach; the rational approach to consider the space through models. Modernism developed as a consequence of the Enlightenment when the rational representation of Nature was promoted. The modeling of "space" either as a conception or a perception about space around the Earth provides Geospatial models for its representation as rational models. These may differ only about the Philosophical perspective on *what is space* (see next paragraph), which is also related to its impact upon phenomena or human activities. In addition, there are users of space who consider also enlarged definitions about its use beyond its mapping, e.g. Gieryn (2000), Lefebvre (1992). These users have perspectives of ideologies, policy, human interests in context of their professional interest and thus any set of coordinates about "places" keeps an added structure about "space" beyond its representation. The added structure relates to the implementation of ideological approaches.

The approach about the cultural/human use of space, which is the content of this paragraph, was initiated by dialectic philosophy of the middle of nineteenth century (postmodernism). It has been adapted as a perspective about "space" during the last decades of the twentieth century. For instance Lefebvre considered about space three classes of perspectives: (1) the spatial practice (the perceived space—"first space") (2) the representation of space (the conceived space—"second space") and (3) representational spaces the *lived space as conceptualized by* users (scientists, planners, social engineers, or others). Only for reasons of completing the postmodern perspective the exact citation is added:

> I define as Third-space as another way of understanding and acting to change the spatiality of human life, a distinct code of critical spatial awareness that is appropriate to the new scope and significance being brought about in the rebalanced trialectices spatiality—historicality—sociality. (Soja 1996)

In fact, postmodernism represents a quite complex set of ideas, which may be adapted to any approach about a modeling structure of "space" by simply considering the duality of "space" as a form of modeled representation and as a physical/cultural entity which interrelates geographical "objects" (website-2; website-3).

18.4 The Philosophical Perspective

The type and the geographical extent of a mapped form of "space" or "places" depend on the exact objective of a particular application; hence the precision of any description form about "space" includes objective and subjective perspectives. There exist various coordinate systems in use to describe any objective form of a "geometry" about the space-time continuum (=the definition of "space" in Modern Physics). The type of these systems depends on the geographical extent of the illustrated space or follows a topology (data base structure of "places" in perspective of Informatics) which relates to the illustrated Geographical information (user determined "objects"). In practice, all possible descriptions about "space" are implemented through measures of various physical variables or properties, geographical variables or user-defined properties about "space". *All these vary in a common space-time continuum at different rates of variation.* The rate of their importance as variables varies according to the professional objective as well as the impact of special coordinates.

The transition between a philosophical perspective about space to a representation form involves both principal professional perspectives: (i) the most familiar is related to the mapping disciplines and concerns to the *controversy between Newton and Leibnitz about "space"* (ii) those which associate to thematic qualifications of "space" that may characterize any feature, property or "object" within it; hence there is room to incorporate ideologies in using the geographical "space". This second perspective is divided to (i) perspectives in the context of the type of qualification (physical or human) and (ii) perspectives in context of probability distribution for particular illustrated geographical "objects".

All disciplines having as objective a mapping form of "space" (e.g. printed and electronic maps, satellite imaging, GPS positions, GIS positioning platforms) for its use in any professional goal are founded on Physical and Mathematical representation approaches. These start in the context of a perspective about the physical space, which is founded upon one of the two main viewpoints with regard to the definition of space according to Newton or Leibniz (Belkind 2013).

Is space "real," or "ideal" in some sense? Is it a substance in its own right, a property of some substance, or neither? Is it somehow dependent on relationships among "objects" or independent of those? What is the relationship between space and the mind? These philosophical questions are built in the presently used perspectives about "space".

For disciplines of mapping, the "space", the view that space/time is actual entities (=they already exist independently how they are perceived) is meant to represent the Newtonian position related to a *conceived* space. The view that space/time is only determinations or relations of things follows the Leibniz's standpoint, which is close to the *perceived* space. Leibniz's point of view is at some extent close to Soya's and Lefebvre's works on the geographical conception of space, in which an ideological perspective dominates. In context of implementing representations about "space"/"place", the difference between perceived and conceived form may be illustrated with the example of the difference between a coordinate system and a coordinate frame, where a frame of coordinates just an implementation of a particular coordinate system.

However, the restriction of the human perception about physical space to only three dimensions involves as sensed coordinate of height the orientation of the actual vertical, which follows the local plumb-line (= direction of the actual gravity force). This sensed direction determines the local or global shape of the Earth's surface (either as the real Earth's terrain relief or as a Mathematical or physical model of horizon—MSL—see Fig. 18.2) and differs from the mathematical perpendicular. The previous description reveals well the inter-dependence of a geometry about "space" to its physics (=the impact of the Earth's gravity field—relativistic theory). It illustrates the contribution of relativism and of non-Euclidean geometry in the description of space.

In professional practice, this duality of a meaning about "space" as a geometric structure or as physical entity, *appears with the parallel use of two different Earth models and two height systems*. The used Earth's models are: (a) a perfect ellipsoid of revolution—a *geometrical model* (b) a physical body with shape composed by the heights of the Mean Sea Level above the previously adopted ellipsoid—a *physical model*. The heights are defined after the length and the direction of measure as: (1) along the direction of the local plumb-line staring from a perceived MSL (*physical model*) (2) along the mathematical vertical on the mathematical shape of horizon starting from this model surface (mathematical model). After these two different definitions, the height systems in use are implemented by a number of benchmark points of known height. The two systems are interrelated but *for environmental use and many physical processes, the use of the MSL based system is obligatory demand for reasonable results*.

Euclidean geometry stood unchallenged for centuries as the unique mathematical model to describe the space. The discovery of the non-Euclidean geometries during the nineteenth century had an impact far beyond the boundaries of mathematics and science. Kant (1724–1804) a central figure in modern philosophy with his "critical philosophy" established a synthesis between rationalism and empiricism and set the terms for much of nineteenth and twentieth-century philosophy. Actually, Kant initiated a scientific revolution in the approach of science in which the way to consider Nature was changed (website-4). These changes include the considerations about the use of space and ways of its rational representation; both professional perspectives in the presented classification.

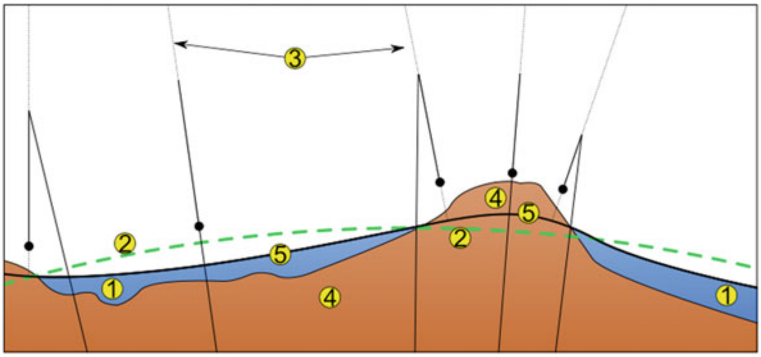

Fig. 18.2 Illustration of the direction of height along plumb-line, Terrain relief, Mean Sea Level (MSL), perceived MSL (- in green)

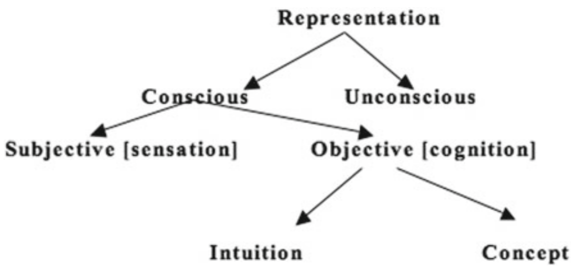

Fig. 18.3 A schematic illustration of perspectives about representation of space (retrieved from https://plato.stanford.edu/entries/kant-spacetime/#IntrPhilQuesAbouSpacTime)

These changes include the extension of Euclidean geometry to non-Euclidean forms during the nineteenth century, by Lobchevsky, Bolyai, Riemann (website-4). Non-Euclidean geometries had an impact upon Victorian England in many ways. It is worthy to mention the caused re-examination of the teaching of geometry based on Euclid's Elements, a curriculum debated by a book written by the Mathematician Dodgson (known as Lewis Carroll) (Raymond et al. 2011).

Completing this general review on philosophical perspective about the representation of space, it should be added that the debate between the Leibniz's and Newton's perspectives concerning the status of space and time, had formed a part of the essential background to Kant's views during his career (Kant 1998). Although Newton originally formulated his conception of space/time in response to Cartesian views (Newton 1999) by the turn of the eighteenth century, he and his followers were involved in an extensive debate with Leibniz, who raised his criticisms in the correspondence with Samuel Clarke, a defender of Newton's ideas.

Figure 18.3 represents that Soya's and Lefebvre's considerations about geographical space compose the subjective (sensation) of space and Newton's or Kant's ones are represented under objective (cognition) viewpoints (at the right side of next figure).

18.5 The Perspective of Rational Mapping—Geospatial Mapping

The perspective of mapping the "space" as human need appeared very early: (i) to map the Earth's surface, trace borderlines between landowners and compose maps for a description of the geographical space (ii) to satisfy the human interest to learn "where we are" and "how is the Earth". Evidently, the first reason is close to engineering, military, geographical and land use applications, while the second one is related to the determination of "places" in Universe. The second reason initiated the branch of Astronomy in parallel with Euclidean Geometry for a description of "space".

The history about mapping of the "space" and determination of places is long following the development of (i) the human needs to organize various activities in geographical space (ii) The independent evolution of scientific, technological branches, measuring possibilities, computational facilities and several other issues. In a way, the forms of a rational mapping of space and the Earth's surface have followed (i) the initiation of needs to construct maps, (ii) the development of human thought and (iii) the impact upon scientific and technological branches.

An important contribution for a rational description of the "first space" by maps (a perspective of objective representation for natural sciences) has been the invention of coordinate Algebra by Descartes and Fermat for the description and the modeling of "objects" in space. Their invention was founded upon the earlier work of Fibonacci (born as Leonardo Pisano) (Singler 2002) who popularized—according to historical considerations—the Arabic numbers to Europe. *Through the coordinates, the perspective to describe the continuous space by "approximation" in digits or pixel elements had been founded*.

Another impact upon the mapping of space came after the invention of printing and its consequences as to explode the needs of humans for literacy, map creation and the expansion of geographic interest. The use of printed maps to describe themes of human interest, appears by the end of eighteenth century (Campbell 1997). For about two thousand years, the adjective "Euclidean" was unnecessary to define the used geometry because no other sort of geometry had been conceived until the first part of nineteenth century. Out of the contributors for non-Euclidean geometry, Bolyai mentioned "that it is not possible by only Mathematical reasoning to decide about the sort of geometry to describe the physical space as this is an issue of Physical sciences". The implication of relativistic physics has shown that physical space itself is not Euclidean but much more complex. The Euclidean description is still only a good approximation where the gravitational field is weak.

The use of an extended physical space out of Earth to observe or to acquire measures about the Earth's surface, its inner structure or features about spatial places started more than a century before. At first, special designed cameras launched on various moving vehicles (airplanes, helicopters, rockets, satellites) provided the first photos. During the geospatial technology in less than 40 years, the optical rays were replaced by a large variety of signals emitted from complex measuring systems mounted on vehicles with known trajectory in physical space. The trajectory of moving vehicles either in static or dynamical acquiring of measurements is subjected mainly by the gravitational forces. Hence the dual nature of physical space as geometric and physical entity is involved for its mapped representation. The gravitational structure of space has to be known for its description through geometry. This necessity caused by the complex dual structure of space is fully resolved in practice by Geospatial Technology. There are three main technological developments (a) The invention of GPS system, which provided a universal way to determine places in a standardized World System. (b) The continuous monitoring of the Earth's gravity field by satellite missions and the operation of International Institutions (e.g. http://icgem.gfz-potsdam.de/home) which provide raw and processed data and other "products" to estimate the impact of the Earth's gravity field for various objectives (c) Google Maps the Web mapping service using satellite imagery, street maps and views, public services more than a decade now.

Finally, the variety and the availability of complex in structure measuring devices for acquiring various sorts of data made possible almost any application among quite many disciplines. Hence there is a general impression of possible professional users "*that everything is simple expertise with technology*". This is not exactly true. There is a difference between a simple mapping of geo-referenced "information" and the use of a representation form of space as a parametric variable for natural phenomena. It is crucial to emphasize that a formal representation of space (e.g. visual, verbal, mathematical, digital, topologic) under whatever background model and a determination of places, is an issue which deserves the attention and the professional knowledge of the final user. Only a user can be fully aware about the importance of a description of space and its impact on the own particular problem. The reason that the human perception perceives and interprets the space as only 3D, explains why all complex mathematical formulations eventually used in context of mapping disciplines to describe the space in the past, end up with an evaluation in context of accuracy and resolution in terms of 3D geometry. Last but not least the various users of models about space interpret the term model space quite differently.

Engineers consider, as model of space, any available form of representation (e.g. a sort of map) they are working with and the official system of mapping coordinates representing a projection of 3D real natural space in context of a topology structure. Cartographers consider, as model of space, a basic geometry of the Earth (a spherical or ellipsoidal space; the simplest Riemann spaces) with Earth-centered surface geographical coordinates φ, λ and a separated system for heights. Geographers mind most the impact of a particular qualification of space or of a "place" upon the geographical "objects". Indeed, a perspective about space may have a fully different meaning among the various users. However, geospatial technology made possible the standardization of the various representation systems about space for regional or global scale. A globally unified resolving capability of such systems is expected to greatly support the achievement of many ongoing and new applications.

18.6 Concluding Remarks

There are various disciplines and professions which use commonly Technological "tools" (measuring systems, imaging, GPS, GIS) in connection to the physical "space" for particular, simple or complex, professional applications. However, the meaning and the role of "space" varies as the terms "place"/"space" are variously considered and interpreted by Engineers, Geographers, Planners, other users. One may define "places" within any mapped form of "space" using any of available coordinate frames but the requirements of accuracy and resolution of mapping the "space" are much stronger for geo-referencing natural "objects" or processes and dynamical phenomena than in case of human-related activities. The rates of these requirements should be known by users; there is a need for mutual understanding among the various users of "space" on the perspective of using "space".

With regard to the philosophical perspective about "space" and its impact, there is no definite conclusion as there is no evidence that all what a human perceives about the World is "real" or "correct" or *what is conceived as a model* approaches the reality. Of course this applies also to "space" for its mapping and its impact.

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Chapter 19
Visual and Spatial Thinking in the Neogeography Age

Juan Antonio García González

Abstract The twenty-first century brings us a globalized world, interlinked, virtual and mobile-connected. The Internet provides us huge amount of data that is available. It has modified the number of people who can communicate globally, the formats, the audience and the direction of information flow among others. Information changes continuously, even being modified in real time. All that seemed permanent turns ephemeral, distant becomes close. We are overwhelmed by the information we continually received. The difficulties of management provoke the increase of forms of visual communication in front of the traditional writings. Video graphic, photographic, infographic and cartographic files are growing exponentially. The ability to be connected anywhere and anytime causes location being more and more vague and space and time smaller. Place and location are soaring with the cloud's virtualization and globalization. However, management of spatial information, geolocation and maps are increasing every day. The use of maps has been democratized thanks to the Internet, cheaper and powerful devices and geolocation. Cartography is the visual expression of spatial information. Maps have the capacity to change our perception of the territory and facts happening there. They help us to understand the world and our life. 'Where?' is one of the most basic question words, which are intrinsic to our existence.

Keywords Neogeography · VGI · GIS · Spatial thinking

19.1 Twenty-First Century and Geography

The Internet has brought major changes to our lives, altering the way of studying, working, shopping and relating to both people and background. Connection is available in more and more places with increasing quality, thus allowing us to be permanently linked. The Internet has become a permanent link which supports

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our everyday choices. A globalized and interwoven world has created a flexible and malleable reality. Eventually, paradigm shifts in a 'liquid society' are claimed to be happening (Bauman 2013).

The relationship with the territory has also become clearly affected. The world has reached a more accessible size, with countless information being available from everywhere (Brooks et al. 2017). Since it is possible to implement tasks irrespective of our location, the concept 'place' becomes more ethereal and vague. Traditional concepts of space and time revolve around the Internet connectivity. Geographic Information Technologies (GIT) put together all technical possibilities working with data, which may contain whatever kind of spatial component. During the second half of the twentieth century, both change and improvement in spatial information became consolidated through IT development, the space race and improvements in telecommunications. A true revolution happened both in tools and data collection methods. In the twenty-first century, the 2.0 Web and democratized access to geographic information have allowed a huge number of the Internet users to create and manage a massive amount of spatial data, thus boosting what has been named 'Neogeography'. Spatial information is no longer the property of governments and official institutions. Different sides of Neogeography enable non-expert users to use and generate geo-referenced data; an overwhelming stream of possibilities leads to growth in more synthetic and visual methods of communication. Image becomes empowered as opposed to the traditional dominance of writing in everyday communication. The use and circulation of cartography are continuously rising along with geographic information.

The present chapter deals with the increasing use and generation of geographic information and cartography by citizens within the frame of Neogeography, noting the paradox reflected in the growing use of spatial information along with loss of value of Geography as an academic discipline. Finally, prospects of spatial and visual thinking in Geography are discussed. Their scarce use causes a devaluation of the opportunities that geospatial technology makes available to us in the twenty-first century.

19.2 Democratization of Geographic Information and Neogeography

Management and control of information have been a recurrent controversial issue throughout the history, being restricted to a small number of people linked to power. Now, this has changed: we are living a historical moment which faces major challenges, the most relevant of which may be based on our ability to receive, understand and manage the volume of data which we are constantly getting. Traditional ways of reading have changed their format, directionality and comprehension methods. Sender–receiver flow has been replaced by a bidirectional one, in which any side may play either the sender's or the receiver's role. Web surfers' active attitude is substituting readers or viewers passive approach. We are living in a historical period like no other, especially for those who are curious and with an ability to communicate (Adell 2011). Anybody can communicate globally and instantly when connected. The way in which we read also changes by moving from the concept of text to that of hypertext and interlinked websites. The written text becomes shorter and shorter, eventually reaching the paradigmatic 140 characters. A communicative shift from analogic to digital format seems unstoppable, provoking both the reduction and equalization of costs of text and image. Additionally, due to the fact that we receive more and more stimuli, simple, faster and easier-to-read information is consumed. Visual screen communication (photos, video, infographics, cartography, even written text) is highlighted. Change seems just irreversible and is regarded as more relevant than the invention of print or the industrial revolution (Pons 2013, p. 20), with the Internet galaxy being compared to the Gutenberg galaxy (Castells 2001).

In such a context, both geographic information and cartography are living an exponentially-growing golden age, which has filled our pockets with mobile apps, our dashboards with GPS navigators and our homes with numberless everyday tasks. Three-quarters of web surfers claim to be regular users of maps and geographic information (Crespo and Fernández 2011, p. 403). Such rebirth is not restricted to tracking a place or looking for a route. ICA 'International Cartographic Association', at the fourth session of UN's Committee of Experts in Management of Spatial Information, nominated 2015 as the International Year of Cartography, in order to promote the importance of maps and geo-information.[1] This development has been named Neogeography for more than a decade (Turner 2006), a concept coined to refer to the relationship between Geography and changes happening due to non-expert people and communities using GIT (Goodchild 2009), which is understood as spreading access go GIS and digital cartography (Cerda 2015, p. 73). Accordingly, different terms are used to define the same concept: Neocartography (Chabaniuk and Dyshlyk 2016), Geomatics 3.0 or Geotechnosphere (Buzai 2014a). Such ample definition has been tailored by the scientific community by making a distinction between the ability to generate data and the construction of geographic knowledge (Bosque 2015). Generation of knowledge implies a more complex and thoughtful process deriving from theories and principles. Being relevant and not belittling them, many of the activities related to IT provide huge amounts of data which are one step below scientific work. Data are linked to observation, although they are eventually generated imperceptibly by users. They are the basis of knowledge and, occasionally, difficult to obtain, thus becoming so important. Information means a higher stage, where data are filtered and processed. Ultimately, knowledge implies construction of general principles abstracted from information (Goodchild 2009, p. 84).

Neogeography involves a number of aspects interconnected with spatial information. Outstanding ones are the so-called voluntary and collaborative geography, Big Data, map viewers, network-generated data, etc. (Cortizo 2015, p. 8). What is undoubtedly claimed by the authors reviewed is that GIT have consolidated Neogeography's new paradigm, a multi-faceted approach which is changing the geographic

[1] http://internationalmapyear.org/.

subject by implementing new contributions to the geographic corpus. Innovative conceptual elements of geography derive from a revolution in the way how geo-referenced data are obtained and generated.

In addition to widespread permanent Internet connection, excipient components of the present state of geography are founded in a number of interwoven elements: global access to geolocation, inexpensive hardware and software and increasing amount of geo-referenced data.

Geolocation is defined as tracking a place or object on the Earth's surface from a coordinate system. Currently, geolocation has reached a peak thanks to GNSS technology (Global Navigation Satellite System), since it has been implemented in a huge number of devices such as smartphones. The exponential growth of the use of geolocation technology finds its turning point on May 1st 2000. The United States removed the signal degradation (Borruso 2013, p. 8), which caused bias and inaccuracy at the receivers' response: from 100 m to the 6–8 m currently supported by most devices (Haklay et al. 2008). American GPS opened the path, which a number of projects followed, namely European Galileo, Compass, Glonass, etc. (Saxena et al. 2014).

Another core element of change may well be found in lowering costs and improved quality of both physical and logic components of the IT system. Performance of smaller, diversified and mobile devices has also improved through the introduction of apps which are more interactive and usable for any person with a limited knowledge of IT. Such applications' implementation has been parallel to cheaper devices and apps running inside them. FOSS (Free Open-Source Software) open-source apps have become consolidated. Desktop tools are now available in the Web, and multiple downloadable versions appear for a wide range of devices. A clear example may be found in the overwhelming evolution of GIS towards web cartography and hybrid applications (*Mash up*). Data from several sources integrated into one only tool are combined (Frith 2014), a kind of apps which have been growing since Google launched its API in June 2005 and Google My Map in 2007 (Jiménez 2011).

Last but not least, we find the continuous appearance and availability of data including some spatial components, which can be simplified into three categories: public, private and voluntary. Public data are the most traditional ones, having started their major development with the so-called Photogeography: the LANDSAT-1 launching in 1967. Just in one orbit, data equivalent to what man had obtained until the fifteenth century were collected; in the second orbit, data obtained reached what was available until the nineteenth century (Buzai 2014b). Many of the data generated so far are available, regulated and validated through Spatial Data Infrastructures (SDI), a series of standards and protocols coordinating, spreading and improving geographic information. Data are additionally provided by private institutions and the twenty first century is being revolutionized by non-professional users, through two main ways: Big Data, (either via social network or other sources) and collaborative geography.

Big Data refers to a huge amount of data, not only geo-referenced, which is generated in a wide array of ways, through multiple sensors, even unintentionally (Gutiérrez-Puebla et al. 2016). They may range from institutional sensors, such as the ones coordinating Smart cities, to the simple interaction of a single person in a social network LBSN (*Location-Based Social Networks*). Availability of both mass and individual data allows modifying the working and analytical unit, enabling change from administrative to individual scales. Also, Big Data allows higher closeness to fresh everyday reality. Individual data's subjective component supersedes objective geometry, and quantitative components coexist with more qualitative ones close to behavioural paradigms, going as far as discussing 'emotional geo-processing' (Beltrán 2015, p. 114). Such highest-potential level of detail is not without privacy issues, as Chorley (Rhind and Mounsey 1989: 580) warned more than 30 years ago. Moreover, one of the elements which better reflect Neogeography is the so-called VGI (Volunteered Geographic Information) (Goodchild 2009). All of the aforementioned has involved the growth of 'amateur geography' and 'wikification' of GIS, (Sui 2008) with OSM (Open Street Map) project being a clear benchmark. Any citizen is empowered to generate and share cartography in a collaborative way.

19.3 Geography in the Twenty-First Century

All changes mentioned so far have rekindled the ever-open geographic issue. Geography keeps a discussion over the nature and purpose of geographic knowledge, as well as social access to such knowledge. It is assumed that any person needs some kind of geographic knowledge in order to be an autonomous and critical individual who fully participates in the society in which they live, not merely being a 'suitcase of knowledge' (Major 2013), often mocked at as a plain memorisation of toponyms which constitute a basic instruction. We settle for counting and describing territory. Besides the contents, the learning process is added, often a learning-by-role approach which make contents fall onto passive knowledge frequently involving neglect. The world has increased its complexity through both globalization and the virtual relationships offered by the Web. Currently, geographic knowledge learned at school is becoming less and less useful. The viability, necessity and utility of geography at school now is now merely general culture, thus forgetting the true potential and power of the subject. Social and professional underestimation suffered by geography nowadays stems from the citizens' perception of the knowledge and from the use they make of such knowledge. A fact-based subject is required rather than a conceptual one (Jackson 2006, p. 199). Geographical technologies should be complemented with human background knowledge, flexible thinking and imagination (Andrienko et al. 2007).

Permanent epistemological swings of academic geography have not reached educational levels under college and, subsequently, the majority of the population. Examples such as spatial analysis positivist models or the subjective and humanist perception of behavioural geography are generally unconnected from the descriptive geography which is taught at school. The world may be understood and explained by geography, or simply described by it. Whereas, in the first case, the citizens relate to the subject actively and collaboratively, in the second one they are just passive receivers of knowledge.

David Lambert compared geography learning with language learning (Jackson 2006, p. 199). Metaphorically, the vocabulary of any language is similar to a list of toponyms and geographic spots. Grammar and syntax are compared to the concepts and theories which help such places and words make sense. Learning a language needs words, but they are as essential as the rules organizing and building it, providing the whole with sense and meaning. A similar example could be that of mathematical language. It is necessary to know numbers and their different ranges (integers, natural, real, etc.) which, in fact, is what students primarily learn. Not less important are algorithms and equations which make such numbers interact. The geography that every student learns reaches that first stage of contents, not going deeper into the causes and algorithms which make geographic concepts interact. Not going beyond, the subject becomes orphaned due to the fact that it does not provide connection and relationship between different territorial elements. The citizen does not eventually get the real application of 'geographic language', and lacks ability and skills to understand, not just perceive, a world which is more and more complex. People also lack concepts which help make sense of all places, figures and activities related to the human being in an orderly way. Many of the skills and theories converge on visual and spatial analysis.

19.3.1 Spatial Analysis

Our lives are filled with elements which meet spatial patterns. A case in point is that of Mendeleev's periodic table of 1869, one of the most recognizable spatial structures in science (Newcombe 2013, p. 26). The surface of the Earth has an overwhelming number of spatial structures and variations (Cosgrove 2008, p. 121). Causes and explanation of spatial structures are a subject of study through spatial analysis.

Spatial thinking refers to knowledge, skills and habits which make use of spatial concepts, maps, graphs and processes in order to organize and solve problems (Gersmehl 2005). A cross-curricular subject which derives from Piaget's psychological and teaching approach (West 2014), also from mathematics (Castaño 2006) and, of course, geography (Brooks et al. 2017; Shah and Miyake 2005; Metoyer et al. 2015; Sinton et al. 2013; de Càrdenas et al. 2017). It deals with tracking objects, shapes, relationships and spaces they occupy in their movements. It tends to be measured through tests and forms with approaches to mind images (Newcombe 2013; Lee and Bednarz 2012), being a fundamental skill in order to solve space-related problems, tools for representation and reasoning processes (NRC 2006). Together with reading and mathematics, spatial thinking is one of the most relevant skills for human being (Scholz et al. 2014; NRC 2006). European Erasmus + projects such as VISTE (Empowering spatial thinking of student with visual impairment) add value to the interest in spatial thinking, even for persons with a disability (Brock and Hachet 2017). Rediscovery of spatial models is underway (Rebeca Ramírez 2015) and geography is increasingly being taught in a different way, with different approaches to thought and research, from spatial and visual points of view (Jiang

2015). Major geographic institutions in the USA[2] have come up with a roadmap for twenty-first century's geographic education, where priority is set in the development of geographic skills at all levels, based on geographic thinking and acting (Guo 2014, p. 83).

Our everyday decisions related to places lean on spatial analysis. Their use promotes daily basic actions (how to go from A to B; where are things? people's choices such as housing purchase, which neighbourhood is better connected? orientation and weighing of price, etc.). At a higher stage, spatial thinking is used to better understand the world and the increasingly complex modern society. Finally, a third stage deals with professional spatial analysis, based on scientific theories and procedures towards understanding both the territory and the inhabited area from an abstract space. The mentioned level, professional and academic, is utterly unconnected to the previous ones regarding transmission of geographic knowledge to society through geographic learning. Concepts, strategies and tools related to spatial and visual analysis are hardly used in order to understand the reality surrounding us. The core of spatial thinking only rarely appears in school curricula (Metoyer et al. 2015; de Miguel 2015). It should be necessary for the enforcement of spatial skills in all levels of educational system. Recent initiatives in Europe is trying to systematize the spatial learning in secondary schools[3] (De Lázaro et al. 2018; Donert 2016).

Spatial analysis is geography's DNA. IT tools have made this fact visible since GIS first appeared. It embraces geometry, topology and, above all, relationships and implications of geographic elements, including natural, social and humanistic aspects. Interaction of cross-curricular geographic spatial thinking is reflected through technology in other humanistic subjects: Geo-humanities (Gregory et al. 2015). Spatial analysis develops students' critical thinking and works in a multi-scale way at ranges, which are both perceptible and understandable for citizens, fostering hierarchy and prioritization, promoting multi-causal explanation and multiple problem-solving. It also becomes a major tool for understanding a more complex and interlinked reality (García 2012).

The most usual method of study, analysis and presentation of spatial thinking is through images and maps. Visual and spatial thinking are intimately ingrained at cartographic representation.

19.3.2 Visual Analysis

Maps are one of the longest-standing and most powerful methods for understanding the background. Their origin is difficult to trace, being regarded as even earlier than writing, linked to the moment in which the human beings first become aware of the area they inhabit and need to display it for a particular purpose (Peters 1992, p. 9).

[2]National Geographic Society (NGS), American Association of Geographers (AAG), American Geographical Society (AGS) and National Council for Geographic Education (NCGE).

[3]http://www.gilearner.eu.

Where? is one of the basic questions in human existence. 'Almost anything happens anywhere' (Longley et al. 2015). We feel the need to spread our relationship with the territory. All of us have a potential cartographer inside (Goodchild 2009 in Gartner 2009, p. 75), like a Borgian man with a firm purpose of drawing the world (Borges 2005, p. 854).

Cartography has been long considered a science of princes; even 'drawing maps of the Earth meant being its owner' (Harley 2005, p. 46). Maps have always been linked to power. Being scarce and in the hands of a few gave them an aura of exclusivity and reliability. No such privileges can be found nowadays, but maps keep full potential. Power of cartography does not lie either in exclusivity or in technicalities or complexity at the generation stage. Its true potential derives from the type of information that it displays how it is displayed and in the huge power of communication that it has. Sometimes, a simple sketch may find an enormous level of spatial and visual thinking, even higher than computer-aided designs (Barkowsky and Freksa 1997, p. 348; Agrawala et al. 2011, p. 64).

The map and its creation have considerably varied through centuries. Moments of major developments, such as the Renaissance period, late eighteenth and early nineteenth saw big efforts being made in accuracy and impact of maps, linking them to science and moving them away from the more artistic and philosophical side which prevailed in earlier times. It was at that moment in the subject's history that theme maps appeared, designed not only by cartographers but by experts in a range of other subjects (E.g. map of cholera in London, 1840). Cartography moved from describing places to explaining by showing invisible distributions spatially (income, illnesses, etc.). Linking visual and spatial thinking has become a reality, which is not without problems with representation or even conceptualisation, such as the so-called 'ecological fallacy' (Cosgrove 2008, p. 163).

Maps are the visual display of spatial information, released in a synthetic way (MacEachren 1995) and contain a high degree of communicative capacity in a global language. Monosemic language means that every single sign displayed has a unique meaning in the map key (Bertin 1967, p. 6). Symbolisation follows a set of rules and protocols that make cartographic language a universal one with high rates of creativity and communicative potential. It is possible to read any map of any part of the world if we understand the elements of the keymap. Cartography, as a language for communication, matches its universality to that of music or mathematical; a communicative whole which perfectly fits in the hyperlinked global world.

Robinson mentioned a number of further approaches to systematization of the geographic subject by mid-twentieth century (geometrical, technological, presentational, artistic and communicative) (Robinson et al. 1987). Either the mathematical or the geometric component provide representation with positivism, leading to rigour and truthfulness that such representation often lacks as far as objectivity, neutrality and impartiality are concerned. Not only do maps depict territory but they also create it. Maps alter our perception of the territory and the facts happening within it. A clear example of this can be the ignorance about the real size of Africa, as generated from planispheres represented through the Mercator projection, which makes a distorted image of the world prevail. Cartographic projection itself necessarily involves distortion of reality (Peters 1992).

The technological component has been reinforced with GIT and neogeography. The increasing number of simple apps for map production has made the number of people making maps and using spatial information grow substantially. More and more people are making maps, the concept of cartographer versus that of mapmaker being coined (Goodchild 2009, p. 94). The more maps and geo-referenced information are used, the more spatial information is produced, a feedback process. Technology has eventually made it easier to process large amounts of data and, of course, to update and analyze data much more consistently, even developing and analyzing data in real time. Multiple forms of geographic information are accessible now for a number of people, which was unimaginable just some time ago Never before has the number of people making maps been so high (Crampton 2010, p. 11). The potential scope of receivers is increasingly high due to the flexibility and versatility of the possibilities that mapmaking offers: photographic repositories, purchases, real estate websites, as well as an extended list of niche areas where geo-referenced information can be displayed, analyzed and presented, thus allowing a far easier organization, management and decision-making about spatial issues. Both visual and spatial analysis have grown, largely due to the use of such data.

Topics about spatial choices, which are useful for decision-making process, are multiple. They are used in different disciplines and in diverse lines of geography, especially applied geography. It could be grouped into three typologies (Andrienko et al. 2007): (1) Complex nature of geographic and temporal spaces. In this group, we have questions about location decisions, geomarketing, site selection, facilities management, supplies managements, decision-making in emergencies, among others. (2) multiple actors with different roles. We can find questions about politicians and management of administration affairs. (3) tacit criteria and knowledge. In this case, the analysis and evaluation are the priority with scenarios and projections to the future.

With the advance of the cartographic subject, it is the artistic component that has been the most damaged one. However, deeply rooted interaction of all components makes it detrimental for the whole. Loss of visual and communicative quality becomes obvious, pursuant to GIT standardization of cartographic composition rules (Slocum et al. 2005, p. 6). Fordian cartography repeats the same visualization pattern over only a few choices on which to display data just by changing the thematic component, be it temporal or spatial. Many of the intuitive and communicative applications are supplied with mediocre and repetitive visual solutions.

It may be thought that technology fills the needs created by users' lack of knowledge and skills. Fascination at the intuitive and dramatic blurs the true elements that makeup quality results. The extended use of word processors has facilitated the arduous task of writing. However, being of great help, they are not enough to produce quality texts. Similarly, the use of modern digital cameras facilitates the task of taking a shot: However, this can never replace consistent training in photo taking. The growing number of cameras has increased the number of photographs taken, the places and moments displayed. Despite such fact, quality has not run along with quantity.

Improving the quality of photography depends on something else rather than plain technology. Some expertise to be acquired by the person who takes photographs is also necessary. Something similar happens at cartographic production. Diverse and accessible technology has boosted the number of available maps, in which simplicity of production becomes more important than communicative optimization and visual quality of what is represented. Reading, perceiving and producing maps largely depend on our knowledge of cartography, design, visual language, spatial analysis, etc., aspects which are rarely covered at basic training and are becoming increasingly more necessary.

Both the communicative and presentational components of a map have gained added value within a technical and interactive visual background which is increasing. However, the map's communicative value is underrated, mainly using tracking features and ignoring other possibilities, such as evolutions, distribution patterns, spatial variations, etc. It is not necessary for people who make maps to reach the knowledge of a cartographer, although it seems advisable for them to possess great spatial and visual literacy, which are skills always present in geographic expertise and which prove to be up-to-date as ever in our global society. Visual and spatial thinking skills are not exclusive to territorial approaches, being present in multiple subjects. They have become working tools for many professionals (Kai and Shah 2004; Sengupta et al. 2007; Andrienko et al. 2007). Multidisciplinary features of such cognitive skills reinforce the need for them to be improved towards multiple aspects of both professional and personal life. During the 1960s and 1970s, Geographic Information Systems, the spearhead of the geographic subject's technological revolution focused on the 'S' for computing and programming systems. In the following two decades, the goal was to improve feeding these systems and focused on the 'I', on getting and supplying quality data. The twenty-first century, once the growth of quality spatial data is overwhelming, must focus on the 'G' for geographic, on improving learning of theory, concepts and methodology which enable proper use of data with the tools available (Buzai 2015a, p. 59). Geography as a subject is ready to reinforce visual and spatial analysis's learning.

19.4 Conclusions

After these brief considerations, it is necessary to reflect on the vertiginous moment that geography lives in today's society. Availability of permanent connection anywhere, of collection and production of geo-referenced data, changing formats, reduction in cost of devices and forms of visual communication have caused the way in which we relate to territory to be continuously changing. Places become flexible due to the versatility offered by 2.0 Web. Many of the changes that technology is bringing to geography converge on the term Neogeography, such changes increasingly being taken into consideration by the scientific community. From descriptions of Greek travellers until well into the twentieth century, descriptive geography has played a fundamental role for centuries. It has brought the features of distant and inaccessible places for millions of people. First, the transport revolution and the subsequent revolution of communications have made available to any user, anywhere in the world, a flood of images and information from almost the whole surface of the earth. Such data have completed and improved traditional descriptions. The citizen uses more spatial information than ever before and yet their geographic knowledge is increasingly unconnected to new opportunities. It is commonly claimed that geographic knowledge is losing utility in a world where images and cartography exceed our capacities of understanding.

Discussing what kind of geography we want is not trivial as a consequence of the fact that different technological advances of neogeography are separating people's geography from academic geography even further. There are more maps and tools in which both spatial and visual components are fundamental. However, teaching geography in the classroom at all academic levels, including university, is losing momentum, with such contradiction becoming more evident in recent years. It is not only what kind of geography we want now, but what kind of geography will survive in the future, almost a philosophical debate. Heyes, (United Kingdom, 1920s) and John K. Wright (United States 1947) stated the meaning and purpose of geography as geosophy: an ideal and more philosophical meaning of geography (Cosgrove 2008, pp. 8, 121), which involves analyzing geography at all levels, both the scientific and commonsensical one (Lindón et al. 2006, p. 360).

Geography is crucial to understand and comprehend the complex geographical area which includes Euclidean space, the physical one, the human one, the perceived one together with a long etcetera of nuances that make up the space in which we live and which we inhabit. It allows development of personal skills about perception, understanding, orientation and systematization of space. Educational geography largely focuses on social and civic competences in order to raise environmental and civic awareness. Geographic ideas may contribute to changing the perception of the world, which has far more accessible dimensions nowadays. There is a permanent interaction between individual and territory that can be summarized in permanent learning that leads to improvement and optimization of spatial decisions in the same place, by the same person but at different moments. Geographic thinking enables interaction between natural and human sciences, between quantitative and qualitative methods. The enhancement of geographic transversal feature must be based on two cornerstones: visual thinking and spatial thinking. Spatial and visual thinking expand geography over its disciplinary limits (Buzai 2015b). It changes to a transdiscipline closer to its conception as a holistic and synthesis science.

Growing knowledge about spatial analysis and cartographic communication is increasingly becoming a learning need in order to optimize the prospects currently being offered by technology and that we use on a daily basis. The link between maps, spatial analysis and geography has become obvious. Likewise, there is a strong connection between maps and territory, not just because of the obvious representation of one in the other. Memories of unknown places are created through maps. People who have not been to certain places have maps and geography as a reference to such an approach. A map is the representation of an interpretation of reality, a tool for spatial analysis and a complex cultural process, which makes it possible to go far beyond a mere descriptive location of places according to standards. Map making involves a construction towards spreading spatial knowledge, a cognitive and imaginative process whose potential gets increased by analyzing spatial relationships between the elements displayed and their context. Full understanding of a map requires understanding the historical, social and technical context within which it is ingrained (Cosgrove 2008, p. 156). Planispheres and globes are the doors to understanding the planet in a holistic way, bringing planet-sized elements to a human scale.

Geographic learning must be comprehensive and reflective, rather than descriptive. It should improve understanding of distributions, patterns, relationships of places so that meta-concepts of spatial analysis may be prospectively extrapolated by people in the places and moments which they may consider appropriate. Geography must be active, alive and, as far as possible, individualized in order to meet the needs and personal situations to come. Focus should be set on what is learned rather than on what is taught; geography of proximity that is built every day for different people. Each individual covers a time and a personal space which is perceived differently. Therefore, it is not just about knowing or describing the place in a repetitive way and in a uniform way for all. Time and place must be individualized. Similarly to learning subjects such as languages or mathematics, geography has many applications towards individual development. Knowledge of spatial thinking through maps should be the challenge that ought to increase both the social and professional value of twenty-first century geography.

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Chapter 20
The Tail Wagging the Dog: Developing Business Processes to Enable Spatial Systems

Stephen Glackin

Abstract The growth and accessibility of spatial systems have seen geographical analysis become one of the key tools for the effective management of business and government. This has been accompanied by significant growth in spatial research and the development of tools for scenario modelling, decision support and planning. Though many of these tools have the ability to provide insight into a range of phenomenon, most of them are automatically retired to the application scrap-heap; due to lack of use, maintenance, and therefore system failure and obsolescence. This is mainly a product of these systems not adhering to the established processes and logic within organisations, and occurs regardless of, or, in many cases, due to, the system's visionary or transformative nature. To illustrate this, the chapter provides an example of how business process and policies had to be created to enable the use of geographical decision support systems. As the business processes were developed after the software, this was largely a case of reverse engineering the business case, or, as the title suggests, a case of the tail wagging the dog. However, this process has now established a methodological roadmap, providing Australian geographical researchers and programmers with the information they need to ensure that their systems are in a position to affect positive change. As such, this chapter attempts to negotiate the literature on transformative change; tempering it with practical methods that lead to better system uptake.

Keywords Spatial systems · Business processes · GIS · Australia

20.1 Spatial Software and Its Uptake

Rapid increase in the use of online applications has made the use of map-based systems a daily occurrence for large segments of the population. Aside from providing data mining companies with astronomical amounts of geocoded information,

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it has also largely normalised the use of maps by the general public; promoting them from the car glovebox and into business, recreation and social activity. Similarly, the amount of research in the spatial sciences has grown considerably. In the Australian context, research organisations such as the Cooperative Research Centre for Spatial Information (CRCSI), the Australian Urban Research Infrastructure Network (AURIN), among many others (incl. CRCWCS, CRCLCL, SBEnrc) have been collating nation-wide data-sets and developing multiple spatial applications across a variety of disciplines, including: spatial housing data modelling (Glackin 2013); spatial Infrastructure modelling (Pettit et al. 2017); spatial carbon modelling (Glackin et al. 2016); overland spatial stormwater modelling (Lowe et al. 2017); transport modelling (Dia et al. 2017) among many others. However, regardless of the calibre of data collection, the openness and accessibility of both the applications and their codebases, as well as the rigorous auditing of these commonwealth funded projects, next to none are being taken up by the sectors of government they were designed for.

The critical issue, as will be argued by this chapter, is the transformative nature of many of these systems. The research nature of the above systems, combined with the current research focus on transitions theory (for example, Boyer 2014; Lahon and Murphy 2011; Coenen and Truffer 2012) as we move into systems involving big data, machine learning and algorithmic decision support systems, is producing tools that, while innovative, are too novel to be utilised by government sectors that already have enshrined business practices for performing their work. Rather than complain about the inertia of governance agencies, lamenting the roadblocks to change or the inability of government agencies to move with the times, or at least listen to experts in the field, this chapter will explore, first, why these tools are not being taken up by the proposed user-base, and, second, how to create the environment where novelty can lead to change. This second issue is, in effect, how to go about reverse engineering business processes, be it in planning, legal, policy or otherwise, that would accommodate the use of the spatial tools. This approach flies in the face of software engineering methodologies, which rely on obtaining system specification prior to building, and is "the tail wagging the dog", or a reverse of normal causation, referred to in the title. The rationale for this approach will be expanded on below, but, simply put, it rests on the visionary nature of new technology, its transformative capacity and that, due to its novelty, there are no specifications to gather, as there are, as yet, no users or business practices that require these new, and large disruptive, technologies. This phenomena has led to the metaphorical "application graveyard", where innovate software goes to die after its developers give up trying to push it onto stakeholders who *could* use it but *do not* use it because its use (or benefit/aim) is not yet in their job description.

In order to practically illustrate the above, and provide some localised research, policy and cultural norms, we will use a real-world problem, the set of tools used to address the issue, the blockages to use and how these were overcome through adapting the policy environment and business practices of relevant practitioners. The aim of this chapter is to show one of the critical issues in the geospatial environment, as a realistic assessment of the additional complexities that need to be addressed outside the realm of data and software. It will also provide a roadmap of how to go about addressing these externalities, which can assist research projects to move out of the lab and into the public realm.

20.2 A Case in Point: Urban Sprawl, Data and Technology

"Greening the Greyfields" is a research project established in 2011, under professors Peter Newton and Peter Newman and funded by the Cooperative Research Centre for Spatial Information (CRCSI), as well as two Australian state planning departments (Western Australia and Victoria) and three municipal governments, which were to act as pilot areas for project outcomes. The project aimed to develop new methods to reduce urban sprawl in Australia, where low-density sprawl is among the worst in the world.

Greyfields are, in the Australian context, areas where the buildings are no longer performing to today's standards and dwellings are either being significantly renovated, or, more typically, knocked down and rebuilt into two or more units as a subdivision plan (Newton 2010). These areas occur in the middle suburbs of large cities, where the value of the land outweighs the value of the dwelling; placing significant market pressure on the land's redevelopment (Newton et al. 2011). This differs markedly from the American context where greyfields refer to unused shopping malls and the like. Lead researchers identified that piecemeal (lot-by-lot) redevelopment was slowly, but drastically, altering the built form of these areas, however, it was occurring in an uncoordinated fashion; producing suboptimum design, inefficient use of land and, significantly, providing no additional community or infrastructural capacity to the local environment, despite at least doubling the densities. Also, at the current rates this form of development would not achieve the 70% infill (building on existing occupied land) rates recommended by state governments nationally (The Victorian Department of Environment Land Water and Planning 2017; Department of Planning and Environment 2014; Department of Planning and Local Government 2010; Western Australian Planning Commission 2010; Queensland Government 2009). The vision for the research was that the existing model of urban redevelopment could be significantly modified to promote regeneration at a precinct scale, instead of the fractured way that it is occurring currently. However, due to the complexity of lot amalgamation, and no existing business case or data to illustrate the benefits of this scheme, business as usual redevelopment would continue; which was the rationale for the project.

"Greening the greyfields" was divided into four modules. The first was to establish the economic rationale for reducing sprawl, and instead redeveloping existing residential land, otherwise known as urban infill (Newton et al. 2012). The second was to develop a system capable of identifying dwellings that had a high redevelopment potential (under-capitalised in strategic areas) with the aim of generating redevelopment precincts, instead of small-scale lot-by-lot redevelopment. The product of this module was ENVISION (Glackin 2013), an online GIS system capable of predicting development across the entire urban environment. The third module was to generate a 3D, precinct scale, visualisation and assessment tool, which produced Envision Scenario Planner, an online tool where users can construct redevelopment precincts by placing pre-assessed housing typologies onto a 3D map viewer (Glackin et al. 2016; Trubka and Glackin 2016). The final module aimed to implement the full system of lot amalgamation with property owners (Newton and Glackin 2017). However, due to the complexities of implementation, which, we will cover in the chapter, this module remains ongoing though a project extension.

For the sake of clarity, and to summarise the above, the project aimed to develop a set of tools to provide governments with alternatives to low-density sprawl, the outcomes of which would then encourage groups of landowners to amalgamate land and achieve higher densities with better design outcomes. The endeavours undertaken during the research produced two pieces of software, a 2D mapping and identification tool and a 3D scenario planning tool, presented in Figs. 20.1 and 20.2.

The first publishing on ENVISION occurred in 2013, through the same editing group behind this edited collection (Glackin 2013). At the time of writing, there was an assumption that simply by existing, the tool would be used and that systematic change would occur in the Australian housing market. This was not the case. Though the tool was endorsed by the (then) Victorian Department for Transport, Planning, Land and Infrastructure there was no uptake. Large housing-related organisations saw the tool as pointless, due to the complexities of lot amalgamation and dealing with

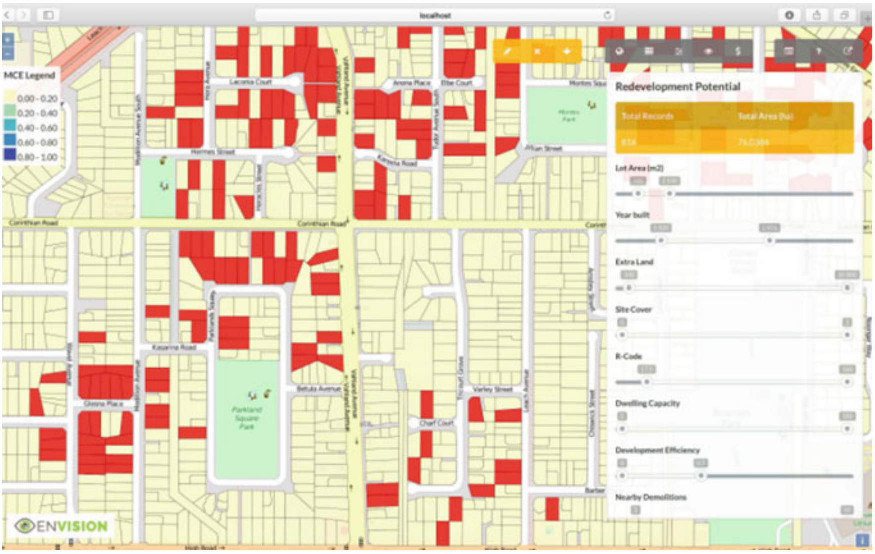

Fig. 20.1 ENVISION 2D precinct identification tool. The aim of which is to locate precincts of land parcels that, due to high land to building value ratio, age, lot-size, poor development efficiency and so forth, have significant market pressure on them to redevelop. This tool shows where potential redevelopment precincts could then occur if landowners developed simultaneously

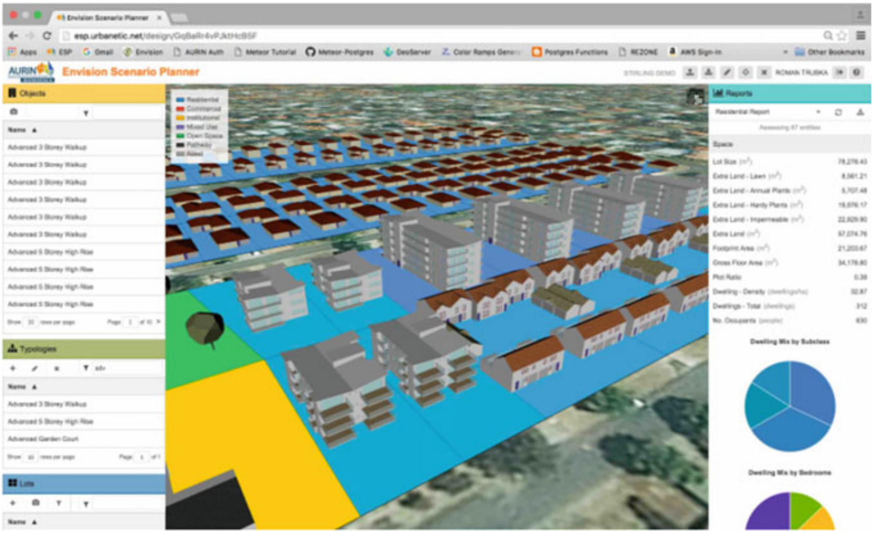

Fig. 20.2 Envision Scenario Planner (ESP) precinct design and assessment tool. This tool allows users to design redevelopment scenarios which can be compared for a range of indicators related to financial, environmental and social performance

individual landowners. Other planning organisations were not interested in the tool as they already had their policies for the future in place and had invested significant amounts of time and money in developing these policies and practices. Even the municipality that was signed on as the project partner did not have the capacity to act on any information provided by the tool, as they had little clarity on what it was they were aiming to deliver, little power in changing zones to accommodate more densities, a lack of the skill sets necessary to engage the community on financial, legal an design issues, and, most importantly, did not have the additional staff required to take on work that was not within their current policy or business objectives. So, regardless of the massive amount of data in the system, the relevance of that data to metropolitan objectives, the quality of that data, the simplicity of the interface and the ease of access to the free online system, the system was unused, and effectively failed, due to, among other issues:

- Each organisation having its own established policy and direction (high-level).
- Each organisation having its own internal business practices (ways of doing business, be it governance or commercial).
- No incentive (other than theoretical) to alter business as usual practices.
- No proof that the system could achieve anything more than precinct identification—i.e. no real-world outcomes and no methodology for this implementation.
- A lack of skills within organisations to implement the project on the ground (including low GIS skills, little design skills, low engagement skills).

- No additional staffing and no political or business pressures to obtain additional staffing for the project's implementation.

This list of issues comes from the past four years in the field, dealing with every relevant organisation across three major cities, as such, though it is quite abstract, it is also reasonably indicative of the blockages to uptake. We now turn to the raison d'etre for the chapter; how these obstacles were, or are, being overcome.

20.3 Wagging the Dog: Creating a Business Case for New Technology

With the software well and truly field-tested, and having little uptake, other than novel interest from futurist planners and postgraduate students, it became evident that in order to advance the grander project (precinct scale regeneration and the following reduction in urban sprawl) it would take more than simply having a vast amount of data and software available; there had to be a reason for doing this—other than altruism.

On direction from the Victorian Department for Environment, Land, Water and Planning (the current state planning authority for greater Melbourne), the project was advised to be included in a municipal housing strategy. The rationale for this was that, by becoming part of municipal policy, the project could show that it was being taken seriously, had municipal support and was beginning to work within the existing business processes of government.

Working closely with the municipality of Maroondah, and ensuring that municipal staff time was kept to a minimum, researchers began providing the municipality with the information required to deliver their housing strategy and assistance with the community engagement aspect of delivering the strategy (see Fig. 20.3). This approach, of alleviating the pressures on staff time to accomplish necessary tasks, allowed municipal staff to allocate time to the research project. This, along with close municipal staff engagement, incorporating aligning the research with municipal policy, assisting the municipality with community engagement activities, and generally working within the policy reality of the municipality, led to the research being included in the local housing strategy (see Figs. 20.4).

To bring this back to the point of the chapter, we have now begun to make the research impactful, as it has taken its first step out of academia and into activation. "Reality" may not be the most appropriate terms, particularly for spatial scientists. As pointless as policy may be to some (being a human system outside of the rationale of logic; insofar as bureaucracy, at times defies, all immediate rational thinking) the rationale underlying the system's philosophical underpinning have now left the realm of software and data, and into the system of governance. This first step into human (over data) systems began a process where there was evidence of the ability of the software, or belief in the concept, to have impact in the world.

Fig. 20.3 Researchers on the cover of the Maroondah engagement strategy (Maroondah City Council 2016a), which is indicative of the level of commitment to imbedding the research into real-world environments

With the project now included in municipal policy the municipality registered that, for the project to succeed, statutory law would have to change; to allow higher densities than existing residential zones. As such, researchers were advised that, without the direct support of the state planning authority, and inclusion of the project in a high-level policy document, this was unlikely to happen.

In the Australian, urban planning context, and aside from actual legislation, there is no more powerful document than the plans for the greater metropolitan areas.

Focus Area 2. Managing growth and changing housing needs

There are detailed initiatives that can support the managing of population growth and change, and the resulting change in housing needs. In particular, Council has identified the federally funded 'Greening the Greyfields' project as a major initiative to manage growth through housing regeneration in the middle suburbs in a sustainable way.

Key Direction 2.1

Work in partnership with State Government and Swinburne University on the concept of 'Greening the Greyfields' in Plan Melbourne Refresh to deliver better development outcomes than existing subdivisions

The term 'Greyfields' is a housing redevelopment term for development that is occurring in areas with ageing populations and housing stock, as opposed to greenfield (urban fringe) and brownfield (ex-industrial land).

The Plan Melbourne Refresh contains a statement of support for greyfield renewal along with an objective to investigate planning scheme mechanisms to achieve coordinated and sustainable renewal of greyfield areas.

Furthermore, the community engagement process highlighted the need for areas other than the larger activity centres to take their fair share of development, but also wants to maintain the character of the suburbs of Maroondah and maintain affordability. Furthermore, transport and accessibility were identified as the major infrastructure concerns of the community and designed and located greyfield development should be able to cater to these housing needs.

Fig. 20.4 "Greening the Greyfields" research project in the Maroondah Housing Strategy (Maroondah City Council 2016b). An example of how research needs to imbed itself into the policy agenda

Examples are Plan Melbourne (The Victorian Department of Environment Land Water and Planning 2017), A Plan for Growing Sydney (Department of Planning and Environment 2014), Directions 2031 (Western Australian Planning Commission 2010). These documents set the policy directives for each of their respective cities; indicating the areas of strategic focus in terms of residential growth, business growth, infrastructural expenditure and how the city will develop for the next 20–30 plus years. It is from these documents, and the policy priorities coming from them, that dictate the funding commitments, as well as the rationale behind staffing commitments for both state and municipal governments. As such, inclusion in this document equates to a funding stream for project implementation, however, inclusion in this document requires a level of political de-risking and proof of concept prior to being signed off on by the Minister for Planning.

Inclusion in the municipal housing strategy, combined with the obvious need for a public show of support from the state planning authority, led to the need for the projects inclusion in the metropolitan strategic document. However, for this to be done the project had to show a clear methodology for success and expansion to additional municipalities; potentially expanding to the all municipalities in the greater metropolitan area. Thus, began a series of work with the municipal government;

defining the process required to implement the research through the existing planning, statutory and engagement protocols, plus how these protocols should be altered to accommodate the concept of a precinct. These included the following:

- Whole of (local) governments workshops, identifying the areas that need specific precinct additionality or broader community benefit.
- Initiating a community advisory committee, comprised of local landowners, community members and representative community interest groups. This group field-tested many of the assumptions, directed the choice of pilot areas within the municipality and added to the list of precinct additionalities (see Fig. 20.5). As in all effective community development projects, this group also identified the existing active community groups, who would be engaged to generate the groundswell required to activate the process from the ground up—effectively putting pressure on the municipality to implement the scheme. This was necessary regardless of municipal commitment to implementation and was advised by external communications and governance experts.
- A set of statutory workshops with lawyers and planners at both the municipal and state level to establish new residential zones or amendments to existing zones.

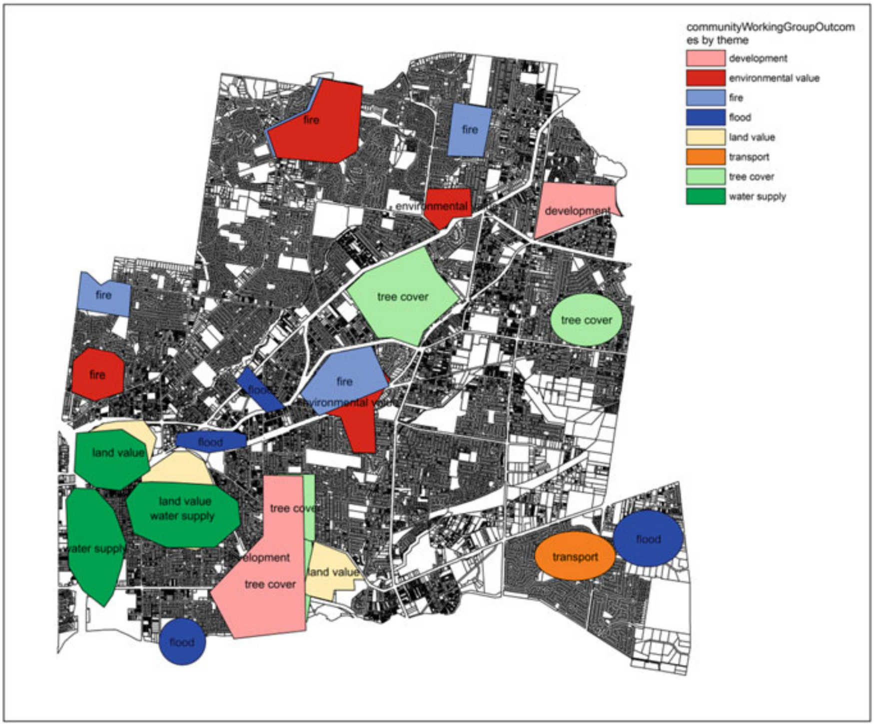

Fig. 20.5 Map of community identified additionality, including flood mitigation, areas needing trees, areas of poor walkability

- Viability assessments of various scenarios, illustrating the benefits of various development scenarios to landowners and municipal government.
- Compiling a set of legal instruments that landowners could use to work in partnership, as a joint venture, incorporate and so forth.
- Establishing a planning pathway with the municipality, where landowners could be guided through the development or lot assembly process by the municipality.
- Developing a landowner engagement protocol, involving all of the above and ensuring that this process could be assessed and agreed upon by both municipal councillors and the ethics board of the respective universities.
- Working with local real-estate professionals to create awareness of the project, test our feasibility assumptions and create a business groundswell for the project.

The above are set to become part of the engagement manual for greyfield precinct scale renewal. It was this commitment to providing all the details for successful implementation and the attention to politically de-risking the process, that led to the project becoming on agenda items in Plan Melbourne 2017, the major metropolitan statement for the future of the city: “Methods of identifying and planning for greyfield areas need to be developed. A more structured approach to greyfield areas will help local governments and communities achieve more sustainable outcomes” (The Victorian Department of Environment Land Water and Planning 2017, p. 51)

Inclusion in this document, combined with the ongoing efforts of researchers, has led to the project, or rather the resource-poor municipality, to legitimately begin committing staff to the issue. The outcomes of this has been to see the bullet points above now having commitment and resource outside of the research group. More fundamentally, it also means that a rationale for delivering the project has been achieved, and, should the deliverables required by the state planning authority be delivered, that the project can now move into implementation for the entire metropolitan area. Furthermore, inclusion in the greater metropolitan document was also the rationale for the federal government becoming a new partner and co-funding the project to provide additional implementation staff within the municipality.

This success, as well as the evolving engagement methodologies, has resulted in additional funding from an additional Cooperative Research Centre (for low carbon living) in a new Australian state (New South Wales) with a new planning agency (the Office of Environment and Heritage) becoming involved as funding partners in the project; which further legitimates the work.

At the time of writing, all engagement activities are ongoing and working towards the commitments of both local and state government partners. There are no guarantees that this will amount to change, but through the many engagement activities, we are poised to implement not only the oncomes of a geospatial software, but also all the legislative and government processes required to deliver the product in Australia, or at least legislating it. The concluding section will break this down into a method for application and successful activation of geospatial software.

20.4 Abstraction of a Method

Process mapping: The first step in making the tools have impact was to determine the business processes of how the envisaged outcomes would be delivered; i.e. how lots could be amalgamated. This required a significant amount time spent in the field with planners at both the state and local level, asking "what would need to be true for this to work". This produced a systems diagram illustrating the range of stakeholders and their part in the process, which is presented in Fig. 20.6.

Narrative and business logic development: Once the system was mapped, including the order in which stakeholders had to commit to the process, the next stage was to determine the rationale for each stakeholder's involvement and the narrative (or business logic) that would make most sense to them. To reiterate, the rationale for this being that each organisation has its own interests, which may compete with the interests of other relevant stakeholders, meaning that separate narratives need to be created for each organisation. This is illustrated in Table 20.1.

Communications: The third step was to establish a communications plan for each organisation which focused on the narrative specific to each organisation, following which significant work was done on committing each organisation to their part of the process.

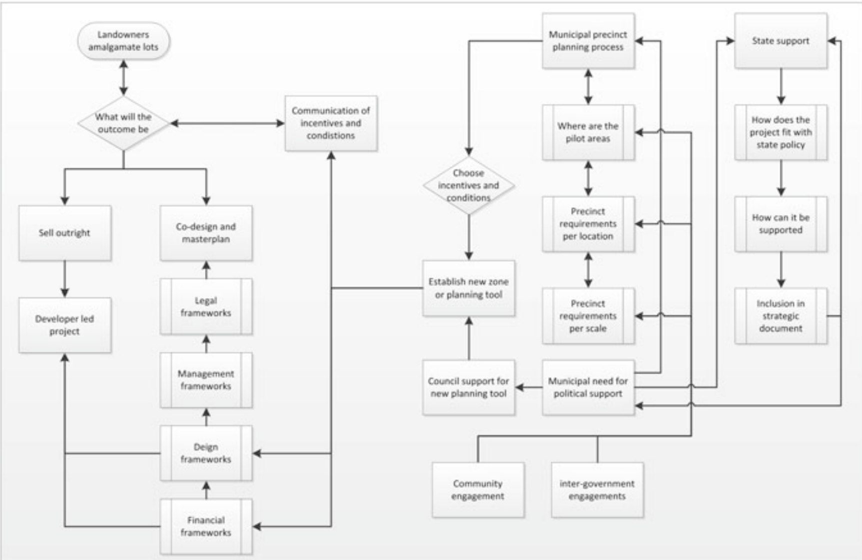

Fig. 20.6 Process mapping of precinct scale regeneration in action (Glackin and Gudes 2017). The far right illustrates the support required from the state government (or national in non-federated nations). Moving to the left are the process occurring at the municipal level; incorporating the engagement required to move to implementation. Finally, on the far left are the processes needed to allow for landowner led redevelopment

Table 20.1 Stakeholders, rationale precursors and narrative

Stakeholder	Event/Object	Incentive/Rationale	Precursor	Narrative or business logic
Property owners	Collaborate on land assembly	Increased sale value Opportunity for codesign Opportunity for joint venture	New zones (potentially) New planning guidelines Design templates Exemplar legal forms Exemplar financial models	Build faith in the process (show its relative simplicity and formality) Show benefit (financial and otherwise)
Broader community	Supportive of development	Social/Environmental benefit	New engagement techniques linked to new planning and development process	To show the community the potential for benefit
Municipal government	New zones to allow development incentives, value capture and social/environmental good	Reach policy objectives Potentially save on municipal purse	Proof of concept (due diligence) Political will (and de-risking) to push to council. Adequate design, planning, and engagement staff Public statement of support (local policy)	Implement local policy (sustainability and housing) Implement state policy (more infill) Satisfy community concern Save municipal purse
State government	New scalable processes for precinct scale residential infill	Promote sustainable communities and reach infill targets	Proof of concept (due diligence) Political de-risking Municipal support	Implement state policy (more infill) Support municipal planners Gain a political win if successful
Housing industry	Acceptance of new regulations	Access to larger yields	Proof of concept (due diligence)	De-risked multi-lot redevelopment with costed requirements and development concessions

Application: the final phase was developing the specific objects required for each partner organisation, such as the policy brief for state government, the statutory and broad engagement tools for municipal government, and the full stack of community engagement tools for landowners. With the fourth stage of this process almost complete, we are now, finally, in a position to establish the software as part of the land-use redevelopment model.

20.5 Conclusion

The aim of this chapter has been to briefly illustrate the complexities behind activating cutting edge geographical tools, and therefore implementing the outcomes of research projects. As illustrated, simply building a tool does not guarantee its use. Rather, the business case needs to be created in order to show its benefit. This is counter to the typical development lifecycle of software, which is a product of industry demand. However, it is largely the way in which research-based systems come about; as a response to deep inquiry into a phenomenon. In fact, the novelty inherent in research outputs almost guarantees that an existing business case for its use does not exist, which means that, to have effect, a rationale for system use must be created. This is the "tail wagging the dog", or the reverse causality referred to in the title; where demand is created after system development.

This process comprises of four key activities: process mapping; narrative and business logic creation; effective communications strategies; and a pathway to application, all of which are described above. By effectively examining the entire system that the tool/method must work within, and mapping the needs of each organisation, as well as their existing business practices, it is possible to then develop the most effective narrative as well as the business requirements that each organisation needs to see to find value in the system. Flowing from this, a communications strategy will highlight the sensitivities and the practical necessities of each group, after which the researchers behind the tool/method should be well placed to identify the areas where innovation in engagement and application is required to drive uptake.

This is obviously idealised and glibly put path to success, however, it should point out that in order for research outcomes to have any affect they need to be embedded in the world where decisions are made, i.e. in policy and business. The complexity of code, data, logic and system architecture are only the first hurdle; embedding the system into less-than-ideal business and bureaucratic processes is the often missed aspect. In reality, this is far more complex than developing the actual system, as it requires diplomacy, communication, political understanding and negotiating the vagaries inherent in any human system; where the variables vastly outweigh those of a piece of research software.

To conclude, maps have become normalised; geospatial data is a reasonably common commodity; open-source GIS are freely available and coding is no longer a dark art known by few. If so, why then are so many organisations unable to harness geographical information and, in particular, take up geographical research outcomes? In the spirit of the book, where the issues central to advancing geospatial inquiry are explored, it is the opinion of the author (and research associates) that the critical issue to overcome is the inability of geo-research (and GIS broadly) to imbed itself into the existing business practices of organisations. Advocating for geospatial awareness or simply building a system is not enough. To move forward, the spatial community needs to work outside of the spatial community and engage with the wider policy and business world it resides within. So, unlike many academic papers, this chapter does not end with a call to arms for more research; rather the opposite. What is required is a movement from the lab to the arenas of policy and business, where the battle for the uptake of geospatial systems is won or lost. That being said, and on advice from the editors, these linkages are apparently being made in Europe and further afield (see Streilein et al. 2016). Even in Australia there are movements towards this; with the federal government sponsoring applied Smart Cities and Suburbs research (Department of Infrastructure Regional Development and Cities 2017), which this body of work benefitted from, and the ongoing efforts of peak bodies in spatial data to unite research, government and business (Frontier SI 2018). However, and as covered by Pettit et al. (2017), as well as significant personal time in the field of spatial implementation, the gap between spatial systems, existing business and governance processes, and the capacity of users to make use of new systems, remains vast. Until this divergence is addressed, and until spatial research is more fully imbedded in business process (or sets about to recreate them—i.e. the tail wagging the dog), we will continue to see a lack of uptake of the outputs of our field.

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Chapter 21
Multihazard Risk Assessment from Qualitative Methods to Bayesian Networks: Reviewing Recent Contributions and Exploring New Perspectives

John Tsiplakidis and Yorgos N. Photis

Abstract Natural processes are interacting components of natural systems. Under certain circumstances, they can be transformed into threats for humanity, environment, and development. Examples such as the 2006 Pangandaran earthquake–tsunami and the 2011 Tohoku earthquake–tsunami–flood–nuclear catastrophe point out the necessity for an integrated multihazard risk assessment tool. This paper presents the critical steps and improvements in approaches to multihazard risk management. From the first qualitative, semiquantitative techniques with which risk is calculated through individual processes to more powerful techniques which try to capture and evaluate the interactions (trigger, cascade effect) among the natural hazards, such as Event Tree (ET) and Bayesian Networks (BNs). Especially Bayesian Networks and recently, their extensions as Dynamic Bayesian Networks (DBNs) and Hybrid Bayesian Networks (HBNs) offer a great opportunity for a more realistic and flexible multihazard risk assessment.

Keywords Risks assessment · Hazards · Models · Network

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21.1 Introduction

Facts and figures from a variety of reports coupled with several incidents all over the world conclude that the number of disasters or catastrophes related to natural or technological hazards has been on the increase throughout the years. Hence, it is only a matter of time before another disaster strikes again. At the same time, the huge proliferation of population, the climate change and the relentless pressure of urban sprawl on the available space have altered the mechanisms of natural phenomena and their characteristics by triggering crucial changes to the way they respond to environment and humanity. (Fausto Guzzetti 1997). As a result, experts have to identify the new hazards and illustrate the major impacts derived from climate change, rapid urbanization, and development pressure in the foreseeable future.

Moreover, studies in the multihazard risk assessment field illustrate that many areas are not affected by only one single natural hazard. Mountainous regions might be exposed to landslides, avalanches, and earthquakes and coastal zones usually suffer from floods, typhoons, and tsunamis throughout the year. Examples such as the 2004 Indian Ocean earthquake–tsunami, the 2006 Pangandaran earthquake–tsunami, the 2011 Sikkim earthquake–landslides and the 2011 Tohoku earthquake–tsunami–flood–nuclear catastrophe indicate the necessity for an integrated approach to multihazard assessment, which considers hazards and their possible interactions in an integrated framework. Although the interpretation of multihazard risk assessment is not captured in detail yet, previous globally inspiring work, (Arnold et al. 2005; Asimakopoulou and Bessis 2011; Bartel and Muller 2007; Bell and Glade 2004; van Westen; Ciscar et al. 2014; Delmonaco et al. 2006; Dragicevic et al. 2011; Durham 2003; El Morjani Zel et al. 2007; Glade 2012; Granger et al. 1999; Greiving and Fleischhauer 2012; Greiving et al. 2006; Heinl et al. 2006; Kappes et al. 2012b, c; Lung et al. 2013; Marzocchi et al. 2012; MATRIX 2010–13; Nadim and Liu 2013b; Ronchetti et al. 2013; Sandri et al. 2014; Schmidt-Thomé et al. 2006; Schmidt et al. 2011; Tarvainen et al. 2006; Tate et al. 2010; Thierry et al. 2007; van Westen 2013; Westen et al. 2002) has addressed the challenges, by suggesting a basic five step approach, which: (1) identifies all the hazards on the selected area (2) adopts a space–time window for all the hazards (3) selects the qualitative or quantitative method for the proposed model (4) defines the type of elements at risk, and (5) calculates the damages and losses.

This rapid acquisition of knowledge in the field of multihazard risk assessment fails to intercept the detrimental effects to human life and environment considering that the losses from natural hazards continue to grow. (Nadejda Komendantova 2013; White et al. 2001) At the same time, stakeholders and government managers do not feel capable of reacting efficiently to dangerous hazardous events although they are an inherent part of our world (Ji et al. 2013). Evidently, it may not be feasible to contain the repercussions of a disaster so what will be a success in multihazard risk assessment? Diminishing impacts by establishing innovative implementation procedures based on preventative strategies with a view to enhancing the quality of our preparedness against natural and technological hazards will be a success.

Multihazard risk assessment as a tool can establish and increase the awareness of new and existing risk levels, respectively, through a joint analysis of all hazards that potentially may affect a territory. Thus, making it possible for authorities and stakeholders to be: (a) familiar with all types of natural and technological hazards that raise a potential threat in their area (b) informed through significant quantitative or qualitative data of the risk and the potential losses. In this way, the authorities have all the indispensable information to provide specific guidelines for emergency plan, spatial sustainable development, and secure land-use planning (Kappes et al. 2012c; Neri et al. 2013; Bell and Glade 2004; van Westen et al. 2002).

In multihazard field, the main question remains perennial. Do we stand any chance of assessing risk from different natural hazards and their interactions in a common and transparent framework for different elements at risk? Many authors have been trying to come up with an answer to this question, suggesting various models which deal with hazards in different ways. These models utilize the available data to assess the danger from natural hazards, based on qualitative, semiquantitative, and quantitative techniques. The evolution from qualitative to quantitative approach have been happening because authors have been facing the challenges which emerge in the field of multihazard by realizing the demand to investigate and manage in a quantitative way various types of technological and natural hazards that can potentially threaten humanity and environment in a specific area.

Qualitative techniques provide a relative risk assessment while risk, related to a variety of hazards, is calculated through individual processes and results are summed or multiplied to derive the final multihazard risk index/classified map (El Morjani Zel et al. 2007; Greiving et al. 2006; Bell and Glade 2004; Tate et al. 2010; Thierry et al. 2007; Wipulanusat et al. 2011). The main disadvantage is the subjectivity in the decision process while risks and hazards are ranked and classified empirically or according to authors' expectations and their ability to understand the hazards.

Several authors, with the view to exceeding the subjectivity problem in the evaluation procedure have implemented statistical techniques and methods (probabilistic analysis) in their models for more realistic results. These models and specific applications like Hazus, RiskScape, Capra, and RiskCity have provided the stakeholders with the capability to calculate direct or indirect losses and quantify risk objectively. (Apivatanagul et al. 2011; Arnold et al. 2005; Bartel and Muller 2007; Bell et al. 2007; CAPRA 2008–2012; Cardona et al. 2010; FEMA 2011; Frigerio and van Westen 2010; Ji et al. 2013; Liu et al. 2013; Mahendra et al. 2011; Reese et al. 2007; Schmidt et al. 2011; Syphard et al. 2012; van Westen et al. 2010) They utilize probabilities as a means of providing crucial information such as probability of exceedance, annual losses and damage ratio in a given period without having evasive results. These numbers elucidate the level of risk or losses outright. Hence, authorities assimilate the danger from different hazards in a well-rounded way. The main disadvantage with this approach is that experts have difficulty finding and collecting reliable data for their models taking into consideration that there is a significant correlation between the results and the quality of data.

Natural hazards do not function independently of each other in the same area as they are influenced by one another as being components of a bigger system. This situation is often described as hazard chain cascade or domino effect (Buzna et al. 2007; Carpignano et al. 2009; Delmonaco et al. 2006; European 2011; Kappes et al. 2012c; Marzocchi et al. 2012; Tarvainen et al. 2006; van Westen et al. 2010, 2014). In order to consider the interactions spatially and temporally among hazards, only a few techniques have been proposed until now and the challenges in this field are great. They mainly are a) interaction matrixes (De Pippo et al. 2008; Jiao and Hudson 1995; Kappes et al. 2012b) which identify possible relations among hazards, (b) the platform technique (Isabella Bovolo et al. 2009) which allows a user to combine more than two related models so as to illustrate the interactions between hazards, and (c) the family of probabilistic graphical models like Event Tree or Bayesian network (Garcia-Aristizabal et al. 2013a; Hong et al. 2009; Marzocchi et al. 2004; Neri et al. 2008; Neri et al. 2013; Newhall and Hoblitt 2002; Einstein et al. 2010b; Liu et al. 2014; Nadim and Liu 2013b).

The aim of this paper is: (I) to illustrate the evolution progress and crucial steps in the field of multihazard risk assessment. From the first qualitative techniques to more powerful ones which try to capture and evaluate the interactions (trigger, cascade, and domino effect) among the natural hazards, (II) to identify the future steps in multihazard field. Therefore, it is structured according to the following steps: (a) Qualitative methods (b) Probabilistic/statistical techniques (c) Techniques/methods for taking into consideration interactions and interrelations among hazards, and (d) Challenges and future steps for an integrated risk assessment. For each step, the approaches are described and discussed while examples are presented. Nowadays, more and more countries are calling for better preparedness and mitigation measures. Thus, an integrated multihazard risk assessment tool is needed more than ever; this paper without claiming completeness provides a thorough analysis of the techniques/methods in the field of multihazard risk assessment.

21.2 Proposed Methods to Multihazard Risk Assessment

Recently, the impacts of disasters have confounded the authorities and questioned the wisdom of our strategies of expansion to areas which are prone to catastrophes or disasters due to the presence of natural or technological hazards. A variety of extreme events, namely, wildfires, nuclear accidents, earthquakes, chemical fires, landslides, volcano eruptions, tsunamis, storms, and river floods threaten societies all over the world. Stakeholders, planners, and policy-makers, who are responsible to deal with natural and technological hazards, have realized that if they want to protect people from these hazards, they have to improve their efficiency to identify the threats and the vulnerability for a community. This can be achieved by experts who can utilize a profound understanding of different disciplines combined with experiences from several past disasters all over the world in order to help stakeholders with their decisions. Proposed methods are presented with a number of different methodological approaches. These approaches include qualitative, semiquantitative, and quantitative techniques based on indices, classification methods, platform techniques, interaction matrixes, and probabilistic graphical models in order to illustrate the natural hazards and risks related to them in a better way.

21.2.1 The Qualitative Approach for Multihazard Risk Evaluation

Qualitative techniques based on index or classification method provide a relative risk assessment. In index method, the indices are composed of major groups (people, infrastructure, buildings, etc.) for which a number of indicators are used that can be spatially represented. Each of the indicators is usually standardized between 0 and 1 (Westen et al. 2002). Classification method is an alternative choice to compare various hazards. Usually, variables which reflect the characteristics of hazards such as intensity, magnitude, and frequency are categorized by experts so as to classify hazards, respectively (Kappes et al. 2012c).

Multihazard risk assessment incorporates the terminology of technological/natural hazard (H), vulnerability (V), elements at risk (E), and risk (R). Several authors refer to definitions that provided by UNDHA (1992), IEC/FDIS (2009) and European (2011). From these references the risk, usually defined as a function of hazard, vulnerability, and elements at risk:

$$\mathcal{R} = H \times V \times E \tag{21.1}$$

Equation (21.1) depicts the correlation between risk and the three other variables which satisfy all the necessary requirements of a disaster. Especially for more than one hazard, several authors estimate vulnerability and hazard value/class separately and subsequently sum or multiply the results to derive/obtain the integrated risk values/classes from them. This technique can be formulated as

$$\mathcal{R} = F\left(\sum_{j=1}^{n} \mathcal{H}_{j+/*} \sum_{j=1}^{n} V(E)_j\right) \tag{21.2}$$

($\mathcal{R}$ is the integrated multihazard risk, as a formula of hazard (H_i) and vulnerability ($V(E)_i$) for hazards i to n)

Greiving et al. (2006) utilized this approach to present the Integrated Risk Index for a spatial risk management (Fig. 21.1). Five classes were defined for vulnerability and all the intensities of hazards. The individual maps are added to produce the final risk map. Vulnerability map incorporates the capability of elements of risk to counteract their exposure to the hazards. Finally, the integrated hazard map and the vulnerability map are summed up to provide the integrated risk map.

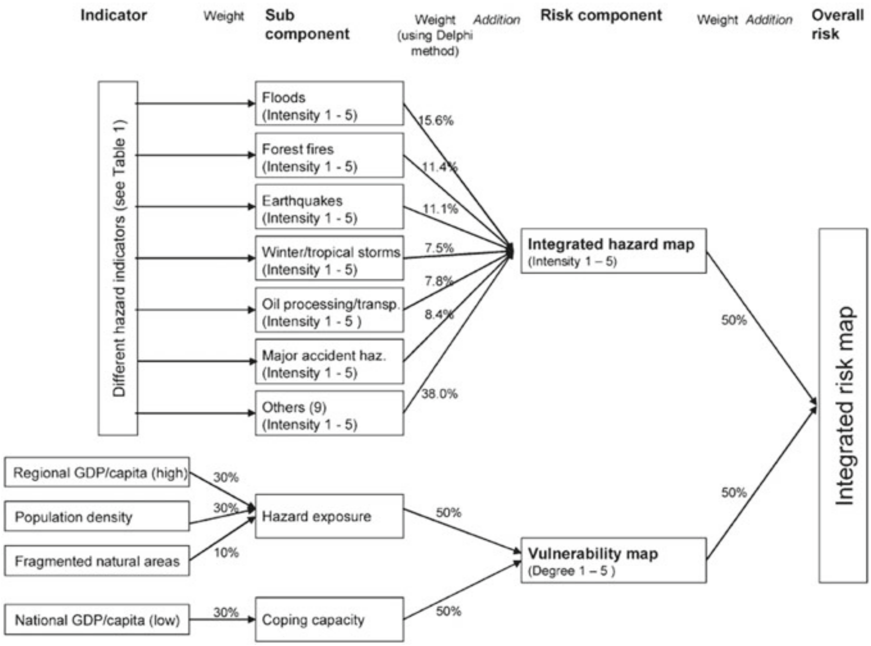

Fig. 21.1 Calculation of the integrated risk index (Greiving et al. 2006)

Similar El Morjani Zel et al. (2007) proposed the Atlas of Disaster Risk. In their project, they calculated in a qualitative way the spatial distribution of multihazard by taking into consideration seven hazards and the population's exposure to them. A map is produced for each individual hazard and subsequently the multihazard map is produced by summing the resulting maps, having used weights which reflect the importance of each hazard. The combination of the hazards and population distribution of the study area illustrated the population exposure to natural hazards. Tate et al. (2010) illustrated the same method for multihazard vulnerability assessment. The study area is Charleston County and seven hazards (earthquake, flood, hurricane wind, storm surge, tornado, wildfire, and fixed-facility hazardous material spills) pose a threat to the selected area. Authors used variables as frequency, losses and the social vulnerability index as a means to calculate risk, infrastructure impact and vulnerability for humans, respectively. The historical frequency of occurrence is computed as the inverse of the period of records. For example, if there are 45 years of tornado records, the frequency of each individual event is 1 divided by 45. In this way, every event for a given hazard type is assigned the same frequency. The hazard frequencies for every hazard are summed in each spatial unit to develop a multihazard frequency map. The results show where hazards occur the most in the study area. The classification technique was selected to produce maps with three levels of intensity (high, medium, and low) while the authors wanted to provide only the relative spatial distribution of risk. The final multihazard-vulnerability assessment map is an outcome based on formula $H = R \times V$. Here, the frequency map serves as a proxy for risk (R), the economic loss and social vulnerability maps were summed to represent vulnerability (V).

Many authors propose a slightly different technique based on Eq. 21.1 to estimate multihazard risk in a given area. A single hazard risk index/classified map is calculated for each individual natural or technological hazard to the exclusion of all the other hazards in the study area and subsequently sum or multiply them (possible with different weights) to construct the integrated multihazard risk index/classified map. It can be formulated as

$$\mathcal{R} = \sum_{i=1}^{n} R(\mathcal{H}_i, V(E)_i) \tag{21.3a}$$

$$\mathcal{R} = \prod_{i=1}^{n} R(\mathcal{H}_i, V(E)_i) \tag{21.3b}$$

($\mathcal{R}$ is the integrated multihazard risk, as a formula of hazard (H_i), vulnerability ($V(E)_i$) for hazards i to n)

Wipulanusat et al. (2011) used this approach in their study for the Pak Phanang Basin in Thailand. Two hazards are considered in this project: drought and flood. For each hazard, a risk map was produced based on historical data and then an integrated multihazard risk map was created by summing the two maps. Classification method was selected to categorize the final map in 3 levels of intensity (low, moderate, and high). Bell and Glade (2004) in their paper suggested the same method to calculate the final risk for three hazards (avalanches, debris, and rock falls) which affect the study area in Bildudalur, Iceland. They estimated individual risk for each hazard by calculating the probabilities of hazard impacts, seasonal and temporal exposure and losses based on Eq. (21.1). The highest risk is calculated for the debris flows. The resulting risk values for each hazard are summed to produce the final multihazard map by utilizing the classification method.

Bartel and Muller (2007) based on historical data and reports, authors calculated probabilities, to estimate risk for different hazards in Horn of Africa. Earthquakes, droughts, floods, and swarm of locusts were considered hazards. An individual risk map is produced for each hazard through a probabilistic analysis taking into account different elements at risk. The annual probability of drought is estimated based on historical rainfall data and the risk calculated as a formula of the spatial density of agricultural productivity which was affected by drought, flood probability is calculated from data of the Dartmouth Flood Observatory, the population density is the measure for the intensity of the hazard and Locust Infestation was estimated with data (monthly reports) from 1992 to 2006 by the locust control office of the United Nations. The Earthquake risk map is produced considering population density and the peak ground acceleration values based on data from the Global Seismic Hazard Assessment Project without computing the annual probability due to the fact that the earthquakes have completely different time scale occurrence from the other hazards in the study area. The final multihazard risk is estimated as the joint probability of one or more hazards which will threaten the area in a specific period without taking into account earthquakes.

Evidently, the above models are useful to identify the areas where risk level is potentially high so as to start emergency preparedness programs and mitigation actions. However, they do not offer calculations in a quantitative analysis and they are useful only in a relative sense. The main criticism of those techniques is the lack of impartiality in the risk assessment process (Fall et al. 2006; Leroi 1997; van Westen et al. 1997). Risk and hazards are ranked, and classified according to authors' expectations which depend on how well they know the study area and understand the hazards. Therefore, it is possible different authors to produce different hazard maps for the same area (Carrara 1993). Moreover, risk assessment involves different types of uncertainty. Uncertainty can be part of the selected technique/method or may emerge from the quality of the available data. More sophisticated techniques have been illustrated by authors to overcome these challenges. Analytical techniques have been proposed based on statistical inference to surpass the lack of impartiality, and consider the uncertainty in risk assessment at the same time (Dai et al. 2002).

21.2.2 Probabilistic/Statistical Techniques in Multihazard Risk Assessment

Multihazard risk assessment can be a useful tool as a decision support system or as a part of it. It can provide crucial information to authorities thereby reducing the potential impacts on communities and the environment by selecting appropriate risk treatment options (Durham 2003). The capability to assess the risk in a quantitative way is extremely important to depict the danger legibly. It is an undisputed fact that the majority of stakeholders assimilate the danger of hazards or the necessity to take emergency or preventative measures in a better way when they have numbers. Therefore, several resourceful authors have applied themselves to quantitative techniques by exploiting the flexibility of probabilities to be able to express direct impacts or indirect losses and risk of hazards as a percentage (Fragiadakis and Christodoulou 2014). This has been a great evolution because stakeholders have been allowed to estimate risk objectively and the validation process of the model is viable for different locations (Corominas et al. 2013).

Parametric and nonparametric techniques are mainly the two types of analytical approaches in multihazard risk assessment. The quality and availability of the data define which technique is suitable for our model. Parametric statistical procedures are more powerful than nonparametric ones, with their advantage being that the validation of our model can be done easily by experts in the statistics field (Livingstone and Salt 2005). Nevertheless, parametric statistics presume that our data always follows a specific and known distribution which in many cases is impossible to do and models can be very numerous and complex (Ji et al. 2013). Subsequently, the parametric method is not always able to be used successfully and another technique is required. Nonparametric techniques are an alternative approach to risk assessment by providing a more flexible one. They make fewer assumptions leading to the results being not easily interpreted as in the case of using parametric techniques (Ullah and Wang 2013). Nonparametric approaches use histogram density estimation method to derive probabilities from historical data but many authors claim that the results can be distorted. (Chongfu 1996; Huang and Ruan 2008; Liu et al. 2013).

Ji et al. (2013) illustrated a nonparametric method for flood risk evaluation in their model for China owing to their inability to implement a multiple linear regression between social vulnerability, weather, and surface features. The classification and regression tree method are used to establish the relationships between the three components. The weather conditions seem to have a major impact on flood risk assessment for the study area. Similarly, Syphard et al. (2012) in their paper for two regions in southern California, used nonparametric models (Generalized Linear Models) to identify how the spatial distribution of structures affect their endurance against fires. Their fire hazard maps illustrate that the majority of losses are located in low-risk territories. Similarly, (Apivatanagul et al. 2011) in their study of North California suggested a new method called optimization-based probabilistic scenario (OPS) for hazard assessment. By using a mixed-integer linear optimization procedure, they defined the annual occurrence probability for hurricanes.

A major advantage of multihazard risk assessment is its versatility. It can be used to identify the hazards in a specific area, calculate the potential losses provided there are data and define the vulnerability of elements at risk. Although the ultimate purpose of risk assessment is to provide all the above information in a package for decision-makers who are not experts but have the responsibility for deciding, whether risk should be ignored or actions should be taken. But for the devoted authors in the field of multihazard risk assessment, there would not have been studies and software tools like Hazus (FEMA 2011), RiskScape (Frigerio and van Westen 2010; Schmidt et al. 2011), Capra (CAPRA 2008–2012) and RiskCity (Westen et al. 2002) which offer the capacity to provide the stakeholders with a clear picture of the hazards and their potential impacts on elements at risk. Most of them embed GIS applications and calculate damage ratio, absolute economic losses, annual expected losses, maximum losses, and exceedance curves of elements at risk by considering a variety of hazards like volcanic activities, earthquakes, tsunamis, hurricanes–floods and landslides.

van Westen et al. (2010) as a contribution to the Mountain Risk and SafeLand projects presented a tool for mountain risk assessment. The package was developed for the Barcelonette area in the French Alps by using ILWIS software for hazards such as landslides, rocks fall, avalanches and floods, which threaten constantly the area. Quantitative or qualitative risk assessment can be provided based on risk curves method and the equation: $R = P_t \times P_s \times V \times A$. ($R$ is Risk, A is the number of Elements at Risk exposed to the hazard. V is the vulnerability, (in the current version has been simplified to 1). P_t is the temporal probability of major, moderate, and minor triggering events, which are estimated, based on the available multi-temporal inventory and P_s is spatial probability.

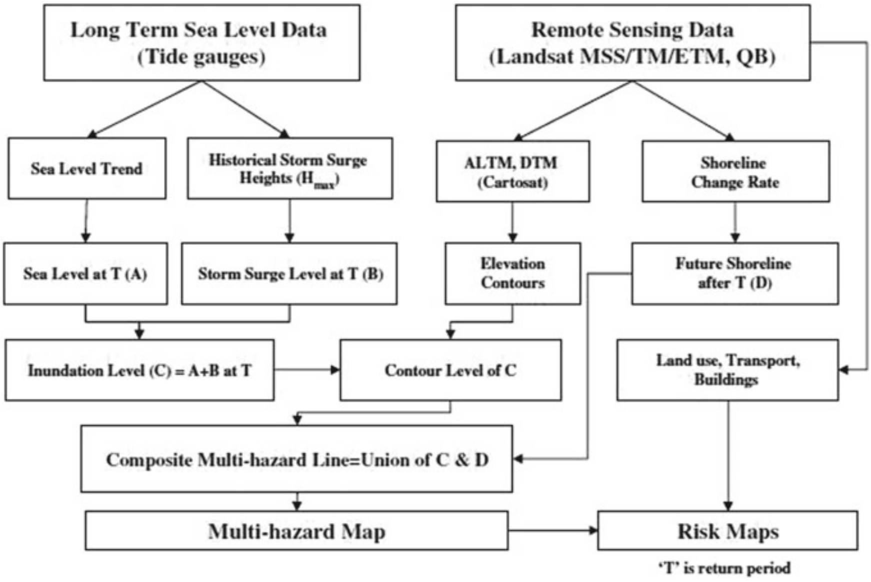

Fig. 21.2 Flow chart of the approach technique (from Mahendra et al. 2011)

Mahendra et al. (2011) in their study for the coastal zone along the southeast coast of India, propose a method for coastal multihazard assessment based on Remote Sensing, GIS tools and non-exceedance probability (Fig. 21.2).

Authors combined the rate of change indicators to depict changes to shore line and sea level, respectively, in conjunction with historical data and elevation contours so as to produce risk maps and evacuation routes. 0.085 mm/y, 5.5 m/y, and 6 m/y were estimated to be the changes in sea level, shoreline erosion, and accretion respectively, based on the probabilistic analysis of data. The risk map for the study area was produced by taking into consideration the max shoreline erosion, sea level, and max storm surge.

Liu et al. (2013) claim that information diffusion theory confers a few advantages to multihazard risk assessment. According to them, the information diffusion theory coupled with probabilities produce more reliable results than models incorporating other statistical procedures such as parametric and nonparametric methods. Additionally, the exceedance probability can be calculated efficiently even if there is a limitation of data. Only two specific natural phenomena are regarded as hazards for the Yangtze River Delta region in China, namely, typhoons and floods based on numbers of deaths in this specific area. The suggested model adopts the information diffusion theory to transform the deaths per million people for each hazard as a probability distribution, respectively. Finally, the multihazard risk is calculated as the exceedance probability of deaths for the region. The advantage of this approach is that it surpasses the difficulty finding and collecting data. This is crucial characteristic for quantitative multihazard risk assessment since there is a strong correlation

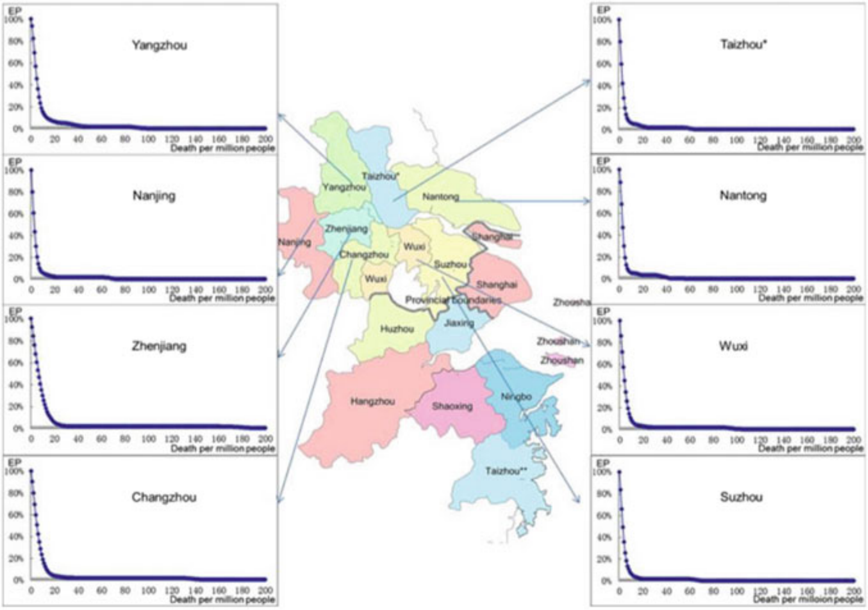

Fig. 21.3 Multihazard risk to human life in the Yangtze river delta region (Liu et al. 2013)

between reliable results and the quality of the data (Fall et al. 2006). A drawback of this approach may be the fact that excessive computational demands for the statistical calculation of the combinations of variables affect the time response of the model in a negative way (Fig. 21.3).

21.2.3 Techniques for Interactions and Interrelations Among Hazards

Until now, most of the proposed models and techniques rely on the assumption that hazards do not function independently of each other in the same area. Interactions and interrelations are not considered among hazards as a means of calculating risk, in contrast to some authors who have mentioned that hazards influence each other as components of a bigger system. This phenomenon, often described as hazard chain, cascade, domino effect (Delmonaco et al. 2006; Kappes et al. 2012a, d; Khakzad et al. 2013b; Malet et al. 2010; Marzocchi 2009; Marzocchi et al. 2012; Tarvainen et al. 2006; van Westen et al. 2010, 2014) can extend the overall hazard level higher than the simple approach according to which every single hazard just sums up to calculate the final multihazard values. Disasters based on domino or trigger effects always have the most rampart impacts on humanity and environment. The Fukushima disaster exemplifies clearly this situation. On March 2011 an extreme earthquake triggered a massive tsunami causing a flood followed by a nuclear accident. The nuclear facilities proved sturdily built to the magnitude of the earthquake and the hit of the tsunami, although the catastrophe was extensive in the coastal area including infrastructure and thus making accessibility to facilities impossible. The flood was the reason for the tremendous nuclear disaster sinking the emergency generators and the seawater cooling system into the water. Thus, it is highly important not only to identify the natural and technological hazards in the same area but also to take into consideration the possible interactions as part of a trigger or domino effect scenario. Only a few techniques have been proposed to consider the interactions spatially and temporally and it is sure, that challenges in this field are great.

21.2.3.1 Interaction Matrix Method

There are discrepancies in the way different approaches describe the interactions among hazards. Some of them encounter the challenge by investigating the simultaneous occurrence of different hazards in the same region even if directed linkages are not prominent among them, as opposed to other that implement probabilistic procedures to indicate correlations between hazards based on the available data (Delmonaco et al. 2006). The interaction matrix method belongs to the former approach. By using matrix experts encode all the possible relations among hazard to the study area. The final multihazard risk can be estimated by overlaying all the spatial information consecutively. Jiao and Hudson (1995) proposed the interaction matrix method as an interrelated system to assess risk for rock engineering projects. De Pippo et al. (2009) illustrated a similar approach in their study for the northern Campanian in Italy. A 6×6 matrix was constructed with the six hazards to be the six diagonal elements each in order, while the other 30 elements determine the interactions on cause-effect relations. An indicator from 0 to 4 and a constant value from 0 to 6 have been adopted by the authors to depict the priority of each interaction and weigh the influence of each hazard to their model, respectively. Finally, the overall hazard is estimated by adding the results of the indicator and the constant value after being multiplied for each hazard.

21.2.3.2 The Platform Technique

Glade (2012) and Kappes et al. (2012a) presented an alternative technique based on the interaction matrix method. In their study, they suggest the MultiRISK platform that incorporates single hazard risk assessment with the capacity to process the linkages between hazards in the same region. Five types of natural hazards are considered in their application and simple empirical models have been chosen for each hazard. The links between hazards were identified using the interaction matrix method. The output of one model used as input for the linked model so that updated information can assess the new hazard level. The capacities of the MultiRISK—platform have been designed and tested for the Barcelonnette case study in the South French Alps.

Earthquakes are not included in the analysis due to the unavailability of finding a suitable model which can be included in the set of the other five models (Malet et al. 2010). The platform technique is an innovative approach that allows a user to combine, more than two, related models. These can be linked in many ways depending on the project (Isabella Bovolo et al. 2009). In this way, platform technique provides a versatile approach to multihazard assessment as the end users have the ability to calculate risk from the selected model in accordance with their perception of danger. Besides the user's agility to link related models, collaboration of the models is a tall order since each model applies different spatial–temporal scale based on distinct assumptions and data have a variety of formats. Finally, it may be difficult to find models that can work together in a common platform.

21.2.3.3 The Probabilistic Graphical Models Technique

Probabilistic graphical techniques are more powerful than the interaction matrix method and platform technique. Probabilities are used to estimate risk and graphs represent the scenario. In the field of multihazard risk assessment, Event Trees are graphical presentations of a sequence of incidents that stem from the initial disastrous event and they are analyzed as a discrete evolutionary process jointly with nodes that represent resulting events with two possible states. Risk is calculated by estimating the consequences of the resulting events with the probabilities of occurrence. (Garcia-Aristizabal et al. 2013b; Hong et al. 2009; Marzocchi et al. 2004; Neri et al. 2008; Neri et al. 2013; Newhall and Hoblitt 2002).

Newhall and Hoblitt (2002) in their study implemented the Event Tree method and built an Event Ttree to depict a hypothetical volcanic process by estimating probabilities in each temporal step. Their nine stage event tree (Fig. 21.4) follows a logical discrete process from a primary event to final results that reflect vulnerability. Information about the nine stages—events are more accurate as we move ourselves along the side of the stages and their branches. Probabilities of each event are calculated by exploiting the theorem of conditional probabilities in conjunction with the Bayes's rule, which means the conditional probability for event a is $P(a_t|a_{t-1})$, given that event (a_{t-1}) has already happened, for the same events Bayes's rule can be formulated $P(a_t|a_{t-1}) = \{P(a_{t-1}|a) * P(a)\}/P(a_{t-1})$. According to authors, their model can be applicable to other volcanic regions on condition that the event tree is modified to designate the specific volcano case.

Marzocchi et al. (2004) based on Newhall and Hoblitt's event tree proposed a similar methodology for volcanic hazards at Mount Vesuvius. The main difference between their method and Newhall and Hoblitt's one is that they join a known probability distribution at each node of the event tree instead of numerical values. A three-step procedure that incorporates Bayesian features has been established as a typical approach for all nodes of the event tree to formulate the probability distributions. In the first step, they define the "a priori" distribution based on assumptions or theory while in the second step they modified the parameters of the "a priori" distribution based on statistical evidence of historical data by utilizing the Bayes's

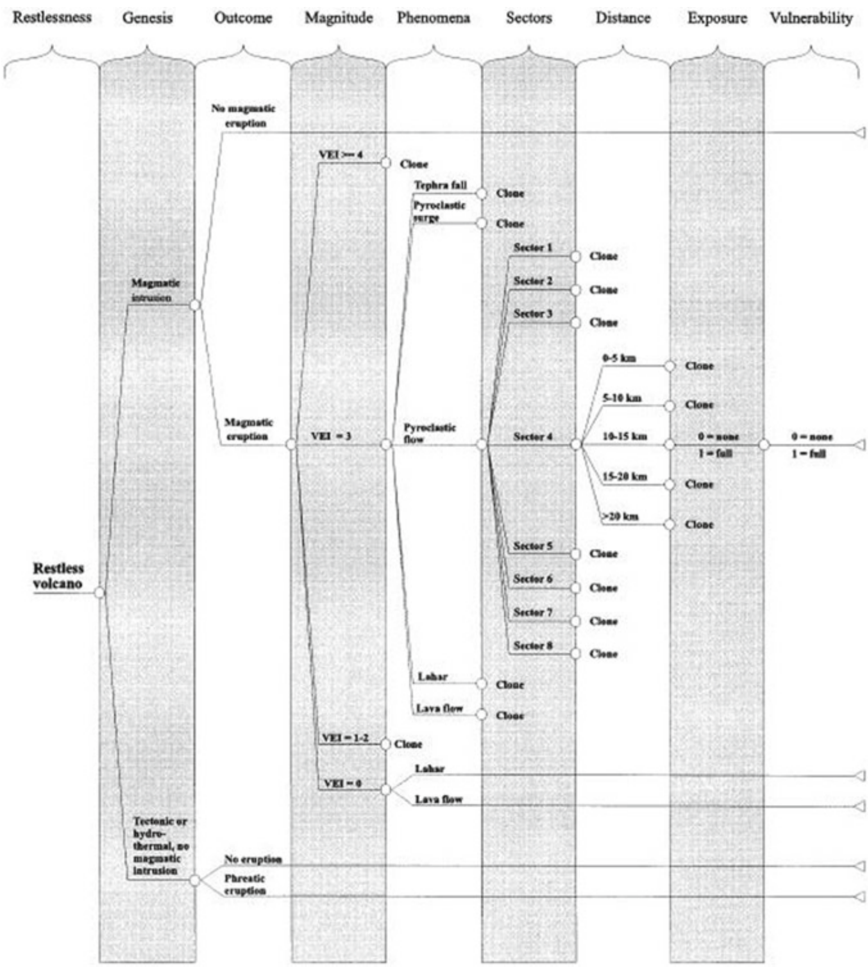

Fig. 21.4 An event tree for volcanic hazard risk evaluation with nine steps of estimation progress (Newhall and Hoblitt)

theorem; hence a new distribution is presented. The third step involves the information of contemporary monitoring data and a new probability distribution is presented by modifying the distribution of the second step and using Bayes's theorem again. Authors contend that their approach improves Newhall and Hoblitt's study since this model can be applicable for long-term risk assessment and uncertainty is monitored in a formal way.

The event tree method is a quantitative approach without increasing the complexity. From this point of view, it is a useful technique which can quantify the occurrence probability of the risk and take into account the interactions among hazards in a discrete scenario. However, there is a crucial drawback due to the structure limitation.

Events trees can have only a single starter point, for that reason they can not handle scenarios with more than one primary event which can be possible in multihazard risk assessment.

21.2.3.4 Utilizing the Bayesian Networks (BNs) in Multihazard Field

Our society is grappling with the rising threat of natural and technological hazards while multihazard risk assessment is in the spotlight. As long as it is impossible to impede a natural disaster, techniques, and methods to limit our exposure to them must be developed. Until now the most unresolved issues are: (a) the lack of objectivity on outcomes (b) the non-flexibility of updating procedure of the results (c) the inability to represent nonlinear relations among hazards successfully (d) integration of different models for multihazard risk assessment being generally problematic (e) usually models enclosing uncertainty. Bayesian networks have drawn authors' attention to encounter these challenges in risk assessment by exploiting their features (Aguilera et al. 2010, 2011; Einstein et al. 2010; Liu et al. 2014; Nadim and Liu 2013b; Neil et al. 2005; Pollino et al. 2007; Qiu et al. 2014; Weber et al. 2012). BNs are part of the probabilistic graphical model classification and they are made up of a graph and conditional probabilities. The graphical structure comprises nodes and arrows and it is the qualitative part of the technique whereas conditional probabilities are the quantitative one. The structure of the graph explains with transparency the concept of our model based on cause–effect relations. Variables are presented by input (cause) or/and output nodes (effect) and arrows in the network revealing dependency among variables. That means the arrow from node A to node B specifies the information that values of B are dependent on given values of A. Usually A is identified as parent of B whereas B is defined as child of A. A node is conditional independent of all the other nodes in the graph except its parents, its children and parents of these children, as a result the joint probability can be reconstructed to a product of simpler components (Ben-Gal 2007; Charniak 1991; Jensen 2001; Khakzad et al. 2013a; Smith and Gelfand 1992). If $x_1, x_2, x_3, \ldots x_4$ are variables from a typical BN, the joint probability distribution can be calculated:

$$
\begin{aligned}
P(x_1, x_2, x_3 \ldots x_n) &= \prod_{i=1}^{n-1} P(x_i | x_{i+1} \ldots x_n) * P(x_n) \\
&= \prod_{i=1}^{n-1} P(x_i | \text{parents}(x_i)) * P(x_n) \qquad (21.4)
\end{aligned}
$$

The conditional probabilities of the variables are organized in tables and can be calculated by statistical or empirical rules. One characteristic that makes BNs be one of the best practices in multihazard risk assessment is that by using Bayes's theorem (inference procedure) the probability distribution of $\text{Variable}_{\text{effect}}$ is updated given the probability distribution of $Variable_{cause}$ and vice versa, depending on the availability of data (Uusitalo 2007). The Bayes's theorem in a conceptual way is

$$P(\text{cause}|\text{effect}) = \frac{P(\text{effect}|\text{cause}) * P(\text{cause})}{P(\text{effect})} \tag{21.5}$$

The graphical structure of the model can be built by experts based on the subjective knowledge of the researchers or by using learning data algorithms to provide the dependencies among variables and the structure of the BN (Lauritzen 1995). In multihazard risk assessment, the former is prevalent because it may be impossible for an algorithm to recognize and imitate hazards and their interactions reliably (Chen and Pollino 2012; Nyberg et al. 2006). With BNs, authors manage to propose models that support updating procedure. Not only can they update the final results but also all the information in the network when there is new evidence (beliefs, monitoring data) in a specific node. In this way, BNs capture the uncertainty of the model and provide an almost real-time risk assessment procedure.

Furthermore, trigger or domino effect phenomena always amplify the final danger on elements at risk and deplete our sources heavily, hence it is crucial important to be taken into consideration in multihazard risk assessment. The graphical structure of the BNs depicts the cause-effect relationships among hazards and in this way all the possible interactions can be part of the assessment.

21.2.3.5 Applications of BNs Models in Multihazard Risk Assessment

Thorough research in the literature was carried out to identify risk assessment models based on BNs. It shows that (a) although there has been a huge proliferation of models that exploit the BNs theory only a small number of them are related to multihazard risk assessment (b) there is a global awareness of hazard interactions in risk evaluation owing to authors having realized that paying relatively less attention to some hazards than other or not taking under consideration the interactions among hazards can be highly dangerous. The total hazard level can be underestimated, having rampant consequences on elements at risk. (c) There is a high level of interest from authorities and decision managers to have access to tools such as (MATRIX 2010–13) that provide an integrated risk assessment in operational framework. Table 22.1 provides a summary of recent BNs models in the literature of multihazard risk assessment. The papers were selected to point out the discrepancies in graph building, selected software pack, scale of model and types of validations among the proposed models.

The intricacy and dependability of a BN model are crucial factors for its success. Both of them impair its capacity to work effectively and be adopted by decisions makers. Usually, a high complex graph structure demands a huge amount of data, more calculations and stakeholders may not be able to understand the concept of it and thus we have a low acceptable model. Nevertheless, a less complicated graph may fail to represent with accuracy the natural phenomenon hence it will be considered a low-performance tool and subsequently be rejected again. A balanced development

Table 21.1 List of the recent BNs models in multihazard risk assessment

Author	Natural/technological hazard	State of nodes	Software	Validation
GIS et al. (2006)	Avalanche	Discrete	Hugin	Sensitivity analysis
Liang et al. (2012)	Debris flow	Discrete	Bayes net toolbox for MATLAB	Comparative analysis
Song et al. (2012)	Earthquake–landslides	Discrete	Bayes net toolbox for MATLAB	Sensitivity analysis
Nadim and Liu (2013a)	Earthquake–landslides	Discrete	Bayes net toolbox for MATLAB	Sensitivity analysis
Bayraktarli et al. (2005)	Earthquake	Discrete	Bayes net toolbox for MATLAB	Sensitivity analysis
Gutierrez et al. (2011)	Coastal erosion	Discrete	Netica	Sensitivity analysis
Money et al. (2012)	Nanoparticle	Discrete	Netica	Authors discussion
Yates and Cozannet (2012)	Coastal erosion	Discrete	Netica	Sensitivity analysis
García-Herrero et al. (2013)	Nuclear hazard	Discrete	Hugin	Sensitivity analysis
Hapke and Plant (2010)	Coastal cliff erosion	Discrete	Netica	Sensitivity analysis
Blaser et al. (2011)	Earthquake–tsunami	Discrete	BN learning	Authors discussion
Straub and Grêt-Regamey (2006)	Avalanche	Discrete	Not mention	No sensitivity analysis
Peng and Zhang (2012)	Dam-break floods	Discrete	Hugin	Sensitivity analysis
Dlamini (2011)	Fire	Discrete	Netica	Sensitivity analysis
Wang et al. (2013)	Earthquakes, landslides, barrier lakes floods	Discrete	Not mention	No sensitivity analysis
Fenton et al. (1997)	Nuclear	Discrete	Hugin	Sensitivity analysis
Einstein et al. (2010)	Rock instability	Discrete	Not mention	Sensitivity analysis
Aspinall and Woo (2014)	Volcano hazard	Discrete	Netica	
Khakzad et al. (2014)	Chemicals	Discrete Dynamic BN	Hugin	Sensitivity analysis
Matellini et al. (2013)	Fire	Discrete	Hugin	Sensitivity analysis
Papakosta and Straub (2013)	Wildfire	Discrete	Hugin	No sensitivity analysis
Pagano et al. (2014)	Water impacts	Discrete	Netica	Sensitivity analysis
Cai et al. (2013)	Offshore oil explosion	Discrete	Netica	Sensitivity analysis
Mediero et al. (2007)	Flood	Discrete Dynamic structure	BN learning	Validated by simulating operation

(continued)

Table 21.1 (continued)

Author	Natural/technological hazard	State of nodes	Software	Validation
Quantitative multirisk modeling and management using Bayesian networks (Liu et al. 2014)	Earthquake–tsunami, rockslide	Discrete	Hugin	Validated by an event tree model
Bayraktarli (2006)	Earthquakes, soil liquefaction	Discrete	Hugin	No sensitivity analysis
Špačková and Straub (2011)	Geotechnical conditions	Discrete Dynamic BN	Not mension	Sensitivity analysis
Wu et al. (2015)	Road damage	Discrete Dynamic BN	Not mention	Sensitivity analysis
Molina et al. (2013)	Climate change impacts	Discrete Dynamic BN	Hugin	Sensitivity analysis
Khakzad (2015)	Heat radiation, explosion	Discrete Dynamic BN	Hugin	Authors discussion
Venkatesan et al. (2013)	Landslide	Discrete	Not mension	Authors discussion
Lee and Lee (2006)	Nuclear waste disposal	Discrete s	Not mention	PRA technique

procedure based on experts' knowledge and stakeholders' perception is the key to providing a functional model. In the review papers, the total numbers of nodes have a range from 5 to 40. Even if some models have a relatively big number of nodes (>30), these nodes have states with Boolean characteristics to constrain the size of the probability table.

The urban sprawl in new areas has brought to the surface a variety of natural hazards. Mountainous regions might be exposed to landslides, earthquakes and avalanches and coastal zones are threatened by floods, typhoons, and tsunamis. Several of these hazards have a low probability of occurrence or the number of their observations is inadequate for quantitative techniques. In these cases, risk assessment is impossible to do by statistical or analytical methods. BNs have the ability to incorporate knowledge or empirical rules when the model is not supported by observations. Graphs can be built by data learning implementations or experts. Data learning is an indirect approach to learn the structure of the network. Data can be transformed to graph by algorithms that screen observations of the variables and check for any dependencies among them. Experts' building is a direct tactic to construct the network based on authors' knowledge and ability to understand the phenomena. Most of the models listed in Table 1 used the second approach due to limitations on data and the weakness of the algorithms to understand the hazard interactions and their impacts on society. Only two applications use data learning algorithms to define the final network.

Furthermore, a natural or technological hazard can be modeled by empirical or simple mathematical applications as a single risk evaluation action. BNs have the capability to represent both types of approaches as sub-models in the network structure. In this way, models that referred to different phenomena can be joined together in an integrated framework providing multihazard risk assessment. The majority of the models in Table 1 use simple mathematical formulae based on empirical rules to depict hazards and their impacts on elements at risk. Hugin and Netica software packs are prevalent among the selected models. Both of them are innovative programs by supporting a range of statistical tools for working with BNs. They are not open source programs such as the Bayes Net Toolbox for Matlab (Murphy 2001) and less flexible to accommodate different types of data from other software.

Sensitivity analysis, experts' evaluation, cross-checking approach, and simulation are used as a means of validating a model. A sensitivity analysis determines which node of the network has the biggest influence on the output nodes. It is a tool for experts to screen whether the model reflects their understanding of the phenomenon. Evaluation by experts is an alternative procedure to check model behavior by discussing the output results of different scenarios of the model in accordance with stakeholder's beliefs. Simulation and cross-checking methods are simpler than the aforementioned techniques. Experts use their model to simulate a renowned incident or implement different methods to check their results.

In our days, Bayesian Networks (BNs) are probably one of the most promising techniques of modern approach in multihazard field. BNs can encode variables with a variety of hazard characteristics, vulnerability, risk, and elements at risk while their capacity to support updating procedure provides real-time risk assessment once the network is build. It is a transparent technique and users can understand the reasoning behind the model which is very important for stakeholders not wanting a black box as decision support system in risk assessment. However, there are few drawbacks. BNs are not compatible with feedback patterns, continuous data in the network need to be discretized and dynamic modeling is cumbersome (Uusitalo 2007; Jensen 2001 #165). Their recent extensions such as Hybrid Bayesian Networks (HBN) (Lerner 2002) and Dynamic Bayesian Networks (DBN) (Murphy 2002) have tried to overcome these limitations by implementing advanced inference algorithms which handle continuous values and dynamic behavior (time) in a better way.

The Hybrid Bayesian Networks

Hybrid BNs are spin-offs of research in inference algorithms of BNs to tackle variables with continuous observations. HBNs have variables that use continuous and discrete data simultaneously. The most appropriate methods to encompass both types of variables into a BN are (a) the Conditional Gaussian model (CG) (b) the MTE model, (c) the MCMC method and (d) the Discretization technique. Discretization suffers from loss of information caused by the fact that it captures the probability distribution roughly and the amount of the discretization error affects the quality of the outcomes (Friedman and Goldszmidt 1996; Aguilera et al. 2010). The Conditional Gaussian model (CG) avoid the discretization of the variables but there are restrictions in the model structure since discrete variables cannot have continuous parents and continuous variables must have a multivariate Gaussian distribution (Castillo et al. 1998; Faes et al. 2011). The MTE (Mixtures of Truncated Exponentials) method is similar to discretization by using a linear formula of exponential functions instead of constant values (Cobb et al. 2007; Langseth et al. 2009, 2010; Moral et al. 2001; Rumí et al. 2006). The MCMC technique is an alternative approach which utilizes the law of large number. Instead of using functions, sampling method is used to estimate the required probabilities (Bennett et al. 1996; Chib 2001). All of these approaches share the same aim of having continuous and discrete variables simultaneously in a BN, but the practical work for each one is quite different.

The Dynamic Bayesian Networks

Time is also an important dimension in the field of multihazard. Natural hazards are dynamic phenomena which change their characteristics with time. Moreover, interactions between them and their impacts on elements at risk are highly connected with time. Short time risk evaluation involves different types of hazards as opposed to the longtime ones. However, BNs do not provide direct mechanisms for representing temporal dependencies. For this reason, authors suggest Dynamic Bayesian Networks (DBNs) instead of the traditional BNs to model phenomena with dynamic characteristics. (Cox Jr 2013; Dean and Kanazawa 1989; Fenton and Neil 2007; Jha and Keele; Kim et al. 2003; Murphy 2002; Peng and Zhang 2013; Sarshar et al.; Špačková and Straub 2013). Authors can add temporal dimension to a BN with various ways (adding a node from historic data linked to the corresponding node in the Bayesian network or by running selection of Bayesian networks that can be used at appropriate time, given the particular state of the system or by having structure changes in the Bayesian network when beliefs in one node, surpass a threshold value and trigger some structural changes) depending on what they want to illustrate and the type of data. However, structural changes, time slices and temporal connections in the DBN can lead to complex structures (Friedman and Goldszmidt 1996; Ghahramani 1998). For that reason, the DBNs usually follow the Markov property which means that the model at $state_{\mathbf{t}}$ depends only on the $state_{\mathbf{t-1}}$ of the same model. In this way, DBNs provide temporal feedback in the network and encompass time-dependent values effectively (Rowe and Lester 2010).

Multihazard risk assessment can be a useful tool as a decision support system or as part of it. It can provide crucial information to authorities thereby reducing the potential impacts on communities and the environment by selecting appropriate risk treatment options. Inspired authors based on the analysis-synthesis concept (Ritchey 1991) evaluate their techniques to introduce each time an improved approach in risk assessment. From qualitative to quantitative methods a lot of progress has been done in multihazard field. In our days, experts have the ability to develop models based on quantitative methods which can illustrate the interactions among hazards in a better way. But there are still a lot of challenges to overcome in order to develop an integrated method which will be able to assess risk for natural hazards more effectively. The absence of common definitions about hazards, the different format of data, the difficulty to access data, and the variety of computation techniques for different hazard models are some of the critical points should we want to overcome the challenges in multihazard risk assessment.

21.3 Challenges and Future Steps (New Perspectives)

Natural hazards threat humanity and environment more than ever in our days. Multihazard assessment is a crucial tool for our society. We can evaluate the potential hazard level or total risk in order to establish preparedness and mitigation plans against natural hazards. But multihazard assessment is a complicated procedure with many challenges in every step namely collection and format of data, definitions of hazards, types of interactions among hazards and computation techniques for different hazard models. Experts and authors have developed a multitude of methodologies and techniques to overcome these challenges. Trying to answer fundamental questions like, how can we have high-quality data? How can different hazard models be integrated into one platform? How can interactions among hazards be captured in a better way? How can we validate the results of the proposed approaches? It may be a way to find the related solutions. Future steps and research directions are juxtaposed in the following paragraphs after having examined all the methods and techniques mentioned in this review.

21.3.1 Data Access and Collection

Access to reliable data is a serious problem in the multihazard field. Providing detailed risk assessment in a quantitative approach, usually requires a lot of data (such as the topologies of hazards, historical data of crucial events, observations data, etc.). In many cases there are no acceptable data or access to data is difficult due to a series of reasons including confidentiality and privacy issues. This happens because data mostly are intellectual property of private organizations and companies like insurers. As the collection of data is very difficult and expensive, licenses are difficult to be achieved by authors. (Goodchild et al. 2009; Kappes et al. 2012c). A joint effort has to be made by government organizations, research communities, and private companies to establish a unified framework so that everyone can have access to high-quality data. This action may prove of great help in two ways, new data can provide the basis to validate current models and techniques and they can provide the required information so that experts can develop new models or adopt a novel technique. Furthermore, there is no standardized data collection methodology for natural hazards which is acceptable of all. Until now organizations or experts use their own format for data depending on what they need for their models or applications. A common methodology will save time from transforming the data every time we want to use a different approach or technique. In this way, a rapid analysis will be easy to be done.

21.3.2 A Common Framework About Definitions

If we want to compare different techniques with specific criteria such as quantity and quality of input data, types of interactions among hazards and hazard types, we need a common reference framework about definitions in multihazard field (type and characteristics of hazards, type of interactions, type of vulnerabilities, etc.). Different definitions of risk, hazard, elements at risk and social or economic vulnerabilities are used by various methods; as a result, models may capture different aspects of risk and sometimes produce conflicted results. Common definitions to multihazards field will help experts, authors, and end users to compare the results from one technique to another or make use of them to new approaches as starting points. This can be done because it will be able to understand the analysis used.

21.3.3 Validation

Validation is very crucial for the operational applications and the development of techniques in risk assessment because it provides the necessary feedback for improving the existing techniques. Models are usually evaluated by comparing the model outputs to the historical data or case studies. But we should be careful because natural hazards are changing with time and the historical data cannot reflect the current reality or the dynamic interactions among them. The validation step requires the existence of some guidelines, standards, and rules for evaluating a model with a comprehensive and objective way which will be acceptable of all.

21.3.4 An Integrated Approach to Multihazard Risk Assessment

Although based on literature studies, there is a growing awareness of relations between hazards for a given area, still many approaches or applications evaluate the most dangerous phenomena for the study area and ignore the less dangerous and the interactions among all hazards in the study area. Giving relatively less attention to some hazards than other or not taking under consideration the interactions and relations among hazards can be potentially dangerous because the total hazard level can be underestimated and it may have rampant consequences on elements at risk. An integrated modeling framework to capture all the potential hazards and their interactions in a given area is more desired for a comprehensive multihazard approach.

21.4 Conclusions

In order to protect humanity and environment from natural hazards, authors have proposed many techniques to estimate the risk level. The selection of the method, the data availability and the consideration of hazard interactions are crucially important issues to risk evaluation. As long as there is no direct relationship between prior disaster experiences and good disaster preparedness, the goal is still the same. To develop appropriate techniques and methods that will capture the coexistence of natural hazards and their interactions so as to calculate the impacts on elements on risk effectively. In sum, multihazard risk assessment is an evolving process that has many challenges to face in the future. This article presents an introduction about the techniques and methods in multihazard risk assessment to new scholars in the field, identifies the challenges and proposes possible future steps for better and more realistic approaches.

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