Geoinformatics for Climate Change Studies

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The Energy and Resources Institute

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"Lighting a Billion Lives"

– a commitment to enlighten a billion lives with a handful of sunshine

To displace the use of fossil fuel, thereby mitigating climate change while illuminating the lives of a billion people

dies.

Foreword

"Warming of the climate system is unequivocal!" While climate change debate has been at the fore of international political agenda for the past few decades, the uncertainty surrounding the science, and its mitigation and adaptation aspects have brought the scientific community to the limelight. Anthropologically forced climate change is one of the most significant challenges humankind has ever faced and presents a significant opportunity for increasing the scientific understanding about our planet and about the human activities having major impacts on the global processes governing it.

The science demands a huge amount of spatio-temporal data to dwell with. Handling spatio-temporal data gathered from different sources, for example, the earth observation satellites, weather stations, GPS, and society, requires a very specific skilled and trained cadre in geoinformatics. As the technology is developing by leaps and bounds to collect and make available such data, it places greater responsibility on us to handle it well.

The book *Geoinformatics for Climate Change Studies* is a unique combination of two sciences—climate change and geoinformatics. While the former is the most exigent challenge of the era, the latter brings the knowledge of the most sophisticated technology to handle the wide variety of data required addressing such a challenge. This book provides an in-depth understanding of geoinformatics (remote sensing, GIS, GPS, ICT, and others) as well as an awareness of the causes and consequences of climate change.

A large part of the process of addressing climate change is our ability to learn from the previous experiences. This book brings such experiences in a lucid way so that students, researchers, and professionals interested in climate change and geoinformatics can gain from these. These case studies will also hold immense relevance from an academic standpoint as many of the institutions are coming up with promising programmes to develop a special cadre of trained and skilled manpower to provide solution to make the earth sustainable.

Better understanding of these processes will ultimately give researchers sufficient insights into how to move forward to preserve the ecosystems and environment we have and slow down the negative impact of our past actions. As geoinformatics holds a key role in enhancing our knowledge to address climate change, a thorough understanding of the procedures and techniques used in geoinformatics is a must.

I congratulate the editors in bringing out such a wonderful compendium on the much needed subject. I am sure readers will find the contents of the book interesting and worth applying in their subject areas.

R K Pachauri, PhD
Director-General, TERI

Preface

In recent years there has been an increasing awareness of the effect of climate change on the Earth and its resources. There has also been a dramatic increase in support for research in climate change studies. In particular, fundamental variables of climate such as past, present, and future data on biophysical attributes of the Earth's surface and atmosphere, and tools and methods for processing such data have become increasingly important in a vast array of climate change research and studies. Considerable recent research has focused on global studies and at global scale using such tools and datasets. The growth of research has been marked and is perhaps most apparent with the development of a new field of study—climate change.

Although there has been a long standing interest in global warming and its impact on the Earth's resources, the ability to work at different scales arises in part from advances in technology. Geoinformatics as the primary science and technology for spatio-temporal data analysis is of particular importance and significance. Geoinformatics encompasses remote sensing, geographical information system (GIS), data collected using global positioning system (GPS), information communication technology (ICT), and social interactions. Remote sensing now routinely provides information on the Earth and its environment at the local to global scales. GIS provides a means to store, analyse, and visualize spatial data, including those derived from remote sensing and collected from the field. Together with associated advancements in communication and computational facilities, tools are now often provided to efficiently handle and share a great amount of data of large areas. There are also specialist tools that recognize spatio-temporal characters. The opportunities presented by this situation help to make the area of overlap between climate change and geoinformatics of great interest for research; an area that fits neatly within the core for identifying and communicating climate change research.

Over the last three decades, the scientific evidence for human-induced climate change has become overwhelming. Such research places heavy demands for reliable climate information, which includes spatially distributed information about select climate elements. Similarly, the need for spatially distributed information about weather and climate has increased over the same period, in keeping with the increasing attention given to global warming and climate change by both scientists and policy-makers. Geoinformatics is playing an increasingly important role in climate change

research. It is seen as a vehicle for depicting past, present, and future land use, land cover, and climate patterns; for integrating data from various sources with potentially different data models so as to provide a basis for comparison and evaluation; and for visual presentation of the results in a policy-supportive, decision-making environment.

The focus of the book is to fill a gap in the available literature on the subject by bringing together concepts, theories, and experiences of various experts in this field. It is a collection of 16 chapters by scientists who work within the field of climate science and geoinformatics and whose papers reflect the state of research in their respective discipline. All of the chapters are significant contributions to document and understand climate change using geoinformatics, hence the title *Geoinformatics for Climate Change Studies*. The volume also includes chapters by the editors, who felt it appropriate as it reflected continuing contribution to the subject and a hands-on approach.

The diverse chapters in the book include aspects of remote sensing and GIS, but each is mainly focused on climate change research related to different aspects of human beings. The chapters presented vary greatly in conceptual framework, broad concepts, and specific application of new approaches to spatial modelling and applications. Some chapters present grand overview of concepts, while others provide results of large-scale projects and a few report results from pilot studies. All chapters, however, help illustrate ways in which geoinformatics is being or may be used in climate change studies. Most of the representative areas common throughout the globe are touched upon and it is hoped that others may be developed for later use.

Informed, thoughtful science represents humankind's best opportunity for understanding and managing the complexities of climate change. The first two chapters present a common setting of geoinformatics for climate change research and studies. In Chapter 1, Artz and Dangermond propose a GIS-based framework for earth systems modelling and global design that crosses academic, scientific, and industrial domains. A number of existing frameworks and programmes are reviewed to glean best practices and identify gaps. Visualization and exploration including modelling and designing are discussed as useful methods for understanding and responding towards climate change. This chapter is useful in many ways, and is written by top-notch scientists and philosophers of GIS from the Environmental Systems Research Institute (eSRI). The chapter also gives actionable recommendations in the areas of data, education, ethics, organization, models, and design to support the establishment of a GIS-based framework to help provide answers to this global challenge.

In Chapter 2, Joshi, Baruah, and Singh present an overview of the potential of geoinformatics. The chapter provides a series of application scenarios to illustrate the utility of the system, which seems particularly valuable in

exploring numerous applications simultaneously. This chapter discusses potential multiple roles of geoinformatics in integrated climate change research. Using case studies, an attempt is made to illustrate geoinformatics in action, from predicting the impacts of climate change as hypothesized future events to presentation of evidence of current climate change.

GIS has become a widespread and popular tool in climate and earth system studies. The next seven chapters on GIS applications present a variety of topics. Bolch and Wheate in Chapter 3 elaborate on glaciers as one of the key indicators for assessment of climate change in remote mountain areas where climate stations are rare or even non-existent. They advocated for multi-temporal remote sensing imagery over the conventional ground-based studies. Geospatial tools provide the opportunity to obtain information on glacier area, width and length, motion, and mass balance as well as other important characteristics such as debris-cover and equilibrium-line altitude. This chapter provides an overview of the advantages, challenges, and limitations of both optical and radar space-borne remote sensing data to map and study glaciers. The examples given refer to different glacier types across the world.

Chapter 4 discusses sea level rise is a coastal hazard, which not only threatens the coast with inundation but is exacerbated by storm surges and wave action. Young highlights the role of geoinformatics in assisting planners by providing the tools necessary to help assess the vulnerability of the coastal environment to sea level rise. The chapter discusses the limitations of current tools and provides high resolution data (example, LIDAR) for profusion of coastal vulnerability mapping.

In Chapter 5, Joshi, Priyanka, and Giriraj discuss the importance of geoinformatics in assessing the forest ecosystems under climate change trajectories. The chapter discusses modelling strategies for predicting the potential impacts of climate change, with examples from different forest ecosystems. The chapter lists some published examples and uses some of the original work to elaborate upon available tools and techniques to understand the impact of the climate change on forest ecosystems.

In Chapter 6, Flügel presents concepts, methods, and toolsets for comprehensive environment and river basin system assessment triggered by ongoing climate change with relevance to Integrated Water Resources Management (IWRM) and sustainable resources management. The synergetic potential of geoinformatics is highlighted in more detail with reference to the regionalized landscape concept of process-oriented response units. Taking examples from South Africa and Germany, the functionality and structural design of the Jena Environment System Analysis Toolset (JESAT) and its different tool components are discussed. In conclusion to the results presented, future research requirements are specified and briefly explained.

Chapter 7 brings a unique setting of climate, population, and energy. Stein and Lemke estimate changes in global future energy demand caused by heating and cooling buildings. Using 64 800 grid cells (180 lines of latitude × 360 lines of longitude), population and climate were calculated for every cell of the grid for 2007 and 2050. For 2050, the calculations were done for two different scenarios (A1FI and B2). This chapter forms a base for the integration of renewable energies in building sustainable planning solutions using geospatial tools.

Diodato, Ceccarelli, and Bellocchi discuss geoprocessing in evapotranspiration data in Chapter 8. This involves transformation of initial dataset derived from primary data sample and topographical information into a larger primary dataset using a topographically weighted radial basis function (TWRBF). In this way, the generated primary large-dataset can be subsequently used in geostatistical analyses for yielding at each unsampled grid-point, instead of a single class, a vector of probabilities of occurrence of different evapotranspiration-threshold data. This was applied to a cropland test site of the Tammaro sub-regional basin (South Italy) where the procedure was used to develop a baseline estimation of evapotranspiration at hilly slope scale incorporating a preliminary analytical GIS. This method can help devise a monitoring scheme for efficiently sampling the most agroclimatically sensitive and uncertain sites.

Chapter 9 introduces the issues of disease and linkage with climate variables. Tripathi, Chaikaew, and Jeefoo discuss the impact of climate on human health. Taking examples from two case studies on diarrhoea and malaria conducted in Thailand, the authors highlight the effect of climate variability on human health. The outcome is expected for better governance in applying strategies to prevent outbreak in future and save thousands of lives.

The next four chapters elaborate on the results of investigations at the national level, pressing contemporary applications in climate change research. Salami and Adepoju demonstrate the use of remote sensing technology for developing a system for land degradation management in Nigeria. Satellite measurements of the Normalised Difference Vegetation Index (NDVI), or greenness, for the period 1982–2006 were used as a proxy for net primary productivity (NPP). This is in contrast with conventional methods of land degradation assessment and monitoring in Nigeria, which are more often localized to specific regions and exist in a disaggregated format, often inaccurate, time consuming and are difficult to obtain in near real-time. Presenting a case from Bangladesh, Salami and Adepoju demonstrate the importance of satellite data to study variations in Land Surface Temperature (LST). Based on MODIS, the annual and seasonal changes in the surface temperature have been analysed based on the satellite data from January 2000 to December 2007 for every 8-day interval and the daily temperature

data of last 60 years (1948–2007) collected from 34 stations. Daily temperature is one of most important local phenomena contributing to global climate change.

In Chapter 12, Babqiqi, Messouli, and Kasmi demonstrate a technique to produce high resolution scenarios by using Statistical Downscaling Model (SDSM) and atmospheric general circulation model (HadCM3). The authors elaborate the trends of future temperatures, precipitation, and cold and heat waves over Morocco using SDSM between 1961 and 2099. These scenarios present a reference database of impact assessment models of climate change on socio-economic sectors such as agriculture and water resources.

In Chapter 13, Pradhan discusses the application of GIS technologies to natural hazard detection, modelling, and monitoring. The chapter demonstrates the importance of such technologies over other surveying tools to understand the complexity of the relationship between climate change and its impact on natural hazards. Taking examples from Malaysia, the effective utilization of GIScience tools have been discussed to study natural disasters and address technical requirements. Case studies are also presented to as lessons to adapt in other countries and to help at the time when disaster management is required.

The last three chapters focus on the future use of the technology and elaborate the importance of Spatial Data Infrastructure (SDI) and geoinformatics for climate change, adaptation, and disaster risk reduction. The last chapter focuses on issues related to climate change hazards. In Chapter 14, Paudyal, McDougall, and Apan advocate SDI, a coordinated framework of technologies, standards, and data supported by policies and institutional arrangements that enable sharing and effective usage of spatial information. This chapter discusses differing perspectives of SDI and its components. It proposes improved information management that could help address global issues like climate change at the regional scale. It supports building SDI at catchment scale to improve natural resource management and provide insights into climate variability and change.

In Chapter 16, Joshi, Munsi, and Joshi provide an overview of various adaptation strategies being developed for climate change adaptation (CCA) and disaster risk reduction (DRR), existing institutional frameworks, policies, risk management strategies, and early warning systems. Detailed review has been done on the use and effectiveness of ICT, SDI, and remote sensing and GIS in DRR, which will further help in CCA.

In the last chapter, Marincioni and Abeti discuss the impoatance of ICT, including spatial analysis systems, as an essential tool for the study and management of climate change hazards. However, to become truly effective, ICT innovations must be supported by a culture that favours changes and the sharing of information. This chapter looks into possible applications of ICT to study and manage climate change hazards and discusses known patterns of perception and use of these technologies.

The aim of this book is to provide a clear description, including drawbacks, of the use of geoinformatics in climate change studies and its use for modelling. The editors hope they have provided a timely book that will be a resource for students, researchers, and practitioners. Finally, it should be noted that the chapters in book all benefited from constructive critical comments, notably from colleagues working in these fields and from graduate students and also from discussions with the contributors. This type of input from the community is important and gratefully received.

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