N. Janardhana Raju
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Management of Water, Energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges

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Co-published by Springer International Publishing, Cham, Switzerland, with Capital Publishing Company, New Delhi, India.

Sold and distributed in North, Central and South America by Springer, 233 Spring Street, New York 10013, USA.

In all other countries, except SAARC countries—Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka—sold and distributed by Springer, Haberstrasse 7, D-69126 Heidelberg, Germany.

In SAARC countries—Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka—printed book sold and distributed by Capital Publishing Company, 7/28, Mahaveer Street, Ansari Road, Daryaganj, New Delhi, 110 002, India.

ISBN 978-3-319-05968-6 ISBN 978-3-319-05969-3 (eBook)
DOI 10.1007/978-3-319-05969-3
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014942847

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Message from Alexander von Humboldt Foundation

Maintaining a dynamic exchange of ideas and gaining new insights – this deep interest makes us human beings. Fostering and supporting people's scientific curiosity has been the Alexander von Humboldt Foundation's mission for 60 years now. Since its establishment in 1953, the Alexander von Humboldt Foundation sponsors top-level scientists and scholars from abroad who come to Germany within the scope of our fellowships and awards to work here in close cooperation with German colleagues. The fellowships and awards of the Alexander von Humboldt Foundation have earned a considerable reputation worldwide. We aim to support excellence and to create an expanding global network of cultural and scientific dialogue on highest levels. Until today, the Alexander von Humboldt Foundation has sponsored more than 26,000 scientists and scholars from all over the world embracing over 130 countries and including 49 Nobel Prize winners. We never set any quota for countries of origin nor fields of research in the selection of future Humboldt fellows. Our only criterion is scientific excellence. So far, the Alexander von Humboldt Foundation has granted well above 5100 research fellowships and awards to excellent scientists and scholars from Asia, amongst them 1781 from India. Today, roundabout 1200 Humboldt Alumni live in India. They form one of the largest regional Alumni networks in the world having established 16 active, self-organized Humboldt Alumni Associations in the country. The Humboldt fellows on the Indian sub-continent are vividly and enthusiastically participating in national and international Alumni activities.

"Once an Humboldtian, always an Humboldtian" – from the very beginning this was the hallmark of the Alexander von Humboldt Foundation. Humboldt sponsorship is enduring: the foundation is a lifetime partner, maintaining connections on a long-term basis through its alumni sponsorship programmes. Moreover, the foundation encourages its Alumni to undertake their own initiatives and collaborations across disciplinary and national borders. As a result, many Humboldtians make use of the foundation's extensive Alumni sponsorship offers. It was in this context that the Humboldt Kolleg "Management of Water, Energy and Bio-resources in Changing Climate Regime" took place in Delhi in February 2013. The Humboldt Kolleg was hosted by Humboldt Alumnus Professor Dr. Nandimandalam Janardhana Raju from the School of Environmental Sciences at the Jawaharlal Nehru University choosing a topic of major importance to the development in Asia for the conference. The Humboldt Kolleg served as a forum for scientific exchange and networking between Humboldtians and other young and experienced researchers from various disciplines. In total, 231 researchers participated in the conference, amongst them 35 Humboldt Alumni, 135 young academics, seven scholars from Germany and 54 other experienced researchers. A total of 135 presentations were given; another 63 scholars introduced the audience to their fields of research interest during a scientific poster session.

Dealing with the changes of our earth climate and its impacts on natural resources and the environment is one of the biggest challenges for mankind in this century. Worldwide, experts call for action against climate change and its negative environmental, fiscal, social, and cultural effects. As the organizers and presenters during the Humboldt Kolleg pointed out correctly, fragile and conflict-ridden societies will be especially prone to climate change and its impacts, as diminishing resources like groundwater and increasingly unequal distribution will tighten competition and will potentially evolve violent consequences.

On behalf of the Alexander von Humboldt Foundation I would like to thank Professor Dr. Janardhana Raju and the organizing committee at Jawaharlal Nehru University for their dedication and the initiative to conduct the Humboldt Kolleg whose outcome is published in the proceedings of this conference. The Alexander von Humboldt Foundation is most grateful to its Humboldtians, who support our aims and goals of fostering academic cooperation across borders and bringing forward the next generations of top-class international researchers. I wish all participants in the Humboldt Kolleg and the authors of this conference volume success and the best of luck for their future plans.

Dpt. Secretary General Dr. Thomas Hesse
Alexander von Humboldt Foundation
Bonn, Germany
August 2013

Foreword

This volume entitled *"Management of Water, Energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges"* contains many papers presented during the International Alexander von Humboldt Kolleg that was held at Jawaharlal Nehru University, New Delhi (India), on February 8–9, 2013. The meeting, convened by Dr. N. Janardhana Raju, School of Environmental Sciences, brought together about 200 scientists from different parts of India and overseas including Germany, USA, Brazil, Croatia, Taiwan, Tajikistan, Bangladesh, Iran, Ethiopia, Nepal and Sri Lanka. This book brings out different aspects of natural resources management addressed during the meeting and is divided into three broad sections: (i) Water Resources Management, (ii) Energy and Bio-resources Management and (iii) Climate and Natural Resources Management. The themes and topics covered amply show the broad spectrum of multidisciplinary scientific activities. Most of the papers are written by eminent scholars in their fields, but also by some young scientists, and are very informative with lots of data and methods with suggestions for improvement and conservation.

Environmental sciences require a broad knowledge that goes beyond the boundary of any single discipline and covers multiple objectives of researchers from various subjects. Thus, combining knowledge of different aspects of geosciences can greatly assist in coping with mechanisms for sustainable development and management of natural resources. Scientific evidence is needed to support decision making at national and international levels in order to protect and manage natural resources, to conserve ecosystem services and environmental challenges. Water shortages are caused mainly by increasing population, waste and pollution resulting in negative impacts on the environmental, socio-cultural, political and economic spheres of society. Water contamination can be due to geogenic and anthropogenic sources and continues to be one of the critical challenges adversely affecting natural ecosystems, agriculture and human health. The environmental problems caused by the increase of pollutant loads discharged into the natural environment require adequate legislation, too. An additional factor for future water shortages in certain areas that is currently much discussed may be climate change and its resultant impact on water resources.

Overall this book addresses water, biomass and energy needs, which must be the core objectives of all governmental policies and strategies in their future course of action. Future water shortages, their reuse and remediation methods, which challenge human health and the environment, are also discussed. The book holds interest for all those who are keen to know about the management of natural resources such as water, energy and bio-resources and should make an important contribution to a better understanding of natural resources management. I hope that this book will serve those concerned to acquire additional scientific information and experience required for ensuring natural quality and quantity aspects to protect natural resources from indiscriminate exploitation and consequent environmental degradation and to stimulate future work for sustainable development and management of natural resources.

I complement all the authors of the articles. I also congratulate the editorial team for their tremendous effort in bringing out this edited book. I trust the volume will serve for many years as a scientific information base for future planning of the management of water, energy and bio-resources and energize synergy among academicians, researchers, stakeholders and policy makers for documentation and dissemination of knowledge in natural resources management.

Martin-Luther-Universität Halle-Wittenberg
Germany

Gerhard H. Bachmann

Preface

Earth is a bounty for the sustenance of life and the very existence of human beings depend on natural resources and congenial environment on the planet. Water, biomass and renewable and non-renewable energy are the most fundamental resources for any civilization and demand for these resources is ever increasing at an alarming rate and is moving towards unsustainable levels. Degradation and erosion of natural resources, that are used to produce food and other valued goods and services essential for our survival and prosperity, are also the root causes of the agrarian crisis in the world. Diminishing water resources and their unequal distribution in the changing scenarios will increase competition for water which may turn potentially to violent events/wars in future. The water shortage that may be caused by a changing climate regime results in negative impacts on environmental, socio-cultural, political and economic spheres of the societies. No present or intended use of natural resources should condemn our children to endless toil or deprivation.

The natural resource management incorporates the understanding of the scientific and technical aspects of these resources distribution and ecological systems which help in supporting the healthy survival of life on the planet 'Earth'. The rising demand of water with increasing population density along with energy and biological resource management in the changing climatic scenario become prime concern for any country's economic growth and healthy environment for humans, fauna and flora to survive and flourish. The majority of the population are looking forward for energy efficient system to enhance the judicious conservation of water and bio-resources of our environment but the human pressure and their anthropogenic activities are slowly but steadily deteriorating these resource management capacities. In spite of the rapid development in technology the situation to conserve these resources are not improving; rather it is declining. It also involves the management of whole environment including social aspects and impact of climate change which are closely interrelated to the resource depletion and thus urges the need for an effective management plan. These aspects were kept in mind while bringing out this volume.

The book contains papers of multi-disciplinary views, discussing the management of water, energy and bio-resources for better management of such resources in the changing climate scenarios. It is thus aimed to interest all those who are keen to know about the management of natural resources and hence contribute to a better understanding of the Earth's resources. The papers are contributed by distinguished scientists and academicians from various important universities and institutions from all over the world including India who are contemporary workers in this field.

This edited book is the outcome of the International Humboldt Kolleg held from 8-9 February, 2013 at the Jawaharlal Nehru University (JNU), New Delhi, India. It contains twenty eight chapters which are grouped under three sections viz., (a) Water Resources Management, (b) Energy and Bio-resources Management and (c) Climate and Natural Resources Management. The volume presents recent case studies and examples from various parts of the world in the context of climate change scenarios and their management. Each chapter demonstrates the need for managing the demanding resources due to change in climate, land use, industrialization and the need by each country to take initiatives and commit themselves to manage these resources in a sustainable way.

We would like to thank all the contributors for expressing their individual views and also acknowledge our colleagues for their untiring efforts to review the manuscripts. One of the editors (N.J. Raju) would particularly like to thank his collaborators and research scholars for supporting his research activities over two decades which helped him in the process of bringing out this contribution. The generous support extended by the Alexander von Humboldt Foundation, Germany and the added support of other agencies in organizing the International Humboldt Kolleg (IHK2013) at JNU is gratefully acknowledged. We hope this book will be very useful for managers, environmentalists, hydrologists, water resource and energy managers, and for governmental and other regulatory bodies dealing with water, energy and bio-resources. Finally, we thank the publishers for taking efforts in bringing out this volume.

New Delhi, India — N.J. Raju
Halle, Germany — W. Gossel
New Delhi, India — AL. Ramanathan
New Delhi, India — M. Sudhakar

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About the Editors

N. Janardhana Raju Dr. Nandimandalam Janardhana Raju did his PhD from Sri Venkateswara University, Tirupati, India and is currently Associate Professor at the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India. He has vast experience in Hydrogeology and Environmental Geosciences and is engaged with research on rainwater harvesting systems, hydrogeochemistry and groundwater quality (arsenic and fluoride) in collaboration with a number of universities in India and overseas. He has been a visiting scientist at Ruprecht Karl University, Heidelberg, Germany; Martin Luther University, Halle, Germany; Asmara University, Eritrea, NE Africa; and Federal University of Fluminense, Rio de Janeiro, Brazil and is the recipient of the Alexander von Humboldt Fellowship, Germany. He has guided PhD scholars in hydrogeology and environmental geology and published more than fifty research papers in refereed journals. He has also contributed a chapter in the book 'Geochemical Processes: Conceptual models for reactive transport in soil and groundwater'. He has travelled widely participating in several national and international seminars/conferences/workshops. He is a member of the International Association for Mathematical Geosciences (IAMG); Geological Society of India (GSI); International Association of Hydrogeologists (IAH) and International Association of Hydrological Sciences (IAHS).

Wolfgang Gossel Dr. Wolfgang Gossel holds a PhD (1999) degree from the Freie University, Berlin, Germany and completed Habilitation (2008) from the Martin Luther University, Halle and is presently working as Senior Scientist, Hydrogeology and Environmental Geology, in the same university. He has contributed more than twenty research papers in refereed journals and has published a book 'Interfaces in coupling of hydrogeological modeling systems'. He has travelled widely participating in national and international conferences/workshops and also conducted training programmes in Egypt and India, and International Training Courses in Germany on GIS and Hydrogeological Flow and Transport Modeling. Dr Gossel has completed major research projects pertinent to groundwater flow modeling and salt water intrusion in Egypt, Mexico and Germany. He is a member of the International Association for Mathematical Geosciences (IAMG); and International Association of Hydrogeologists (IAH). He has served as referee and associate editor for many national and international journals.

AL. Ramanathan Dr. AL. Ramanathan did his PhD in sedimentary geochemistry from Centre of Advanced Studies in Geology, Panjab University. He is currently Professor in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India. Prof. Ramanathan has specialized in coastal biogeochemistry, hydrogeochemistry and glaciology aspects and worked extensively on the mangroves, estuaries, coastal groundwaters and glaciers of India for the past two decades. He is engaged in environmental research projects, with a number of universities and research organisations in India, Norway, France, Australia, Russia, USA etc. He has guided seventeen PhDs in the above subject and published more than seventy papers in reputed refereed journals. He has also published six books and several chapters in many books by reputed international publishers. He has received the IFS Sweden (Project) Award thrice on his work on mangrove biogeochemistry. He is a member of the editorial board of *Indian Journal of Marine Sciences* and served as referee for many national and international reputed journals as well.

M. Sudhakar Dr. Maruthadu Sudhakar did his PhD in Applied Geology from Indian School of Mines, Dhanbad, and M.Sc. in Law of the Sea and Marine Policy (1990) from London School of Economics and Political Science, UK. He worked in two premier institutions of the country i.e., National Institute of Oceanography (NIO) and National Centre for Antarctic and Ocean Research (NCAOR), Goa for 27 years in research and development, survey, planning, teaching and administration in the field of oceanography/offshore surveys/polar science/marine technology. Currently he is an Advisor to the Government of India, Ministry of Earth Sciences (MoES), New Delhi and heads the Outreach and Awareness, Research Vessels Programmes of the MoES. He has been the project leader of various major programmes and has led several oceanographic expeditions to the Indian and Southern Oceans and Antarctica. Dr. Sudhakar is an elected member of the International Seabed Authority (ISA) in Legal and Technical Commission from 2007 till 2016 and represents India in ISA. He is associated with many professional bodies and has published 50 research papers in refereed international/national journals and conference proceeding volumes and in seminar/symposia. He has been serving in the National Standing and Technical Committees of Govt. of India.

Section I
Water Resources Management

3D Geological and Hydrogeological Modelling – Integrated Approaches in Urban Groundwater Management

Peter Wycisk

Introduction

Urbanisation has a major impact on groundwater recharge in both quality and quantity as well as groundwater flow beneath cities. The impact is due to the import of large quantities of water as well as the extensive use of the ground for effluent discharge, waste disposal and groundwater extraction. Hence, effective management of urban aquifers has to incorporate the negative effects on groundwater resources in the underlying groundwater systems. The effect on recharge arises both from modifications to the natural infiltration system and changes in natural drainage. These changes are induced by leakage from water mains and by wastewater seepage. The resultant effect on the quality of recharge is generally adverse with urbanisation processes being the main causes of severe, but essentially diffuses pollution of groundwater and rising levels of salinity. Widespread groundwater contamination results from chlorinated hydrocarbons and other organic compounds. Additional adverse effects on a more localised basis are due to pathogenic agents in upper aquifer systems with insufficient sewage and waste-disposal infrastructure. Changing groundwater related issues could affect urban buildings and infrastructure resulting from lowering of groundwater levels by high extraction rates for water supply as well as by rising water tables. The general change in water quality can create significant problems especially in the latter situation.

Morris et al. (1997) point out that, for a sustainable urban groundwater management, there must be a coherent understanding of the local groundwater/aquifer system, which is unique at each location in respect of its particular groundwater setting and aquifer architecture. It implies an adequate knowledge of the subsurface

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N.J. Raju et al. (eds.), *Management of Water, Energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges*,
DOI 10.1007/978-3-319-05969-3_1

geology that establishes the basis of the groundwater interaction influencing engineering, infrastructure and related water resources problems. Aquifer vulnerability mapping, a specific need in most of the developing countries, is based on land use as well as on the upper groundwater conditions defined by the aquifer geology. Therefore, land-use planning has to follow robust matrices that indicate what activities are acceptable and what has to be done to increase awareness of the role and susceptibility of the subsurface to contamination.

In order to provide subsurface geological data for urban groundwater management, over the last 10 years, digital 3D modelling of geological structures has markedly increased, moving from a 2D mapping to a 3D modelling culture related to advanced software and IT capabilities. There is natural progression in data handling and in subsequently coupled modelling strategies and decision support in regional management.

Recent examples from Brussels and Vienna show that data preparation of subsurface information is, to some extent, done using Geo-Information Systems, which allow only 2.5 D processing. Nevertheless, the increasing examples of 3D mapping and geological modelling of different cities in Europe, such as Glasgow by the BGS (UK) (Culshaw, 2005), Vienna (Pfleiderer and Hofmann, 2004), Magdeburg by the State Geological Survey of Saxony-Anhalt (Germany) (Neumann et al., 2006), as well as the city of Halle (Saale) (Wycisk and Schlesier, 2006) show the increasing applicability of this digital 3D modelling concept in practice.

Due to future needs involving consistent data management, developing countries such as Bangladesh are also implementing 3D geological mapping and modelling for the Greater Dhaka City area. The major objectives of this project are to provide subsurface information for hydrogeology and geotechnical applications as well as environmentally related planning issues using a flexible and dynamic model-based system. Objective and project defined results on demand indicate the progress of this approach rather than the static 2D analogue map printed solutions. This progress will be of future importance for most of the developing countries.

Depending on the available information and quality of data for urban water management, the coupling of urban drainage models with numerical groundwater simulations for integrated water management is becoming increasingly important (Schrage et al., 2005; Morris et al., 2007). This integration provides the needed basis for sustainable strategies using the 3D-generated subsurface digital information for integrated modelling and management. This paper describes examples of different and, to some extent, innovative applications from urban areas of Germany.

3D Geomodelling in Urban Management

Model Concepts and Requirements

With advances in 3D modelling software and visualisation tools over the last few years, as well as the increasing 2.5D and 3D GIS applications, digital subsurface information of local to regional scales has become more applicable and available (Culshaw, 2005; Wycisk et al., 2002). This aspect is in line with the increasing needs of conceptual and structural geological models in the broad fields of urban groundwater flow and transport simulation, of geotechnical investigations, as well as for predictive results of geological subsurface information for infrastructure planning.

Due to the complexity of 3D modelling software tools and the specific situations of regional geology, users might be not aware of the differences in their models or resulting limitations and disadvantages. The availability of subsurface data in quality and quantity could limit the modelling approach. Apart from this general question, the regional setting and coverage of subsurface drilling information has to often bridge large information gaps. 3D modelling software and visualisation tools are available using geostatistical algorithms (e.g. GoCAD, EVS/MVS, Rockworks) that are working completely differently than the TIN-based (triangulated irregular net) interpretation using intersecting cross-sections (GSI3D). The shortcomings of automatic contouring by statistical and geostatistical algorithms are compensated by the use of constructive intersected cross-sections and mapping information.

The major obstacles in regional 3D modelling have been summarized by Berg and Keefer (2004) and can be confirmed by our experience from different regional models. Geological data verification is time-consuming, and many projects that require groundwater modelling investigations have not had sufficient time or money to obtain the detailed geologic interpretations needed. The interpretation of complex geological sequences, especially in the Quaternary, requires experience in regional stratigraphy and sedimentology. Without this specific regional knowledge, any 3D mapping and modelling will be either incomplete or will fail.

The expected results of visualisation and analysis of geological 3D models offer more advantages when compared to classic two dimensional analogue methods of urban groundwater management. The main aspects are:

- Visualisation and analysis of the subsurface to deliver a decision support system for urban planners, managers and decision makers;
- Integration of various methods of investigation (hydrogeology, hydrochemistry, geophysics, geotechnics, infrastructural planning);
- Attributing and coupling to groundwater and surface water models;
- Analysis prediction and visualisation of subsurface information; and
- Consistent GIS-based IT-infrastructure, consistency of the data base, adapted to monitoring and management systems.

Constructive Cross-section Net-based Interpolation

The use of constructive cross-section net-based interpolation approaches are of advantage when one has unbalanced regional coverage of drilling information in complex and heterogeneous lithological subsurface units. The modelling process with GSI3D is based on the creation of a series of intersecting user-defined cross-sections. The entire stacking order of all deposits in the study area has to be defined stratigraphically and sedimentologically, and a generalized vertical section has to be created. The lithostratigraphic classification of the sedimentary succession within a consistent regional stratigraphic framework is more helpful than a pure grain-size of lithology-based approach for groundwater modelling. Most of the software tools allow the input of 2D mapping or surface information, especially from areas with a less dense borehole record. GSI3D allows modelling of the distribution and geometry of sedimentary layers by knowledge-based control of the modeller, which is especially needed for heterogeneous aquifer systems and/or artificially formed lithological units within urban settlements. GSI3D is currently intended for use in the near-surface modelling of surficial and Quaternary sediments (Neber et al., 2006). The software is used by the British Geological Survey on different mapping scales and, in combination with GoCAD for deep subsurface investigations and geological modelling (Culshaw, 2005), also for regional investigations of urban groundwater contaminated mega-sites (Wycisk et al., 2002; Wycisk et al., 2005).

Statistically Based 3D Interpolation

Uneven and spotty distribution of geological drilling information is one of the major obstacles in regional subsurface modelling with automatically contoured distributions and thickness of layers in urban areas. In the case of known geology or sufficient coverage of drilling information, the statistically based interpolation tools provide a less time-consuming modelling approach. As an example, EVS (Environmental Visualization System; C Tech Development Corp., Santa Barbara, Ca.) provides true 3D volumetric modelling together with 2D and 3D kriging algorithms with best fits of variograms to analyse and visualise geoscientific and environmental data. EVS/MVS allows the seamless integration with ArcView GIS, as well as with Modflow and MT3D. The 3D modelling of the subsurface geology with EVS is based exclusively on selected drilling information and the geostatistical interpolation of the individual layers. This procedure can lead to different results in cut-and-fill structures of Quaternary sedimentary channel fills, as well as any artificial structures e.g. subsurface dumps.

Interactive 3D-modelling of the Subsurface Geology

In conjunction with the City of Halle (Saale), a digital 3D spatial model was constructed for the total city area of 135 km^2. Consequently, Halle is one of the first cities in Germany to have available an extremely sharp and detailed 3D volume model of its geological subsurface, composed of 24 layers (Fig. 1A). The 3D spatial

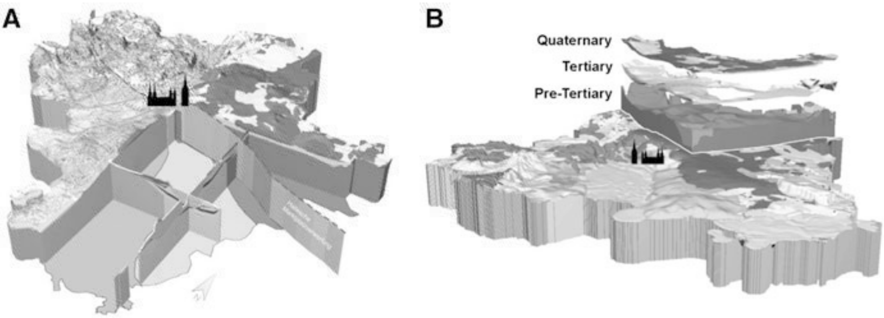

Fig. 1 Geological model of Halle/Saale. Fig. 1A shows virtual cross-sections and the main faults striking through the city. In Fig. 1B the distribution of 24 individual layers, e.g. aquifers and aquitards, is visualised to give insight to potential aquifer connections and layers with high adsorption capacities

model provides the basis for a future GIS supported information and prognosis system. Such a system also provides the basic framework for future extensions to information and decision-making systems. The possible applications lie in the areas of geological and geotechnical recognition of particular locations of interest, of groundwater and environmental protection, as well as for environmental and city planning.

Geodata and Model Construction

Innovative use of the 3D spatial geological model of Halle (Saale) City is based on the extremely precise modelling of the geological subsurface. At the same time the ordering and juxtaposition of the geological layers in the domain provides information on the most important groundwater aquifers and aquitards. The heterogeneity of aquifers and aquitards is very high and is due to the structural geological setting. The urban hydrogeology is characterized by different porous aquifers with frequent local aquifer/aquifer contact areas as well as by fractured aquifers of different lithologies (Fig. 1B).

The basic data for the model are obtained from a network of 32 cross-sections based on drilling information. The precision of the horizontal resolution of the spatial model is 40 m $\times$ 40 m, while the vertical resolution is of the order of cm depending on available core data.

Completely new interpretation and evaluation possibilities arise from the superposition of information at different depths in the subsurface in the form of spatial views of individual layers, "virtual" cross-sections, as well as hydrogeological analyses with "real" views from aerial photographs or maps.

In the future, this "augmented reality" will allow one to obtain a new level of quality in the geosciences and environmental disciplines. This can be presented in the forms of maps or interactive digital 3D visualisations, and can be used for specific technical questions in real time. The possible uses of an interactive device, such as a subsurface viewer, enable the direct investigation of geological and hydrogeological information. The results can be presented as virtual boreholes, as vertical and horizontal sections, as thematic maps, as well as locating 3D bodies contained in the modelled area with sharper spatial precision.

Interactive Modelling in Real Time

The advantage of the modelled system allows interactive modelling in real time using an independent viewer system. This subsurface viewer is based on the independent model construction by modellers and also on the application with the viewer system by users, who do not need specific modelling knowledge. The separation of the modelling system into an active part, which includes modelling and subsequent improvement by implementing new drilling information, and a user-oriented part, allowing only the analytical and predictive features of interpretation, ensures the integrity and quality of the primary 3D modelling database. The software-tool is linked to each respective model, enabling users to investigate the 3D setting of the geological subsurface immediately in an easy to understand format. The colour coding of each modelled geological unit is defined according to analogue standards of geological maps. In addition, it is possible to visualize the model colour scheme according to specific applied geological parameters such as hydraulic conductivity, geotechnical values, etc.

Integrative Modelling Concepts of Contaminated Urban Aquifers

Environmental Setting of the Former Industrial Mega-site

Large scale groundwater contamination sites such as the urban area of Bitterfeld-Wolfen in Germany are characterized by different environmental impacts caused by the former chemical industry and extensive landscape devastation by lignite mining over the last 100 years or more. Due to the multi-source regional contamination in the upper and lower aquifers, an integrated assessment is needed of the groundwater quality and of the local risk areas. Therefore, a regional 3D spatial model of distinct individual environmentally related core modules has been developed for the urban Bitterfeld-Wolfen area. Two investigation projects have assessed the long-term development for the urban and industrial areas in terms of a risk-based land management approach (Fig. 2).

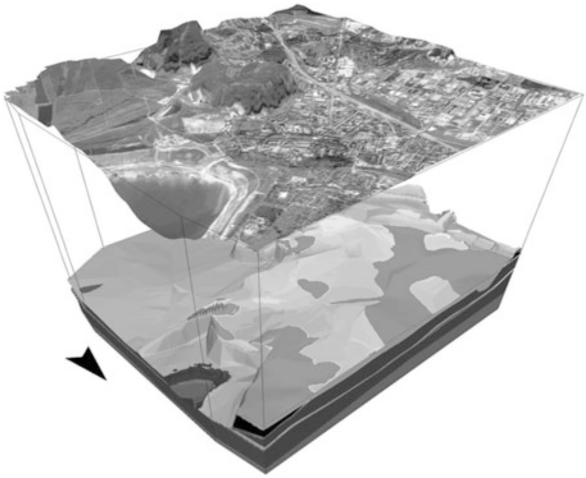

Fig. 2 Former and future land use are an important factor for contaminated upper urban aquifers. Geological structures defining aquifer/aquifer contacts, as shown here for the Bitterfeld area, are influenced by abandoned mining and infrastructure projects. Both aspects give a completely new view to management strategies

Due to the large affected urban area and rural vicinity of more than 60 km^2, an intensive groundwater monitoring programme has been operative for more than 15 years. More than 170 individual organic substances, as well as 30 inorganic substances, have been monitored. The importance of the former industrial area is characterised by more than 40,000 chemical plant workers during GDR time, by 15 industrial toxic land-fills, and by more than 5000 individual chemical substances during the nearly 80 years of industrial production in an urban environment.

The most frequent substances are Tetrachloroethene (PCE), Tri-chloroethane (TCE), cis-1,2 Dichloroethane (cis-1,2 DCE), Vinylchloride (VC), 1,4-Dichlorobenzene (1,4 DCB), 1,2-Dichlorobenzene (1,2 DCB), Monochlorobenzene (MCB), and Benzene. The regional distribution of contaminants reflects their different and multiple sources and pathway relations. The cities of Bitterfeld and Wolfen, as well as several villages and the rural landscape of the alluvial plain of the high flood affected River Mulde, describe the environmental sensitivity to humanity and natural resources (Heidrich et al., 2004; Wycisk et al., 2003).

GIS-based Multi-source Data Management

To assess the complex environmental situation of the Bitterfeld-Wolfen area, a GIS-based spatial model was required that includes the heterogeneous aquifer setting in 3D and in as much detail as possible (Fig. 3). The subsurface information had to be available for a GIS-based assessment and predictive calculations correlated to surface information of potential receptors.

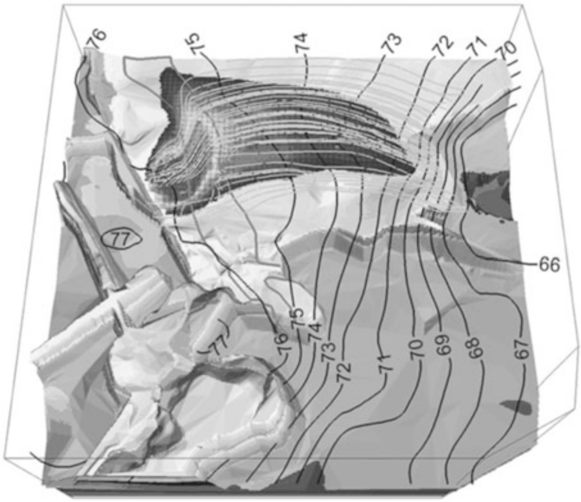

Fig. 3 Groundwater flow system in a complex geological structure in the case of the Bitterfeld area. The groundwater contours do not help in construction of the pathways. Only groundwater flow and transport models (based on detailed geological models) yield numerically appropriate results that can be used for the assessment of contaminant spreading

Therefore, the following major information modules have to be integrated into the spatial model on a local scale, including the specific objectives and used modelling tools:

- Land-use classification;
- Groundwater contaminants;
- Hydrogeological data; and
- 3D model of the subsurface geology.

The GIS data management for all hydrogeological and hydrochemical data was done with ArcView 3.x and ArcView 8.x (ESRI). The spatial model includes point data such as borehole data (lithology/stratigraphy), hydrochemistry, contaminants monitoring data, etc. (Wycisk et al., 2007). The geological cross-sections, with their vertical 2D structure, were held in a special device for geological 3D models. The geological structures had to be held in a GIS database to obtain an interface to numerical groundwater modelling tools such as Feflow or Modflow. These data are stored in GRID of point formats in ArcView.

Integrated Modelling of Urban Aquifers

To support the integrated modelling concept the high-resolution 3D structural model of the entire area was enlarged to about 65 km^2 (Wycisk et al., 2005). This model allows volumetric calculations of partial or distinct sedimentary units, such as lignite-bearing strata, that are relevant for assessing the natural absorption potential and retardation processes inside the aquifer. The digital data set of the true 3D structural geology was used with reference to the hydraulic characterization for subsequent flow and transport models. The numerical groundwater model was carried out with two objectives:

1. Description of the hydrodynamic system and the pathway prediction assessing the exposure route of local contaminants as well as for optimizing the well observation sites; and
2. Predictive calculations of the changed hydraulic situation after the once-in-a-century flooding of the Goitzsche mining lake and raised groundwater level in August 2002.

The numerical model consists of two parts: A groundwater flow model and a transport model based on the flow model. The modelling systems Modflow, ModPath and MT3D with the Visual Modflow 3.0 preprocessors and postprocessors were used for the studied areas. Figure 3 shows the integration of simulated results from high-resolution 3D geology as well as from flow and transport modelling. The resulting impacts of laterally changing hydraulic conductivity inside the aquifers by channel-fill structures or anthropogenic activities by humans are clearly shown and are underestimated in most hydrological models.

Conclusions

To generate an almost realistic scenario of urban areas, it is necessary not only to gather high-resolution land-use information, but also to have a model of the aquifer systems corresponding to the real world scenario of the geological subsurface setting. The "true" regionalization of hydraulic and contamination data is also needed. This statement is valid for most Quaternary sediments underlying urban areas representing heterogeneous aquifer conditions, especially from fluvial and deltaic environments. The 3D geological model also serves as a future consistent data base and for the prediction of modelling provides groundwater and engineering related deliverables for urban management. The new approach of digital 3D geo-data management also enables municipalities of developing countries to produce a capable upgrading system and forward looking management tool.

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Long-term Saltwater Intrusion Modelling – Case Studies from North Africa, Mexico and Halle

Wolfgang Gossel, Reiner Stollberg, Eduardo C. Graniel, and Thomas R. Ruede

Introduction

Coastal saltwater intrusions threaten drinking and irrigation water resources along coastlines. On the other hand submarine groundwater discharges in nearly the same areas. The interface between saltwater and freshwater shifts over time and is mainly influenced by the seawater level and aquifer characteristics. During the last 140,000 years, seawater level fluctuation was very rapid. After a fast rising of about 120 m in the last interglacial, a slow drawdown of the same magnitude followed during the last glacial within 100,000 years. In the last 10,000 years, the water level again rose very fast and then it remained stable. Different aquifer types are influenced by these fluctuations in different ways. The two examples from North Africa and Mexico show how not only shelf platforms are flooded but also the interface in the ground water shifts over time. Both investigation areas are transboundary aquifers and the water supply of the population is affected directly by the hydrogeological development.

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N.J. Raju et al. (eds.), *Management of Water, Energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges*,
DOI 10.1007/978-3-319-05969-3_2

Nubian Aquifer System

The interface in the Nubian Aquifer System seems to be stable nowadays but the model results show the slow dynamic effect of seawater level changes over this time frame. The amount of intrusion water is limited by the hydraulic conductivities. The flow velocities are in a range of 0.002-0.003 m/day during the times of the fastest rising seawater levels at the end of the last glacial and beginning of the holocene as shown by Gossel et al. (2010). Figure 1 shows three steps of the

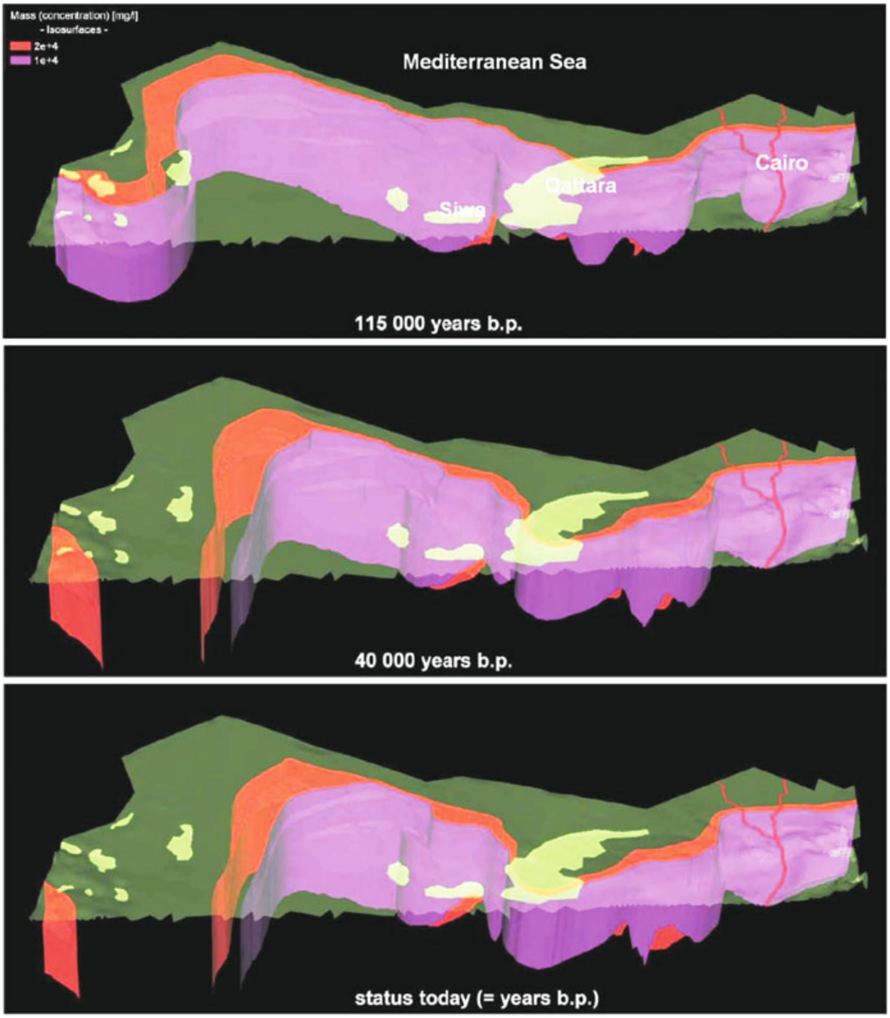

Fig. 1 Visualization of the interface at three steps during the last 140,000 years (isosurfaces of 20,000 and 30,000 mg salt/L). The first step (top) shows the situation about 120,000 years b.p. with high seawater levels at the end of the last interglacial or beginning of the last glacial. The second step shows the interface with lowest seawater levels (16,000 years b.p.) and the third outlines the interface about 10,000 years b.p. with a seawater level as today