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Inhalt - Content

Megacities as Challenge for Interdisciplinary Research: The „Risk Habitat Megacity“ Research Initiative

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Abstract
Megacities are places of unprecedented growth, population density, concentration of economic and political power, and environmental change. They represent both a space of opportunity for sustainable development and a space of risk. As laboratories of change, they pose fresh challenges for research. The „Risk Habitat Megacity“ research is an interdisciplinary and international collaboration that takes up this challenge. It investigates risks in Megacities and explores implementation solutions for sustainable development with a geographic focus on large urban agglomerations in Latin America. The Metropolitan Region of Santiago de Chile is the first case study. This article outlines the research approach. It discusses the framework of cross-cutting concepts risk, sustainable development and governance, and describes the range of problem fields to which these concepts are being applied. Using the example of socio-spatial differentiation processes, land use changes and flood risk, the approach is illustrated. A final section summarizes the state of research progress and next steps.
Key Words: megacity, interdisciplinary research initiative, Latin America Santiago de Chile, flood risk

Kurzfassung
Das Wachtum der Megastädte ist geprägt durch ein beispielloses Bevölkerungswachstum und -dichte, eine Konzentration ökonomischer und politischer Macht sowie tiefgreifende Umweltveränderungen. Als Laboratorien des Wandels stellen Megastädte neue Herausforderungen and die Forschung. Die Forschungsinitiative „Risk Habitat Megacity“ greift die Herausforderungen auf. In ihr werden Risiken in Megastädten in Lateinamerika untersucht. Santiago de Chile dient als erste Fallstudie. Der vorliegende Beitrag stellt die Forschungsinitiative vor. Er erläutert den Forschungsansatz und stellt sowohl seinen forschungleitenden konzeptionellen Rahmen mit den Themen Nachhaltigkeit, Risiko und Governance als auch die gewählten Problemfelder vor. Am Beispiel des Landnutzungswandels, sozialräumlicher Veränderungen und ihrem Einfluß auf Überflutungsrisken wird die interdisziplinäre Herangehensweise erläutert. In einem abschließenden Kapitel wird ein Überblick des bisherigen Arbeitsstandes und der nächsten Aktivitäten gegeben.
Schlüsselbegriffe: Megastadt, interdisziplinäre Forschungsinitiative, Lateinamerika, Santiago de Chile, Überflutungsrisiko

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1. Megacities: facing the challenge of the „urban millennium“

Urbanization is one of the most dramatic processes of global change. Particularly in megacities, it anticipates trends with both regional and global consequences that are not yet well understood. Mega-urbanization involves not only unprecedented growth, high population density, and a concentration of economic and political power, but also a complex variety of simultaneous and interacting processes.

As human activities will continue to shift to cities, the future of the world community depends more and more on urban sustainability (McGranahan et al. 2001). The scale, the speed of change, the growing mobilization of people, information, goods and capital, and the global connectedness of megacities all combine to create new physical, economic and social dynamics, a new complexity, and new dimensions of risk. This places cities at the centre of the challenges for global sustainable development.

Megacities are laboratories of change, representing both a space of opportunity and a space of risk. On the one hand, they are the engines of global economic growth. They generate a huge share of the gross domestic product of their respective countries and provide extensive opportunities for employment and investment (World Bank 2000). On the other hand, the development of mega-agglomerations causes a number of risks and dangers for the inhabitants and for protected goods. „Urbanization affects disasters just as profoundly as disasters can affect urbanization“ (Pelling 2003, 7).

Levels of sustainability and potential risks depend greatly on urban governance, i.e., how decisions on publicly relevant affairs are made in and between the spheres of the state, the civil society and the private sector. Extreme air and water pollution, deterioration of infrastructures, the spread of violence and crime, transport gridlocks, and social and spatial polarization make well-designed governance strategies indispensable to resolving and overcoming these problems and their attendant risks (UN Habitat/ DFID 2002). On the other hand, there is evidence that poor governance performance can amplify or even produce risks to and negative impacts on human security (Hardoy et al. 2001).

While the scale, the velocity of change, the global connectedness and complexity of mega-urbanization pose fresh challenges for research, megacities are rarely explicitly, let alone systematically, taken up as a distinct category or focus of empirical research.

These challenges require research involving a comprehensive approach and an integrative perspective as a basis for modelling and scenario techniques. Research needs to embrace a problem perspective, linking the generation of orientation knowledge with action-oriented knowledge and the implementation of solutions. This involves the transfer of results into both academic and professional education, and to local stakeholders.

2. The Risk Habitat Megacity research initiative

The research initiative „Risk Habitat Megacity" faces the research challenges outlined above with a comprehensive and interdisciplinary approach. By investigating the pro-cesses and associated risks of mega-urbanization and developing implementation solutions for sustainable urban development, it presents new knowledge for orientation and application. It intends to widen the skills required to analyse the complex urban habitat and the knowledge to propose and monitor adequate policies. While research of this international initiative has its focus on megacities in Latin America in general, Santiago de Chile is the first study case and platform for knowledge transfer and networking. The research plan adopts an integrative research approach that combines basic theoretical and conceptual considerations with empirical and application-oriented analysis. It makes use of several integration tools such as common conceptual-analytical concepts, the application of jointly elaborated scenarios and indicators, involvement of a wide spectrum of disciplines and cooperation with the relevant local stakeholders, in particular local authorities.

Objectives of the Risk Habitat Megacity Research Initiative

The overall objective of the research initiative is to deepen the understanding of the complex urban processes, interactions and feedback mechanisms that turn megacities and large agglomerations into a habitat of risk and opportunity. It intends to evaluate urban risks under sustainability criteria, to develop analytical tools and instruments for action-oriented knowledge to tackle the risks of mega-urbanization, and to derive paths for a more sustainable development. It seeks answers to several core questions:

(1) What risks, or indeed opportunities, are associated with mega-urbanization?
(2) How can the transformation of the complex Megacity be predicted and described?
(3) What specific strategies and policies can steer the Megacity towards a more sustainable development?
(4) What institutional and organizational preconditions are required for their effective implementation?

Research Partners

The „Risk Habitat Megacity" research initiative reflects the joint work of a network of about fifty natural and social scientists and engineers from more than ten Universities and research centres from Latin American countries and the *Helmholtz Association* in Germany.

In Latin America, the main partners are the *Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas and the Pontificia Universidad Católica de Chile,* represented by the *Instiuto de Estudios Urbanos y Territoriales of the Facultad de Arquitectura, Diseño y Estudios Urbanos.* Further partners with on particular case studies are the *Universidad Alberto Hurtado and the Pontificia Universidad Católica de Valparaíso.* In addition, the *Economic Commission for Latin America and the Caribbean* of the United Nations (ECLAC/CEPAL) plays an important role for the initiative with respect to stakeholder involvement and the regional perspective. ECLAC/CEPAL is one of five regional Economic Commissions established by the United Nations. ECLAC/CEPAL is represented by the *División de Desarrollo Sostenible y Asentamientos Humanos (DDSAH).*

The German *Helmholtz Association* is a community of 15 national centres. As the largest research organization in Germany, its mission is to contribute significantly to solving grand challenges which face science, society and industry. Five research centres participate in the „Risk Habitat Megacity" research initiative: the German Aerospace Centre (DLR), the Forschungszentrum Karlsruhe (FZK), the Helmholtz Centre for Infection Research (HZI), the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, and the Helmholtz Centre for Environmental Research (UFZ).

Main characteristics of „Risk Habitat Megacity"

The „Risk Habitat Megacity" research initiative has three main characteristics. First, it is an interdisciplinary and intercultural project. Second, it is dedicated to capacity building of young researchers. The „Risk Habitat Megacity" research initiative has established several instruments to integrate more than twenty PhD students. Depending on the focus of individual PhD projects, the young researchers are attached to different participating institutions both in German and Chile. In addition to individual supervision, they receive joint training on interdisciplinary research. The „Risk Habitat Megacity" research initiative has been endorsed as an „Official German Project of the UN Decade of Education for Sustainable Development" 2009/2010. The third important aspect of „Risk Habitat Megacity" is its aim to transfer the scientific results to practical application. The project engages stakeholders in the analysis of explorative scenarios about alternative future sustainable development paths, and in the elaboration of strategies and measures.

3. Focus on Latin America

The geographic focus of the research initiative is on Latin America. Two salient features characterize the region: it is by far the most urbanized developing region in the world, and has the distinction of being the most inequitable one (ECLAC/CEPAL 2005). The region's overall urbanization coefficient of 76 % compares with that of Europe (75.5 %), and substantially exceeds that of other world regions, such as South-East Asia (36 %) and Sub-Saharan Africa (35 %). In some Latin American countries, the urban population has reached 90 % and beyond (ECLAC/CEPAL 2000).

Starting between 1925 and 1950 (Rodriguez 2002), the intense urbanization rate in Latin America and the Caribbean led to a concentration of the region's population in its principal cities. This explains the significant number of vast agglomerations and megacities. Since the peak decades in the latter half of the 20th Century, urbanization rates have started to slow down. Patterns of urban concentration have become more diversified and directed also directed towards smaller cities (Rodriguez 2008). Therefore, urbanization in Latin America has reached a turning point. The predominantly rural-urban migratory flows have given way to migration from one urban area to another, to intra-metropolitan, and to international migration. Urban growth and conversion of rural land for urban expansion is taking place at an unprecedented rate (UNEP 2004). Urban sprawl has accentuated a range of typical trends, such as socio-spatial fragmentation and segregation (Coy/ Pöhler 2002; Sabatini et al. 2001; De Mattos 2002). Unequal distribution of resources or political power coupled with weak institutional controls goes hand in hand with extremely high rates of urban violence and insecurity (UN Habitat 2006). Increasing transport problems and air pollution (ECLAC/CEPAL 2000; 2005), inadequate housing conditions (Gilbert 2005), deficits in the supply of water and sanitation, inefficient transformation and use of energy, and deficient disposal and treatment of a rising amount of solid waste all impact on environmental health (ECLAC/CEPAL 2005). The major cities in the region are likewise extremely vulnerable to natural disasters and the technological risks inherent in high-risk activities (ECLAC/CEPAL 2005).

Santiago de Chile - the „anchor" city

Santiago de Chile is the „anchor city" for the initiative. The partners have established a „research and training platform" for megacities, which connects „Risk Habitat Megacity" with the existing relevant programmes of the partners. The metropolitan region of Santiago de Chile is also the pilot case. The choice for Santiago de Chile rests on five arguments:

(1) Santiago de Chile gives access to a wide range of representative problems associated with megacities, permitting the design of a conceptual framework and its transfer to other urban agglomerations in the region.
(2) The advanced stage of urbanization in Santiago de Chile makes it possible to detect emerging problems and opportunities and to draw lessons from the strategies adopted in response to the challenges of urban development.
(3) As the centre of regional networking, Santiago de Chile holds a strategic position. It is home to key international institutions, in particular the Economic Commission for Latin America and the Caribbean (ECLAC/CEPAL).
(4) Santiago de Chile offers excellent research partners, infrastructure and data. The Helmholtz Association centres involved have established links with a range of research organizations in Chile, and the cooperation with the partners at the Universidad de Chile and the Pontificia Universidad Católica de Chile is particular strong.
(5) Stakeholders have expressed their profound interest to collaborate with the initiative.

4. Research approach and topics

The research plan adopts an interdisciplinary and integrative research approach that combines basic theoretical and conceptual considerations with empirical and application-oriented analysis. To implement the research approach and to offer a common framework for orientation, the research initiative applies three well-established, theory-based analytical concepts: the concepts of *Sustainable Development, Risk and Governance.*

The concept of *Sustainable Development* formulates the target dimension of the initiative. Based on an existing sustainability concept developed in the Helmholtz Association (Kopfmüller et al. 2001), it provides orientation towards basic goals by defining specific sustainability criteria in close cooperation between the Chilean and German partners. Based on this concept the key questions of sustainable development in „Risk Habitat Megacity“ are:

- To apply and contextualize the integrative sustainability concept of the Helmholtz Association to Santiago de Chile and other Latin American megacities;
- To analyse and assess the sustainability performance of Santiago and other Megacities, and
- To contribute to the ongoing development process of a sustainable urban development strategy in Santiago.

The *Risk* concept focuses on the extent of the problems and their severity. In addition, it helps to identify and analyse the conditions for and impacts of the emergence of risks that pose a potential threat to future sustainability. For this purpose an appropriate combination of natural, applied and social scientific risk research approaches will be applied to the perspectives of hazardous events and the vulnerability of the „System“ Megacity.The main objectives of the risk studies are:

- To develop a heuristic for a qualitative risk assessment, and
- To generate a comprehensive and dense description of the mechanisms of risk production in Megacities in general and in particular for Santiago de Chile.

The Governance concept concentrates on the actions to be undertaken. This will be achieved by analysis of current efforts to enhance sustainability in megacities, and by the provision of knowledge and recommendations relevant to the appropriate solutions to specific problems and their potential for implementation. Local political and administrative authorities will be involved in the process of working out targets for sustainable urban development and of proposing appropriate ways to meet them.

The study of governance aspects includes the following key goals:

- To facilitate the implementation of strategies for sustainable urban development by clarifying the framework conditions set by existing governance structures;
- To assess in how far existing governance structures enhance certain risks and impede the attainment of sustainability goals, and to use the findings of „Risk Habitat Megacity“ in order to support the improvement of governance performance;
- To generate theoretical insights into how current trends in terms of decentralization, participation, privatization as well as the matter of informality can either obstruct or facilitate the governance of megacities, and
- To provide general recommendations on the modification of governance structures in the study region.

The initiative applies these three „cross-cutting concepts“ to several typical megacity issues, such as Land use management, Socio-spatial differentiation, Energy system, Transportation, Air quality and health, Water resources and services, and Waste management, which are the seven „Fields of Application“ (see Figure 1).

The Fields of Application were selected in the first place for their relevance to megacity development. Santiago de Chile, like other megacities, has an outstanding role as consumer of resources. *Land use management* is one of the seven Fields of Application that stands for this role. Based on an assessment of how land use and land use change modify metropolitan areas, research identifies risk-prone areas in the context of the predominant risks (earthquakes, flooding), and the adequacy of existing land use planning and risk management approaches to the relevant governance.

Resource consumption is also reflected in the *Energy* field of application. Energy consumption in Santiago increases rapidly. The objective of research is to identify structures and characteristics of the energy system with respect to the city and their relation to the environment, to evaluate the current situation, and to develop a model for future energy system development under varying frameworks,

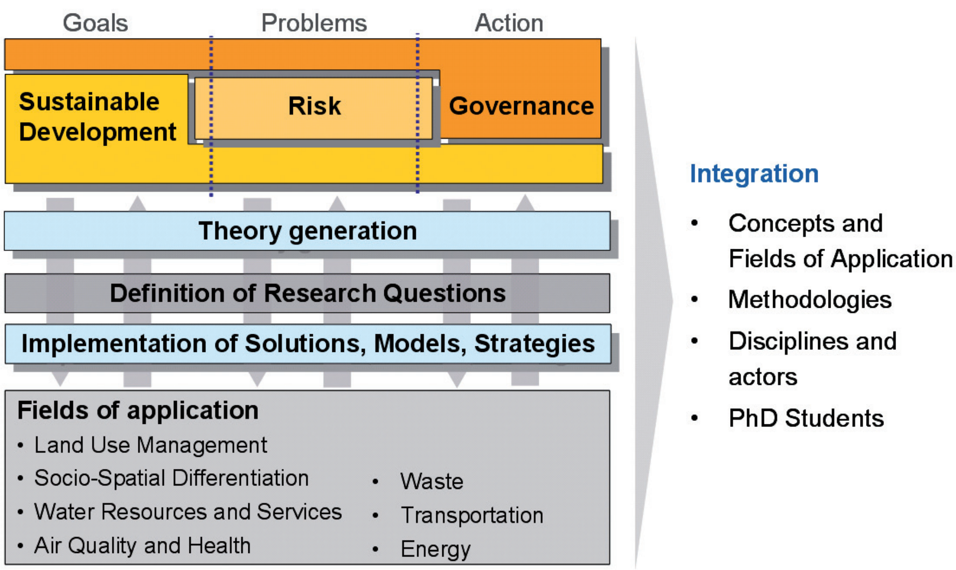

Fig. 1: Project architecture (Source: authors, own elaboration)

leading to an „im- age“ of a more sustainable energy system for a megacity.

Although Santiago de Chile is known for its high level of coverage, efficiency and quality in water service provision, distinguishing it favourably from most other cities in Latin America, there exist several hygienic, economic, ecological and technical risks. They are investigated in the *Water Resources and Services* Field of Application with the objective to develop a general implementation strategy for sustainable water supply and sewage treatment.

On the other hand, Santiago de Chile - although working with advanced technologies than other megacities of Latin America - highlights the critical function of large agglomerations as major producers of *Solid waste*, pollution and associated health effects. The effects arising from inadequate solid waste management can lead to severe health and environmental problems. Therefore, one objective is to analyse the current waste management system in the metropolitan region of Santiago de Chile and to analyse different scenarios for waste management and development of strategies to accomplish a more sustainable system of waste management.

The unceasing spatial expansion of Latin American megacities such as Santiago de Chile which is subject to the Field of Application *Land use management* is closely linked to a growing demand for *Transport*, which in turn generates a permanent need for new infrastructure. As the extreme dynamics in the transportation sector jeopardize the sustainability of megacities and create specific risks, research focuses on the assessment of the extent that the transportation sector contributes to air pollution throughout the city and on how the analysis of the vehicle fleet structure can improve the forecast of emission distribution models.

In the face of the expected growth of urban populations, rise in standards of living, etc. air quality is a predominant factor for environment associated diseases. The *Air quality and health* Field of Application assesses to what extent traffic emissions and air quality in megacities and their surrounding regions depend on vehicle fleet composition and traffic flows. Furthermore, the contribution of traffic emissions to health conditions and health risks associated with housing area/ housing type using the evaluation of different housing areas/ types is assessed.

Finally, Santiago de Chile like other megacities in the region is characterized by intensive *Socio-spatial differences* that have a powerful impact on land use patterns. In the last decade Santiago has witnessed an emergence of vast private or public real estate projects in previously disadvantaged areas. As a result, in

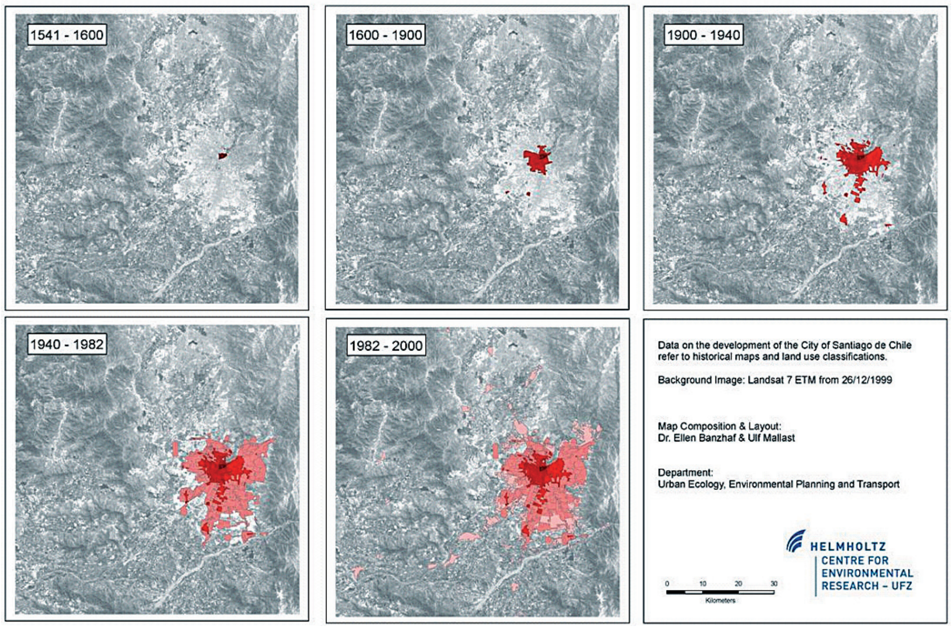

Fig. 2: Urban land use change of Santiago de Chile between 1600 and 2002

some cases, upper and lower income groups now live closer to one another than was the case in the past (Rodriguez 2008). The objective of research in this Field of Application is to assess opportunities and risks of new patterns of segregation, in particular whether spatial proximity promotes social integration, and to assess the role of housing policies in processes of socio-spatial differentiation.

5. Land use changes, flood risk and socio-spatial differentiation: an example of the interdisciplinary research approach

Using the fields of application „Land use management“ and „Socio-spatial differentiation“ as an example, this section illustrates the interdisciplinary approach.

Santiago de Chile is confronted with two principal and interrelated development trends. On the one hand, the city experiences a spatial and functional restructuration leading to changes in land use and urban morphology as two standard processes related to urbanization. This trend is first of all directly linked to changing population numbers. Since the first decade of the 20th century, when the urbanization process started, the population in the Metropolitan Region of Santiago de Chile increased significantly from from 1.3 in 1950 to Million to about 6 Million in 2005 (INE 2006). Intensive land conversion from non-urban (e.g. agricultural, natural forests or wetlands) into urban uses (housing, industry and services) was necessary to meet the increasing demand. This trend has been significant in absolute terms and has even intensified recently (Heinrichs/Nuissl/Rodriguez 2009).

The detection of changes in land uses over time on the basis of satellite images of different spatial and spectral resolution is one of the main objectives of the Field of Application „Land use management“.

The increase in population and the expansion of urban land uses are paralleled by socio-spatial differentiation processes and changing segregation patterns (Sabatini/Salcedo 2007). Like in other Latin American large agglomerations, these processes are driven by different factors such as the urban land market as a principal determinant for the localization of different housing types, the construction of houses and housing estates by private enterprises for middle and higher income groups (promoting voluntary relocation of households belonging to these groups), and social housing programmes (responsible for involuntary relocation of households from the low income groups. The analysis of the drivers and effects of changing segregation patterns is subject to the field of application „Socio-spatial differentiation“.

The investigation of land use changes associated with rapid urbanization, the development of new settlements and processes of socio-spatial differentiation further includes the identification of risk-prone areas associated to earthquake and flood risk. The underlying model for this analysis is the *Pressure-and-Release-Model* of BLAIKIE et al. (1994), who conceptualize risk as the sum of natural hazards and vulnerability. Taking this model as the basis for research means, on the one hand, to analyse the natural hazard and, on the other hand, to identify the „social dimension“ of risk relating to vulnerable groups.

Flooding is one of the main risks and, aside from earthquakes, a major research interest.

Fig. 3: Flooding in the municipality of Puente Alto in a Social Housing Estate (Photo: Carolin Höhnke)

Among other aspects, it is directly connected to impervious cover leading to a higher vulnerability towards floods (Romero 2004; Romero/Ordenes 2004). The guiding question for the investigation is: Which changes in the land use may help to minimize flooding and flood risk in Santiago de Chile? Departing from this question, the analysis concentrates on the components that influence flood risk (elements at risk, vulnerability, risk) through high resolution satellite images and Geographic Information System (GIS). This is then again the starting point for interdisciplinary research because it is important to find out which are the most vulnerable people - those who directly effected by flood events.

In geographic terms, this particular study focuses on the Andean Piedmont. The area has attracted middle and upper class households who relocate into luxurious gated communities. In some cases, these new settlements are constructed in areas that are „traditionally" inhabited by lower income households. These new settlements have significantly reduced the amount of permeable soils producing a much higher frequency of sudden flash floods (Romero/Vásquez 2005). The consequences are, according to the main working hypothesis, above all borne by the poor population living in the area. By integrating social components like the socio-spatial differentiation, intra-urban migration processes and land prices into the hydrological models used in the environmental risk assessment, a risk prevention model will be developed.

6. Current status of 'Risk Habitat Megacity and perspectives

During the current three-year implementation phase (2007 – 2010), the involved partners generate knowledge in the several fields of applications mentioned above. While developing implementation solutions for the pilot case Santiago de Chile, they likewise test the applicability of the overall integrative concept. So far, the development and adjustment of indicators and a status analysis in all fields of application have been finalized. Currently, first evaluations are carried out based on scenario and modelling techniques. Based on this measures policy recommendations are being developed in all Fields of Application. A next step will be their integration into a consistent sustainability strategy and recommendations for improved integration of risk mitigation and risk management in urban governance in Santiago de Chile.

The implementation of the programme includes annual status conferences. They provide a science policy window for continuous dialogue on the results of the initiative and permit societal groups to participate and contribute to the debate from their respective points of view. From an early stage of implementation, the consortium encouraged furthermore the participation of research communities (including PhD students) and policy-makers from other megacities in the region. These conferences play a significant role enabling interested partners to join the process, to cooperate in developing the concept and take it up for replication in other cities.

The second annual status conference in September 2009 will be connected to the international scientific conference „Megacities: Risk, Vulnerability and Sustainable Development" at the Helmholtz Centre for Environmental Research. The conference will offer a unique opportunity for the participants in the „Risk Habitat Megacity" Initiative to present and discuss current results with international colleagues, and to bring together the work from the two complementary research programmes with focus on megacities in Germany: the program „Research on the Sustainable Development of Megacities of Tomorrow: Energy- and climate-efficient structures in urban growth centers" of the Federal Ministry of Education and Research (BMBF) and the priority program „Megacities – Megachallenge: Informal Dynamics of Global Change" of the German Research Foundation (DFG).

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Mega-Urban Societies at Risk

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Abstract

In the last decades a worldwide trend towards rising fatalities and economic losses due to natural and man-made hazards can be observed. Although there is a broadly disconnected relationship between disaster-related deaths and damages in the developed world, the number of people affected in the developing world is increasing. One major influencing factor is the growing urbanisation, which leads to increasing spatial concentration of people and values as well as massive land use and land cover changes. Particularly cities and megacities in coastal and delta regions are prone to natural and man-made hazards. Additionally, mostly low-key processes, such as resource supply crises, social fragmentation etc. have to be considered, which after a slow onset can result in sudden crises. This is partly due to a loss of governability and steering as well as often extreme dynamics of development, which contribute to a destabilisation of the urban systems. Against this background we have to consider cities and megacities as regional and global risk areas in which at least parts of the population are growingly vulnerable to internal and external shocks and destabilisation.

1. Megacities as global risk areas

In the context of changing risks current general urbanisation processes play a key role. Until World War II urbanisation had primarily been a feature of developed countries, only since then has rapid urban growth also begun in developing countries, encouraged by intensified industrialisation and migration to the cities. Since 2007, for the first time in human history, more than half of the world's population have been living in cities (UN 2008), a development addressed commonly as the "urban turn". Worldwide, the proportion of the population as a whole living in cities rose from 29.1 % (1950) to 37.3 % (1975) to 46.6 % (2000), and it will probably increase to 50.6 % in 2010 or 59.7 % in 2030 (UN 2008). In the industrialised countries 71.2 % of the population was living in cities by 1990 (ca. 818 Mio.), while in developing countries the corresponding figure was only 35.1 %, although in absolute figures it was 1,456 Mio. It is assumed that the rate of urbanisation in industrialised countries will only increase slightly to 79 %, i.e. 995 Mio. people, while in developing countries the increase will be enormous, although it may vary from state to state. With an estimated 53 % of the total population, probably more than 3,589 Mio. people will live in cities here in 2025 (UN 2008, fig. 1).

Megacities have particular significance in this world-wide process of urbanisation. New scales have evolved („mass matters"), including new dimensions of large high-density concentrations of population with immense sprawl (Fig. 2) and a serious increase in infrastructural, socio-economic and ecological overload. Furthermore, these may develop extreme dynamism in demographic, economic, social and political processes. Both phenomena – the new scale and dynamism – make megacities vulnerable, especially where administrative steering is absent or weak.

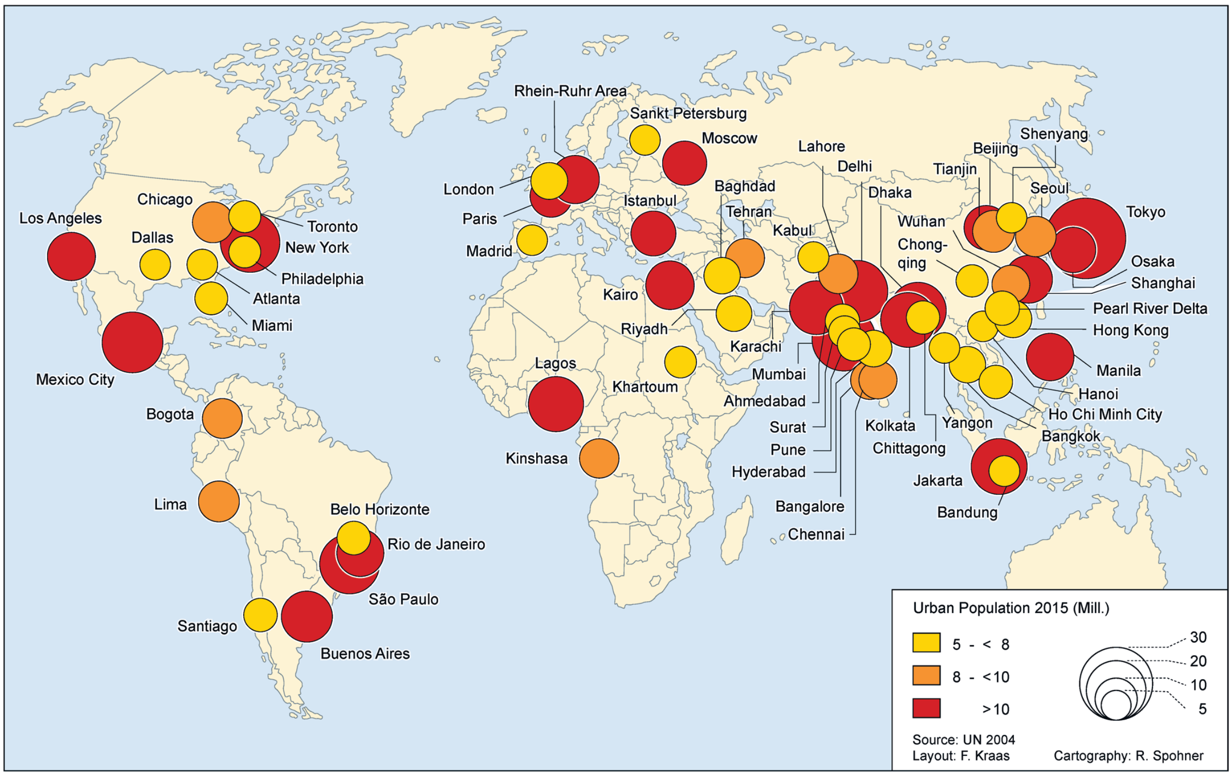

Fig. 1: Megacities in 2015

Fig. 2: Emerging megacity Pune/India is expanding rapidly into the urban fringe (Photo: Kraas, 2009)

Megacities[2], as new phenomena of worldwide urbanisation, are gaining more and more importance as junctions of globalisation processes and nodal points in a world increasingly dominated by urban networks. Megacities are not only characterised by hitherto unknown dimensions and developmental dynamics of population growth and urban sprawl as well as high concentrations of population, infrastructure, economic power, capital and decisions. More important than these quantitative aspects are the qualitative aspects, which include the simultaneous and overlapping nature of the diverse ecological, economic, social and political processes with their multitude of interacting and partially self-enhancing acceleration and feedback effects. Also new is the increasing loss of governance and control in the megacities, with concurrent increases in informality and in the number of stakeholders with their multiple-scale interweavements (Hardoy/Mitlin/Satterthwaite 2001; Kraas 2007).

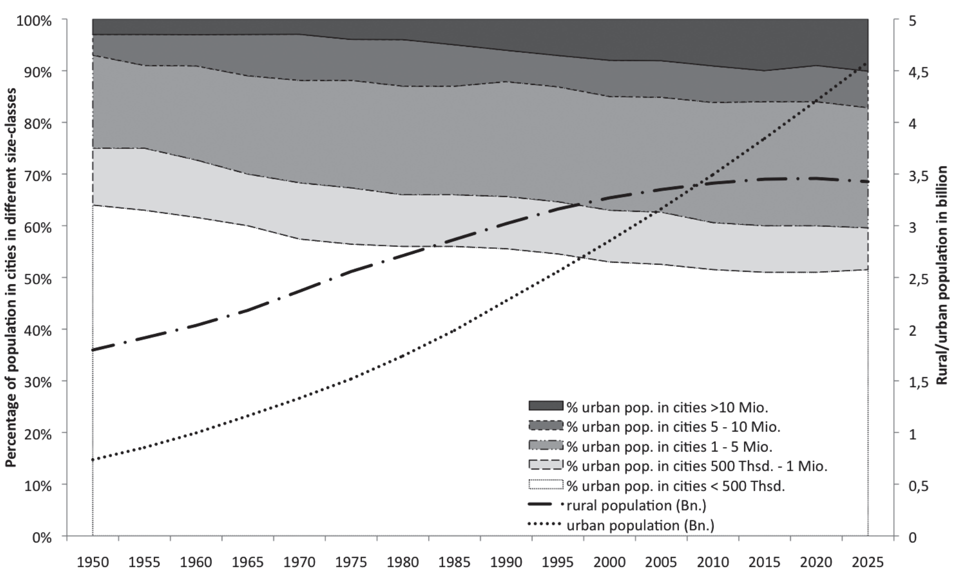

Fig. 3: The urban turn (Draft: Butsch; Source: UN 2008)

While in the 1950s there were only four cities with a population greater than 5 Mio., by 1985 there were already 28 and in 2000 39. Depending on the threshold accepted as a lowest population value for a megacity, there are currently 16, 24 or 39 megacities worldwide; in the year 2015 there will probably be almost 60. Before World War II megacities were a phenomenon of industrialised countries; today by far the greater number is concentrated in developing countries and Newly Industrialising Countries (NICs). Two thirds of the megacities are now in developing countries, most of them in East and South Asia. At the moment roughly 540 Mio. people live in cities with more than 5 Mio. inhabitants, most of them in the developing world. In 2015 there will be about 614 Mio. people living in megacities (UN 2008). In some of these – Mexico City, São Paulo, Seoul, Mumbai, Jakarta and Tehran – the population figures have almost trebled between 1970 and 2000, Dhaka and Lagos even sextupled in the same time (UN 2008; Fig. 3).

[2] Megacities are usually differentiated according to quantitative attributes and are thus – in accordance with various definitions – metropolises with populations of at least five, eight or ten million inhabitants (Fuchs et al. 1994; Kraas 2007). Various authors define threshold levels for the population density (at least 2,000 inhabitants/km²) and only consider cities with mono-centric structures (Bronger 2004) or also include poly-centric agglomerations as functionally integrated mega-urban regions. For instance, in the latter case, the Rhine-Ruhr-Region, as Europe's largest mega-urban region or the Pearl River Delta, South China, as a „world factory" are counted as megacities.

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Due to these developments megacities are not only global risk areas because they are home to an increasing share of the world population. Furthermore, they are especially exposed to risks, at least partly associated with globalisation processes, which take special concretion in these globalised urban agglomerations. In turn, crises in these junctions of global networks can affect our global risk society with sudden magnitude - as for example the terrorist attacks in New York revealed.

2. Increasing damages and losses: complex reasons

The major reasons for increasing disaster-related fatalities and damages in urban areas, even if the frequency of geophysical events remains unchanged and despite a number of efforts for disaster reduction, are to be found in the following complex processes (Coy/Kraas 2003, Kraas 2003): (1) Population growth: The number of people likely to be affected by hazards are growing due to constantly rising population numbers and densities and owing to decreasing security of food supplies, malnutrition, inadequate health care and fragile livelihoods. (2) Population dynamics: Mainly migration leads to the concentration of growing numbers of people in cities, particularly in often unsafe, overcrowded, badly built and predominantly coastal cities. (3) Inequality: Disparities and fragmentation in cities continue to increase (Fig. 4), thereby exacerbating the vulnerability of the different societies. (4) Welfare systems: While developing countries cannot offer a coherent welfare system for large parts of the population, even the developed countries appear to be reducing their commitment to internal welfare and development aid. (5) Economic growth: The increasing amount of built property, the complexity of economic dynamics, shortages of building land and growing spatial demand contribute to growing exposure to catastrophic property damage. (6) Technological innovation: Technology offers better forecasting, safer construction techniques and immediate reaction, but also leads to growing dependency and additional potential for hazard as our societies increasingly depend on so-called critical infrastructures. (7) Social expectations: Wealthier societies in particular expect absolute security of supply and services, thus relying more on public systems than on their own coping strategies in case of an emergency. (8) Global interdependence: The functioning of the world economy is reinforcing hazard vulnerability and growing interdependence affects others far outside the immediate area of impact.

So far, the consequences which global environmental change will impose on megaurban societies are unforeseeable. Sea-level rise will affect those cities that are situated in coastal regions, changing precipitation patterns will lead to an increase in the number of flood events and at the same time put energy supplies at stake, heat waves - such as the one in Europe in 2003 - will affect mostly cities with their heat-islands (Kasperson/Kasperson/Turner 1995). Furthermore, there will be severe changes in spatial patterns of diseases due to the changing distribution of disease vectors.

Fig. 4: Socio-economic disparities within short distances in Dhaka/Bangladesh (Photo: Kraas, 2007)

3. Multiple risks in megacities

Megacities are particularly endangered as they are increasingly affected by natural and man-made hazards, and megacities can be both victims and producers of risks. Still, it must be kept in mind that until now only few megacities have experienced disasters, which unleashed the full catastrophic potential inherent to the given vulnerability, thus anticipative projections are necessarily speculative (Blaikie et al. 1994: 37-39; Mitchell 1999: 22-35; Wisner 2003).

Generally it is necessary to distinguish between the terms „hazard (or cause) as a »potential threat to humans and their welfare« and risk (or consequence) as »the probability of a specific hazard occurrence«" (Smith 1996: 5). When large numbers of people are killed, injured or affected, the event is termed a „disaster", without a universal definition of its scale; more qualitatively it is defined to be „an event, concentrated in time and space, in which a community undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfilment of all or some of the essential functions of the society is prevented" (Smith 1996: 20). Increasingly a new perspective in research is added to the discourse on hazards, risks and disasters, stressing the fact that disasters can only occur if a society – knowingly or unknowingly – exposes itself or parts of itself to risks. In order to express this „man-made shar" in every disaster some authors propose the term „social disaster" (in German: „Sozialkatastrophe"; Felgentreff/Glade 2008: 3).

Due to their particular characteristics and problems mentioned above, megacities prove to be highly vulnerable in crises and social disasters: sudden supply shortages, heavy environmental degradation or major catastrophic events can quickly lead to serious bottlenecks or emergencies for a vast number of people, or aggravate further those of the socially weakest groups among the population (Wisner 1999). Constraints and conflicts may acquire multiple dimensions, as they arise amid poorly co-ordinated administration and planning, the growing influence of an increasingly globalised economy, growing socio-economic disparities and intensifying environmental burdens. Risks are therefore shaped by a complex constellation of hazards, factors and networks.

The two general spheres of environmental and man-made hazards and risks need to be examined at least to an extent under the growing influence of global change processes. As far as the impacts of hazards with sudden or slow onset are concerned, one has – in a not entirely static way – to consider gains and losses as well as direct and indirect, tangible and intangible, short-term and long-term effects (Smith 1996). In the following remarks several examples of cities and megacities which were affected by social disasters in the past are mentioned. Only some had been megacities at the time of the disastrous events and only severe „big event" hazards are included – while excluding the „everyday" social disasters, such as of malnutrition and poor health (Blaikie et al. 1994; Wisner 1999):

- *Environmental hazards include:*
  - *Earthquakes and volcanic eruptions:* The earthquakes near Calcutta 1737 and the Kanto earthquake in Tokyo 1923, for instance, killed up to 300,000 and 140,000 people. In Mexico in 1985 more than 10,000 people were killed, nearly 41,000 injured and about 80,000 became homeless (Puente 1999: 306-307; Blaikie et al. 1994: 174-181, Flüchter 2000). In Kobe 1995 about 6,300 people were killed and the damages went up to more than 100 billion US$ (Mitchell 1999: 2, 13, 510; Shaw/Goda 2004).
  - *Tsunamis:* Lisbon 1755 as well as cities in Java and Sumatra, for example, were affected heavily by a tsunami in connection with an earthquake and the Krakatoa eruption in 1833 (Kondratyev/Grigoryev/Varotsos 2002: 57-58). The tsunami in the Indian Ocean in 2004 caused more than 230,000 victims, with highest number of victims in cities in coastal areas (Brückner/Brill 2009).
  - *Storms:* The storm events of the cyclones in Calcutta 1864, Haiphong (near Hanoi) 1881 and Mumbai 1882 killed „tens of thousands“, 300,000 and 100,000 people. The Ise Bay typhoon in Japan 1959 killed more than 5,000 people (Mitchell 1999: 1, 510). The hurricane „Katrina“ in 2005 left enormous damages (Fassmann/Leitner 2006), and in 2008, the cyclone „Nargis“ in the vicinity of the megacity Yangon caused up to 200,000 casualties and up to about 2 Mio. people, though only partly in urban areas, affected by the loss of their livelihoods (Kraas 2009).
  - *Inundation and floods:* The severe monsoonal floods which regularly hit the capital of Bangladesh, Dhaka, are sometimes exceeding normal levels, such as in 1988 or 2007, thereby causing enormous destruction (Blaikie et al. 1994: 138-143, Braun/Shoeb 2008).
  - *Landslides:* In major landslides losses are often affecting the most vulnerable population groups, as it was the case for instance in Rio de Janeiro in 1988, where about 277 people were killed, 735 injured and more than 22,000 displaced (Blaikie 1994: 183), or in Manila in 2009 in combination with a tropical cyclone.
  - *Droughts and heat waves:* In summer 2003, numerous cities including the megacity of Paris were affected by massive heat effects which surmounted regular urban heat island effects. Megacity New York, for instance, is preparing for a much higher number of days with unusually high summer temperatures through global climate change (Confalonieri et al. 2007, Rosenzweig/Solecki 2001).
  - *Snowfall, frost and avalanches*: In the higher hemisphere, numerous cities are threatened by these winter effects.
  - *Global rise in sea-level*: As numerous cities and megacities are located in coastal and delta areas, they are threatened by and often already preparing for reacting on global sea level rise (for instance for New York: Rosenzweig/Solecki 2001, for cities in Vietnam: Garschagen/Binh/Thach 2009, or for Mumbai: Revi 2008).

- *Man-made hazards include:*
  - *Air, water and soil pollution:* Here, inadequate or non-existing provision for waste disposal – which led for example to the 1994 spread of plague in Surat (Lin 1995) – and sewage treatment, as well as the degradation and contamination of water and soils is contributing to high risks.
  - *Fires and accidents:* The so-called „haze“ in 1997 strongly, even if indirectly by air pollution, affected major cities in Southeast Asia; extensive bush and forest fires during the dry periods affect cities like Sydney, Los Angeles and San Francisco. For instance, the forest fires in Los Angeles 1993 burned more than 200,000 acres, destroyed over 1,000 houses and caused losses exceeding US$ 500 Mio. (Wisner 1999: 403).
  - *Industrial explosions:* The release of toxic gas in Bhopal 1984 caused between 2,000 and 6,400 deaths, 34,000 eye defects and the migration of 200,000 people (Smith 1996: 321, 326-328).
  - *Sinking land surface and inundation:* Many cities, particularly in coastal and delta regions (e.g. Bangkok, Ho Chi Minh City (Fig. 5), Jakarta, Mumbai), are facing a substantial speed of land subsidence (partly up to several cm per year in alluvium soils) due to ground water extraction, compaction of soils and the weight of high-rise-buildings.
  - *Diseases and epidemics:* Not only in past centuries did diseases, such as the black death, great plague, cholera and typhoid, cause hundreds of thousands of victims (in London, for instance between 1349 and 1861 more than 250,000 fatalities; Parker 1999: 189-191, Tanaka et al. 1996) but also today known and emerging urban diseases are on the rise, such as SARS in Guangzhou and Hong Kong in 2003 (Stich et al. 2003), dengue fever, bird and swine flues or chikungunya.
  - *Socio-economic crises:* They contribute strongly to an increasing vulnerability and destabilisation as well as growing risks especially for low-income groups (e.g. so-called Asian crisis 1997; Douglass 2000).
  - *Civil riots and terror attacks:* In numerous megacities riots, bomb and terror attacks as well as social and political conflicts have contributed to massive disorder, partial destabilisation in the societies, such as they took place in Los Angeles 1992, Jakarta 2000, New York 2001 or Mumbai 2008 (Wisner 1999; Gamerith 2002).
  - *Nuclear accidents:* Even though nuclear accidents have not occurred frequently until now, they are forming a substantial risk to be taken in mind (e.g. Chernobyl 1986; Smith 1996: 328-330).
  - *War, germ and nuclear warfare:* Cities and their dwellers are most prominent victims in war and warfare. Not only in

Fig. 5: Monsoonal inundation in the Mekong delta near Ho Chin Minh City (Photo: Kraas, 2009)

Fig. 6: The skyline of terrorism: while the Taj hotel is associated with the terrorist attacks in 2008, the neighbouring gateway of India is linked to the blasts of 2003 (Photo: Butsch, 2008)

the Second World War a high number of large cities and megacities were affected, like London, Paris, Moscow, as well as Dresden 1944 and Hiroshima 1945, but also in recent decades war and civil war are particularly damaging cities (Blaikie et al. 1994: 43-44, Dittmann 2004).

4. A society-environment hazard: Human health at risk

Health as a product and a prerequisite of human development is subject to complex interacting processes – especially in the urban context (Glouberman 2006). While cities offer comparatively good health infrastructure (at least for parts of the population) and medical facilities and are nodes of health information networks, several aspects, especially of megaurban life, jeopardize megaurban health. These negative implications of urban health increase typically with a city's size.

Urban health was already a topic under intense discussion during the industrialisation in Europe and the USA in the 19th century. Due to the degradation of urban environments and the precarious living conditions of the industrialising cities of these times, the health status of urban dwellers was significantly worse than that of the rural population. In imperial Germany, for example, the child mortality rates of major cities were significantly higher than those in the surrounding rural counties (Vögele 1998). It was due to joint efforts of medical scientists, engineers and politicians that – mainly through sanitary reforms – the health status of urban dwellers could be significantly increased. Today the megacities of the developing and emerging economies face problems, which are caused by similar mechanisms: degradation of urban environments, unhygienic living conditions for marginalised communities, crowding and the absence of health governance. It is mainly these conditions that increase the burden from infectious diseases: The degradation of urban environments (in combination with changing patterns of climate) leads to the re-emergence, for instance, of malaria and the emergence of dengue epidemics. Shortfalls in the provision of safe drinking water and the inadequate provision of sanitary facilities as well as sewage disposal lead to the transmission of mainly gastro-intestinal but also other infectious diseases. Air pollution induces severe respiratory disorders in urban dwellers. Changes in lifestyles and diet cause the increase of chronic diseases. In India for example the prevalence of diabetes in urban adults has reached a share of 11.8 % while it is 3.8 % in rural areas. Therefore, megaurban dwellers in the developing world are increasingly exposed to a double burden of diseases, i.e. infectious and chronic diseases (Stephens 1996; Reddy 2005).

Fig. 7: Unhygienic living conditions in a Delhi slum (Photo: Butsch, 2009)

However, completely new health threats are rising due to the multiple and complex interdependencies within megacities and due to their global interconnectedness. The SARS epidemic has to be seen in this context: In the specific setting of the crowded Chinese megaurban agglomeration of the Pearl River Delta the virus could cross the human-animal boarder and due to the global connections spread over several continents within days (Stich et al. 2003) causing not only loss of life but also severe financial losses. These new threats are evolving in an environment where health systems are barely functioning. In most parts of the developing world public health care systems are underfunded and offer only rudimentary services. These systems under stress are in most cases not able to cope with the growth of population, leaving megaurban dwellers with the only choice to seek treatment in the private health care sectors. These are often unregulated and uncontrolled, offering at one end of the spectrum services at and above international standards, though at the other end services of an often doubtful quality for those who are financially deprived (Bork et al. 2009). This means that populations facing a variety of health stressors in the midst of a health transition are exposed to a double burden of diseases with no or only few sources of adequate health care to mitigate the adverse health effects that megaurban life imposes on them.

Fig. 8: Informal settlement Seelampur, Delhi/India (Photo: Kraas, 2009)

To reduce the risks for human health in the growing megaurban settings urgent action is needed which has to address two major issues: Firstly, information on the health status of the megaurban population is needed to develop sound and adjusted strategies for the improvement of megaurban health, secondly, access to medical care has to be universally available at acceptable standards, as also demanded in the most recent issue of the World Health Report, which stresses the need to resuscitate the Primary Health Care idea (WHO 2008). However, these two measures only work in combination: Effective health care interventions have to be knowledge-based, therefore standardised treatment documentation is needed to gather data for health monitoring systems. Together with measures aiming at increasing the hygienic situation in megacities (improvement of water supply, sewage treatment, waste management, improved housing situations etc.) sustainable megaurban health can be achieved (Yusuf/Nabeshima/Ha 2007).

5. Civil Societies strengthening megaurban resilience

With the loss of social cohesion and the emergence of fundamentally differing life realities within direct neighbourhoods – driven by forces of globalisation – a divide of urban societies into „winners“ and „losers“ of globalisation can be observed. Especially the latter are facing an increasing vulnerability if growing neoliberalism is threatening traditional social protection measures (Gerometta/Häussermann/Longo 2005). Socio-economic polarisation and fragmentation as well as social disintegration endanger their stability and development, especially when these are prone to disruption because of large socio-economic disparities.
Civil society as collective of voluntary civic and social organisations and institutions that are acting beyond the cognisance and responsibility of governments and the private sector takes over important functions and competencies, namely of social and societal action, and thereby forms the basis of a functioning society. With its comprehensive action around shared interests, purposes and values the institutional forms can be similar to those of the state, family and market, but are not necessarily comparable – as they are often more informal and negotiable, more dynamic and flexible. As civil society can include organisations and institutions such as religious groups, non-governmental organisations, community and neighbourhood groups, micro-credit groups, women‘s organisations, self-help groups, social movements or informal business networks, these can have a substantial share of responsibility in fast growing cities worldwide, particularly in emerging and developing countries (Bontenbal/Van Lindert 2008; Carley/Jenkins/Smith 2001). Here, a growth of self-organised and informal structures beyond regulated activities can be observed. These range from the expansion of informal settlements (Fig. 8) and informal economic sectors to forms of semi-legal, partly illegal activities. Increasingly, a multitude of informal networks and self-organised actor groups develop alongside formal public and private economic institutions; both basic forms also overlap. Along with actors in the established administrative system and the economy, there are more individual actors and protagonists in self-organised institutions. As yet it is hardly known, however, how the complex governance mechanisms, negotiation processes and discourses of these new and heterogeneous types of social organisation forms are influencing actions in the case of hazards and risks as well as in respect to an increase of megaurban resilience (Adger 2000). With respect to the administrative capacities, it has been shown that conventional concepts, standards, strategies, tools, and priorities of risk preparedness, mitigation and adaptation neither answer, for instance, conditions of urban poverty nor are they suitable for accepting self-organisation and informality as a widely prevalent basic principle of urban life, economy and settlement. Decentralisation and devolution of decision-making authorities are increasingly accepted as solution strategies; however, the necessary willingness and capability for participation are still underdeveloped (Douglas/Friedmann 1998).

6. Risks – and chances?

Hazards and risks, as mentioned above, are at least partly symptoms of ecological overload and „consumption“ of space and will in future increasingly concentrate in megaurban areas. Megaurban metabolisms are consuming resources (e.g. energy, water) at rising rates, thereby increasing the so-called „ecological footprint“ (Wackernagel/Rees 1997). For some megacities already today, for instance, sinking land levels have become a problem as many megacities are located along coasts and in flood plains. As far as global societal changes are concerned, particularly megacities are prone to growing socio-economic vulnerability because of pronounced poverty, socio-spatial and political fragmentation, sometimes with extreme forms of segregation, disparities and conflicts. The loss of social cohesion and the division of urban societies into „winners“ and „losers“ of globalisation can be observed. Socio-economic polarisation and fragmentation as well as social disintegration endanger their stability and development, especially when these are prone to disruption because of severe socio-economic disparities. Uncontrolled sprawling as well as the absence of land-use planning and control are mainly due to the enormous dynamism of growth. The cumulative result of different causes, effects and feedback effects in problem areas are interconnected at many levels and reinforce each other, which impedes the analysis of material flows and their management. Thus the risk potential, on the one hand, increases rapidly in a complex manner.

On the other hand, the positive development chances inherent in megacities as global junctions should also be perceived (Ehlers 2006): Megacities offer positive potential for global transformation, for instance, in respect to minimisation of „space consumption", high efficiency of resources applied or efficient disaster prevention – insofar as corresponding strategies for direction and provision have been developed (e. g. Tokyo: Taniguchi 1999). There is substantial potential due to the wide range of available financial and human resources as well as widely networked and interacting stakeholders, especially as pioneers on the way to sustainable development, for instance through decreasing spatial consumption per capita, efficient resource use or improved education and health care. Furthermore, technical innovations in megacities can be realised cost-efficiently and integrated in the existing structures (e. g. transport systems, networks, process innovations; Herrle/Jachnow/Ley 2006).

7. Disaster- and crisis prevention: increasing megaurban resilience

Recently the relation between vulnerability and social resilience is being discussed (Adger 2000), mainly stressing that both concepts are somehow interconnected and aiming at understanding how given structures are influenced by external changes. Whereas research on social resilience focuses on understanding what makes systems persist when they are exposed to changes, vulnerability aims at understanding which combination of different forms of capital enables a population group to cope with stress. These two perspectives sometimes are seen as complementary perspectives with different foci (Butsch/Etzold/Sakdapolrak 2009). In relation to megaurban disaster- and crisis prevention this means that it is essential to understand which factors determine megaurban resilience and vulnerability. Furthermore, measures to increase the former and decrease the latter are urgently needed. Therefore, systematic risk minimisation and risk prevention are essential in the light of the expected global consequences of the impacts of megaurban social disasters. The areas with the greatest need for action, on which strategies should concentrate, are the following:

- In the area of the environment and health, problems of emission reduction, the provision of clean drinking water as well as sewage and waste disposal are the most important issues. The inadequate environmental situation is already directly responsible for more than a quarter of avoidable health problems. Furthermore, provision of access to adequate healthcare is an urgent need to prevent the increase of already tremendous inequities of the health status of urban dwellers in newly industrialising- and low-income countries.
- The problems of habitat and spatial expansion associated with dynamic population growth, together with inadequate land-use planning and poor achievability continue to be unsolved problems. This is especially relevant as lack of planning increases the risk of social disasters enormously. Unplanned settlements bear a high potential of construction faults in sites, which are potentially hazard-prone (e. g. squatting on steep hill slopes), either due to lack of knowledge or due to lack of alternatives.
- In the case of the rapidly increasing concentration of (international) economic activities, conflict arises between urban economies and national economic interests. Power with its social and spatial effects creates polarised active and marginal economic spaces, at a national, regional and local level. The megaurban economies with their multi-layered interconnections with increasing globalisation and the expansion of the informal sectors have hitherto been little researched. Especially the dual relation of „glocalisation" and megaurban social disasters has so far not been understood: Which effects of globalisation bring about social disasters on the local scale? How do local megaurban social disasters affect processes on the global scale?
- Already now, existing symptoms of economic, ecological, infrastructural and socio-economic overload are increasing dramatically and are thus extreme urban security risks at a global level. This multiple congestion concentrates in space bearing the potential for dramatic multiplication effects and increasing the magnitude of the impact social disaster can unleash. At the same time they are causes of the slowly developing disasters as they are increasing base-line vulnerabilities and decrease the resilience of the megaurban systems.
- Increasing disparities and sometimes extreme socio-economic fragmentation with serious social and spatial segregation are sources of social and political centres of conflict. These man-made hazards are increasing due to the globalisation processes and marginalise a substantial part of megaurban dwellers in the developing world by neglecting their entitlements to basic amenities, which again is increasing their base-line vulnerability as well as decreasing the resilience of their cities.
- Natural and man-made catastrophic events are an increasing threat for the world's megacities; disaster prevention planning is increasing in significance. Nevertheless, several challenges in this respect are unmet. Sound and comprehensive plans for disaster planning barely exist in the developing world, which can mostly be explained by the absence of essential tools for monitoring and surveillance.
- Poor governability and controllability inhibit controlling and correcting intervention on the part of state and local authorities in order to minimise or indeed prevent poor conditions.

It is therefore essential for research to provide indicators to measure megaurban resilience and vulnerability. For that reason a comprehensive analysis of natural, man-made and society-environment hazards is needed for individual cities, and upon that the complex nature of risks has to be analysed. Furthermore, applied research needs to address the development of locally adapted strategies to minimise these risks. These must not only consist of technical measures but have to include a strong component of risk communication, which includes cultural and social aspects.

8. Risk governance?

For many megacities, governability, not to mention efficient, sustainable or fair governance, is de facto no longer given, and this loss of governability affects planning and control as much as the comprehensive organization and management of urban responsibilities, the establishment of general order, and control over development processes. This is partly due to (weak) political-administrative decision makers and heterogeneous political-administrative organisations, which are not horizontally interconnected (large numbers of independent departments within local and regional governing bodies as well as separate municipalities within mega-agglomerations). Likewise, central development and environmental planning as well as their implementation is impossible – especially as the megacities' own budgets are not even sufficient for the minimisation of problems, let alone their solution. Beyond government sufficient modes of governance – with the inclusion of multi-stakeholder networks and civil participation which could lead to a broader embedding of all kinds of planning and steering mechanisms on various levels – have not yet been set up.

Given the insufficiency of broader and detailed studies worldwide, especially concerning comparative work, there is a considerable need for research in the field of natural, society-made and society-environment hazards, their implications, the actors involved (hazard and risk politics) and causal networks (Heinrichs/Kabisch 2006). The same holds true for the following themes of risk factors: land-use dynamism, resource consumption, deficits in water supply, waste and sewage disposal, the securing of energy supplies, insufficient transport infrastructure, identification of critical infrastructures and effects of their potential failures, human security, human health, social vulnerability, functional interconnections in megaurban economies, crisis- and disaster prevention-planning, the investigation and development of systems for administrative direction (best practice models), extended primary research, the implementation and improvement of complex methods of steering and management, the best of these with the aid of improved highest resolution satellite images, GIS and modelling and monitoring and surveillance systems. Risk governance, against this background, would therefore include social and political participation as well as technical and managerial solutions for an improvement of efficiency, sufficiency, consistency and precaution as main criteria or (mega-)urban sustainability - also in respect to hazards and risks.

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Megacity Istanbul: Earthquake Risk and Early Warning in a Megacity

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Abstract

In the last fifty years the number of cities in the world with more than five millions inhabitants grew from nearly five to more than 30 (mainly located in developed countries). In particular, while the number of people living in megacities in industrialized countries only slowly increased, the number of people who moved to megacities in developing countries augmented exponentially and it is expected to represent the 80% of this population in 2015. Considering that the rapid grow of large urban areas is not always accompanied by an appropriate design of buildings, the vulnerability of large urban agglomeration dramatically increased.

The number of inhabitants in the megacity of Istanbul, one of the actual megacities, was only of nearly one million until the end of the Second World War but started rapidly to increase in the 50's reaching, at the end of the 90's, approximately the remarkable number of nine million. The number of inhabitants is growing nowadays to the impressive estimated number of 300.000 per year. Considering the high seismic hazard for Istanbul due to the high level of ground motion due to an earthquake that can occur in the area and the vulnerability of the building stock, a significant seismic risk is estimated for the economical capital of Turkey.

In fact, previous studies (Erdik et al. 2004) showed, based on probabilistic seismic hazard estimates, that the peak ground acceleration that can be expected with a 10 % probability of exceedence in 50 year is larger than 0.4 g and might reach 0.6-0.7 g close to the Marmara Sea.

Considering that several authors (Barka, 1996) showed that the seismicity along the North Anatolia Fault (NAF) seems to migrate west-ward in the last century, leaving a seismic gap in the seimogenetic zone in the Marmara sea just in front of Istanbul, several studies focused their attention on preparing seismic hazard and risk scenarios while considering a possible rupture of the NAF compatible with a M=7.5 earthquake.

Particular attention was also dedicated on the soil classification within the urban area. In fact, it is well known that local geology can strongly modify the ground motion also over short distances. Due to the geological and geomorphological variations within the urban area of Istanbul such modifications are likely to occur and should be accounted for in any seismic hazard assessment. Studies carried out by the Kandilly Observatory (Erdik et al., 2003a) and the Japan International Cooperation Agency (JICA)

Fig. 1: Istanbul, one of the actual megacities; Nearly one million of inhabitants after World War II – but it's population started rapidly to increase in the 50's reaching, at the end of the 90's, approximately the remarkable number of nine million. (Photo: Frank Kuehnlenz, Humboldt University Berlin)

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proposed a soil classification map mainly based of the average shear wave velocity in the uppermost 30 meters. Where not available from in-situ investigations, the velocities have been assigned on the basis of the surficial geology. The two classifications provided slightly different zonations. The Kandilli one was following mainly the geological boundaries while the JIICA one provided a classification based on the average characteristic of soil within a the unit of a district.
Taking into account this information earthquake ground motion scenarios have been calculated both in terms of Intensity and of parameters of engineering interests. While the JIICA scenario estimated a maximum expected Intensity of X (very distructive), the Kandilli scenario proposed a maximum value of IX (distructive). Similarly the calculated peak ground acceleration in the Kandilli scenario (max around 0.4 g) were systematically smaller than those derived by JICA (max around 0.6 g).

The ground motionsscenarios were in turn used for loss estimation both in terms of number of buildings with damage beyond repair and of lives. Both scenarios highlighted a larger concentration of losses in the western part of Istanbul where the effect of local geology is likely that of increasing ground motion. The estimated highest financial losses were also observed to concentrate in the European side of the megacity reaching, in some part, even values as high as 40-50 million dollars in some of the considered geo-cells.

Summarizing the results of the two different Kandilli and JICA scenarios Erdik and Durukal (2007) showed that although the discrepancies in the maximum expected ground motions (e.g. pga max of 0.4 g –Kandilli- and 0.6 g – JICA) the estimated losses were pretty similar (40-50000 lives lost for the Kandilli scenario and 73000 for the JICA one). Also the estimated number of building damaged beyond repair was very similar being of 35.000-40.000 for Kandilli and of 51.000 for JICA. These numbers indicate that, in case of occurrence of these scenarios, 0.4-0.7 % of life would be lost and 4-5 % of the existing buildings would be damaged beyond repair.

Interestingly, similar results were also obtained when basing the risk scenarios on the calculated Intensity or spectral displacement values. A slight variability (between 30.000 to 40.000) was observed when comparing the night time with the day time scenarios. However, one of the most striking results was the estimated large amount of injured persons (200.000) that would require hospitalization in case of an earthquake disaster. Such a number would put a dramatic pressure on the actual capability and receptivity of the health care system in Istanbul. Furthermore, to complete the drama triggered by the earthquake it was also assessed that 500.000 households would be in need of shelters after such a catastrophe. It is worth noting that, in the case of repetition of the 1906 San Francisco earthquake, in the San Francisco Bay area, with a population of nearly 10 million inhabitants, the expected number of deaths would only reach 1.800 (night) and 3.400 (day). This large differences in human losses is mainly due to the larger number of „Pancake type" collapse (about 500 buildings) that are expected to occur in Istranbul in case of a strong earthquake.

Although quite difficult to be estimated, for a larger lack of information, industrial losses have been assessed in the order of 6 to 8 Billion dollars with the long term post seismic consequence of an increase of 250.000-300.000 unemployed. Finally the results of these scenarios highlighted that while the Average Annualised Loss (AAL) ratios associated with the building stock in Istanbul is about 0.47 %, the compulsory earthquake insurance premium for the RC structure in Istanbul only varies between 0.22-0.08 %. A clear problem with the financial resources needed in the post-earthquake phase for a rapid and adequate reconstruction is therefore likely to be faced.

Wyss et al. (2003) calculated earthquake risk scenarios in terms of fatalities considering the occurrence of several earthquakes with different magnitude and position with respect to the centre of Istanbul. One of their most remarkable results is that the largest amount of fatalities would not be generated by the 7.5 Magnitude earthquake in the Marmara Sea but in the case of a smaller (M=6.7) event located in the Bosporus (1.500.000-2.000.000). Even a smaller magnitude event in that location might be able to determine between 100.000 and 400.000 fatalities.

All the above mentioned results show on one hand the vital importance of preparing seismic hazard and risk scenarios for Istanbul that might be use for preparedness and risk mitigation, but, on the other hand also the high degree of uncertainty of the results that might weaken their usefulness and comprehension for stakeholders like civil protection agencies and municipalities. To this regard, within the project „CEDIM: Megacity Istanbul", following Bommer et al. (2002) who stated that „Clearly there is the scope of enhancing the model in terms of data such as soil conditions at several locations and in terms of building inventory……" in order to contribute to the improvement of seismic hazard and risk scenario for Istanbul we focused our attention on (1) providing a better soil classification developing tools suitable for large and in expansion urban areas, (2) in deriving empirical ground motion prediction equations and (3) in developing tools for vulnerability assessment that allow to follow the dynamic of the megacity. Other ongoing activities of the GeoForschungsZentrum in the area include the deployment of a vertical array of accelerometers in the western part of Istanbul (Ataköy) for studying seismic wave propagation in the shallowmost crustal layers and soil nonlinear behaviour, the installation of an innovative early warning system based on low cost sensors, the maintenance of a seismic and multi-parameter network at the Armutlu peninsula, the calculation of Coulomb stress variation after the occurrence of the historical mainshocks occurred in the area, the interseismic deformation at the Ganos fault via analysis of PS-InSAR data. Regarding the calculation of Ground Motion Prediction equations for parameters of engineering interest, the large data set of earthquake recordings collected by the German Task Force for Earthquakes was exploited (Bindi et al., 2007). A total of 4047 velocity and acceleration records from 528 aftershocks of the Mw 7.4, 1999 Izmit earthquake were considered. The ground motion models obtained provide peak ground velocity, peak ground acceleration, and spectral acceleration for 8 different frequencies between 1 and 10 Hz. The empirical ground-motion prediction equations, derived for both the larger horizontal and the vertical components, are valid in the local magnitude range from 0.5 to 5.9. Although the magnitude range spanned in our study may appear to limit the applicability of the obtained empirical GrMPEs, we recall that recent moderate earthquakes have occurred in different regions of the world (e. g., the September 7, 1999 Ms = 5.9 Athens earthquake; the 26 May, 2006 ML = 6.2 Indonesia earthquake), causing severe damage and loss of life and hence have shown the importance of reliable local ground-motion prediction equations for the earthquake hazard assessment also in the case of moderate magnitude events. As mentioned above, a moderate size earthquake occurring in the vicinity of Istanbul may lead to considerable building damage, casualties and losses (Wyss et al., 2003). The development of adequate empirical GrMPEs for small to moderate size earthquakes is also important for Monte-Carlo-type simulations involving ground motion predictions for a family of earthquake events representative of regional earthquake statistics for a wide magnitude range. Such considerations are particularly used in loss estimations carried out for insurance purposes.

In order to improve the soil classification in western Istanbul, where an increase of ground motion and damage was observed during the Izmit earthquake, single station noise measurements were carried out at 192 sites (Picozzi et al., 2009a). This extensive survey allowed the fundamental resonance frequency of the sedimentary cover to be mapped (Figure 1), and identify areas prone to site amplification.

The results obtained were in good agreement with the geological distribution of sedimentary units, indicating a progressive decrease of the fundamental resonance frequency from the northeastern part, where the bedrock outcrops, towards the southwestern side, where a thick-

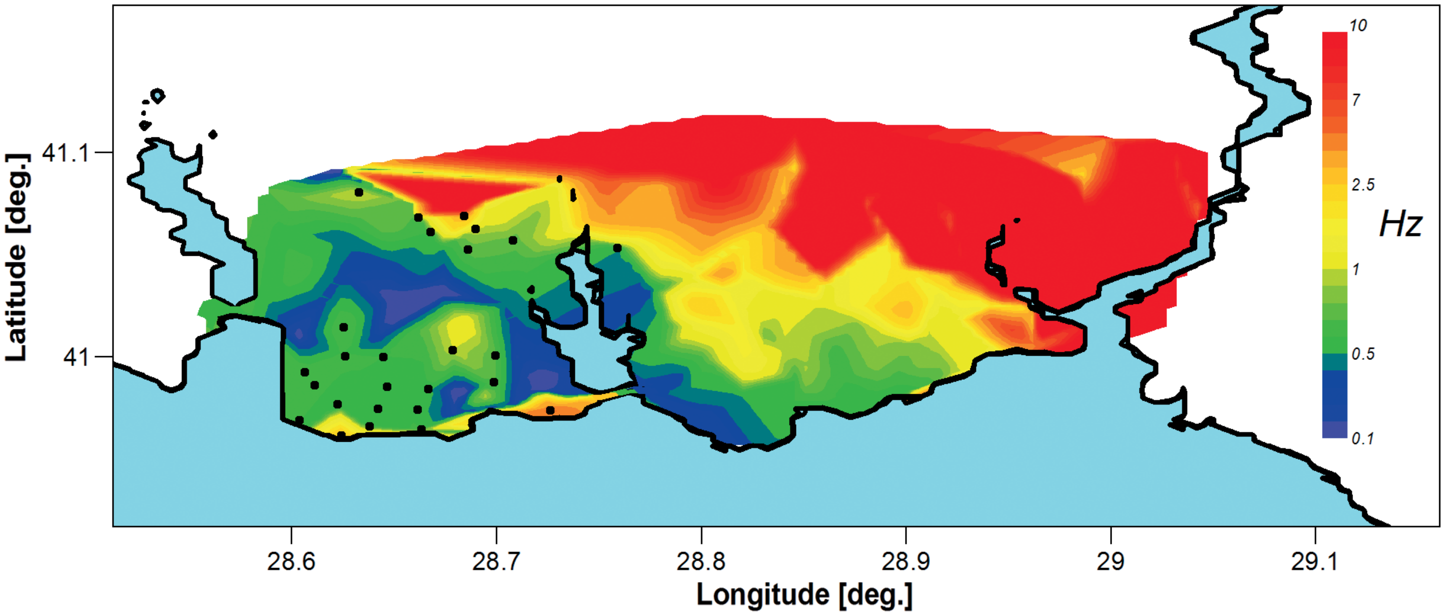

Fig. 2: Map of the resonance frequency of the soil cover in the study area estimated by seismic noise recordings. Measurements where multiple peaks are observed (black dots) are also indicated.

ness of some hundreds meters for the sedimentary cover is estimated. The particular distribution of fundamental resonance frequencies indicates that the local amplification of ground motion might play a significant role in explaining the anomalous damage distribution after the 17 August 1999 Kocaeli Earthquake.

Furthermore, 2D array measurements of seismic noise were performed in the metropolitan area with the aim of obtaining a preliminary geophysical characterization of the different sedimentary covers. These measurements allow the estimation of the shear-wave velocity profile for some representative areas and the identification of the presence of strong impedance contrasts responsible of seismic ground motion amplification. An example of a seismic noise measurement with an array and of the derived S-wave velocity profile is shown in Figure 3.

A Comparison of a theoretical site response from an estimated S-wave velocity profile with an empirical one based on earthquake record-

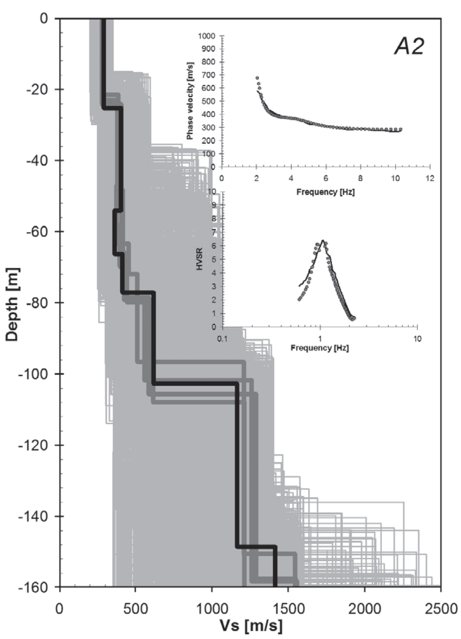

Fig. 3: Top) Array installation in a site in Istanbul. Bottom) Inversion results and fit to the dispersion and H/V ration curves (insets) for the array. The figure shows tested models (thin gray lines), the minimum cost model (black line), and the models lying inside the minimum cost model +10% range (thick dark gray lines). Top inset show the observed phase velocities (black line) and the phase velocities for the minimum cost model (gray dots). Bottom inset show the average observed H/V ratio (black line) and the H/V ratio for the minimum cost model (gray dots).

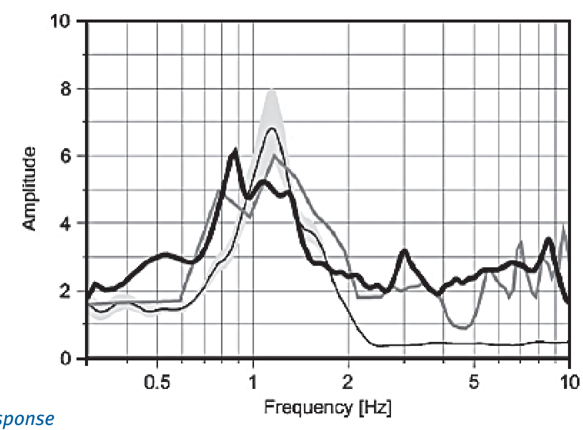

Fig. 4: Right) Istanbul Earthquake Rapid Response System (IERRS) station TOPK. Average H/V spectral ratios from seismic noise (thin black line) +/- 95 % confidence interval (gray area), H/V spectral ratios of an earthquake (dark gray line) with M~4 recorded by IERRS stations , H/V ratios (Thick black line) at the surface station from synthetic seismograms considering the model obtained by the array A2

ings (Figure 3), showing a very satisfactory agreement, strongly encouraged the use of low cost seismic noise techniques for the study of seismic site effects.

Within the activities of the „CEDIM: Megacity Istanbul project" a vertical array of accelerometers was installed in Ataköy (western Istanbul) with the long-term aim of improving our understanding of in situ soil behaviour, to assess the modeling and parametric uncertainties associated with the employed methodologies for strong-motion site-response analysis, and for shallow geological investigations (Parolai et al., 2009). Geotechnical and geophysical investigations were carried out to define the subsoil structure at the selected site. Data associated with 10 earthquakes ($2.7<M<4.3$) collected during the first months of operation of the array were used to image the up- and down-going waves by deconvolution of waveforms recorded at different depths. Results showed that the velocity of propagation of the imaged up- and down-going waves in the borehole is consistent with that of S-waves or P-waves, depending on the component of ground motion analysed but independent of the chosen signal window. In particular, an excellent agreement was found between the observed up and down going wave travel times and the calculated one by using a model derived by seismic noise analysis of array data. The presence of a pulse propagating with P-wave velocity on the waveforms obtained by deconvolution of the horizontal components suggests P-to-S mode conversion and a not normal incidence of the wavefield. This evidence implies that, even when site amplification is mainly related to 1D effects, the standard practice in engineering seismology of deconvolving the surface recording down to the bedrock using an approximate S-wave transfer function (generally valid for vertical incidence of SH waves) might lead to errors in the estimation of the input ground motion required in engineering calculations. Finally, down-going waves with significant amplitudes were found down to 70 m depth. This result provides a warning about the use of shallow borehole recordings as input for numerical simulation of ground motion and for the derivation of ground motion prediction relationships.

Special attention during the „CEDIM: Megacity Istanbul project" was paid in developing techniques, in cooperation with DLR, that allow, through the analysis of remote sensing images, to assess the land cover usage and in particular the building height and roof type. This information was used to derive specific vulnerability curves for the building stock in Istanbul by calibration with building structure data available for the area. This new approach for the assessment of building vulnerability is particular suitable for megacities with dynamic evolution of the urban area usage.

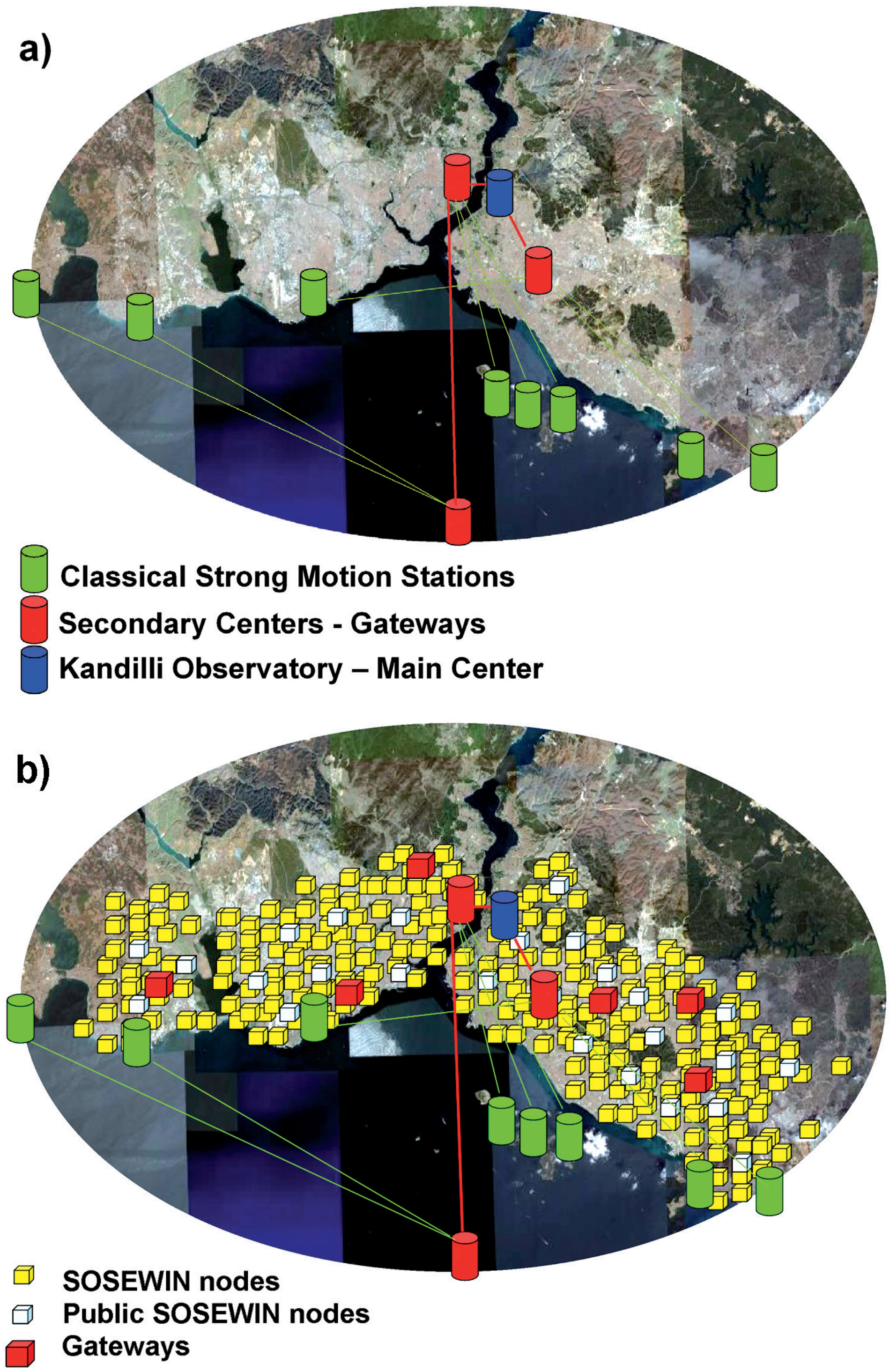

Fig. 5: How the SOSEWIN system compares with a standard network (in this case, the IERREWS, Istanbul). (a) A standard network consists of a relatively low number of stations, that are linked to a central processing centre, either directly or via another „gateway" station. (b) The SOSEWIN, by contrast, will not require a centralised centre, with the alerts being propagated throughout the system following an event's verification. The SOSEWIN nodes may also be part of a public warning system (blue boxes) or owned by members of the general public (yellow boxes). The yellow dots are a projection into the future, as only a prototype system is operational now.

Risk mitigation also includes measures that allow to reduce the impact of an earthquake. In this sense, the rapid characterization of the ground motion during the initial stage of an earthquake is one of the most effective approaches for quantifying the hazard associated with its impact on populated or otherwise sensitive areas. Earthquake early warning systems are based on this approach and aim to mitigate earthquake hazard for a target area by the provision of timely warnings.

In Istanbul a centralized Earthquake Early Warning System, the Istanbul Earthquake Rapid Response and Early Warning System (IERREWS, Erdik et al., 2003b) operated by Kandilli Observatory and Earthquake Research Institute (KOERI) of Bogazici University (Figure 4a), is already existing. This system is made up ten strong motion stations, which are installed as close as possible to the fault zone of the North Anatolian Fault. In the IERREWS a centralized philosophy of early warning is adopted, meaning that there is a continuous telemetry of data between IERREWS stations and the main data centre, where the alarm is decided, the transmission being realized by the use of a digital spread spectrum radio modem system involving repeater stations.

Recently, in the framework of the SAFER (Seismic eArly warning For EuRope, European Commission proposal no. 036935) and EDIM (Earthquake Data Information system for the Marmara Sea, Turkey, German Federal Ministry of Education and Research 0390650A-E) projects the development and establishment of an innovative early warning network in Istanbul was carried out in partnership with Kandilli Observatory and Earthquake Research Institute.
The Self-Organising Seismic Early Warning Information Network (SOSEWIN) is a new concept in earthquake early warning systems. SOSEWIN employs advances in various technologies to incorporate off-the-shelf sensor, processing and communications components into low-cost sensing units that are linked by advanced, robust and rapid communications routing and network organisational protocols that are appropriate for wireless mesh networks.

In contrast to the already existing IERREWS systems, the SOSEWIN network is a new approach for early warning that has its origin in the vision of providing to the wider community a low-cost system relying on modern wireless technology (Figure 5b) including private households. This doubled system, termed the *Self-Organising Seismic Early Warning Information Network* (SOSEWIN), is characterised by the following features (Fleming et al., 2009):

- Each seismological sensing unit or Sensing Node (SN) is comprised of low-cost „off-the-shelf" components, with each unit initially costing several hundred Euros, in contrast to 1,000's to 10,000's for standard seismological stations;
- Each SN undertakes its own, on-site seismological data processing, preliminary analysis, archiving, and communication of data as well as early warning messages. Moreover, each SN will also have the capacity to measure other environmental parameters (e.g. noise, temperature etc.);
- The reduced sensitivity of the SNs compared to standard instruments (due to the use of lower-cost components) will be compensated by the network's density, which in the future is expected to number 100's to 1000's of units over areas served currently by the order of 10's of standard stations;
- The SOSEWIN will be a decentralised, self-organising ad-hoc wireless mesh network (WMN);
- The early warning decision is carried out within the WMN of sensing units, taking advantage of their communication capability and the design of suitable alarming process. Thus, the alarming itself can be done both inside the network (i.e. flooding the alarm to every node), and outside of it (i.e. routing the alarm to the nearest gateway node, and then towards some external administrative centre);
- Its self-organising capability will allow it to adapt continuously to changing circumstances, e. g. the addition/removal/malfunctioning of nodes, interference in communications due to local (and possibly time-varying) phenomena, loss of sections of the network following an earthquake etc.;
- Instruments will also be purchasable by the public. Thus, the SOSEWIN also be able to integrate additional data from private persons;
- For rapid response purposes in the post-event timeframe, the much higher instrumental density of SOSEWIN means tools such as ShakeMap (Wald et al., 2006) can rely more on real data, and less on interpolation schemes.

The first test-bed deployment of the SOSEWIN was carried out in June, 2008, with a network of 20 stations installed in the Ataköy district of Istanbul (Figure6).

The choice of the Ataköy district was based on it being very well characterised from geotechnical and geophysical points of view. This is the result of a number of other facilities in the vicinity:

- The IERREWS strong motion station AKUKO;
- The Ataköy Vertical Array Site (administered by GFZ and KOERI, Parolai et al. 2009), consisting of accelerometric stations deployed at different depths in four bore-holes (25 m, 50 m, 75 m and 150 m deep) and at the surface;
- Single station and 2D-array measurements of microtremors administrated by GFZ (Picozzi et al., 2009a).

The availability of so such information therefore makes Ataköy a very attractive candidate for our experimental SOSEWIN deployment (e. g. the S-wave velocity profile is estimated down to a depth greater than 200 meters). In addition, being close to one of the 10 IERREWS on-line sensors will allow the efficiency of SOSEWIN in undertaking EEW activities (i.e. event detection, issuing alarming messages) to be evaluated.
The issues dealt with in this deployment include

- Gaining experience in establishing such a network in an urban environment;

Fig. 6:
(a) Location map of Istanbul showing the Ataköy district, where the test-bed SOSEWIN is situated.
(b) The location of the Sensing Nodes and Gateways for the test SOEWIN in the Ataköy district, Istanbul.
(c) A typical SOSEWIN Sensing Node installation.

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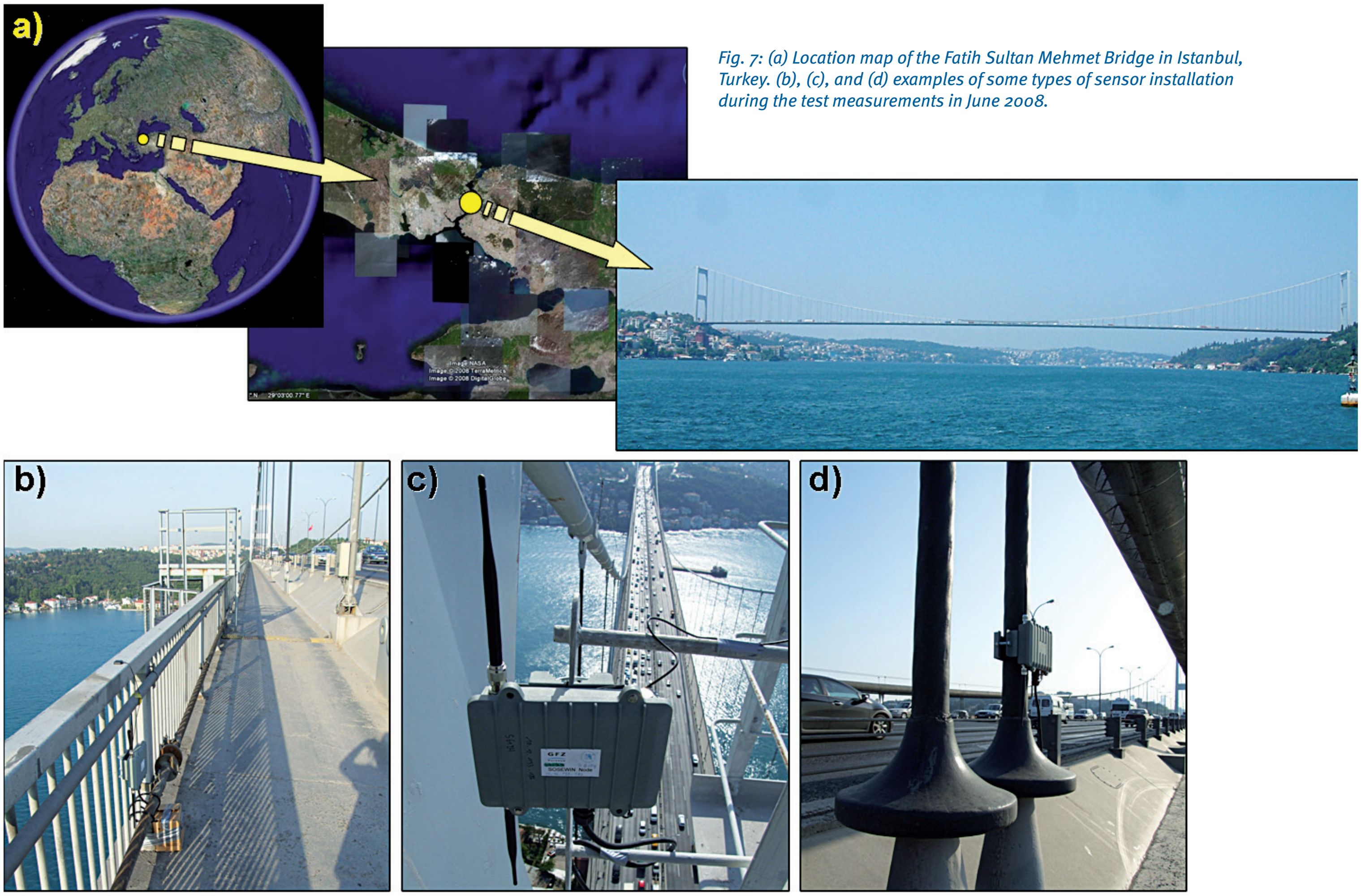

Fig. 7: (a) Location map of the Fatih Sultan Mehmet Bridge in Istanbul, Turkey. (b), (c), and (d) examples of some types of sensor installation during the test measurements in June 2008.

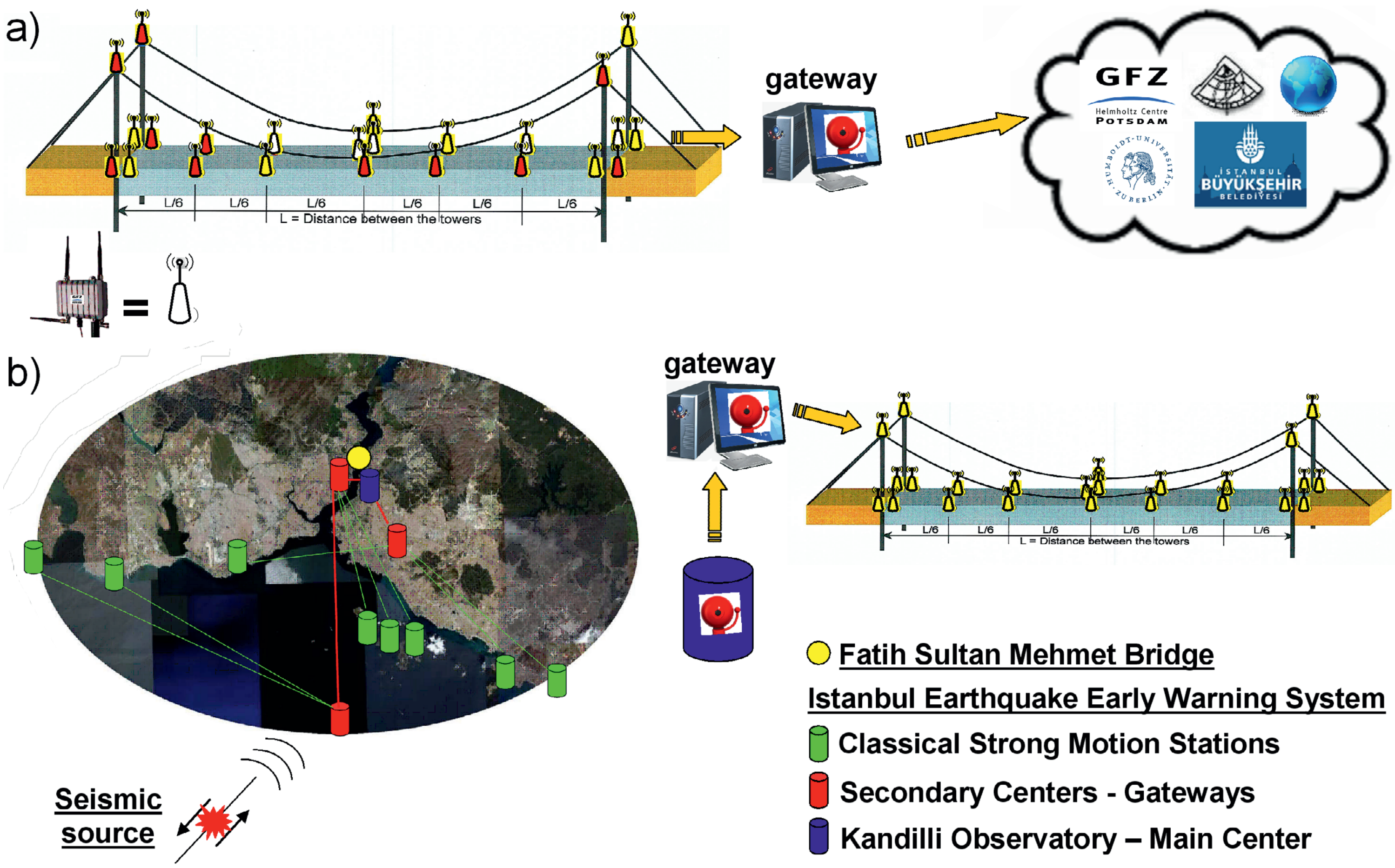

Fig. 8: The possible double way early warning for the Fatih Sultan Mehmet bridge. (a) The warning can be issued by a gateway from the bridge in the case SNs detect anomalous bridge behavior. (b) The wireless network can receive earthquake early warnings from the IERREWS operated by KOERI.

- Reliability of the communications between nodes;
- Reliability of the detection algorithms (i.e. setting different thresholds for different sites);
- Distinguishing between "local" events (traffic, thunderstorms, construction etc.), and earthquakes of possible concern;
- Survivability of the system in the event of a sufficiently severe earthquake.

Figure 6 shows the location of the sensing nodes (SNs), including the two Gateway Nodes (GN), which are SNs connected to the internet via DSL. Finally, the suitability of the SOSEWIN system for monitoring the vibration characteristics and dynamic properties of strategic civil infrastructures was validated during a ambient vibration recording field test on the Fatih Sultan Mehmet Bridge in Istanbul, Turkey. This bridge is the second suspension bridge across the Bosporus strait in Istanbul, Turkey (Figure 6a), spanning the strait between Hisarüstü (European Side) and Kavacık (Asian Side).

Results of data analysis indicate an excellent performance of the low-cost SN, with the data and estimated parameters obtained from instruments placed on similar structural elements of the bridge being highly coherent. Moreover, the main modal properties of the bridge determined from the recordings were found to be consistent with those from the studies of Brownjohn et al. (1992) and Apaydin (2002) (Picozzi et al., 2009b).

The next step might be the application of a dense wireless network of these instruments for a long-term, full scale, ambient vibration monitoring program of the Fatih Sultan Mehmet Suspension Bridge, which might allow the main modal properties of the bridge to be regularly re-evaluated with great detail. Furthermore, thanks to the availability in the instrument of an additional channel, extra functionality to the SN network could be explored, allowing, for example, the long-term monitoring of the wind load on the structure.

Finally, the addition of a dense wireless network of SNs on the Fatih Sultan Mehmet Suspension Bridge would provide an early warning capacity for the bridge itself (Figure 7). In fact, the SN network could be programmed to issue alarms through a gateway to some target (e.g. the Disaster Coordination Center of the Istanbul Metropolitan Municipality) in the case that anomalous bridge behaviour were detected. In the meantime, the wireless network could receive warnings from the Istanbul Earthquake Rapid Response Early Warning System (IERREWS) operated by KOERI (Erdik et al. 2003b) in the event of an earthquake, and, thus, be used to coordinate early safety actions (e.g. stopping the traffic access to the bridge).

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Abb1.: Neapel, ein Ballungsraum mit derzeit etwa 4,5 Millionen Einwohnern, ist flankiert von dicht besiedelten Vulkanen. Foto: National Archives and Records Administration (NARA), College Park, MD.

Neapel in der Zange

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Die Bucht von Neapel ist eine der vulkanisch aktivsten und gefährdetsten Regionen weltweit. Neapel, ein Ballungsraum mit derzeit etwa 4,5 Millionen Einwohnern, ist flankiert von dicht besiedelten Vulkanen: der Vesuv im Osten, und die Phlegräischen Felder im Westen (Abb. 1). Neuere Untersuchungen zeigen, dass beide Vulkanzentren potentiell aktiv sind und derzeit seismische Ereignisse und Verformungen vorweisen. In diesem einführenden Aufsatz werden dem Leser die Problematik der Vulkangefährdung im Allgemeinen, sowie neuere geodätische Überwachungsstrategien an den Vulkanen Neapels im Speziellen nähergebracht.

Vulkangefahren allgemein

Jedes Jahr eruptieren etwa 60 der 550 aktiven Vulkane der Erde. Die Frequenz, Magnitude und der Typ der Eruptionen gelten als nahezu konstant, und werden sich in absehbarer Zukunft global auch nicht verändern (Schmincke, 2006). Jeder sechste aktive Vulkan hat Menschenleben gefordert, und seit dem 16. Jahrhundert haben mehr als eine viertel Million Menschen ihr Leben durch Vulkane verloren.

Es gilt als sicher, dass Vulkankatastrophen in der Zukunft weiter zunehmen. Dies liegt einerseits an der steigenden Vulnerabilität der Gesellschaft etwa im Zuge der Weltbevölkerungsexplosion. Vulkanische Böden sind fruchtbar und daher insbesondere für die Ansiedelung und Landwirtschaft begehrt. Die Bevölkerungsdichte im vulkanischen Umland ist daher besonders hoch und stark im Wachsen, sodass auch zukünftig Opfer zu erwarten sind. Zudem sind durch die rasant zunehmende Vernetzung und Energieanbindung neue Vulnerabilitäten (Stromleitungen, Pipelines, Verkehrswege etc.) hinzugekommen. Eine Zunahme der Opferzahlen ist dabei über Jahrhunderte (Abb. 2) wie auch über die vergangenen Jahrzehnte deutlich. Während Vulkaneruptionen noch in den 1970-er Jahren keine 1000 Opfer forderten, waren es in den 1980-er Jahren bereits über 25.000 (Siebert und Simkin, 2002).
Eine direkte Korrelation zwischen Eruptionsmagnitude und der Gefährdung ist

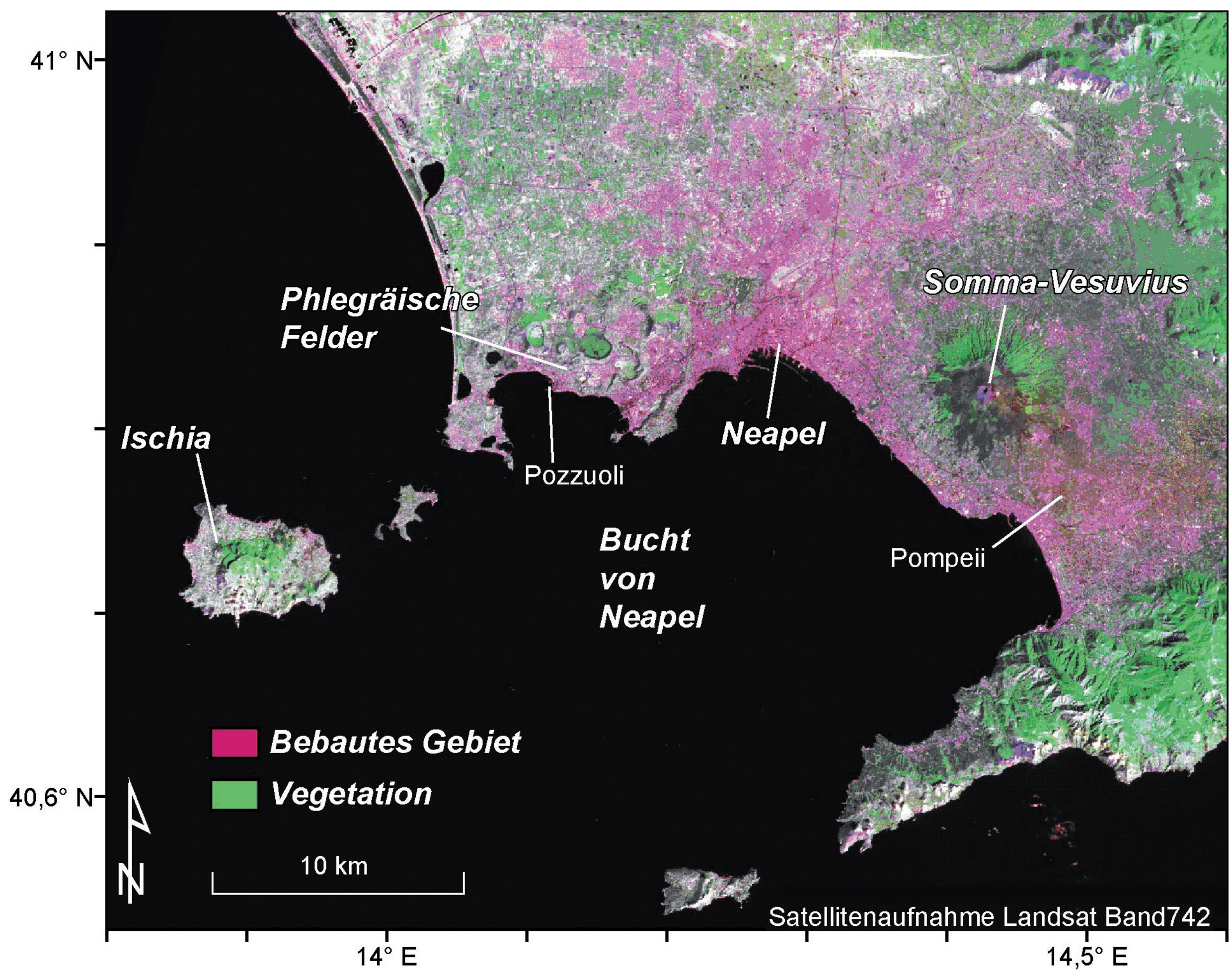

Abb. 2: Die Bucht von Neapel umschließt die weltweit am dichtesten bevölkerte Vulkanregion. Vulkanzentren von Somma-Vesuvius und Phlegräische Felder, beide direkt an die Stadt angrenzend, gelten als potentiell aktiv. Auch die Insel Ischia is ein Vulkanzentrum, jedoch weit weniger verstanden und soll in diesem Aufsatz nicht näher behandelt werden. Satellitenaufnahme von Landsat ist in Falschfarben gezeigt, Vegetation in grünlichen Farben, bebautes Land in rötlichen Farben.

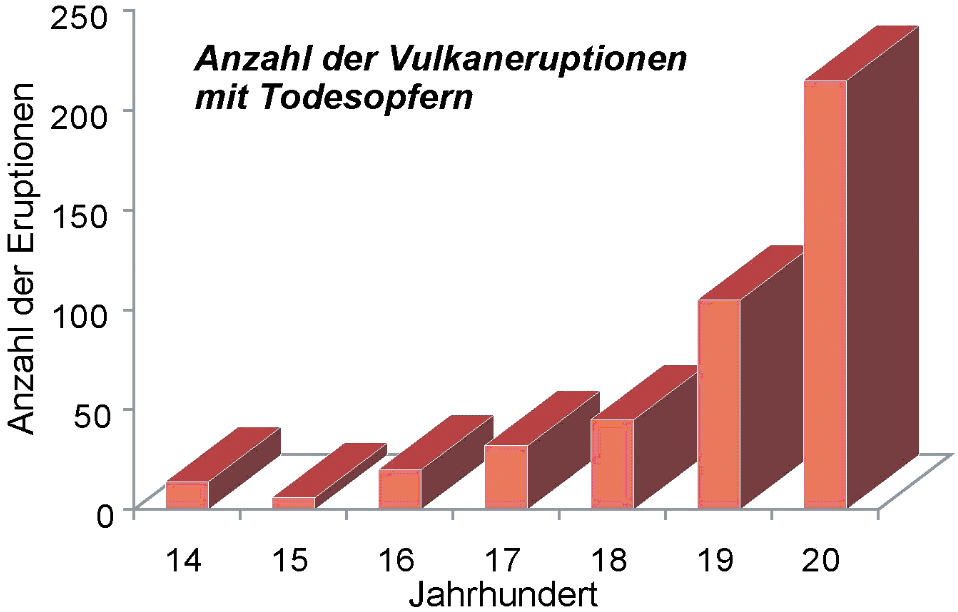

Abb. 3: Die Anzahl der globalen Eruptionen bleibt konstant, jedoch nimmt die Zahl der Opfer deutlich zu. Hier dargestellt seit dem 14. Jahrhundert. Basierend auf Daten des Global Volcanism Program (GVP).

nicht haltbar, da zahlreiche andere Faktoren mitspielen. Insbesondere die Bevölkerungsdichte spielt hier maßgeblich eine Rolle. Die gewaltigste Eruption des 20. Jahrhunderts ereignete sich am Katmai Vulkan im Jahre 1912, wobei über 13 Kubikkilometer Magma gefördert wurden (Schmincke, 2006). Dies geschah gänzlich ohne Opfer, da Katmai im damals unbesiedelten Gebieten Alaskas liegt. Andere, eher kleine Eruptionen, verursachten hingegen zahlreiche Opfer, wie die Eruption des Nevado del Ruiz in Kolumbien im Jahre 1985, wobei obwohl eines Eruptionsvolumens weit unter einem Kubikkilometer über 20.000 Opfer zu beklagen waren.

Zahlreiche historische und archäologische Befunde beschreiben Katastrophen und gar das Verschwinden ganzer Kulturen im Zusammenhang mit Vulkaneruptionen; mit am bekanntesten sind hier beispielsweise die 79 n. Chr. Eruption des Vesuvs, der Kollaps der Minoischen Zivilisation im frühen 17 Jahrhundert nach der Santorini Eruption, oder der zerstörerische Tsunami in Folge der Eruption des Krakatoa Vulkans im Jahre 1883. Diese Beispiele zeigen auch bereits, dass die Gefährdungstypen deutlich variieren können, und im Nah- wie auch im Fernfeld zu wirken vermögen.

Die Internationale Assoziation der Vulkanologie und Chemie des Erdinneren (IAVCEI) definierte gründend auf historischen Daten Haupttypen der Vulkangefährdung, die in sogenannte primäre und sekundäre Gefahren unterteilt wurden. Primäre Gefahren sind direkt mit Eruptionen und deren magmatischen Produkten assoziiert, wohingegen sekundäre Gefahren auch in der Ferne wirkende oder remobilisierende Ereignisse beschreiben. Primäre Gefahren sind demnach Lavaströme, Airfalls, Pyroklastische Ströme und Gase. Sekundäre Gefahren sind Schlammströme (Lahare), vulkanische Hangrutschungen und Tsunami (Abb. 3). Weitere Gefährdungen treten zwar auf, spielen aber in dokumentierten Katastrophen eine eher untergeordnete Rolle.

Im direkten Umfeld von Vulkanen liegen zahlreiche Städte mit rasant wachsender Bevölkerungsdichte und –Anzahl, wie zum Beispiel Tokyo unweit des derzeit erwachenden Mt. Fuji Vulkans, Quito in Ecuador welches auf Laharablagerungen des Cotopaxivulkans erbaut is, Mexico City in unmittelbarer Nähe zum Popocatépetl Vulkan, Yogyakarta in Reichweite des Dekadenvulkans Merapi, Seattle in Reichweite von Mount Rainier, Goma beim Nyiragongo Vulkan, Manila nahe des Taal Vulkans, Auckland aufgebaut direkt auf einem jungen Vulkanfeld, Managua nahe Masaya, und schließlich Neapel in der Zange zwischen Vesuv und den Phlegräischen Feldern. Neapel ist zwar keine Megacity, hat im Bezug auf dessen wirtschaftlichen und sozioökonomischen Bedeutung für Italien und Europa, sowie der Exposition und Vulnerabilität eine besondere Stellung nicht nur für Geowissenschaftler, und soll im Folgenden näher erläutert werden.

Die Bucht von Neapel – Drehpunkt der italienischen Wirtschaft und zahlreicher Vulkanologen

Neapel ist die Hauptstadt der Region von Campania und der Neapolitanischen Provinz, und ist für die reiche Geschichte, Kultur, Gastronomie und nicht zuletzt in jüngerer Zeit auch kriminalistischer Bestsellerbeiträge bekannt. Neapel wurde durch die frühen Griechen vor etwa 2.800 Jahren gegründet (Νεάπολις) und später ein wichtiger Dreh- und Angelpunkt der Römischen Republik. Weitere Eroberungen, Königreiche und politische Wechsel hinterließen ihre Spuren sowohl kulturell als auch architektonisch.

Der Stadtkern hat heute etwa eine Million Einwohner. Der Ballungsraum Neapels gilt mit etwa 4,5 Millionen Einwohnern nach Mailand als das zweitgrößte Ballungsgebiet Italiens. Im Stadtkern ist die mittlere Bevölkerungsdichte mit über 8.000 Einwohnern pro Quadratkilometern sehr hoch (zum Vergleich Berlin: <4.000), und ist gar die weltweit am dichtesten besiedelte Vulkanregion. Die Wirtschaft Neapels hängt zunehmend am Tourismus und Service, aber auch Industrie und einem wachsenden Cargoterminal.

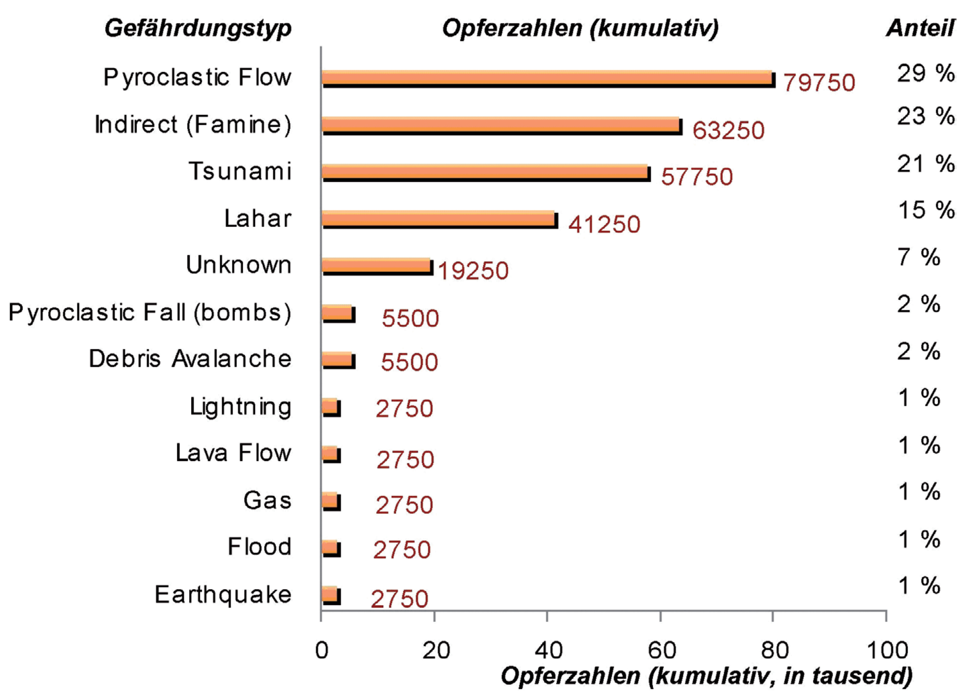

Abbildung 4: Opfer vulkanischer Aktivität (globale Darstellung). Beinahe ein Drittel aller Opfer waren durch pyroklastische Ströme hervorgerufen. Pyroklastische Ströme und deren Entstehung wurden erstmals am Vesuv im Jahre 79 n. Chr. durch den Gelehrten Plinius den Jüngeren schriftlich überliefert. Daten aus Siebert und Simkin (2002).

Im Lauf der Geschichte wurde Neapel und dessen Entwicklung maßgeblich durch die vulkanische Aktivität beeinflusst. Römische Ruinen der frühen Ansiedelungen von Pompeii, Herculaneum und Stabiae zeugen von Vulkanausbrüchen.

Der Vesuv ragt 1.281 m hoch über die Stadt und ist ein sogenannter zusammengesetzter Vulkan, bestehend aus einem älteren und einst weit größeren Monte Somma Vulkan, und dem hier überlappenden heute aktiven Vesuv Gipfelkrater. Der ältere Monte Somma wurde bei der Eruption 79 n. Chr. weitgehend zerstört und hinterließ einen Krater, wo in nachfolgenden Jahrhunderten der heutige Vesuv aufgebaut wurde, sodass heute korrekterweise vom Vulkangebäude Somma-Vesuvius zu sprechen ist.

Die Phlegräischen Felder stellen eine sogenannte Nested Caldera dar, bei der zahlreiche ineinandergreifende Explosionskrater und Calderen die heutige Morphologie prägten. Es ist eine 12 km im Durchmesser messende strukturelle Senke, die wie am Land vermutlich auch unter Wasser verläuft. Der Calderrand hat bis zu 450 m Höhendifferenz und ist zumindest an Land durch eine steil einfallende Randverwerfung markiert. Der innere Teil ist bei wiederholten explosiven Eruptionen abgesackt, wird aber heute von etwa 1,5 Million Menschen bevölkert. Das magmatische System ist heute noch aktiv, wie an jüngeren Eruptionen (1538) und vulkantektonischen Erdbebenschwärmen und Hebungsereignissen (Bradyseism) verdeutlicht.

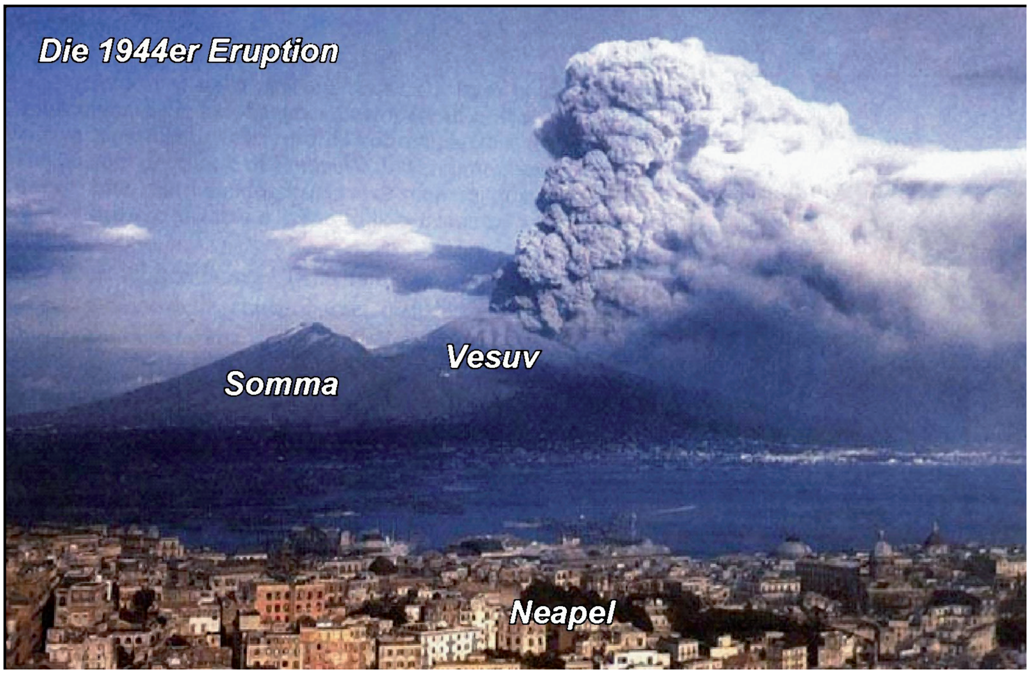

Abb. 5: Der bisher jüngste Ausbruch des Vesuvs fand 1944 statt. Einer der Lavaströme zerstörte San Sebastiano und Massa. Lavafontänen stiegen aus dem Gipfelkrater bis zu 700 m hoch auf, die Aschewolke wurde bis zu fünf km hoch geschleudert, und aufgrund des starken Windes bis nach Albanien verweht. Foto: National Archives and Records Administration (NARA), College Park, MD.

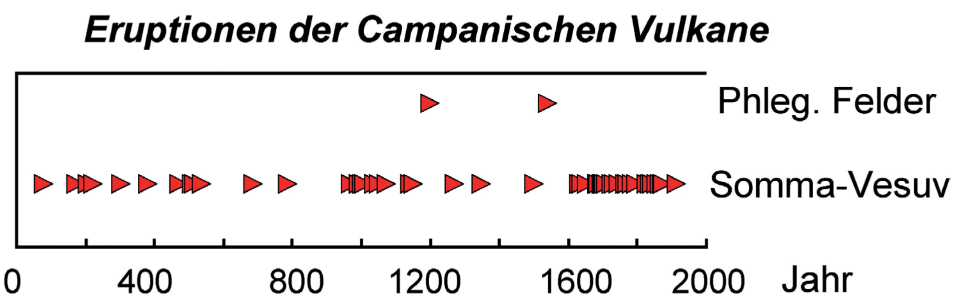

Abb. 6: Eruptionen an den Phlegräischen Feldern und am Vesuv.

Eruptionen

Die bekannteste historische Eruption des Vesuvs ereignete sich 79 n. Chr., was neben archäologischen Funden auch an der detaillierten schriftlichen Überlieferung liegt. Eruptionen weit größerer Magnitude ereigneten sich im Vorfeld am Somma-Vesuvius, wie beispielsweise die sogenannte Avellino Eruption von 1800 v. Chr., einhergehend mit der Auslöschung zahlreichen bronzezeitlichen Siedlungen. In jüngerer Zeit ist der Vesuv sehr häufig aktiv gewesen, so in 172, 203, 222, 303, 379, 472, 512, 536, 685, 787, um 860, 900, 968, 991, 999, 1006, 1037, 1049, 1073, 1139, 1150, 1270, 1347, und 1500 (Siebert und Simkin, 2002). Nach einer über hundertjährigen Ruhephase wurde der Vulkan 1631 wieder aktiv, eruptierte gleich sechs mal im 18. Jhdt und 8 mal im 19. Jhdt (Abb. 5). Eruptionen im 20. Jhdt. ereigneten sich 1906, 1929, und zuletzt 1944 (Abb. 4). Seit 1944 fanden keine weiteren Eruptionen statt, jedoch gehen wir davon aus dass der Vulkan nicht erloschen ist und wieder eruptieren wird. Wann und mit welcher Magnitude dies sein wird ist Motivation zahlreicher Monitoringverfahren. Da Vulkaneruptionen bei engmaschiger Überwachung vorhersagbar sind, geht man davon aus, dass sich eine Katastrophe wie die Pompeii-Eruption 79 n. Chr. nicht wiederholt – diese traf die Bewohner unvorbereitet und war die größte und mit bis zu 25.000 Opfern die zerstörerischste Aktivität des Somma-Vesuvius.

In den Phlegräischen Feldern ereigneten sich mit die wohl größten bekannten prähistorischen Eruption auf dem heutigen Europäischen Gebiet mit einem Vulkan-Explosivitätsindex über sechs, mit der Eruption des Campanian Ignimbrits vor 39.000 Jahren und des Neapolitanischen Yellow Tuffs vor 15.000 Jahren (Fisher et al., 1993). Eruptionen der vergangenen 17.000 Jahre fanden in drei Perioden statt (1500 bis 9500, 8600 bis 8200 und 4800 bis 3800 v. Chr.) die durch deutliche Ruhephasen unterbrochen waren (Di Vito et al., 1999). Die jüngste Eruption fand 1538 statt und führte zur Bildung des Eruptionszentrums Monte Nuovo (Abb. 4). Neuere Untersuchungen zeigen, dass sich die gesamten Phlegräischen Felder derzeit absenken, wobei nur der zentrale Teil episodisch kurzen aber sehr steilen Hebungsintervallen unterzogen ist (Orsi et al., 1996), die wie im Falle der 1983-er Hebung zu weitläufigen Evakuierungen und bisweilen erfolglosen Umsiedlungsplänen führten.

Derzeitige Aktivitäten

Geodätische und seismische Aktivität am Vesuv blicken auf eine nunmehr Jahrzehntelange Zeitreihe zurück. Das erste Nivellierungsnetzwerk wurde durch das Osservatorio Vesuviano bereits 1972 errichtet und bestand aus etwa 300 Benchmarkern. Nach einer Phase erhöhter seismischer Aktivität in den Jahren 1982 bis 1984 wurde dieses Netzwerk kontinuierlich ausgebaut und erneuert. Seit dieser Zeit wurde eine nahe kontinuierliche Absenkung des Somma-Vesuvius gemessen, insgesamt mit über fünf Zentimeter seit 1985 und einer mittleren Absenkungsrate von 0,6 cm jährlich (Pingue et al., 2000). Grundsätzlich wurde dieses Deformationsmuster durch andere Verfahren wie Elektronische Distanzmessungen oder satellitengestützte Verfahren (GPS) untermauert. Mikrogravimetrische Untersuchungen begannen um 1981 und zeigten zunächst einen rasanten Anstieg der Erdanziehung bis 1983, gefolgt von einem gemäßigten aber kontinuierlichen Abfall um ca. 10 microGal jährlich (Pingue et al., 2000).

Die Phlegräischen Felder zeigten in jüngerer Zeit mehr vulkantektonische Aktivitäten als irgend-

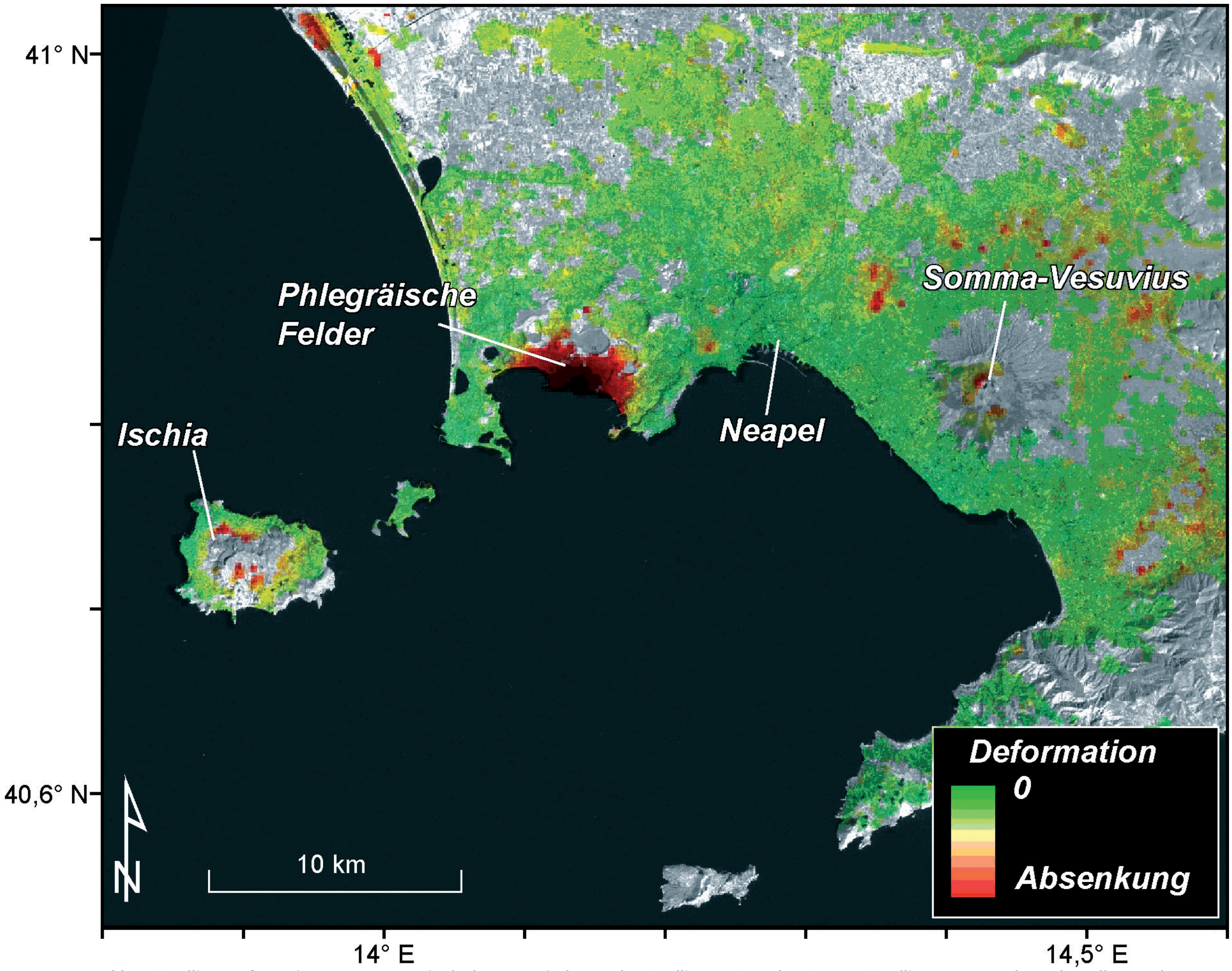

Abb. 7: Satelliten-Deformationsmessungen mittels der Europäischen Radar-Satelliten ERS1 und ERS2. Vom Satelliten ausgesandte Radarwellen werden vom Grund reflektiert und wieder am Satelliten gemessen. Veränderungen der Phase erlauben hochauflösende Deformationsmessungen. Absenkungsgebiete sind hier rot dargestellt. Nach (Lanari et al., 2007) und Shirzaei und Walter (2009).

ein anderes geophysikalisch überwachtes Calderasystem. Ähnlich wie am Somma-Vesuvius ist auch an den Phlegräischen Feldern eine der Hauptaktivitäten die Hebung oder Absenkung des Bodens.

Schon archäologische Studien konnten zeigen, dass römische Ruinen im Küstenbereich der Phlegräischen Felder durch Deformationsereignisse in Mitleidenschaft gezogen wurden. Die am besten studierte Lokalität war der römische Marktplatz (Macellum) in Pozzuoli (siehe Abb. 1), mit Monumenten die bereits um 1750 ausgegraben werden konnten. Eine marine Muschel, Lithodomus lithophagus, hatte sich vielfach in diese Monumente gebohrt und hinterließ nun ihre Schale in mehreren 13 m hohen Marmorsäulen. Über die Datierung dieser Schalenfragmente konnte die langzeitige Hebungs- und Senkungshistorie rekonstruiert werden. In den vergangenen 2.000 Jahren hat sich demnach der Hafenbereich von Pozzuoli im Mittel um 1.1 bis 1.7 cm jährlich abgesenkt (De Natale et al., 2006). Kurze aber steile Hebungsphasen ereigneten sich mindestens dreifach, wie von etwa 1500 bis kurz vor der letzten Eruption 1538. Nach dieser Eruption begann wieder die übliche Absenkung, bis gegen Ende der 1960er Jahre eine neue Hebungsphase begann, die in Pozzuoli bis 1984 über zwei Meter betrug. Nun erlaubten zahlreiche weitere Instrumentierungen die Vermessung dieser und jüngerer Deformationsphasen. Da die vorangegangene Hebungsphase 1538 in einer Eruption kulminierte, entschieden sich die Autoritäten jüngst zu einer Evakuierung der Stadt Pozzuoli. Zu einer Eruption kam es bislang nicht. Weitere Installationen von Messsystemen, wie Seismometer, Gasmessungen, GPS-Stationen oder Nivellierungsmarkern konnten zusätzliche kleinere Hebungs- und Absenkungsereignisse sowie deren Effekte aufzeichnen, wie 1995, 2000 und zuletzt 2006 geschehen (De Natale et al., 2006). Lokale Erdbebenschwärme und Gasfluxanstiege begleiten neu einsetzende Hebungsphasen und dienen daher als unabhängige Datensätze die Aktivitäten der Phlegräischen Felder zu überwachen.

Innovative Satellitentechnologien wurden an Neapels Vulkanen erprobt und derzeit als Überwachungstechnologie eingesetzt. Neueste Messungen mittels Satelliten-Radarverfahren erlauben eine räumlich hochauflösende Überwachung des Deformationsverhaltens am Vesuv und in den Phlegräischen Feldern (Abb. 6). Die gemessenen Deformationsdaten werden am Computer simuliert und erlauben somit eine Abschätzung der Lokalität (Horizontalposition und Tiefe), Geometrie und Druckveränderung möglicher magmatischer und hydrothermaler Reservoire. Unsere eigenen Untersuchungen zeigen hier dass in etwa drei Kilometer Tiefe unter beiden Vulkanen eine Art Reservoir liegt, welches bei Veränderungen des internen Druckes entsprechende Hebungs- und Absenkungsperioden an beiden Vulkanen hervorruft. Das heißt, über Satelliten sind indirekt Veränderungen der magmatischen und hydrothermalen Reservoire im Vorfeld von Eruptionen quantitativ erkennbar – eine außerordentlich wichtige Einsicht in das Innere dieser Hochrisikovulkane! Diese Druckveränderungen in Echtzeit zu analysieren und besser zu verstehen ist Ziel unserer Forschungsaktivitäten sowie eines Bohrprojektes, welches derzeit in der Anfangsphase liegt und an dem das Deutsche GeoForschungsZentrum logistisch, geophysikalisch und geochemisch beteiligt ist.

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