Monitoring megacities:
the MURBANDY/MOLAND approach

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Extensive urbanisation and increasing population growth – especially in the megacities[1] of developing countries – were recognised as being of major concern in 1992, when the United Nations Conference on Environment and Development (UNCED) recommended redressing the various environmental problems caused by urbanisation, and promoting economic, social, and ecological dynamics that would enhance the contribution of the city to sustainable development. More recent evidence has heightened the urgency of monitoring and understanding urban dynamics.

Since 1992, and especially in developing countries, urban agglomerations are still attracting migrants from surrounding regions despite their lack of basic amenities and infrastructure. Consequently, the urban population is increasing at a much faster rate than the overall average. This is exacerbating existing habitat problems such as urban sprawl and the large numbers of people without adequate shelter: ever more people are living in slums in conditions of poverty, unemployment, with dangerous levels of air and water pollution, etc.. Furthermore, the largest urban areas, the megacities, are already affecting the global environment, and have the potential to have still greater impact. These urban areas therefore also indirectly affect the non-urban population.

The global process of urbanisation, with all that this means in terms of migration, traffic, pollution, and natural hazards, is influenced by many forces and comprises many components. Land values, migration patterns, and economies, for instance, all need to be carefully monitored and analysed. Looking at one component of change in isolation could lead to decisions being taken on the basis of insufficient information, which might well compromise progress towards sustainability. Cities in developing countries, in particular the megacities, typically lack the capacity to obtain the necessary data and to carry out

the comprehensive analyses needed in order to set and achieve sustainability targets.

Understanding urban dynamics is one of the most complex tasks in planning sustainable urban development while also conserving natural resources. The complexity and variety of the different components making up the urban environment, and of the interactions among them, are most pronounced in the megacities. In the South, where available mapping is often outdated or very poor, and where there is a general lack of standard and comparable information on cities, such problems are exacerbated. In this context, it is important to develop uniform systems of monitoring the distribution, changing patterns, and growth of human settlements. This will certainly be facilitated by new technologies, tools, and expertise.

In this paper we describe efforts supported by the European Commission (EC) to improve sustainable development strategies in developing countries with the aid of new methodologies based on hi-tech tools.[2] The study examines the use of the MOLAND approach to assess the dynamics of urban areas in Europe and in a subset of megacities in developing countries. This methodology is based on the analysis of land-use changes combined with different layers of information. The first half of the paper describes the technological framework of the MOLAND Project. This is followed by a brief description of the case studies undertaken in Eastern Europe and several developing countries. We then discuss the implications of the MOLAND Project for urban sustainability and draw some preliminary conclusions about its usefulness.

Background and technological framework

Earth observation (EO) is a modern science that intensively studies the Earth's changing environment, using remote-sensing tools such as satellite imagery and aerial photography. The Earth's physical components, such as the atmosphere, oceans, and land, are therefore studied from a viewpoint that is distinct from those of classical geographical and geophysical approaches. This viewpoint improves our understanding of various natural processes, and the effects of our actions upon the environment. Under the EC's Fourth Framework Programme (1995-98) for Research and Technological Development and Demonstration (RTD), the Centre for Earth Observation (CEO) of the EC's Directorate General Joint Research Centre (DG JRC) was responsible for promoting the overall use of EO.

In 1998, under the umbrella of activities carried out by CEO, a pilot study named MURBANDY (Monitoring Urban Dynamics) was launched. It initially sought to provide a way to measure the extent of urban areas, as well as of their progress towards sustainability, through the creation of land-use databases for various European cities.[3] The project progressed quickly, and raised an unexpected level of interest from both its initial potential customers as well as external audiences. As a consequence, the number of study areas was extended to 25, and the project's objectives broadened. MURBANDY became one element of a new, expanded project – MOLAND (Monitoring Land-use/Cover Change Dynamics).

The MOLAND Project: monitoring urban and regional dynamics

The MOLAND Project seeks to set up and define a specific methodology for monitoring the dynamics of human settlements, and to provide information on a significant set of European cities and a second set of megacities in developing countries. Thus, morphological and structural changes are monitored, evaluated, and analysed, in order to characterise past and future trends of urban landscapes (EEA 1999).

The methodology is based on the creation of an accurate land-use database specifically designed for urban areas. To date, such a database has been created for 25 European cities, which have been ordered according to a single land-use classification scheme in order to obtain homogeneous data. The data were derived from satellite imagery and aerial photography, using remote-sensing and Geographic Information Systems (GIS) technologies. The database is the basis for combining environmental, economic, and social data, in order to improve the understanding of dynamics and characteristics of urban growth and related structural changes, commuting issues, and the status of transport and energy infrastructures.

As part of the extension of MOLAND to non-European cities, a pilot study is currently being carried out in seven urban areas – Buenos Aires, Chongqing, New Delhi, Bangkok, Johannesburg/Pretoria, Mexico City, and Seoul (see Table 1). Unlike the first phase of the project in Europe, local authorities are not yet involved. The next step will be to encourage them to participate so that they can provide additional information.

Table 1: Population of developing-country cities involved in the MOLAND Project			
City	Population size in millions		
	1975	2000	2015
Bangkok	3.8	7.3	10.5
Buenos Aires	9.1	11.3	12.3
Chongqing	2.4	4.1	5.8
Johannesburg/Pretoria	2.1	3.3	4.9
Mexico City	11.2	16.3	18.7
New Delhi	4.4	11.6	17.5
Seoul	6.7	12.2	13.1

Source: UNCHS (Habitat) (1997)

The methodology is based upon three interrelated tasks: *change, understand*, and *forecast*.

The *change* task detects modifications to land use. This involves remote-sensing tools for creating a detailed land-use database. Four datasets are produced for each city over a period of 50 years, at intervals of about 15 years. Four additional datasets, with the road and rail networks of the corresponding years, are included in the database. The dataset for current years (i.e. 1997 or 1998) is the 'reference' set; previous ones are 'historical'. The reference land-use classification is based on recent data from the panchromatic Indian Remote Sensing satellite (IRS Pan) – (for the new area sets it also makes use of IKONOS data). The historical database is created using satellite imagery or aerial photography from the mid-1950s, late-1960s, and 1980s. All the images are geo-coded, and land-use maps are produced at a scale of 1: 25,000. The minimum mapping unit is 1ha for artificial surfaces, and 3ha for non-artificial surfaces. In addition, the road and rail networks, and rivers and canals, are digitised as linear features. After data processing, each dataset is validated in order to guarantee a high quality of land-use classification products. The land-use database is provided in a simple GIS format.

The *understand* task attempts to analyse and explain urban land-use changes. It sets out to derive and calculate indicators to allow a better understanding of the dynamics of urban areas, and of the impact of

cities on the global environment. The main task consists of developing a set of spatially referenced indicators, which are expected to help in understanding the complexity of urban problems, providing detailed spatial information at local and national levels, and supporting city managers and decision makers in defining local policies. The MOLAND indicators focus on urban and regional sustainability, and are designed to be robust and long lasting, and flexible enough to accommodate different urban structures. In practice, such indicators are sufficiently standardised to allow comparisons within different urban areas.

A core set of urban indicators for international use, including land-use and socio-economic information, has yet to be developed. One of the aims within the MOLAND Project is to define specific indicators for urban sustainability, since the project is based on the belief that, without accurate spatial information, no set of indicators of urban sustainability can be complete. The MOLAND indicators are divided into (a) spatially referenced indicators providing information on different land uses and changes in them; and (b) cross-sectoral spatially referenced indicators to evaluate more complex processes for landscape changes (e.g. fragmentation). Socio-economic data, prepared in a spatially disaggregated format, are also being combined with MOLAND data. The aim here is to address carrying capacity and other general factors affecting urban sustainability.

For all the cities and regions studied, basic spatial indicators are calculated showing the land-use changes of the three main classes (i.e. artificial surfaces, agriculture, nature) over a 50-year period. In particular, the changes from agricultural and natural areas to artificial surfaces are investigated, documented, and their statistics calculated. In addition, for several cities, changes in the structure (i.e. fragmentation) of the urban landscape are being measured and analysed, using a landscape structural analysis software (FRAGSTATS) that has been modified for the MOLAND database. The trends over time of the various fragmentation metrics (e.g. edge metrics, core area metrics, nearest neighbour metrics, diversity metrics) computed by FRAGSTATS are being interpreted in the light of known environmental and demographic factors for the different urban areas. The land-use datasets are also being combined with socio-economic and environmental statistical information in order to derive urban sustainability indicators. The final product of the *understand* task will be a document with guidelines on how to report on urban sustainability.

The main objective of the *forecast* task is to develop scenarios of territorial evolution for urban and peri-urban areas, by using information derived from both EO and non-space data. The scenarios are produced by using an integrated model of regional spatial dynamics, consisting of a 'cellular automata' land-use model, linked to both a GIS and to regional economic and demographic models.[4] The model allows the input parameters (e.g. the transport network) to be modified, so as to simulate, both quantitatively and qualitatively, the evolution of land use over time. The question of whether a single model can be applied to all cities (with minimal modifications for national, regional, and city-specific factors), or whether different models are necessary, is being investigated. The resulting scenarios will serve as a major input to formulate and evaluate medium- and long-term strategies for the sustainable development of urban areas.

Strategic framework and sustainability implications

The MOLAND Project is currently investigating likely difficulties in exporting the methodology to non-European and developing countries. Meanwhile, several European local authorities have shown such interest in the project that they have even offered to co-fund it in order to have cities and regions under their administrative jurisdiction studied under MOLAND. Workshops have also been organised with representatives from various international agencies, including the United Nations Environment Programme (UNEP), OECD, WHO, and the European Environment Agency (EEA).

Why has the MOLAND Project attracted so much attention? How can one project be of interest to so many diverse organisations? Part of the answer is that the MOLAND methodology requires only a very limited number of highly skilled developers in order to be used. The MOLAND team operates as a 'remote' co-ordinator, so that the methodology can be – and usually is – applied on site by a local partner. Different customers can then assess the outputs at any level of analysis. Such an approach greatly reduces the costs, also because local authorities usually already own the basic material required by the methodology – satellite data, aerial photographs, master plans, statistical information, etc.. When part of this material is not immediately available (e.g. satellite images), it can be easily acquired at a moderate cost.

The initial costs are limited because it is manpower that ultimately determines the cost of applying MOLAND. This means that the cost of studying a certain area in Japan or in Brazil will be proportional to the

difference in cost of living in the two countries. Once the database has been prepared, a minimum effort is required to keep it updated. The MOLAND approach has proved to be quite cost-efficient overall. For example, the average cost of the *change* part of MOLAND was about 90 euros per km^2 for the European areas, though this covers considerable variation between one study domain and another. Moreover, European areas tend to be compact, while elsewhere the phenomenon of 'sprawl' is more evident. For example, the core urban area of Munich is 300km^2, while the core urban area of Bangkok is 1000km^2! The larger the area, the higher the cost will be: studying a megacity is expensive. Clearly, even if the level of detail of the Bangkok database is reduced, the size of the study domain is so large that costs cannot be reduced substantially. The land-use fabric also affects the costs. The more dense the urban fabric, for example, the more accurate the analysis required in order to disaggregate it into detailed land-use classes. On the other hand, if a given region contains, for instance, several water bodies or large areas covered almost uniformly with vegetation, the classification exercise is relatively simple. It is also worth noting that the level of detail required to carry out assessments in Europe is probably higher than that needed in developing countries, where priorities are different.

Considering the level of detail needed for studying megacities, the extent of the areas covered, the cost of specialised personnel, and the cost of materials, we can assume that the methodology is not only affordable for local authorities, but also compares very well in cost–benefit terms.

Moreover the MOLAND Project includes support for technology transfer to non-European and developing countries. In the specific case of Latin America and Asia, the project aims to provide the resources to apply the methodology in the partner cities through specific research programmes. Under the EU's Fifth Framework Programme (1998–2002) for Research and Technological Development and Demonstration, the EC finances international projects within its INCO-DEV (International Co-operation with Developing Countries) programme. The programme envisages three levels of research: (a) policy research to determine the conditions of sustainable development; (b) systems research on the complex interactions in the local environment caused by, for example, rehabilitation and management of natural resources or healthcare; and (c) research to generate tools for system management and policies to promote sustainable development. The programme also aims to reduce the isolation of

scientists in developing countries by enabling them to work at an international level while based in their own institutions, and to provide training opportunities.

Case studies

Central and Eastern European cities

Around two thirds of Central and Eastern European citizens already live in cities (EEA 1998), and urban population growth continues. This trend is leading to a rapid increase in the proportion of land occupied by urban areas and a decline in agricultural and natural spaces. To measure the impacts of these trends on the environment, health, quality of life, and population security, requires new tools for appropriate urban and environmental planning.

MOLAND focuses on European cities, some of which belong to the so-called European ‘less-favoured regions’: the former socialist cities of Bratislava (Slovakia), Prague (Czech Republic), and Tallinn (Estonia); the city of Nicosia (Cyprus); and the city of Heraklion (Crete). Each of these cities has a specific history and development pattern, and faces its own problems. Despite these differences they all need to ensure sustainable development to prevent further economic, ecological, and social deterioration.

Within the process of European enlargement, four of the countries mentioned hope to join the EU in the next few years. In this framework, the MOLAND study is a tool for improving knowledge about the development process of new EU member countries. Because the major cities of Eastern and Central Europe play an especially crucial function as the economic core of their regions, it becomes essential to understand the urban environment. In these cities, MOLAND emphasises environmental and transport issues.

Non-European megacities

Cities in developing countries are generally characterised by very rapid growth and extremely rapid changes in land use, both within the city and in the surrounding territories. As cities expand, spontaneous and informal settlements tend to alter typical environments in peri-urban areas, such as agricultural and natural spaces. A correct analysis of these changes and of settlement characteristics is needed in order to establish planning procedures and, in particular, to assess and monitor disaster prevention, environmental impact and risk assessment, air pollution and solid waste management, infrastructure planning,

population density and distribution, quality of urban life, etc. The general absence of adequate information in developing countries may thus be overcome with the assistance of new technologies and tools. Using new commercial satellites, it is also possible to watch change as it occurs, even in areas where aerial photographs are not available. Such data may be crucial at the beginning of a dangerous event (flooding, refugee movements, civil wars) and may also be of use to other parties, such as NGOs, which could then establish contingency plans in advance.

The example of the Three Gorges Dam on the Yangtze River in China demonstrates how the MOLAND methodology may make it possible to analyse the impacts of multiple environmental changes occurring simultaneously over a large region. For the Chinese city of Chongqing, the main consequences of the dam are the serious contamination of water by the flooding of old industrial areas, the rising water table (30m), and the relocation of communities displaced by flooding.[5] The MOLAND Project provides objective and reliable information which is particularly useful when the involvement of different parties (the Chinese government, private funders, construction companies, NGOs, etc.) might lead to different perspectives and to the lack of objective evaluations. MOLAND will provide the information needed about physical change: how much arable land will disappear, how many informal settlements will be built, the location of industrial and archaeological sites, what the vegetation is like now (changes will affect climate in the region), what the current extent of the city is (in developing countries, including China, the exact extent of the cities is rarely known). Most of this data is not being collected by those responsible for the Three Gorges project, despite the strong demand for it both within and outside China.

In the case of Bangkok, for example, air and water pollution, the disastrous traffic situation, and subsidence due to the sinking groundwater table can all be measured and analysed more precisely with the MOLAND approach.

Conclusions

The flexibility of the MOLAND methodology makes it possible to monitor urban dynamics in different countries. The methodology has been adapted to meet the urgent needs of megacities in non-European and developing countries, which are markedly different from those of European cities. In the South, even the most basic information is often

missing, e.g. the precise extent of the urban area, quantitative information on infrastructure and services, the number and location of legal and illegal landfills, and the amount of agricultural and natural land that is being replaced by artificial surfaces. The MOLAND Project provides such data, as well as a measure of the changes in land use over time. It also offers the opportunity to carry out more in-depth analyses by combining the land-use database with ancillary information, such as socio-economic and environmental data. The level of detail required in setting up the database can be tailored to local needs and to the resources available.

The very high technology adopted in the Project is already commercially available at affordable prices. Moreover, through the financial mechanisms set up by the EC, it is possible to transfer the methodology to those non-European and developing countries that are interested in establishing an accurate and comparable information system. Costs may be further reduced if local authorities own the basic material and information required by the MOLAND methodology, which makes it a relatively cost-efficient approach to data collection and analysis. The response from both local authorities and international organisations has been very positive; the MOLAND Project is co-operating with the EEA, UNEP, the OECD, Eurostat, and several Directorates General of the EC.

The review of seven non-European cities will test how well the MOLAND methodology can be adapted to the challenges posed by megacities. Because of the different methods used by each city or country to collect information, it is extremely difficult to develop common indicators to assess their progress towards sustainable development. The main advantage of this approach is that it permits comparative analysis among cities, and a central database and information system will be held at JRC. International organisations may therefore benefit from MOLAND in their efforts to develop valid common approaches to defining and monitoring progress towards sustainable development. They should also find it easier to develop strategies to do so if they have a harmonised database at their disposal.

Notes

1 We use the term 'megacities' to include large and fast-growing urban areas.

2 This article is a combination of two papers presented at the ESF/N-AERUS annual workshop (Lavalle *et al.* 2000a,b). The authors wish to thank Rachael Mann for weaving the two papers into one.

3 One can measure urban sustainability through the development of appropriate indicators. Indicators can differ between cities, but some core indicators will be the same for every city. We suggest aggregating the core indicators under the territorial dimension in a uniform manner in order to be able to compare the progress of different cities towards sustainability.

4 Cellular automata are computer simulations that try to emulate the ways the laws of nature are supposed to work in nature.

5 The Three Gorges Dam will be the largest hydroelectric dam in the world. It will create a lake 400km long, and 1.5 million people will be relocated. The whole economy of the region will be affected. The environmental problems related to the damming of the river are huge, and have implications for the global environment (it has been calculated, for instance, that such 'megadams' influence the earth's rotation speed).

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