18 Towards a Differentiated Assessment of Geographic Information Sciences for Sustainable Development

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Abstract

Over the last three decades, geographic information sciences (GIS) have seen tremendous development and have been integrated into a wide range of professional and scientific fields. This development took place parallel to the rise of the sustainable development paradigm in research and practice, triggering a sometimes heated debate about the usefulness of GIS for informed decision-making. We analyse this debate, extracting five essential criticisms brought forth against GIS. Without disputing the relevance of the issues concerned, we underline the importance of adopting a more differentiated perspective on the role of GIS in terms of a) the spatial scales of decision-making contexts in which GIS are used, and b) the types of knowledge with which GIS interact. Based on these insights we propose a new approach to assessing the usefulness of GIS in sustainable development research and practice that will make it possible to identify strengths and weaknesses in ongoing projects as well as opportunities and limitations for the future role of GIS in sustainable development. This article is based on the authors' professional understanding of the role of GIS in research activities within the framework of the Swiss National Centre of Competence in Research (NCCR) North-South, and on their experience in sustainable development research and implementation of concrete sustainable development projects.

Keywords: GIS; knowledge creation; ICT; access to information; epistemology; sustainable development; participation.

18.1 GIS and sustainable development: the debate

Geographic information sciences (GIS) developed within the mathematical and geographical sciences between the 1960s and the early 1980s. The breakthrough of GIS into the world of desktop applications in the 1990s triggered a rapid spread to other academic disciplines and to a multitude of professional fields. Eventually GIS were also established as an important approach in sustainable development research. In the non-academic world, GIS are widely used to support planning, decision-making, evaluation, monitoring, and awareness creation. This rapid growth, both in research and in practice, did not take place without the emergence of critical discourse.

Schuurman (2000) provides a good overview of the controversy over GIS in research. In the early 1990s this controversy started off by mirroring the overall discord between natural and social scientists. GIS were often viewed by the latter as incapable of meaningful analyses and as a "return of the very worst sort of positivism, a most naïve empiricism" (Taylor 1990, p 212). Geo-information scientists responded that GIS had made their own limitations an integral part of their research for decades (Goodchild 1991) and that critics seemed to be motivated "not only by a quest for epistemological integrity but also by a desire to retain disciplinary authority" (Schuurman 2000, p 573). From the mid-1990s critics focused on the relationship between power and GIS, and were reinforced by the commercial and academic success of GIS. Maps and GIS were viewed as perpetrating power relations (Monmonier 1991; Law 1994). Criticisms still focused on allegations of epistemological flaws – that is, a lack of consistency in epistemology, ontology, and methods – and objectionable ethics based on positivist assumptions[8]. From the late 1990s onwards, critics became gentler as GIS were recognised as an integral part of geography. New disciplines such as Public Participation GIS (PPGIS) contributed to the democratisation of spatial analysis technology. This movement was supported by increasing accessibility and user-friendliness as well as declining costs of GIS technology and data.

In the context of sustainable development, controversy over the role of GIS arose in relation to the role of technology, as part of a wider criticism of technology-driven development (Kupfer 1997; Pereira and Quintana 2002; Chambers 2006), and in relation to the content disseminated by GIS, as part of an overall concern about the lack of local content – and relevance – in information-based development projects (Chambers 1997; Michiels and Crowder 2001). The increasing popularity of GIS in international coopera-

tion fuelled these concerns. Dangers were also identified in terms of widening power gaps triggered by unequal access to information, knowledge, and information and communication technology (ICT) between elites and marginalised stakeholders (CIDA 2003; Haque 2003). Furthermore, GIS were perceived as incompatible with participatory and bottom-up approaches. Finally, the unfavourable prospects of project durability seen as a result of the technical nature of GIS, their maintenance, and financial requirements have been put forward as an immanent weakness of this technology in the context of sustainable development initiatives (Heeks 2003).

The discourse described above can be summed up in five main critical points concerning the use of GIS for sustainable development:

1. Failure to create development-relevant knowledge
2. Positivist assumptions
3. Hindrance to participation
4. Exacerbation of power gaps
5. Lack of sustainability

These five main critical points are addressed in the present article from a perspective that is sensitive to the spatial scales of decision-making and to the different types of knowledge produced and utilised. The reasons why it is important to adopt such a perspective are outlined in the following paragraphs.

18.2 The importance of a differentiated perspective

The challenges and the opportunities for informed and evidence-based decision-making depend greatly on scale. Correspondingly, the role of GIS, and of any other mode of knowledge production for sustainable development, must be discussed in a scale-sensitive manner. The experiences gathered with GIS within the Swiss National Centre of Competence in Research (NCCR) North-South programme (Breu 2006; Ehrensperger 2006; Epprecht 2006; Heinimann 2006) have consistently shown that the quality of decision-making, planning, and implementation for sustainable development at various scales of intervention depends on decision- and negotiation-support systems that are adapted to these scales, and to the geographic as well as the sociocultural contexts for which the decisions are taken. Perception of reality is a crucial element to be taken into consideration. At the local scale,

stakeholders' tacit knowledge[9] is directly present in situation diagnosis and goal-setting. From the subnational to the national scales, the use of tacit knowledge and real-life experience diminishes, while formalised processes of knowledge creation become more important. At the continental and global scales, real-life experience is only perceivable indirectly, and formalisation increasingly depends on aggregation. For GIS this means that different functionalities are important, depending on scale and context. For example, securing land tenure for small-scale farmers requires a participatory process using tools that, on the one hand, integrate various perceptions and types of knowledge and, on the other hand, provide real-time measurement options (e.g. global positioning system, GPS); the management of urban water distribution depends more strongly on robust database structures with clear spatial attribution; and poverty alleviation at the national scale is most efficiently supported by models that provide relevant socio-economic indicators and trends with sufficient spatial resolution (Ehrensperger 2006; Epprecht et al 2007). Hence, critical arguments about the use of GIS in sustainable development must distinguish between different types of application at different scales. This rarely happens; therefore, the critical discourse outlined above appears to be largely blind to scale and context.

Furthermore, this discourse is often confined to either research or practice and to their respective concerns. Discussions on the alleged epistemological flaws of GIS are conducted from a science-oriented perspective, while arguments regarding empowerment, participation of stakeholders, and sustainability are rooted in case studies or stem from sometimes idealised development perspectives. We believe that such an approach does not provide a sufficient basis for assessment of GIS for sustainable development, as sustainable development depends on both research and practice. Additionally, the potentials and limitations of GIS vary greatly depending on the stages of the knowledge creation and utilisation cycle at which they are used (Ehrensperger 2006). This cycle typically includes five stages: concept development; data collection; data analysis; information and knowledge diffusion; and knowledge utilisation. In some cases the potentials of GIS can be high during the analytical stage but low during the knowledge dissemination stage, while in other cases the opposite is true. For these reasons, we propose to explore the potentials and limitations of GIS for sustainable development from a perspective that takes account of different types of knowledge within the knowledge production and utilisation cycles in which GIS are employed.

18.3 Integrating scales and knowledge types

The above implies that any serious critical review of GIS potentials and limitations needs to distinguish various types of knowledge production, dissemination, and utilisation. There are several ways in which such distinctions can be made. An appropriate common denominator, adapted to the context of sustainable development, is the simple semi-disaggregated model proposed by the Forum for Climate and Global Change (ProClim 1997), which divides knowledge into three interconnected types (see also Nölting et al 2004; Hirsch Hadorn et al 2006):

– **Systems knowledge**, defining or describing a current situation or problem (diagnosis)
– **Target knowledge**, consisting of objectives about the 'ought to be' situation (scenarios)
– **Transformation knowledge**, defining approaches leading to the 'ought to be' status (management and outreach activities)

Figure 1 shows a simplified graph of GIS potentials for sustainable development based on this distinction. In this graph, the x-axis represents scale ranges, the y-axis represents the potentials of GIS, and the three curves represent the

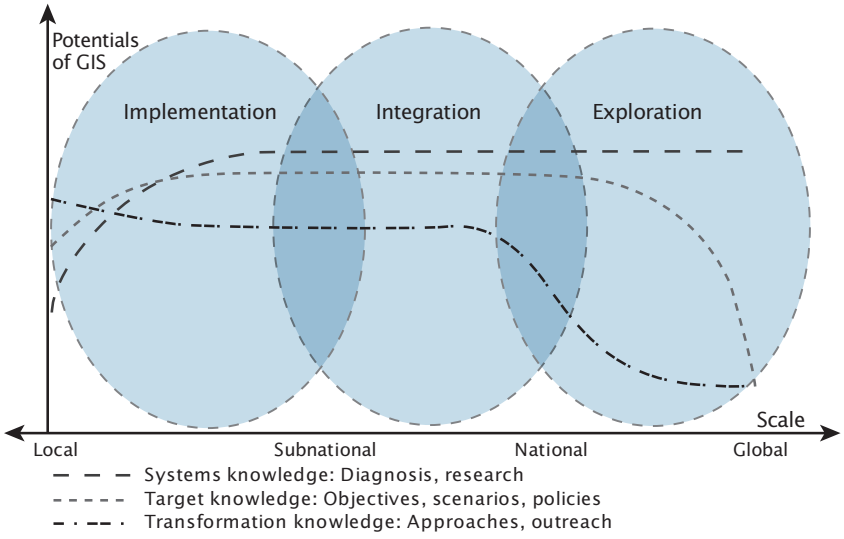

Fig. 1
GIS potentials to support the creation of systems, target, and transformation knowledge in relation to scale.

three types of knowledge. The following paragraphs provide a brief analysis of GIS potentials to support the creation of systems, target, and transformation knowledge in relation to scale, based on this graphic representation.

Systems knowledge: GIS have a strong potential for creating systems knowledge at all scales, apart from the local, where tacit knowledge and direct observation are more suitable. Information aggregation becomes necessary at the subnational to global scales. For example, very complex socio-economic patterns and processes in an urban setting can be analysed and visualised in detail with GIS, whereas at the global scale, corresponding spatial data are either inexistent or too heterogeneous for adequate analysis, making it necessary to aggregate indicators and simplify models. At such scales, GIS potentials reside in their ability to create overviews and conceptualise patterns and processes that are not perceivable through direct observation (Cassel-Gintz 2001). GIS are particularly useful for the generation of systems knowledge when combining spatial variables and the dimension of time. For example, the modelling of patterns of land cover change over time in the lower Mekong basin with the help of satellite imagery and the use of multivariate spatial algorithms has provided completely new insights into regional socio-economic dynamics and trends (Heinimann 2006; Heinimann et al 2007).

Target knowledge: The greatest potential of GIS in relation to target knowledge is at intermediate scales (subnational and national), where modelling and scenario calculations with GIS provide important bases for decision-making and policy formulation. By creating future scenarios and making the spatial consequences of future development interventions explicit, stakeholders concerned as well as potential winners and losers can be identified. GIS can be used to design target areas for development interventions by overlaying maps of different potentials. For example, the recent national irrigation master plan for Tanzania was derived from analyses of water resources, land resources, and socio-economic potentials (MAFS and JICA 2002). Conversely, GIS can be used to simulate the impact of land use changes on water availability using hydrological models. This can support the development of a land use policy that prevents the aggravation of water-related conflicts (e.g. Notter et al 2007). With regard to local phenomena, direct observation and stakeholder participation sometimes yield more precise and concrete definitions of objectives than GIS; at the continental and global scales the ability of GIS to contribute to policy formulation gradually decreases, as shown in Figure 1. Global sociopolitical processes and agree-

ments such as the Kyoto Protocol are based on consensus rooted in political negotiation. In such negotiation processes, GIS can have a great potential for creating systems knowledge (i.e. showing the negotiating parties what the situation looks like or how serious the problem is), but contribute less to the formulation of development objectives.

Transformation knowledge: The differentiation of GIS potentials according to scale follows a slightly different pattern in the case of transformation knowledge. At local scales, GIS have a high potential for planning and management of concrete development interventions. Because such interventions transform reality, tacit knowledge often cannot provide the necessary basis for project management. For example, systems knowledge can indicate that public transport in a particular town is an important problem. This knowledge can be acquired from experience and observation (tacit knowledge). The fact that a new bus terminal is needed (element of target knowledge) can also be observed and confirmed by means of a study. By contrast, the quality of the planning and construction of the new bus terminal (transformation knowledge) depends on adequate information-management and planning tools, among which GIS can play a significant role. This potential of GIS to provide logistical and engineering support is also relevant at intermediate scales for the planning and monitoring of larger interventions, such as infrastructure-development, health, or educational campaigns (Ehrensperger 2006). At continental and global scales, the use of GIS for planning becomes less important. At these scales, its role tends to focus more on monitoring impacts (e.g. of climate change mitigation measures, of AIDS prevention, etc.).

The above considerations of GIS relating to knowledge types and scale show that an aggregate assessment of GIS for sustainable development does not do justice to the complexity and the requirements of reality. Inversely, it also means that GIS practitioners should be aware of the limitations of GIS for sustainable development and attempt to apply them in a way that will maximise their usefulness. Either way, the above considerations allow for formulation of a rough scale-dependent typology, which is a first contribution towards a better understanding of the potentials of GIS for sustainable development. This typology, symbolised by overlapping ellipses in Figure 1, is briefly explained below.

Implementation: The larger[10] the scale (subnational to local), the more promisingly GIS applications focus on planning, management, or monitoring, and the more their functions tend to overlap with those of classic engi-

neering tools. However, at these scales, GIS also have a strong potential for data collection and stakeholder participation in terms of generating systems knowledge.

Integration: GIS have a strong integrative potential at the subnational, national, and transnational scales. They can contribute to the creation of all types of knowledge and provide analytical support for assessments, definition of objectives, and decision-making. They can also efficiently support downscaling and upscaling processes for further utilisation of knowledge at local and global scales. Therefore, the intermediate scales are the ones at which GIS have the widest array of potentials.

Exploration: At the transnational to global scales, GIS have an explorative or descriptive character. The main focus is on describing what is and what could be, on the basis of aggregated modelling and scenario-building. However, the importance of GIS for policy formulation and implementation support tends to diminish as other processes like scenario building, awareness creation, and discussion support gain in importance.

18.4 Towards a differentiated assessment of GIS in sustainable development

Delineations within the typology presented above are frequently blurred and overlapping, as symbolised by the three overlapping ellipses in Figure 1. However, this typology forms an adequate basis for an integrative assessment of GIS for sustainable development. In the following paragraphs, we propose an assessment in five dimensions that responds directly to the five main critical points found in the discourse on the usefulness of GIS in sustainable development initiatives.

Failure to create development-relevant knowledge: The close link between generating relevant information and deriving systems, target, or transformation knowledge must be taken into consideration when assessing GIS. While some early critics (Taylor 1990) argued that GIS are suitable for information management but inadequate for knowledge production, the position adopted in this article is that knowledge can be viewed as information that leads to action (Beesley 2003), or as conceptualised information. This is an idea that can also be seen from an empowerment perspective: "Knowledge – in whatever field – empowers its possessors with the capac-

ity for intellectual or physical action" (David and Foray 2003, p 25). Thus, 1) information and knowledge are mutually dependent and, 2) by generating and processing information, GIS contribute to knowledge production, dissemination, and utilisation at all scales and for all types of knowledge. In the same way that statistical data processed into statistical information can lead, for example, to consolidated knowledge about quantitative socio-economic facts and trends, spatial data processed into spatial information can lead to debates on spatial poverty patterns and trends and subsequently to consolidated transformation knowledge about strategies to mitigate poverty (Epprecht 2006; Epprecht et al 2008).

Epistemological flaws and positivist assumptions: Practitioners and scientists should be aware that there is an increased risk of choosing the wrong objectives, focusing on the wrong research questions, and reaching the wrong conclusions when using GIS in isolation. GIS should be applied as one contributing element within broader analytical processes involving the use of complementary approaches. However, integrating complementary approaches can prove to be difficult at very small scales (continental and global). Therefore, risks of epistemological flaws tend to increase as scale decreases. In order to avoid these risks, upscaling of knowledge gained at larger scales into reflections and models elaborated at smaller scales has to be part of the knowledge production process (e.g. regional overviews informed by case study knowledge). If GIS are applied under consideration of these issues, the allegation of a positivist attitude does not hold up under closer scrutiny. For example, in the Tajik Pamirs, knowledge about the status and dynamics of different dimensions of sustainability was generated using GIS, among other approaches (Breu 2006). At the same time, problems related to land resources, the causes of land degradation, and opportunities for sustainable land management were assessed from a stakeholder perspective. This process led to, and included, appraisal and negotiation of development objectives at different stakeholder levels to develop a strategy for the region. The knowledge gained through this process was eventually fed back into a knowledge-based GIS model, helping to set intervention priorities. In this process, GIS were one element contributing to a better understanding of development problems and opportunities and facilitating the setting of priorities for agreed-upon development objectives in the region. Their use in isolation would have led to biased recommendations, but their integration added value to the research process.

Hindrance to participation: Knowledge creation at local to intermediate scales is the typical situation in which GIS have a strong potential for fostering participation in sustainable development initiatives. For example, it was shown during a participatory mapping of urban development indicators in Nakuru, Kenya, that the graphic mode of information exchange provided by GIS encourages participation by semi-literate stakeholders, helps to integrate different epistemologies, and has a positive effect on the transparency of deliberations (Ehrensperger and Mbuguah 2004; Ehrensperger 2006). A graphic representation of the town under study triggers associations and helps to raise issues that might otherwise remain unexamined. It also enables the moderator of such a process to steer the discussion towards concrete facts and to collect binding statements and information of great value for planning and decision-making. Beyond the local to intermediate scales, increasing epistemological diversity, brought about by increasing diversity of stakeholders and contexts concerned, dictates that meaningful integration of knowledge into any kind of knowledge management tool – not only GIS – cannot be achieved without some degree of formalisation and epistemological reduction. This does not hinder participation per se, but requires a formalised framework for participation to take place (e.g. a referendum).

Exacerbation of power gaps: Two types of situation have to be distinguished in this regard: the integration of systems knowledge and the negotiation of target and transformation knowledge at the local scale, on the one hand, and the reduction of power gaps at subnational to national scales by providing a basis for more equitable allocation of public resources, on the other hand. In the first case, the integration of a traditional epistemology into a formalised information-management system can help to strengthen the community's identity and provides powerful support for informed negotiation and consensus-finding in advocacy processes. This was achieved, for example, in western Kenya, where the empowerment of marginalised ethnic groups was targeted by mapping these groups' ancestral territories using aerial photography, GPS, participatory 3D modelling and GIS (Ehrensperger 2006; Rambaldi et al 2007). GIS can also help to reduce marginalisation and enhance access to services. In Chad, participatory mapping of transhumant movement patterns contributes to better planning of health services for mobile pastoralists, who have so far been excluded from social services (Wiese et al 2004). In the second case, GIS can, for example, help to improve national poverty-mitigation strategies. In Vietnam, advanced spatial modelling revealed a relatively strong correlation between levels of poverty and ethnic identity at a national scale (Epprecht 2006). Such information can

contribute to the empowerment of underprivileged communities by availing them of a platform to assert their arguments and to back up claims relating to their needs.

Lack of sustainability: Issues of sustainability matter most in processes in which dependence on a given technology is created, for example in the case of government agencies introducing electronic data management tools. In such cases, the effort invested in the proper institutionalisation of the process is crucial. Also, the gaps between the design of an e-governance project and the existing realities in the recipient institution play a major role with respect to sustainability (Heeks 2003). Hence, e-governance and other ICT-based initiatives need to be designed to support existing workflows and processes within recipient institutions in the best possible way. By contrast, in one-time assessments conducted in a project implementation process, the sustainability of the technology itself is less a matter of concern than the question of how outputs are disseminated and subsequently used. In such situations, the selection of appropriate dissemination media is of crucial importance. A process of 'translation' might be necessary in order to adequately inform the stakeholders concerned, something that is commonly practised, for example, by agricultural extension services that translate knowledge about agricultural engineering into easily understandable terms for practical use by farming communities, or in health awareness creation campaigns, in which medical knowledge, for example on HIV/AIDS, is translated into broadly understandable recommendations.

18.5 Conclusion

The above reflections focus on geographic information sciences, the function of which is to contribute to the creation and dissemination of knowledge. Hence information and knowledge, and the importance of these resources for sustainable development, are the central parameters of the present article. In the words of Chapman and Slaymaker, "improved information can enable people to better defend their interests and articulate their needs; it increases their bargaining power and ability to influence decision-making processes that affect them" (Chapman and Slaymaker 2002, p 7). Therefore, our reflections ultimately lead us to the question of the impact of the information and knowledge produced and disseminated by means of GIS on decision-making, planning, or behaviour adaptation towards sustainable development. When trying to assess such an impact to gain a clear idea of the

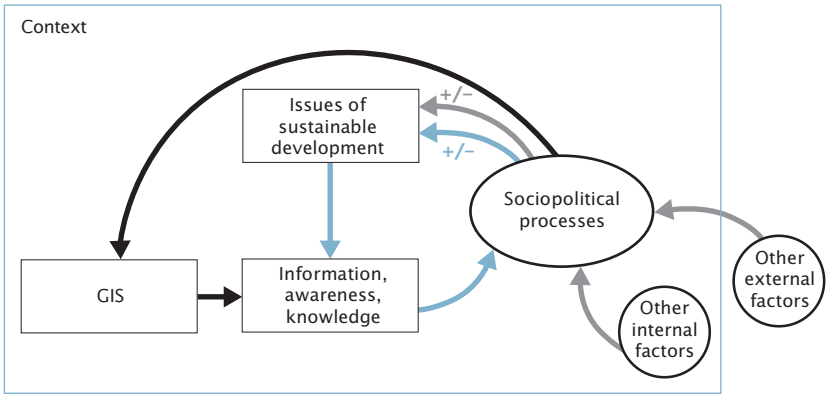

Fig. 2
The position of GIS in sociopolitical processes towards sustainable development, and the influence of other internal or external factors on such processes.

Black arrows represent the integration of GIS into the sociopolitical process; blue arrows represent the iterative process aiming to resolve issues of sustainable development; grey arrows represent the influence of internal and external factors on this iterative process. Decision-making and implementation can have both positive (+) and negative (–) impacts. (Source: Ehrensperger 2006)

potentials of GIS for sustainable development, one is inevitably faced with great difficulties, because "[…] information flows are notoriously difficult to follow and causal linkages between exposure to information, its application and evident impact are difficult to establish with certainty" (Lowe, personal communication[11], cited in Zielinski 2001).

In this respect, GIS are on an equal footing with other information- and knowledge-based contributions to sustainable development, including capacity development in a variety of fields. The ability of an individual, a social entity, or an institution to improve their livelihood or to perform evidence-based decision-making depends on a number of factors, the analysis of which is beyond the scope of this article. Factors that are not evidence-based can have their source within or outside an institutional or social context and can influence sociopolitical processes towards sustainable development in positive or negative ways (Figure 2). Such factors can include political alliances, personal benefits, beliefs, pressure, or conflicts. Our task as geo-information scientists is to try to integrate GIS in sociopolitical processes towards sustainable development in a manner that will foster evidence-based decision-making and reduce the impact of non-evidence-based factors.

Endnotes

Full citation for this article:
Ehrensperger A, Heinimann A, Messerli P, Notter B, Muchemi J, Breu T, Epprecht M. 2011. Towards a differentiated assessment of geographic information sciences for sustainable development. *In:* Wiesmann U, Hurni H, editors; with an international group of co-editors. *Research for Sustainable Development: Foundations, Experiences, and Perspectives.* Perspectives of the Swiss National Centre of Competence in Research (NCCR) North-South, University of Bern, Vol. 6. Bern, Switzerland: Geographica Bernensia, pp 361–376.

Acknowledgements:
The authors acknowledge support from the Swiss National Centre of Competence in Research (NCCR) North-South: Research Partnerships for Mitigating Syndromes of Global Change, co-funded by the Swiss National Science Foundation (SNSF), the Swiss Agency for Development and Cooperation (SDC), and the participating institutions.

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[8] Assumptions that the goal of science is to stick to what can be observed and measured in order to understand and control the world, and that metaphysics has no place in science.

[9] In this article we understand tacit knowledge as defined by Stephen Gourlay: "a form of knowledge that is highly personal and context-specific and deeply rooted in individual experiences, ideas, values and emotions" (Gourlay 2002).

[10] Scale is used here according to its use in GIS: the larger the scale of a GIS application, the smaller the geographic area it covers, and vice versa.

[11] Lucky Lowe, "Knowledge and Information Systems – Learning What We know?", message posted to FAO MediaReality mailing list, mediareality-L@mailserv.fao.org, on 5 December 2000.

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