

MODELLING OF SPATIALLY COMPLEX HUMAN-ECOSYSTEM, RURAL-URBAN AND RICH-POOR INTERACTIONS

Andries Naudé¹, David Le Maitre¹, Tom de Jong², Greg Forsyth¹, Gerbrand Mans¹ and Wim Hugo³

¹Council for Scientific and Industrial Research (CSIR), South Africa

²Utrecht University, Faculty of Geosciences

³MBV Consulting, South Africa

Abstract:

The paper outlines the challenges of modelling and assessing spatially complex human-ecosystem interactions, and the need to simultaneously consider rural-urban and rich-poor interactions. The context for exploring these challenges is South Africa, which has such stark poor-rich and associated rural-urban and other spatial disparities, that it is often described as a microcosm of the global division between developed and developing countries. Instead of rigid rural-urban dichotomies and other absolute, “container” views of space, there is a need to recognise spatial overlaps and complexities such the pervasiveness of so-called translocal livelihood systems. Accordingly, much more *relational, network-oriented modelling approaches* are needed. The paper sets out a list of related requirements and highlights the trade-off that typically has to be made between macroscopic, multi-sector models (Type A) and sector or network specific spatial interaction models (Type B). It concludes with a discussion of ongoing work aimed at developing an adapted Type B modelling system that will provide the capability to explore positions, spaces, and interactions in terms of multiple networks (such as river networks, road networks and networks of service centres).

Keywords: social-ecological system, spatial interaction modelling, rural-urban, developing countries

1. Introduction

The world is a highly dualistic socio-ecological system (referring to sharp poor-rich and associated rural-urban and other spatial disparities)), characterised also by a high and increasing degree of spatial complexity (manifested, inter alia, by fuzzy and/or non-coterminous administrative regions, functional economic/ human activity regions, social networks, internet-based collaboration networks, ecosystems and other spatial system demarcations). And so is South Africa, which is often described as a microcosm of the world. The paper discusses the initial results of the problem formulation, conceptual modelling and requirements specification phases of a series of current inter-related projects aimed at building improved models of both the morphological and the dynamic features of this type of socio-ecological system. Although this series of projects (some of which are only in the project formulation stage) covers a range of topics, the focus of this paper is on the modelling of spatially complex human-ecosystem, rural-urban, and rich-poor interactions.

2. Emerging discourses about urban-rural divides and linkages

2.1 Definitions of urban and rural

Many definitions of urban and rural areas are based on average population or dwelling unit densities. However, in this paper we also consider relative *centrality* – or its opposite, namely *peripherality* – as a basis for distinguishing between functionally urban and rural areas.

2.2 Spatial interdependency of urban and rural livelihoods

There is a growing body of research that have highlighted the translocal or rural-urban interdependency of livelihoods. In a recent South African study, Lohnert & Steinbrink (2005) note that “a growing proportion of the population in developing countries are organising their livelihoods in the context of informal social networks spanning the rural-urban divide” and argue that more attention should be given to the *translocality of livelihood-systems*.

2.3 Macro scale studies of core-periphery patterns and dynamics

There has recently been a resurgence of work on *spatial disparities* (cf. the UNU-WIDER series of studies edited by Kanbur and Venables, 2005); *core-periphery patterns* (cf. the many recent studies of, and political discourses about the EU's core-periphery disparities); and *theories about the underlying causal processes* (cf. the new economic geography [NEG] theories associated particularly with the work of Krugman, 1991). At the risk of over-generalisation, the explanatory findings can be summarised as follows: Aside from stark differences in mineral wealth and other natural endowments, geographically uneven economic development is mainly caused by four factors: i) agglomeration forces/ increasing economies of scale; ii) accessibility to, or remoteness from established centres of agglomeration (implying also – under most circumstances – the closeness of linkages to suppliers and customers), iii) restricted mobility of labour; and iv) institutional thickness/ collaborative effectiveness – referring here particularly to differential abilities to collaborate, manage externalities and critical interdependencies, and create “relational assets” or various types of synergies (including potential win-win core-periphery or rural-urban linkages).

2.4 A new perspective on rural poverty the role of ecosystem services

Taking the phenomenon of persistent and deepening rural poverty in developing countries as the point of departure, there is a long tradition of sociological, demographic and development economics research into how this might be influenced by rural-urban migration (oscillating and permanent), and the development of rural-urban linkages. In a recent seminal article, Gutman (2007) also focuses on the persistent poverty of the world's 2 billion rural inhabitants, but questions whether any significant progress can be made by continuing to manage rural-urban relations in terms of the so-called “old rural-urban compact” – the age-old implicit agreement that rural areas will send people, agricultural and other rural products to towns and cities in exchange for urban services and manufactured products.

In posing the rhetorical question: So what can the rural areas bring to the marketplace other than the traditional products and people? – Gutman (2007) offers what he considers as an obvious answer: *environmental conservation, the provision of a flow of nature-based, human-stewarded ecosystem services that are critical for humankind's survival and quality of life, including climate regulation, disturbances regulation, watershed protection, forest conservation, biodiversity conservation, landscape beautification and wildlife husbandry in support of tourism and ecotourism, and more.* He then proceeds to argue for a new urban compact, in terms of which the urban parts of the world should pay rural communities for these ecosystem services Gutman (2007).

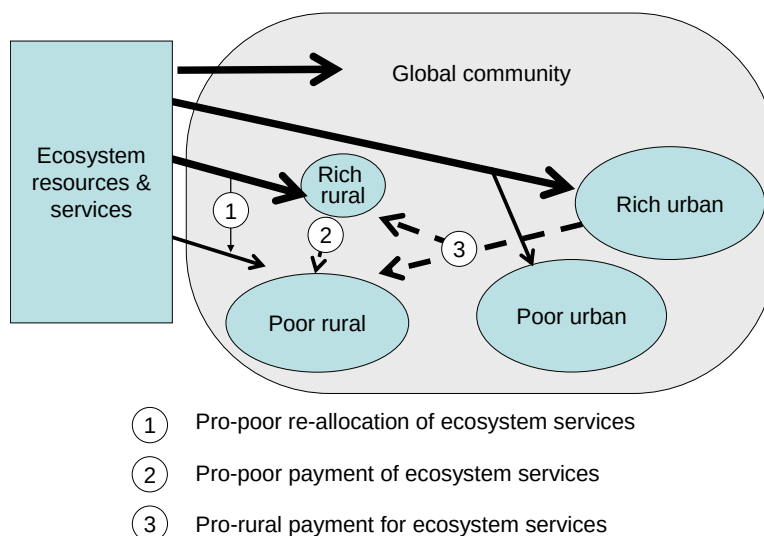


Figure 1. A diagram illustrating three different ways in which the rich can “pay” the poor for ecosystem services derived from land areas managed by the rural poor

There are three ways that these allocations or payments can be made (Figure 1). The most direct (Arrow 1) is increasing the proportion of those services, and the benefits derived from them, going to the poor. The second is where rich rural beneficiaries, for example irrigation farmers, pay the poor to manage their land to increase the benefits that go to the rich. The third is where the rich urban beneficiaries pay both the rural poor and rich to manage their lands in ways that sustain or enhance the supply of ecosystem services reaching the urban areas. The three are not mutually exclusive.

3. Background on the South Africa's core-periphery patterns and issues

Besides certain broad similarities with core-periphery patterns in other parts of the developing world, the patterns in South Africa have a number of extra-ordinary features that can be assumed to reflect the ongoing geographic legacies of the pre-1991 apartheid policies (the South African Group Areas Act was repealed in 1991, following the repeal of the influx control or pass law system in 1986). This is further complicated by *ongoing economic dualisms* – i.e. between the country's so-called 'first' and 'second' economies. One of the legacies of the apartheid spatial policies is the relatively high proportion of South Africa's population that are still located in high density peripheral areas or – as some might describe it – peripheral spatial poverty traps. The location of these areas is shown in Figure 2, together with a bar chart showing that these areas contain 24% of the country's population (11 million people out of a total of 47 million), whilst only contributing 4% of the GDP (all 2004 estimates). The relative poverty of these areas is also reflected by the fact that per capita GDP is only about \$650 per annum, whereas it is about \$4600 per annum in the high density core areas.

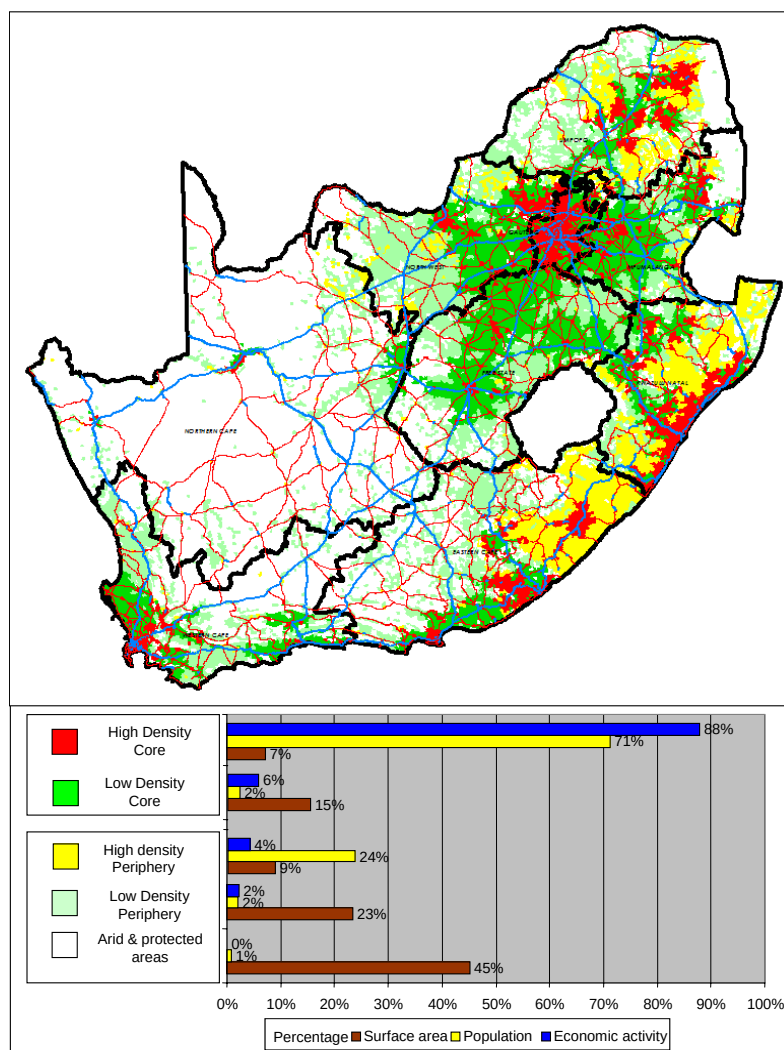


Figure 2. Map and statistical overview of South Africa's core-periphery patterns

4. The derived modelling challenges and requirements

4.1 Dealing with scale mismatches and related spatial complexities

Human development and ecosystem processes occur in terms of a variety of overlapping geographic spaces, and at different scales. Cumming et.al. (2006) focus on *scale mismatches*, defined as mismatch between the scale of management and the scale(s) of the ecological processes being managed. Low et. al. (1999) developed a model of *spatially complex situations* where in which biological resources move from one spatial unit to others. Combining these insights, we developed a diagrammatic representation of increasing levels of spatial complexity. Figure 3 indicates how spatial complexity first increases as a result of human and ecosystem interactions between two sets of spatially coterminous human activity systems and ecosystems (forming two “integrated” socio-ecological systems). The further complexities caused by scale mismatches are also illustrated (see “Level 3” in diagram).

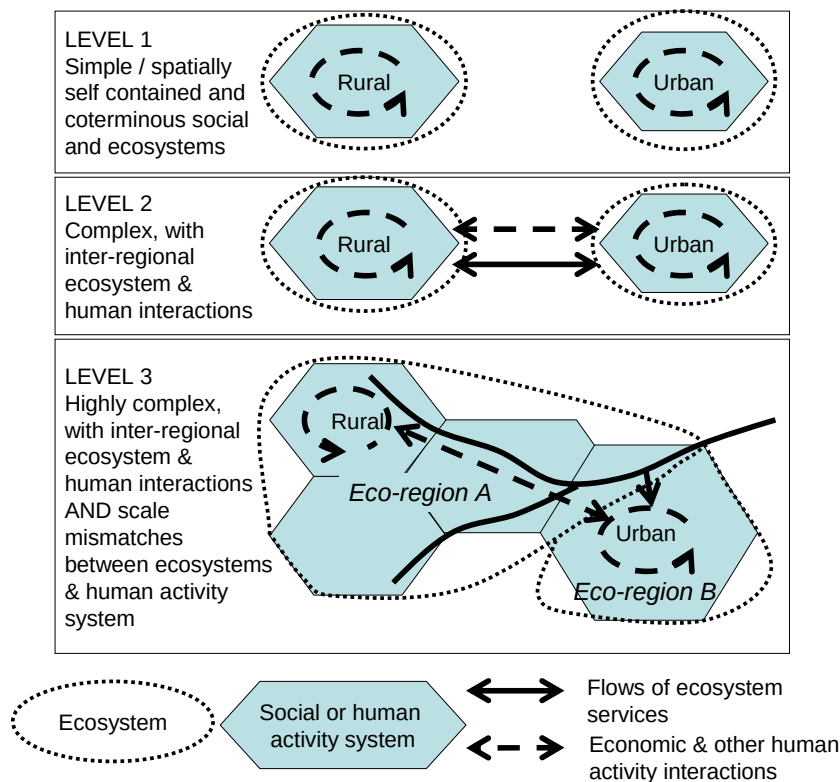


Figure 3. Increasing levels of spatial complexity

4.3 Spatial modelling of multi-layered networks

Drawing from several streams of work in the emerging transdisciplinary field of “network science”, the US National Research Council developed the following generic definition of a network:

A network is described by its structure (e.g., nodes and links), its dynamics (the temporal attributes of nodes and links), and its behaviours (what the network “does” as a result of the interactions among the nodes and links). Thus, a network is always a representation or model of observable reality, not that reality itself. Networks also build upon each other in layers—for example, a network of business process applications is built on a communications network that is, in turn, built on a physical network (Committee on Network Science for Future Army Applications, 2005).

However, the spatial aspects of networks have not been well researched by the new crop of “network scientists” (Boccaletti, 2006). Commenting on this from an evolutionary economic geography perspective, Boschma and Franken (2006) note that the dynamic analysis of urban and regional networks is still in its infancy.

4.4 Summary of derived requirements

The derived requirements for the modelling of spatially complex human-ecosystem, rural-urban, and poor-rich interactions can be briefly summarised as follows:

- i. Instead of descriptions, spatial data models and indicators which tend to portray the geography of human activity and development in terms of rigid rural-urban dichotomies and other absolute, “container” views of space (Couclelis, 1991), much more *relational, network-oriented approaches* are needed;
- ii. Explicit allowance should be made for *scale mismatches* and *complexity-increasing linkages* within and between human activity systems and ecosystems;
- iii. Related to the above, there should be good capabilities for describing the *multi-network connectivity* of basic socio-ecological entities (which might be defined as *nodes, cells, spaces and/or zones*) as well as the variety of *relational attributes* (measured in relation to relevant neighbouring, nearby and distant objects) that these entities might inherit due to their *network positions*;
- iv. It should be possible to specify what threshold levels and combinations of relational and other attributes are necessary for entities to become *hubs*, and how the attainment of further thresholds will allow certain hubs to become cumulatively growing *centres of agglomeration*, whilst relegating surrounding hubs and areas to *dependent satellites or peripheries*;
- v. It should be possible to specify and model how *groups of agents* – who might be members of a translocal household, a social network or a consortium of firms – seek, compete with others, and are able to appropriate combinations of network positions (including hub locations), routes and/or supply chains as their *livelihood or activity spaces*;
- vi. Related to Requirements iv and v above, the required modelling approach or platform should also provide a good basis for describing and exploring the *polarisation and bifurcation processes* that cause human activity systems to segment along developed-developing, poor-rich, core-periphery, hub-satellite and related dimensions;
- vii. There should be a capability to model *stocks and flows associated with specific ecosystems, networks and/or (human) activity spaces*, including: a) ecosystem stocks, and other types of “human activity capital” (financial, social, physical, educational); and b) ecosystem services and the economic and other outputs of (value-adding and livelihood creating) human activity.
- viii. It should be possible to specify and apply rules that describe *network behaviours* – such as that flows in hydrological networks are determined by topography, unless altered by pipelines and other engineered systems – and *trace the origins and destinations of such network flows*.
- ix. In order to model these and other socio-ecological processes and dynamics, there should be good general capabilities to record and model *scale(s) of phenomena, rates of change, strengths of linkages, strengths of equilibrium restoring forces, factors that might cause lags or inertia, boundary conditions, and threshold values*.
- x. Depending on computational capabilities and the purpose and scale of analysis, it should be possible to model and derive *aggregate statistics of cumulative demands, stocks, flows and other interactions* at ideally two scales/ levels: A) a macro scale/ whole system level; and B) a meso scale / subsystem level.

5. Current and ongoing work to address the requirements

Referring specifically to the last requirement above, most operational models are designed to either have high inter-sectoral and low spatial resolution (“A-type”: integrated macro-models), or low inter-sectoral and high spatial resolution (“B-type”: sector or network specific spatial interaction models). The problem with the A-type models is poor representation of spatial linkages and inter-dependencies, whereas the B-type models suffer from poor representation of inter-sectoral linkages and inter-dependencies.

Recent spatial data and operational modelling work undertaken by the authors have focused on adapting the B-type models so that it is possible to explore positions, spaces and interactions in terms of multiple networks. In this way we are effectively creating a hybrid between the A and B-type models, enabling us to address high proportion of the requirements set out above, and move closer to the goal of being able to model spatially complex human-ecosystem, rural-urban, and poor-rich interactions. Given inevitable data and computational requirements, a key breakthrough was the idea of formulation and linking a whole range of network and other datasets to a common meso-scale set of analysis units covering the whole of South Africa (Naudé, et. al. 2007). This set of analysis units – referred to as the South African *mesoframe* – has now been used together with GIS-based network analysis, accessibility modelling, hydrological modelling and spatial-economic modelling tools to model: a) various indices of accessibility/ peripherality (such as shown in Figure 2); b) the supply and demand of job opportunities and other livelihood prospects; c) the potential population migration from areas with poor prospects to areas with better prospects; and d) the flow and allocation of water between different spatial contexts and types of uses and user groups (including rich, poor, urban and rural).

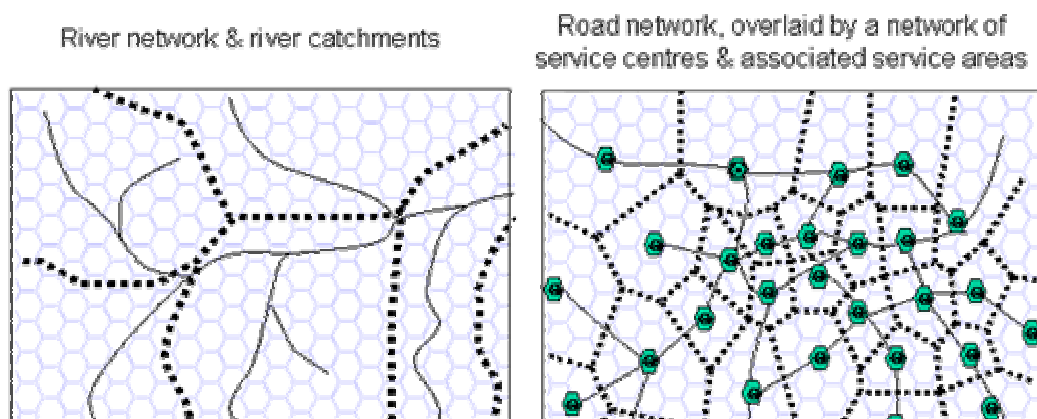


Figure 4. Use of common analysis units to model different network systems

The basic concept of using the same basic analysis units to model different network systems is illustrated by Figure 4. Work is continuing on topics such as the calibration and integration of hydrological/ ecosystem and human activity sub-models, and overcoming the computational challenges of moving from relatively large (50km²) to smaller mesozones.

6. Modelling spatially complex water flows

We provide some results of building and applying a prototype model of key water-related human-ecosystem, rural-urban, and rich-poor interactions in the South African part of the Inkomati basin. This basin stretches from South Africa's eastern highveld region and north-eastern Swaziland to the Inkomati estuary at Maputo Bay in Mozambique (see Figures 5 & 6).

The Inkomati basin within South Africa has a mean annual runoff of about 3361 Mm³ per year. Of this 772 Mm³/yr is currently utilisable water (the maximum that can be used on a sustainable basis from the existing dams and water supply schemes) and could be increased to a maximum of 1307 Mm³/yr through further dam construction. Most water is consumed by irrigation, energy (thermal power stations), industry (sugar and paper mills) and urban residential uses, with very little supplied to high density rural areas, where most of the poor are concentrated (see Figure 5). Together with international obligations, total allocations in the Inkomati basin amount to 838 Mm³/yr. This exceeds the available yield.

Earlier studies – undertaken at a regional scale – examined the impact of upstream human activity (in South Africa) on the shrimp industry in Maputo Bay. In order to extend the analysis to a wider range of interactions and provide more accurate estimates of meso-scale spatial linkages and transfers, we prepared a dataset consisting of: a) a refined mesozone information layer; b) a classification of the mesozones in terms of urban, dense rural and sparse rural occupation types; c) estimates of water production and natural flow; d) water consumption estimates in three categories – see Figure 5; and e) a river and bulk water pipeline network (linking the mesozones).

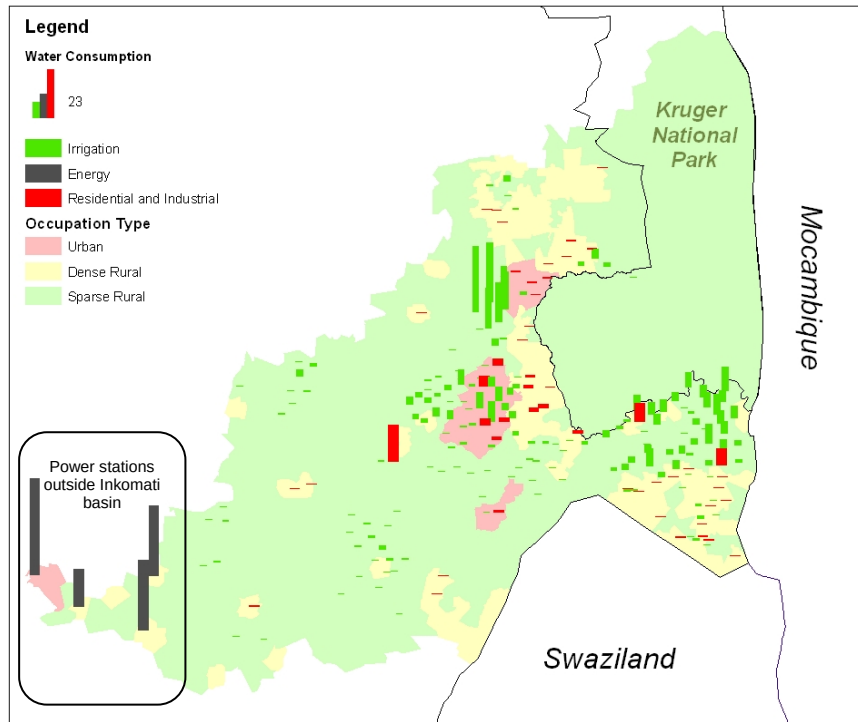


Figure 5. Water consumption per occupation type within the South African part of the Inkomati basin

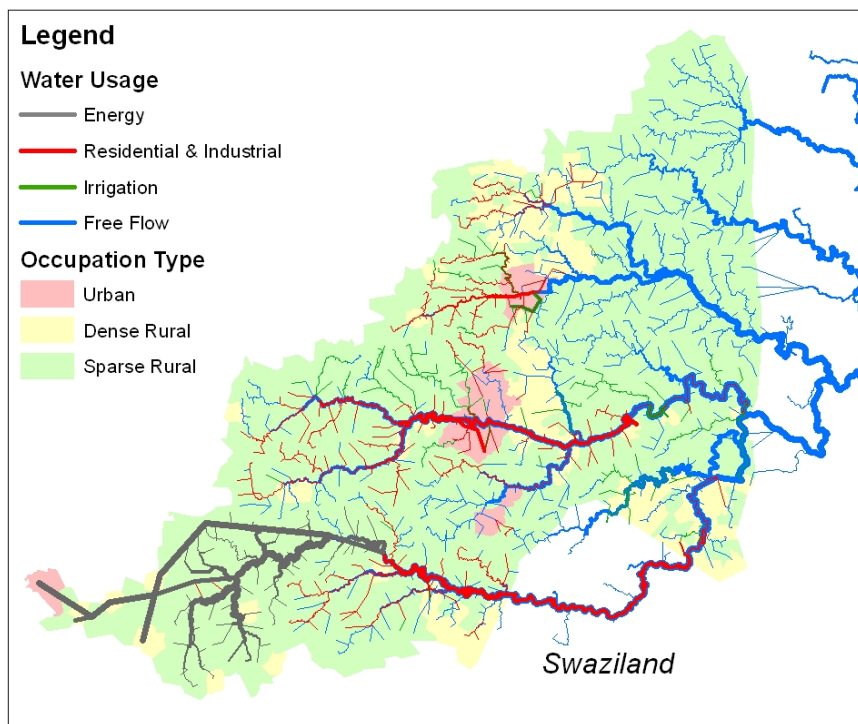


Figure 6. Sources, destinations, categories and volumes of water usage within the South African part of the Inkomati basin

The results shown in Figure 6 were derived by using Flowmap software (<http://flowmap.geog.uu.nl/>). This shows where different categories of water in the basin are sourced and consumed, illustrating the capability of this type of model to trace both the origins and destinations of water flows. For example, in

this case, a significant proportion of the available water (11.5%) is transferred to an adjacent basin (for cooling four thermal power stations). As a second example, most of the free flow water in the South African part of the basin is shown to occur in areas set aside for nature conservation.

Using this model, it is possible to explore different water production and allocation scenarios. For example, it will be possible to explore the extent to which additional allocations can improve the livelihoods of poor rural communities. Initial indications are that they can substantially increase their income while having relatively little impact on overall water requirements.

7. Conclusion

We recognise that complex systems cannot be fully captured in models or reduced to entities or interactions that are separately examined and then re-assembled. We believe that the type of network-focused, hybrid modelling system described in this paper can be used to partially decompose complex social-ecological systems and explore the role of the key socio-ecological entities, interactions and dynamics that characterise them.

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