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Social-Ecological Systems in the Indian Rural-Urban Interface: Functions, Scales, and Dynamics of Transition

General Section

Funding Proposal for Phase I (2016-2018)

submitted by
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1. General Section

Relevance of the research topic

Urbanisation as a global trend

In an ever more densely populated world, the interaction of humankind with the biophysical environment has to be increasingly viewed as a holistic, complex system in which societies are shaped by and in turn shape their surrounding ecosystems. Sustainable resource use and the distribution of ecosystem service provisions and consumption have become pressing issues (Rockstrom et al., 2009a, 2009b; Steffen et al., 2011). In this context urbanisation is a major ongoing transition process in the socio-ecological realm. It is projected that by 2050 as many people will live in cities as currently live on our planet altogether (WBGU, 2011). The urban population in developing countries is projected to double by 2030, and in this process, cities may eventually occupy an area equivalent to 7% of the world's arable land, compared with 3% today (Angel et al., 2005). Megacities, urban conglomerations with a population of more than 10 million inhabitants, represent the most advanced state of urbanisation. They are growing especially rapidly in the Global South (Sorensen and Okata, 2010). Megacities are locations where the human influence on ecosystems is most acutely felt (Cosier and Shen, 2009; UNDP, 2011; Huang et al., 2012). However, the dependence of cities on their surrounding ecosystems has long been neglected and little research has explicitly addressed the changes in agricultural land use, household behaviour, and welfare associated with urban expansion. This paucity of integrated analyses of rural-urban dependencies in the context of interdependent social and ecological systems represents a critical research gap (Elmqvist et al., 2013; McDonald et al., 2013; Seto et al., 2013, Cumming et al., 2014) that will be addressed in the proposed Research Unit (FOR) using an interdisciplinary approach.

Bangalore as focal point of urbanisation

Bangalore in Southern India is an emerging megacity that exemplifies many key characteristics of urbanisation (Nair, 2005; Narayana, 2011; Kraas and Mertins, 2014) such as rapid expansion over the last 40 years (Government of India, 2011), suburbanisation, ecological and infrastructural overloads, uncontrolled development, and heterogeneous land use mosaics. As Bangalore continues to grow, multiple transition processes from rural to urban land use and lifestyles are taking place around it. Processes that elsewhere took decades or even centuries to unfold, are occurring here at a speed that allows real-time observation. In the proposed FOR2432 we will focus on the rural-urban interface (Figure 1) as a particularly dynamic space in which multiple drivers operate at different spatio-temporal scales and shape (bio-) physical as well as social structures. The paths and trajectories of current transition processes will determine the future shape and sustainability of the city and its surrounding environments.

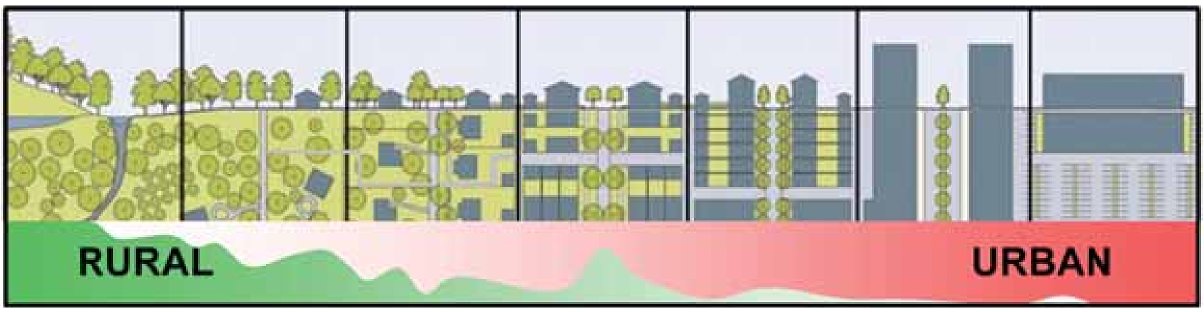

Figure 1. Schematic representation of the rural-urban interface indicating a discontinuous rural-urban gradient (modified after Anonymous, 2014).

While Bangalore is reaching an advanced stage in the transition process, many other emerging megacities in India and elsewhere will undergo similar developments. The understanding and advances in theory and methodology generated by this study will help predict future trajectories in similar megacity settings elsewhere.

Push and pull factors of urbanisation

Our study will also contribute to untangling the complex interplay between the drivers of urbanisation which may differ considerably between locations (Jedwab et al., 2014). Urbanisation is often discussed in context with rural-urban migration. Several social and economic models of migration distinguish rural *push factors* from urban *pull factors*. Rural push factors include poverty, unequitable land distribution, environmental degradation, high vulnerability to natural disasters, and violent conflics; urban pull factors include better employment oppurtunities, higher income, diverse services, and less social discrimination in the cities (Rhoda, 1983; Tacoli, 1998; Vinayakam and Sekar, 2013). These approaches mainly focus on the socio-economic conditions of the migrants. A comprehensive concept that links migration and environmental conditions was proposed by Bilsborrow (2002). It includes ecological determinants of migration in the analyses, and considers feedback effects of migratory movement on the environment at the origin and at the destination of migration. Recent literature increasingly differentiates between diverse drivers of urbanisation and more complex patterns of migration, including re-migration. Glaeser (2013) states that “in closed economies, agricultural prosperity leads to more urbanization, but that in an open economy, urbanization increases with agricultural desperation”. Young (2013) points out that outward migration from cities also occurs, and that bi-directional migration results in a self-sorting by human capital and skills. Finally, Jedwab et al. (2014) present evidence that a substantial part of rapid urbanisation is due to the additional urban push that is generated by internal urban population growth.

Bangalore is generally considered to be an example of urban pull dynamics. It would thus be tempting to contrast Bangalore’s rural-urban interface with that of a typical rural push example. Such a straightforward contrast, however, is questionable in the light of the research cited above. Furthermore, the evidence on Bangalore itself is nuanced, with studies suggesting that despite the importance of pull factors there, push factors contribute to almost half of the observed rural-urban migration (Sridhar et al., 2010). Therefore in a first step we will strive to gain a deeper understanding of the interplay between these forces and consider the possibilities of including a potential contrasting location when we prepare Phase II of FOR2432.

Transition processes

Agricultural land use systems everywhere reflect a millennia-old history of transitions in the use of land, water, labour, and capital, the four critical resources on which all agricultural production systems depend. While the functions, scales, and dynamics of these transition processes are site-specific, the initial ecosystem services were always affected by the planting of crops, establishment of pastures, water drainage, irrigation, and construction of physical infrastructure which resulted in a ‘managed mosaic’ (Fedick, 1997). Sustainable land use systems evolved by balancing the pressure on natural resources by means of cultural rules and norms to avoid over-exploitation. These systems were sometimes able to adapt and persist for hundreds of years until continued population growth and changing conditions forced them to either upscale or collapse (Cumming et al., 2014).

There are two types of transition process: steady adaptations within a given system, and non-linear dynamics approaching a tipping point, followed by breakdown and transformations to a new system (Biggs et al., 2009). Both will be considered in the proposed FOR2432. To guide our activities, we will focus on the following four central questions from which we derive the hypotheses-driven research agenda described below.

Question 1: *How do agricultural production systems and household structures change at different stages of urbanisation?*

Question 2: *How does urban expansion affect the ability of regional ecosystems to provide food and other ecosystem services?*

Question 3: *How do exchange processes between agroecosystems, producers and consumers, or different social groups change as urbanisation advances?*

Question 4: *How do social and ecological systems interact where rural and urban livelihoods, traditions, aspirations, and forms of land use clash?*

Concepts of coordinated research

The Social-Ecological Systems framework

Agriculture is one of the oldest examples of a coupled Social-Ecological System (SES), in which environmental and societal components (nature and human beings) mutually depend on each other. Using the SES framework as the overarching concept of analysis in FOR2432 we view the rural-urban interface of Bangalore as a coupled system of interrelated agro-ecological, economic, and social sub-systems, in which the output of one sub-system provides inputs for others as they partly share or compete for common resources (Eigen and Schuster, 1977; Kurakin, 2011). FOR2432 aims at systematically exploring these interrelations within and between plant-based and animal-based production systems, agricultural/non-agricultural households, supply chains and marketing channels, and larger-scale social and physical structures and patterns.

All existing SES frameworks are rooted in systems theory. Thereby a system is defined by the interaction of its internal components and is embedded in an external environment (Hall and Fagan, 1956). In dissipative systems the maintenance of structure and performance depends on the continuous input of energy and exchange of matter with the environment. Apparent stability is a result of continuous self-reproductive cycles within the system (Prigogine, 1972). When links are also established between systems coexisting in the same environment, a higher order structure emerges, forming a hyper-system of higher complexity (Eigen and Schuster, 1977), and implying a multi-scale, nested overall architecture. Complex systems exhibit several defining characteristics, including feedback, strongly interdependent variables, extreme sensitivity to initial conditions, multiple metastable states, and a non-Gaussian distribution of outputs (Kastens et al., 2009).

Adaptive Cycles: One of the first system approaches to analyse SES, the *Adaptive Cycle* proposed by Holling (1987, 2001), originated in the context of ecology. This concept emphasises that complex systems adapt to changing conditions by running through sequences of stages which he labelled *reorganisation*, *growth*, *conservation,* and *release*. Release is followed by reorganisation, thus initiating a new cycle. The adaptive cycle concept has been extended to introduce *resilience* as a key dimension of SES, pointing out that immature, growing systems are characterised by lower levels of connectivity and of fixed capital, and therefore tend to be more resilient than more mature systems characterised by highly connected structures to which accumulated capital is fixed (Folke et al., 2003, Cumming, 2008, 2011; Pickett et al., 2014). This extended concept also acknowledges that lower-scale systems are nested in higher-scale systems and connected by *revolt* and *remember* linkages (Holling and Gunderson, 2002), whereby disturbances at a lower-scale system can transmit to higher scales, and memory conserved in a higher-scale system can influence reorganisation at a lower scale. Cross-scale interactions have received particular attention in recent work related to the resilience of protected areas (Cumming et al., 2014; Maciejewski et al., 2014), but are likewise relevant to other complex systems (Sundstrom et al., 2014), including agricultural or urban SES. While this approach is strong in interpreting system dynamics and transition processes, it remains rather qualitative and vague in diagnosing actual system states, especially with regard to their social and political implications.

Ostrom's approach: Ostrom's approach complements SES analysis (Ostrom, 2007, 2009) with an institutional perspective. Its starts from the observation that attempts to sustainably regulate the use of common pool ecological resources sometimes succeed and sometimes fail. The Ostrom framework distinguishes *resource systems*, *governance systems*, *resource units*, and *actors* (all embedded in broader *socio-economic, political settings* and *related ecosystems*) that meet in a focal *action situation* (McGinnis and Ostrom, 2012). After delineating these first-tier subsystems the analysis proceeds to identify by successive decomposition specific system variables − such as the size of the system, the number of users, shared norms and beliefs, and the predictability of system dynamics − that influence the likelihood of successful coordination leading to a sustainable SES. This concept is amenable to quantitative analysis and has been successfully applied to coordinate conflicts over the use of welldelineated common resources in a number of case studies. However, it has some limitations with regard to dynamics and incorporation of knowledge from the ecological and natural sciences (Epstein et al., 2013).

Ecosystem Services: The work of Ostrom has inspired the sustainability framework and concept of Ecosystem Services (ESS). Sustainable development as defined in the Brundtland Commission's report is "development which fulfils the needs of the present generation without jeopardising the possibilities of future generations to fulfil their needs" (Bruntland Commission, 1987). Three issues are highlighted as the cornerstones of sustainability. In order to be sustainable, development must be economically profitable, ecologically proper, and socially acceptable. In the ESS approach Ostrom's “extraction of resources” is seen as a *provisioning service*, amended by three other categories of *supporting, regulating,* and *cultural ecosystem services* which together form the basic links that couple ecological to social systems. These services affect important dimensions of human well-being such as basic material for good life, health, security, good social relations, and freedom of choice. Humans both use ecosystem services and attempt to coordinate this use, creating feedback loops that affect an ecosystem's ability to maintain the delivery of services. This applied framework was used for a holistic functional assessment in the Millennium Report (UNDP, 2011).

SES research is thus not a unified field, but rather comprises a broad palette of conceptual and methodological approaches. Debate on how to reconcile and integrate these approaches is ongoing. A major challenge in this debate, pointed out by Epstein et al. (2013), lies in the different epistemological traditions in natural and social sciences. Case-based, inductive reasoning relying on quantitative methods such as regression, experiments, or comparative studies needs to be combined with rule-based, deductive reasoning that uses knowledge about facts to predict or explain outcomes. While the Ostrom framework accounts for various rules within the governance system, it does not include a corresponding formal link to knowledge from the natural sciences. Epstein et al. (2013) therefore suggest introducing *ecological rules* as an additional first tier subsystem to improve the incorporation of biophysical facts into the framework and thus widen its interdisciplinarity. The hierarchies and formal components at lower tiers of the Ostrom framework were re-evaluated by Hinkel et al. (2014), who draw on the methodology of semantics in software engineering. These authors propose distinguishing between variables, concepts, four types of relationships (attribution, subsumption, process, and aggregation relationships), and outcome metrics, in order to provide clear criteria for structuring the tiers. They also argue in favour of better representing dynamics, and adding new variables and concepts in particular from biophysical sciences.

So far, this theoretical discourse has been shaped primarily by ecologists, economists, and social and political scientists, with only marginal contributions from agricultural sciences. The proposed FOR2432 will contribute to this discourse by drawing from the interdisciplinary repertoire of agricultural research, bundled in the collaborative study of transition processes in the rural-urban interface of Bangalore, as an *in situ* laboratory of change. System-oriented data collection will be one major principal for detecting scale relationships and requires recurrent feedback with the synthesis of results. For example, if due to increasing human demand in a megacity's periphery a certain ecosystem service is exploited (e.g. water provision for irrigation), this might be at the cost of other services (e.g. cultural services of lakes as recreational areas). Some SES variables may be shared not only by different subsystems in the nested tiers, but also by different projects in FOR2432. New ecological rules for agricultural systems in the rural-urban interface may be formulated inductively from the proposed field studies, and in turn be deductively applied to study higher scale SES. In a recent interdisciplinary paper (Cumming et al., 2014) we discuss the effects of intensification-driven transformation processes on ecosystem- and non-ecosystem-service supply and demand as well as on direct and indirect feedbacks between ecosystems and societies in SES. With the data and concepts generated in FOR2432 we will critically examine, elaborate, and push forward this debate within the environmental sciences.

Space, time, and scale dimensions

To ensure and facilitate the integration of results with land use and land cover patterns all projects will share a common research space (Figure 2). We emphasize the use of remote sensing as a powerful tool to capture and analyse landscape patterns, and predict transitions based on geo-referenced data collected at the field or household scale, or on mapped marketing chains, such as for dairy, across scales. In technical terms this will be supported by a joint database for data management, quality control, and long-term storage according to DFG standards (DFG, 2014; see also 'Data handling and communication', p.12) and a specifically established geo-server. A preliminary version of the geo-server has been test-implemented under http://134.76.21.147/maps/26/view.

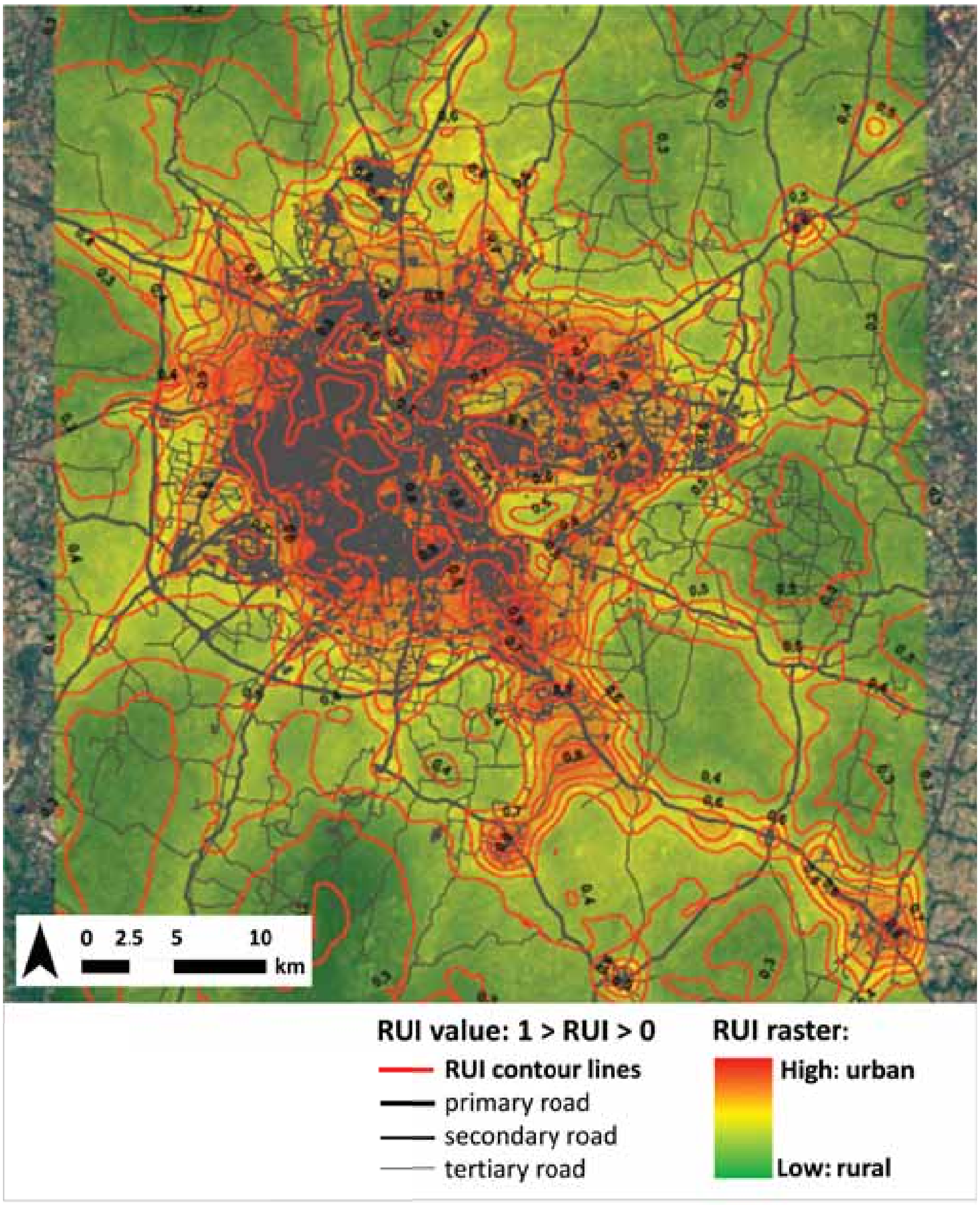

Figure 2. Rural-urban index map of the Greater Bangalore region (India) based on a SPOT6 satellite image of 2013. The full picture is available on the geo-server http://134.76.21.147/maps/26/view.

Defining the common research space: Various approaches are used to characterize the rural-urban interface. Some are based on economic, social, and political indicators, others on the land cover classification inventory of city planning (Ghelfi and Parker, 2001). Related agricultural research (Maxwell, 1995; Binns et al., 2003; Graefe et al., 2008; Predotova et al., 2010a;b) has perceived this space primarily as a specific production environment in which large income opportunities are accompanied by negative externalities. A generic definition of the rural-urban interface has been lacking, as has a quantitative measure that can be used to distinguish it from well characterized rural or urban situations. The rural-urban index (RUI), developed recently by geographers (Schlesinger, 2013), overcomes this problem. Based on remote sensing data, it uses two spatial features, building density and the road network, to construct an index for each grid cell of a satellite image. This index can take a value between zero (totally rural) and one (totally urban). It thus measures the degree of urbanity at a given point in the rural-urban interface and makes it possible to delineate comparable areas. In preparation for the proposed FOR2432 this analysis was performed for the Greater Bangalore region (Figure 2). By connecting cells of equal RUI, a matrix was generated that resembles contour lines or isobars, superimposed on the city map. By correlating spatially explicit data, such as on agricultural intensity, consumer preferences, or environmental functions with the RUI, new insights into the driving forces that urbanisation exerts on SES may be generated.

Approaches to spatio-temporal analysis: Remote sensing has been employed to monitor the growth of cities over time (for Bangalore see Taubenböck et al., 2008; Ramachandra et al. 2012). Historical satellite images may allow extending the spatio-temporal analysis into the past, but are of limited informative value without corresponding ground data from ecological and socio-economic studies. If, however, these data are systematically collected, mapping can augment the investigation of functions and processes to identify, for example, areas of ecosystem service supply and demand (Burkhard et al., 2012), or trade-offs between provisioning and regulating ecosystem services (Ramos-Santiago et al., 2014; Zhang et al., 2015). The correlation of time series of remote sensing data with socio-economic census data reveales an increasing connectivity between social and ecological variables over the past decades, illustrating how interdisciplinary research can be synthesized using the SES-framework (Munoz-Erikson et al., 2014).

The projects in FOR2432 work at different spatial scales to cover the entire chain from production *via* marketing to consumption, and look at drivers, functions, and outcomes. They combine experimental approaches, such as field trials and choice experiments with econometrics and panel surveys, and are thus strongly interlinked. The project structure presented below (Figure 3) takes account of the specific dependencies in the rural-urban interface of Bangalore, such as vegetable and milk production being spatially separated, but both strongly embedded in value chains.

General hypotheses

The guiding questions of this FOR can only be answered by all of its constituent projects collectively. Our research will thereby be driven by the following four General Hypotheses (GH) from which each individual project derives specific hypotheses or research questions:

GH 1:	*Competition for land leads to intensified agricultural production and increases household vulnerability to contingencies and shocks.*
GH 2:	*Conflicts between provisioning, supporting, regulating, and cultural ecosystem services increase with urbanisation.*
GH 3:	*Diversity of exchange processes of goods and services is highest at intermediate stages of transition and decreases again as food systems become more efficient.*
GH 4:	*Ecological constraints and economic opportunities increase with proximity to the urban centre and make decision processes more complex.*

Competition, diversity, and conflicts are major challenges for a large number of individual and institutional actors in the rural-urban interface of a rapidly growing megacity such as Bangalore. As a result, efficiency and complexity are expected to rise in the investigated SES. The mechanisms and institutions of formal and informal governance that emerge from this represent an even higher scaling level and are therefore beyond the scope of the proposed FOR2432. They will, however, be addressed in Phase II of FOR2432 and/or in separately funded Indian partner projects (see below).

Project structure

Research Clusters

In Phase I FOR2432 is structured in three Clusters, each of which comprises projects with more an ecological or a more socio-economic focus, and addresses several of the General Hypotheses listed above.

Cluster A: Intensification and efficiency of resource use

The three projects in Cluster A share a strong focus on experimental agricultural research, and address primarily GH1 and GH2. They work at the field and household level (microscale, with small samples), and aim at providing empirical evidence for agricultural intensification processes in response to urbanisation, in agronomy and crop production (A01, A02) as well as in dairy production (A03). Two agronomic projects (A01, A02) conduct the interdisciplinary plot and field experiments needed for a detailed and comprehensive data set. This allows distinguishing agroecosystems at different intensification stages, in terms of production efficiency (GH1) and trade-offs in ecosystem services (GH2), and predicting biological, physical, and chemical consequences of transitions. The project dedicated to animal husbandry (A03), the main agricultural activity in the inner city of Bangalore, is not only included to cover the full range of agricultural production systems (up to highly specialized forms of landless dairy production, which addresses GH3), but also because of the cultural importance of the dairy sector in India, with corresponding dynamic market channels and consumer preferences. By defining the ecological constraints of agricultural (food) production, all three projects also contribute indirectly to GH4. In the context of FOR2432, Cluster A will provide input data for the economics projects (B03, C04/C05), for ecosystem service assessments (B01), related modelling approaches (B01, B02, C03), and calibration of spectral signatures for remote sensing (C01/C02). Finally, results of Cluster A will be used to derive ‘ecological rules’ for the analysis of SES at higher scales. In the overall scenario of transitions in the rural-urban interface we hypothesize that urbanisation first triggers intensification processes that boost production as well as farmers’ income, until finally agriculture is outcompeted by other forms of land use that displace farmers or encourage them to adopt other livelihoods.

Cluster B: Ecology, economy, and service exchange

Exchange processes maintain the connectivity of ecosystems in a fragmented habitat; they determine the balance between different ecosystem services, and form a bridge between producers and consumers. In that sense, exchange processes act as connectors across time and space, across scales, or between different social and ecological sub-systems. The projects in Cluster B focus on these processes, work at a medium aggregation level, and address GH2, GH3, and GH4. Project B01 assesses the biodiversity associated with the agricultural production systems investigated in the A-Cluster, and evaluates pollination under different management conditions as an exemplary regulating ESS (GH2), but also as a spatio-temporal connector of social and ecological system components (GH3). It extends the field scale of analysis by including neighboring landscape features. Project B02 surveys the socio-economic profiles of households in the rural-urban interface. It includes the crop and dairy farms investigated in the A-Cluster within a much larger sample of 1200 households which will provide representative insights into diversity of livelihoods and social fabric in the rural-urban interface (GH3); it also analyses changing attitudes and preferences, and their influence on decision-making (GH4). Project B03 takes up the dairy production parameters of the farms studied in A03, and incorporates them in the larger context of regional dairy marketing chains. Here, we hypothesize that heterogeneity and efficiency play out as opposing forces (GH3) giving rise to highly non-linear relationships between the extent of urbanisation and the functioning of value chains (GH4). Alltogether, the analyses of tradeoffs and efficiencies in Cluster B are conducted at a higher scale than in the A-cluster. Due to their focus on exchange processes, the B-projects are linked to the A- and C-Cluster by intensive bi-directional data flows.

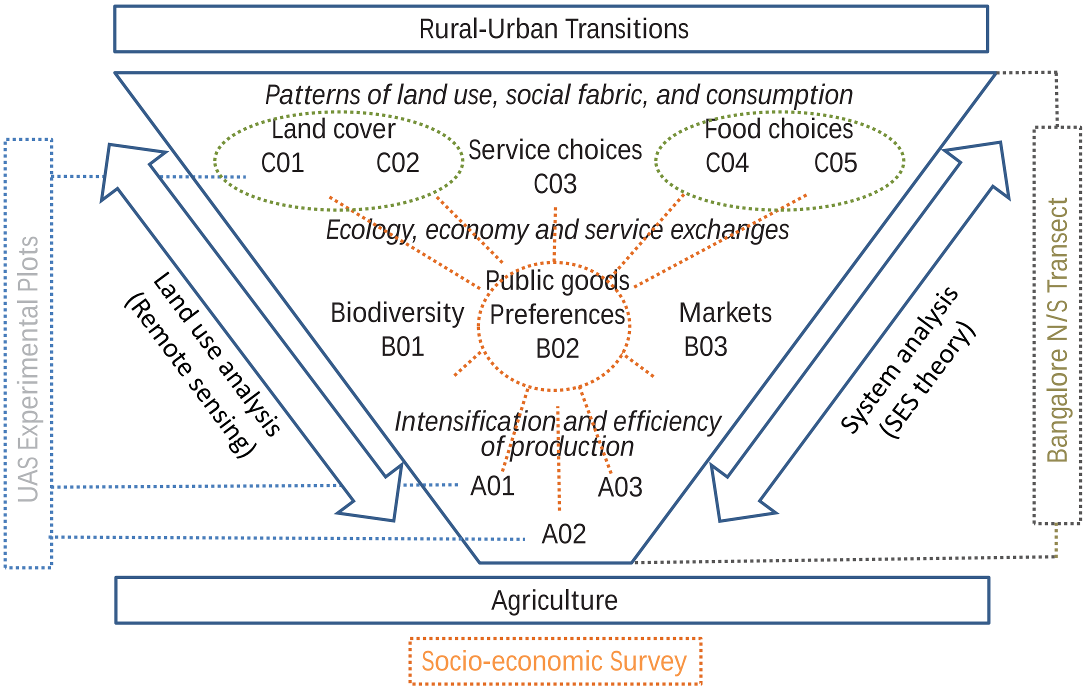

Figure 3. General project structure and integrating concepts of FOR2432: All projects link aspects of agriculture to rural-urban transition processes. The triangular background shape indicates scaling levels, whereby projects using microscale approaches are allocated at the narrow end, and those using macroscale approaches at the wide end. Land use and system analysis are unifying concepts guiding the research across scales and projects. All projects also use the common research transects, indicated by the grey dotted bracket. Projects A01, A02, and C01 jointly establish the experimental plots on the station of the Univarsity of Agricultural Sciences (UAS) Bangalore, as indicated by the blue dotted connectors. Projects C01/C02 and C04/C05 are twin projects (green dotted lines) that work on similar topics, but with different methodological approaches. A large socio-economic survey provides across time panel data of local households to all projects (orange dotted connectors), with different subsamples being investigated in the different contexts. Specificities of information flow and data exchange are detailed in the individual project descriptions.

Cluster C: Patterns of land use, social fabric, and consumption

The outcomes of production and exchange processes ultimately materialise in regional patterns of land use, social fabric, and consumption. Changes in these patterns are important dimensions of the transition process. The projects in this cluster will work across scales, but have a common focus on identifying spatial patterns. They address primarily GH3 and GH4. Projects C01 and C02 employ remote sensing to monitore cropping systems and land use, therefore efficiently exploiting joint data sets (images). In the context of FOR2432, this is a key tool for upscaling the results (C01) of the field and household studies (A-Cluster, B01, B02) and tracing temporal trajectories (C02). These two projects also provide the spatial matrix (based on the RUI) for mapping the results of socio-economic studies (B03, C05, C04), whereby mapping is a key for linking those results to the geophysical/ecological system dimensions. C03 will draw from chemical, bio-physical, and socio-economic data of all other projects and apply a game-theoretical modelling approach to simulate social-ecological transitions. Projects C04 and C05 complement FOR2432 by a consumption-oriented approach to food choices (C04) and food security (C05), building on data input from A01, A03, B01, B02, and B03. They will integrate food system approaches into the wider context of SES. C05 will also coordinate the large sample of 1200 households together with B02.

Synergies expected from the collaborative approach

The key features integrating our research across all clusters and projects are summarized in Figure 3. They are: (i) the common interest in agricultural transformation processes and rural-urban transitions, (ii) the spatial focus on Bangalore as the example chosen for analysis, (iii) joint surveys and experiments, (iv) land use analysis by remote sensing, and (v) a system analysis guided by SES-theory for cross-scale comparisons and synthesis of results. It is this high level of integration which provides added value to each of the participating projects by capturing external parameters and contextualisation that could not be achieved in isolated approaches.

Previous work and specific qualifications of the participating PIs

The proposed FOR2432 will build on established cooperation structures in the agricultural faculties at the universities of Kassel and Göttingen and on complementary scientific profiles in agroecosystems and biodiversity research, land use analysis, and agricultural economics at both universities and with our Indian partners, as detailed in the Annex. All of the participating PIs have reputed expertise as described in the individual project proposals, and some have worked together in previous projects. In the preparatory Phase of FOR2432, the tight networking and the commitment to the SES framework have inspired novel lines of thought that have already led to a first collaborative publication (Cumming et al. 2014).

Collaboration with the Indian partner consortium

The structure of FOR2432 will be mirrored in an associated Indian proposal that comprises a partner project for each of the individual FOR projects, co-funded by DFG's partner institution in India, the Department of Bio-Technology (DBT). Based on field visits to India, the scientific programme has been developed jointly by German and Indian project leaders, such that the research is complementary while avoiding overlaps. Further details on the partnerships are specified in the project descriptions and in the Annex.

Research design

The key features of our integrated research approach are reflected in the operational framework of FOR2432 (Figure 4). First, corresponding to the theoretical concept of nested SES, the comprehensive survey adopts a nested architecture (Figure 4 a, b), such that smaller farm and household samples (chosen for A01, A03) are included in the larger sample sets generated by other

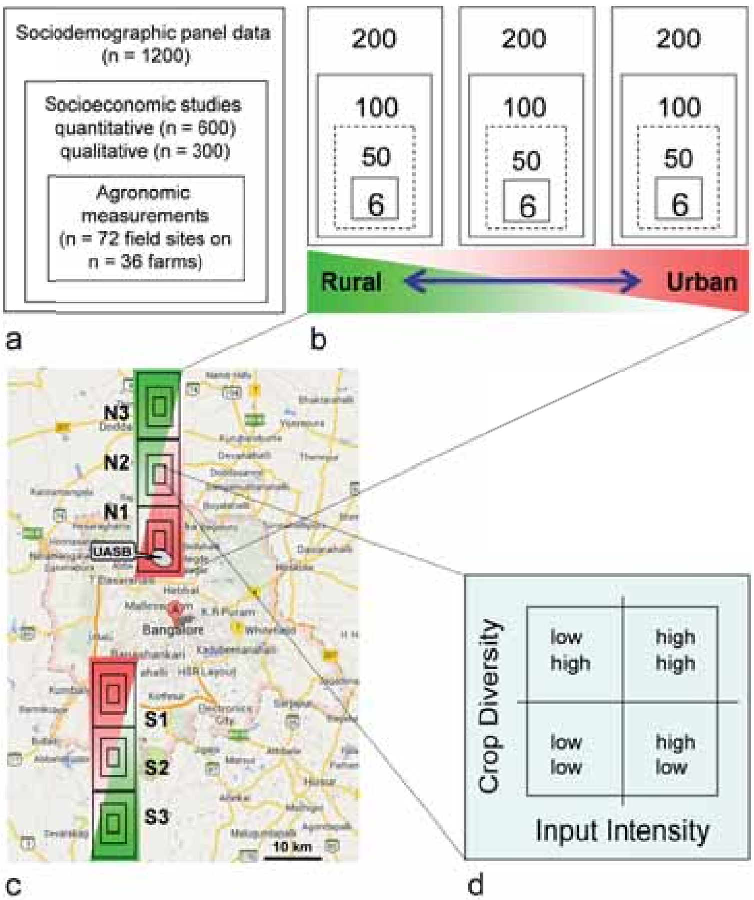

Figure 4. Joint sampling design of FOR2432. (a) Nested design of households/farms included in different project types; n = total number of households in each project type. (b) Distribution of households along a qualitative rural-urban gradient, subdivided in three areas; numbers indicate the study sites selected within each area (for detailed numbers and overlaps of samples see Figure 5). (c) Spatial clustering of sampling sites along two transects in the Bangalore region (northern transect with research areas N1, N2, N3, and southern transect with areas S1, S2, and S3). The final shape and size of the six areas will be based on the RUI-matrix, see Figure 2. (d) Factorial design of on-farm studies of agricultural production systems at the selected study sites (for detailed plot layouts see Figure 6). UASB is the University of Agricultural Sciences Bangalore.

projects (B02, B03, C04, C05). Second, all projects in FOR2432 share a spatial focus (Figure 4 c), successively zooming in from the Greater Bangalore region (C01, C02) to two transects, three areas within each of these transects, and a defined number (specified by the needs of the individual projects) of households, farms, or fields within these areas. Finally, functional processes investigated in the consortium are aligned by the themes of intensification and diversification, which also serve as co-ordinates (Figure 4 d) in the setup of factorial experiments (A01, A02, B01, C01).

Socio-economic panel surveys

Information on socio-economic conditions in Bangalore is available from the Indian government census and academic studies (Balachandra and Reddy, 2013). While these provide valuable background information, it is essential for our intended collaborative research to carry out a comprehensive survey in the target areas of FOR2432. Project B02 will therefore compile socio-economic panel data from 1200 households (900 agricultural and 300 non-agricultural households) along the rural-urban interface of Bangalore at three points in time (Figure 5). The first baseline and some selectively targeted follow-up interviews will be carried out in Phase I of FOR2432 (2016/17). All projects that require smaller household datasets, such as B03 (dairy production and marketing systems) and C04 (food choices), will draw subsamples from this panel. Therefore, a common household questionnaire is required. This will be designed to include questions relevant for each of the three project clusters such as household perceptions of agricultural production factors, biodiversity, food quality, social aspirations, and environmental health (Figure 5). To overcome language barriers, the survey will be conducted by joint teams of German and local Indian PhD students. All collected data will be geo-coded and can thus be mapped to establish a spatial pattern of socio-demographic features. At the same time, aggregation of data collected in individual households over spatial clusters (neighborhoods) or corresponding RUI provides a means for upscaling (Hinkel et al., 2014).

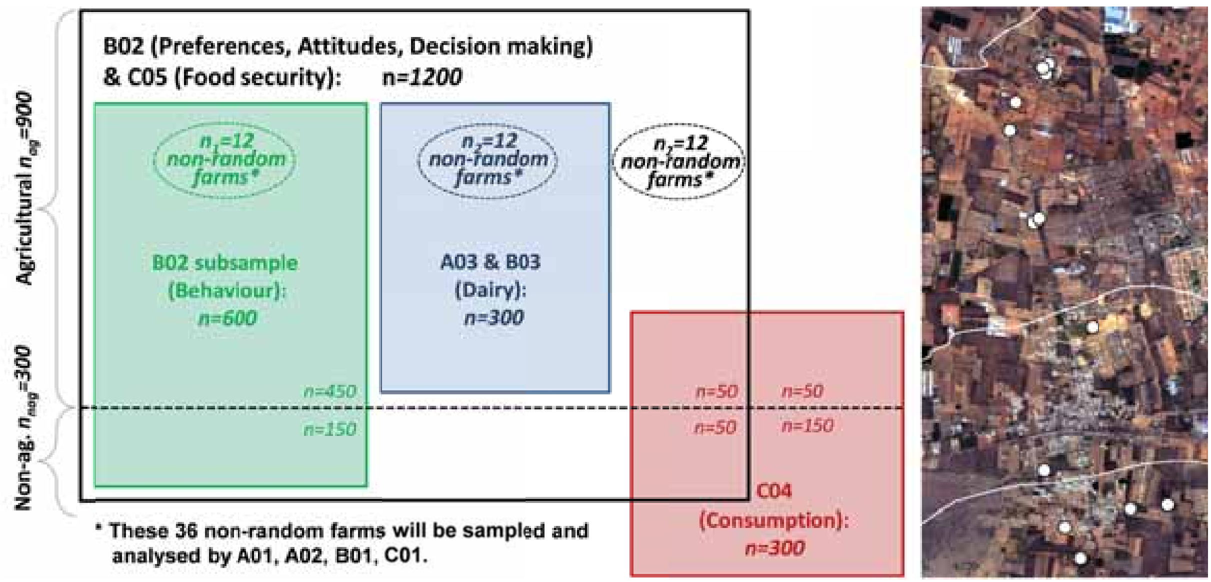

Figure 5. Joint sampling framework showing numbers (n) and overlaps of samples used in different projects. The satellite image to the right gives an exemplary illustration of geo-referenced household positions (white labels O) in different RUI-categories separated by white RUI contour lines (see also Figure 2).

It is often difficult to identify cause-effect relationships using cross-section data due to problems of selection bias. We will revisit sampled households and employ panel analysis methods to overcome these difficulties. Hence, in Phase II of FOR2432, the initial households will be re-interviewed twice (2019/20 and 2021), whereby panel members who have left the study area will be traced or replaced by similar new households. Georeferencing the socio-economic surveys will allow us to analyse patterns and correlations of various social-ecological indices, and, by comparison of different points in time, the dynamics of transitions (Burkhard et al., 2012; Zhang et al., 2015).

Spatial focus and explicity

To analyse changes in the rural-urban interface, FOR2432 will rely in multiple ways on satellite images (jointly acquired by projects C01, C02). These will be used to generate maps, display geo-coded sampling points (see Figure 5), and classify different land uses. Multi-spectral bands provide further information on vegetation cover (C01) or temperature distributon (C02). Novel applications for characterizing crops will be explored in the course of the project C01 to establish a methodology for upscaling observations from the field scale (A01, A02) to the regional scale and back.

Factorial design of agronomic experiments

For an in-depth analysis of lower scale processes, central agronomic field experiments will be conducted on-farm and on-station. They constitute the key platform for projects A01, A02, and B01, and C01. Management intensity (reflected by nitrogen (N)-input and irrigation) and crop diversity are two major factors of land use intensification. Interactions between these factors will be investigated for selected crops and crop rotations that represent important local cropping systems of grains and vegetables, and satisfy the needs of the agronomic as well as the biodiversity-related projects (Table 1). The targeted crops are maize (*Zea mays* L.), finger millet (*Eleusine coracana* Gaertn.), lablab (*Lablab purpureus* L. Sweet), sunflower (*Helianthus annuus L.*), cabbage (*Brassica oleracea* L.), eggplant (*Solanum melongena* L.), tomato (*Solanum lycopersicum* L.), and onion (*Allium cepa* L.).

Table 1. Proposed cropping sequences (year 1 to 3; to be repeated in Phase II of FOR2432) for main plots under irrigated and non-irrigated management in the on-station experiment at UASB, India.

Phase I	**Year 1**		**Year 2**		**Year 3**		Phase II
	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	
Rainfed	Maize	////////////	Millet	////////////	Lablab	////////////	
Irrigated	Maize	Cabbage	Millet	Eggplant	Lablab	Tomato	

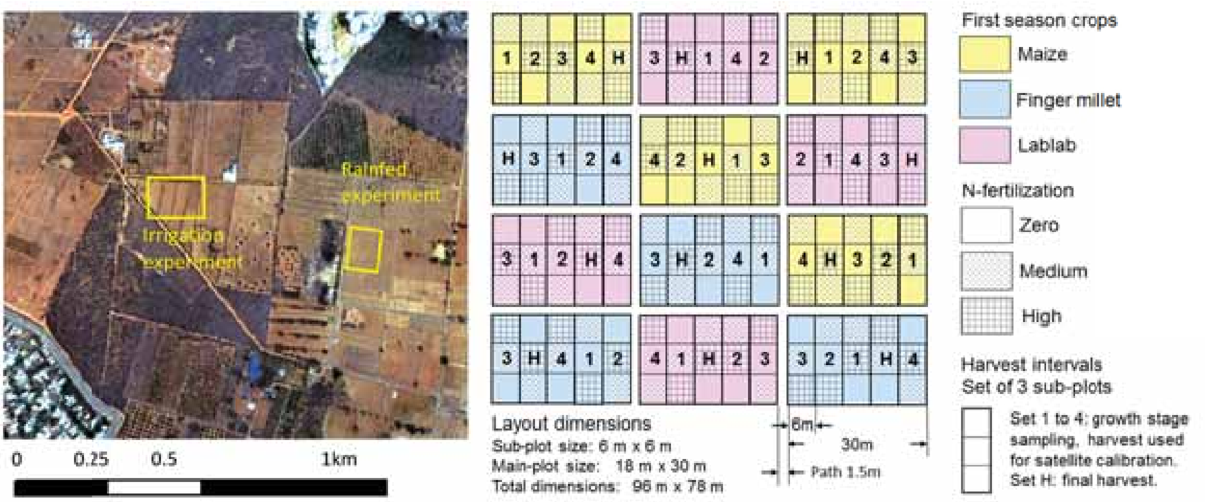

Figure 6. Details of the on-station experiments at UASB, India. (a) Satellite view of the UASB campus indicating the locations foreseen for the experimental plots. (b) Plot layout of the irrigated cropping systems experiment. The first crop is randomly assigned to the main plots; all plots run through two crop rotations in Phase II of FOR2432; three levels of N-fertilisation are applied to sub-plots, sets of three subplots are sequentially harvested in each growth period for crop quality analyses. Sub-plot size allows for at least 4 full pixels in a satellite image. The rainfed experiment is laid out with a corresponding design (not shown).

On-station experiments: Two on-station experiments will be established on plots at the premises of the experimental station of University of Agricultural Sciences, Bangalore (UASB) to back up the on-farm studies (see below). One experiment will be dedicated to investigating the performance of a rainfed cropping system (cropping season May-October) while the other will be used to examine the performance of a representative crop rotation with irrigation during the dry season (November-April) and the wet season (Table 1, Figure 6). Data on seasonal plant growth, matter fluxes, physical and chemical soil parameters will be collected by projects A01, A02, and C01. C01 will further use the plots for calibrating remote sensors.

On-farm studies: For the farmer-managed on-farm experiments, conducted in cooperation with German and Indian scientists, three pairs of farms (households) operating at different intensity will be chosen in the six areas along the two transects. This will result in 36 farms. The two levels of management intensity for water (rainfed *versus* irrigated) will be factorially combined with two diversity levels (monoculture *versus* polyculture) to yield a total of 72 on-farm fields. The crops grown will correspond to the cropping sequence and intensity range of the on-station experiment. Data collection will comprise soil parameters (A01, A02), leaching and volatilisation losses (on selected fields, A01), crop yields (A01, C01), and associated biodiversity (B01). This will allow to link the results to those of the on-station experiment. The selected farms are included as non-random samples in the socio-economic survey carried out by B02 and C05, and also partially overlap with samples in projects B01, B03, C05, and C04.

Data handling and communication

The consortium network is largely based on shared project leaderships, joint field work of the PhD students, and mutual dependence on data exchange between the projects. Hence, regular communication by e-mails, telephone, and personal interactions will be ensured at all stages of FOR2432. The project speaker will maintain the coherence of information flow between Kassel, Göttingen, and Bangalore, supported by key persons at each location, both in day-to-day management and in scheduled project meetings, as specified in the description of the Coordination Module.

FOR2432 will maintain state-of-the-art standards in data handling and policies (DFG, 1998/2013; DFG, 2014). A central database and web-based information system will be hosted by the university computer centres GWDG in Göttingen and ITS in Kassel. This will further ensure that information can be easily shared between projects, reliable backups are maintained, metadata are automatically generated, and data are preserved in acknowledged, long-term archives. A mirror archiving system and regular update schedule will be established with our partners in India. A project website with public and internal domains will serve as an additional communication platform between PIs and project staff, and for the interested public. The website will be linked to the geo-server and the database. The entire IT setup will be under the joint responsibility of the speaker/co-speaker of FOR2432. More detailed information is provided in the Coordination Project (Z) and the Annex.

Research timeline

The present proposal refers to the first 3-year phase (Phase I, 2016-2018) of the proposed FOR2432. The overall scientific and structural planning goals are illustrated in Figure 7. Initially the emphasis will on empirical field work with extensive data collection and integrated SES analysis to identify patterns and processes operating in the rural-urban interface. While methods and research subjects will have to be further developed by the end of Phase I, we anticipate that our initial four overarching research questions and hypotheses will hold for the duration of FOR2432. Structurally, Phase I will be flanked by the establishment of the joint SES professorship at the universities of Kassel and Göttingen, networking with other SES scholars in- and outside Germany and India (e.g. at the Stockholm Resilience Centre), exploring mutual interests and preconditions for an Indo-German RTG, and the setup of a Rural-Urban Center at Bangalore by our Indian partners.

Intensification of agriculture and livestock production is typically associated with increasing application of pesticides and increasing administration of veterinary antibiotics (VA). Since most of the VA are largely excreted unchanged (Halling-Sørensen et al. 1998) and manure is spread onto agricultural fields as fertilizer, both pesticides and veterinary antibiotics may be found in soils and may be exported to surface waters (Schwarzenbach et al. 2006). Some of the surface waters in the agricultural areas of the Bangalore Region such as the Arkavathi River are used for the city's water supply (Lele et al., 2013). Thus, the raw drinking water of Bangalore is vulnerable to contamination by pesticides and VA. Therefore, in the second phase of the FOR, we will investigate the current state of surface water contamination by pesticides and VA along the rural-urban gradient. Farmer questionnaires will help identifying the most relevant substances and their application amounts. Future trends of water contamination by these substances will be estimated using intensification scenarios and catchment scale reactive transport modelling.

In Phase II (2019-2021) we will further extend our research scope to address issues such as resource economics, and governance, including approaches to model transformation processes, project different trajectories of development, and explain spatial shifts in the rural-urban interface. The scientific capacity for these additional topics will be built up until 2018 as vacancies or new professorships will be used to appoint staff with high potential for joining Phase II of FOR2432. Furthermore, the involvement of more distant disciplines, such as urban planning and political sciences will be considered at that stage. Depending on the work experience gathered in Phase I we may consider including another Indian city.

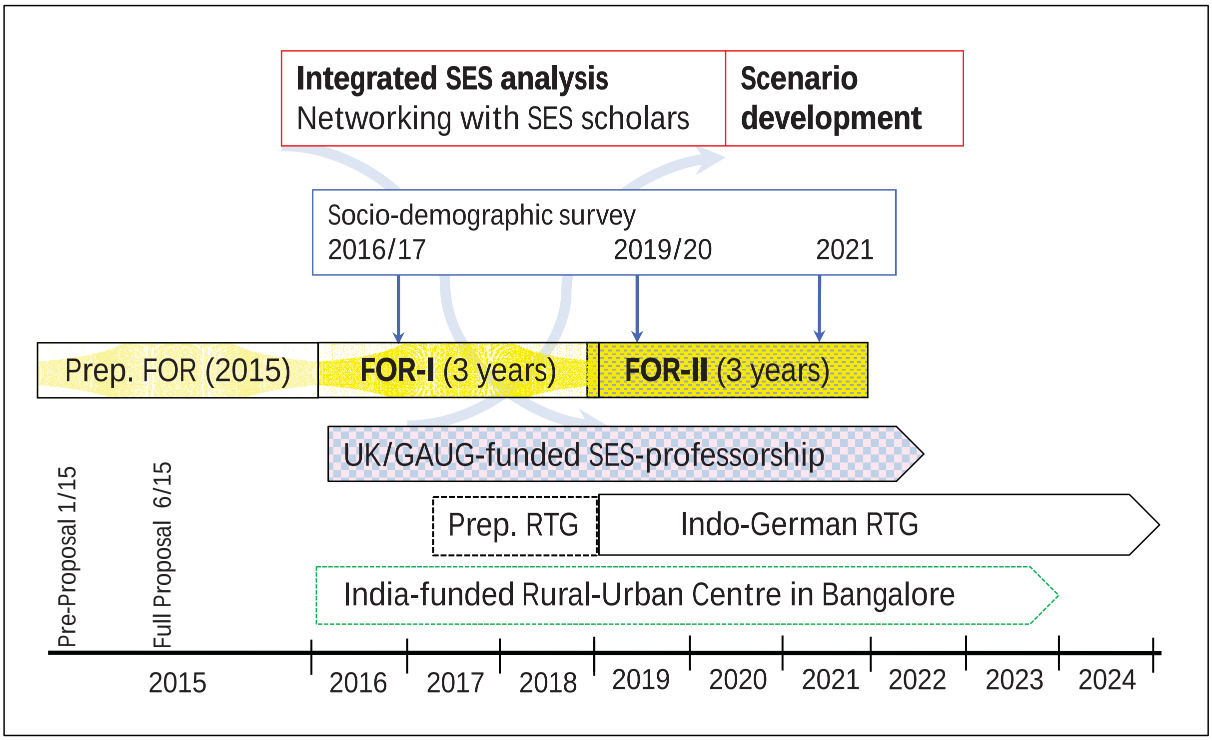

Figure 7. Timeline of Phase I (FOR2432/1) and Phase II (FOR2432/2) showing scientific and structural planning goals.

Expected short-term and long-term results

In Phase I of FOR2432 we will compile a comprehensive interdisciplinary dataset under a coherent theoretical framework, which to our knowledge is unique in terms of extent and disciplinary depth. This dataset will enable us to carry out cross-scale analyses in Phase I, and provide a basis for the generation of longitudinal/panel data in Phase II. Our hypothesis-driven approach, and the systematic interaction of agronomic sciences, economics, and ecology will allow us to advance methodologies for interdisciplinary research, and generate results that can be properly published.

FOR2432 will not only build on existing scientific expertise, it will also make a significant contribution to further developing the research profile of the participating universities. The most important contribution in this regard is the anchoring of SES-theory in agricultural sciences. This will be supported jointly by the universities of Kassel and Göttingen, which have committed themselves to establishing a joint W2-faculty position ‘Social-Ecological Interactions in Agricultural Systems’ if FOR2432 is approved (see annex). This scientific goal shall substantiate the self-concept of agricultural sciences as a systems science and open up new avenues for basic research. In Phase II, FOR2432 will be able to capture the dynamics of transition processes by real-time observation and validate projected scenarios against reality.

FOR2432 will also further strengthen the early carreer support and equal opportunity policies established at both universities. FOR2432 will strive to involve and promote young scientists, and encourage female researchers at all career stages with an array of measures that are detailed in the Annex. In Phase I of FOR2432 all PhD candidates will be integrated in existing graduate schools and will have access to state-of-the-art mentoring and training programmes. Participation of FOR2432 scientists in these measures will be monitored by the speaker team.

As the first Indo-German project with a partner consortium fully co-funded by two national donors, FOR2432 is backed up by an agreement between DFG in Germany and the Department of Bio-Technology (DBT) in India, and a Memorandum of Agreement between the German and Indian cooperating institutions. It is thus also a pioneer project in a wider political sense (Joseph and Robinson, 2014), enhancing Indo-German collaboration in research and academic education (see Annex).

Tabular project overview

Code	Project Title	German PIs	*Research area and field of work*
A	**Intensification and efficiency of resource use in production systems**		
A01	Intensification effects on matter flows in rural-urban cropping systems	A. Bürkert B. Ludwig	*Crop production, environ-mental chemistry, nutrient management, spatial analysis*
A02	Effects of land use intensification and soil management practices on field water cycles and water use efficiency	S. Peth	*Soil physics*
A03	The relevance of nutrient management and primary and functional traits for dairy production in an urbanising environment	E. Schlecht S. König	*Animal husbandry, ruminant nutrition, animal breeding*
B	**Ecology, economy, and service exchanges**		
B01	Agricultural biodiversity and associated services across rural-urban landscapes – field and modelling studies	K. Wiegand T. Tscharntke I. Grass	*Landscape ecology, modelling, crop pollination, agroecology, community ecology*
B02	Preferences, decision-making behaviour of households, and public good provision	M. Wollni O. Musshoff	*Agricultural economics, rural development*
B03	Economic efficiency of dairy production and marketing: A comprehensive value chain approach	B. Brümmer	*Agricultural economics*
C	**Patterns of land use, social fabric, and consumption**		
C01	Assessment of structural and functional characteristics of cropping systems using advanced terrestrial, air-, and space-borne remote sensing applications	M. Wachendorf	*Agronomy, crop modelling, remote sensing*
C02	Spatio-temporal land use patterns in the rural-urban interface	C. Kleinn	*Forestry, remote sensing*
C03	Spatial modelling of individual service choices and their implications for social-ecological transitions	G.S. Cumming K. Wiegand S. von Cramon	*SES-Theory*
C04	Sustainable food consumption practices of middle class consumers	C. Dittrich	*Human geography, food systems*
C05	Patterns and determinants of nutrition and food security in the rural-urban interface	S. Klasen S. von Cramon	*Agricultural economics, food systems*
Z	Coordination	A. Bürkert S. von Cramon	*Coordination*

References

Angel, S. Sheppard, S.C. and Civo, D.L. 2005. The dynamics of global urban expansion. Washington, DC.

Anonymous, 2014. http://1.bp.blogspot.com/_x3SfPgpfzSA/TRAmZgOOQUI/AAAAAAAAAHg/MMMvm8Ns0L0/s1600/urban_rural_popup.jpg

Balachandra, P. and Sudhakara Reddy, B. 2013. Benchmarking Bangalore City for sustainability – An indicator-based approach. South Asia Network of Economic Research Institutes, Sanei working paper series, 13-02. http://www.saneinetwork.net/Files/1212201303584913_02.Final.BSReddy.IGIDR.TNS.pdf

Biggs, R., Carpenter, S.R. and Brock, W.A. 2009. Turning back from the brink: Detecting and impending regime shift in time to avert it. Proceedings of the National Academy of Sciences of the USA 106, 826-831.

Bilsborrow, R.E. 2002. Migration, population change, and the rural environment. ECSP Report 8, 69-94. http://wilsoncenter.org/sites/default/files/Report_8_BIlsborrow_article.pdf.

Binns, J.A., Maconachie, R.A. and Tanko, A.I. 2003. Water, land and health in urban and peri-urban food production: the case of Kano, Nigeria. Land Degradation and Development 14, 431-444.

Bruntland Commission, 1987. Our Common Future. Report of the World Commission on Environment and Development. Published as Annex to General Assembly document A/42/427. http://www.un-documents.net/wced-ocf.htm

Burkhard, B., Kroll, F., Nedkov, S. and Müller, F. 2012. Mapping ecosystem service supply, demand and budgets. Ecological Indicators 21, 17-29.

Cosier, M. and Shen, D. J. 2009. Urban water management in China. International Journal of Water Resources Development 25, 249-268.

Cumming, G.S. 2011. Spatial resilience: integrating landscape ecology, resilience, and sustainability. Land-scape Ecology 26, 899-909.

Cumming, G.S., Buerkert, A., Hoffmann, E.M., Schlecht, E., von Cramon-Taubadel, S. and Tscharntke, T. 2014. Implications of agricultural transitions and urbanization for ecosystem services. Nature 515, 50-57.

Cumming, G.S. 2008. Spatial Resilience in Social-Ecological Systems. Springer, Dordrecht, Heidelberg, London, New York.

DFG. 1998/2013. Proposals for Safeguarding Good Scientific Practice. Recommendations of the Com-mission on Professional Self-Regulation in Science. http://www.dfg.de/download/pdf/dfg_im_profil/reden_stellungnahmen/download/empfehlung_wiss_praxis_1310.pdf.

DFG. 2014. Reusing research data. Suggestions and examples of best practice. http://www.dfg.de/foerderung/antragstellung_begutachtung_entscheidung/antragstellende/antragstellung/nachnutzung_forschungsdaten/.

Eigen, M. and Schuster, P. 1977. The Hypercyle - A Principle of Natural Self-Organization. Naturwissenschaften 64, 541-565.

Elmqvist, T., Redman, C.L., Barthel, S. and Costanza, R. 2013. History of urbanisation and the missing ecology. Chapter 2, In: Elmqvist, T. et al. (eds.) 2013. Urbanisation, Biodiversity and Ecosystem Services: Challenges and Opportunities. A Global Assessment, 13-30. DOI 10.1007/978-94-007-7088-1_1.

Epstein, G., Vogt, J.M., Mincey, S.K., Cox, M. and Fischer, B. 2013. Missing ecology: Integrating ecological perspectives with the social-ecological system framework. International Journal of the Commons 7, 432-453.

Fedick, S.L. 1997. The Managed Mosaic: Ancient Maya Agriculture and Resource Use. University of Utah Press, Salt Lake City, UT, USA. 360 p.

Folke, C., Colding, J. and Berkes, F. 2003. Synthesis: Building resilience and adaptive capacity in social-ecological systems. In: Berkes, F., Colding, J., Folke, C. (Eds.), Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, 352-387.

Ghelfi, L.M. and Parker, T.S. 2001. A county-level measure of urban influence. Rural Development Perspectives 12 32-41.

Glaeser, E.L. 2013. A world of cities: The causes and consequences of urbanization in poorer countries. NBER Working Paper No. 19745. http://www.nber.org/papers/w19745. Harvard University, Cambridge, and NBER, MA, USA.

Government of India, Ministry of Home Affairs 2011. Census 2011.

Graefe, S., Schlecht, E. and Buerkert, A. 2008. Opportunities and challenges of urban and peri-urban agriculture in Niamey, Niger. Outlook on Agriculture 37, 47-56.

Hall, A.D. and Fagen, R.E. 1956. Definition of Systems. General Systems (Yearbook of the Society for the Advancement of General Systems Theory) 1, 18-28.

Halling-Sørensen, B., Nors Nielsen, S., Lanzky, P.F., Ingerslev, F., Holten Lützhøft, H. C., Jørgensen, S.E., 1998. Occurrence, fate and effects of pharmaceutical substances in the environment- A review. Chemosphere 36 (2), 357–393.

Hinkel, J., Bots, P.W.G. and Schlüter, M. 2014. Enhancing the Ostrom social-ecological system framework through formalization. Ecology and Society 19, Article no. 51.

Holling, C.S. 1987. Simplifying the complex: The paradigms of ecological function and structure. European Journal of Operational Research 30, 139-146.

Holling, C.S. 2001. Understanding the complexity of economic, ecological and social systems. Ecosystems 4, 390-405.

Holling, C.S. and Gunderson, L.H. 2002. Panarchy: Understanding transformations in human and natural systems. Island Press, Washington, DC, USA.

Huang, J., Zhang, H.-L., Tong, W.-J. and Chen, F. 2012. The impact of local crops consumption on the water resources in Beijing. Journal of Cleaner Production 21, 45-50.

Jedwab, R., Christiaensen, L. and Gindelsky, M. 2014. Demography, urbanization and development: Rural push, urban pull and... urban push? Working Paper, Department of Economics, George Washington University, Washington DC, USA. http://home.gwu.edu/~jedwab/JGC_Sept2014.pdf

Joseph, M. and Robinson, A. 2014. Free Indian science. Nature 508, 36-38.

Kastens K.A., Manduca, C.A., Cervato, C., Frodeman, R., Goodwin, C., Liben,L.S., Mogk, D.W., Spangler, T.C., Stillings, N.A. and Titus, S. 2009. How Geoscientists Think and Learn. Eos, Transactions 90(31), 265-266.

Kraas, F. and Mertins, G. 2014. Megacities and global change. In: Kraas, F. et al. (eds.) 2014. Megacities: Our Global Urban Future. International Year of Planet Earth, DOI 10.1007/978-90-481-3417-5_1.

Kurakin, A. 2011. The self-organizing fractal theory as a universal discovery method: The phenomenon of life. Theoretical Biology and Medical Modelling 8, 4.

Lele, S., Srinivasan, V., Jamwal, P., Thomas, B. K., Eswar, M., Zuhail, T. Md, 2013. Water management in Arkavathy basin: A situation analysis. Environment and Development Discussion Paper No.1. Bengaluru: Ashoka Trust for Research in Ecology and the Environment.

Maciejewski, K., De Vos, A., Cumming, G.S., Moore, C. and Biggs, D. 2014. Cross-scale feedbacks and scale mismatches as influences on cultural services and the resilience of protected areas. Ecological Applications 25(1), 2015, 11-23.

Maxwell, D. 1995. Alternative food security: A household analysis of urban agriculture in Kampala. World Development 23, 1669-1681.

McDonald, R.I., Marcotullio, P.J. and Güneralp, B. 2013. Urbanisation and global trends in biodiversity and ecosystem services. Chapter 3, In: Elmqvist, T. et al. (eds.) 2013. Urbanisation, Biodiversity and Ecosystem Services: Challenges and Opportunities. A Global Assessment, 13-30. DOI 10.1007/978-94-007-7088-1_1.

McGinnis, M. and Ostrom, E. 2012. SES framework: initial changes and continuing challenges. Working Paper W11-6, http://www.indiana.edu/~workshop/publications/materials/W11-6_McGinnisEO.pdf

Munoz-Erikson, T.A., Lugo, A.E. and Quintero, B. 2014. Emerging synthesis themes from the study of social-ecological systems of a tropical city. Ecology and Society 19(3), 23.

Nair, J. 2005. The Promise of the Metropolis: Bangalore's Twentieth Century. Oxford University Press, USA

Narayana, M.R. 2011. Globalization and urban economic growth: Evidence for Bangalore, India. International Journal of Urban and Regional Research 35, 1284-1301.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences of the United States of America 104, 15181-15187.

Ostrom, E. 2009. A general framework for analysing sustainability of social-ecological systems. Science 325, 419-422.

Pickett, S.T.A., McGrath, B., Cadenasso, M.L. and Felson, A.J. 2014. Ecological resilience and resilient cities. Building Research and Information 42 (2), 143-157.

Predotova, M., Schlecht, E. and Buerkert, A. 2010b. Nitrogen and carbon losses from dung storage in urban gardens of Niamey, Niger. Nutrient Cycling in Agroecosystems 87, 103-114.

Predotova, M., Gebauer, J., Diogo, R.V.C., Schlecht, E. And Buerkert, A. 2010a. Emissions of ammonia, nitrous oxide and carbon dioxide from urban gardens in Niamey, Niger. Field Crops Research 115, 1-8.

Prigogine, I. 1978. Time, structure and fluctuations. Science 201, 777-785.

Ramachandra, T.V., Aithal, B.H. and Sanna, D.D. 2012. Insights to urban dynamics through landscape spatial pattern analysis. International Journal of Applied Earth Observation and Geoinformation 18, 329–343.

Ramos-Santiago, L.E., Villanueva-Cubero, L., Santiago-Acevedo, L.E. and Rodriguez-Melendez, Y.N. 2014. Green area loss in San Juan's inner-ring suburban neighborhoods: A multidisciplinary approach to analyzing green/gray area dynamics. Ecology and Society 19, Article no. 4.

Rhoda, R. 1983. Rural development and urban migration: Can we keep them down on the farm? International Migration Review 17, 34-64.

Rockstrom, J. et al. 2009a. A safe operating space for humanity. Nature 461, 472-475, doi:10.1038/461472

Rockstrom, J. et al. 2009b. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society 14(2), 32.

Schlesinger, J. 2013. Agriculture along the rural-urban continuum: A GIS-based analysis of spatio-temporal dynamics in two medium-sized African cities. PhD thesis, University of Freiburg, Germany.

Schwarzenbach, R.P., Escher, B.I., Fenner, K., Hofstetter, T.B., Johnson, C.A., Gunten, U. von, Wehrli, B., 2006. The Challenge of Micropollutants in Aquatic Systems. Science 313 (5790), 1072–1077.

Seto, K.C., Parnell, S. and Elmqvist, T. 2013. A global outlook on urbanisation. In: Elmqvist, T. et al. (eds.) 2013. Urbanisation, Biodiversity and Ecosystem Services: Challenges and Opportunities. A Global Assessment. DOI 10.1007/978-94-007-7088-1_1.

Sorensen, A. and Okata J. 2010. Megacities: Urban Form, Governance and Sustainability, Springer, New York, USA.

Sridhar, K.S., Reddy, A.V. and Srinath, P. 2010. Is it push or pull? Recent evidence from migration in India. Final Report No. 10-04, South Asia Network of Economic Research Institutes. http://saneinetwork.net/Files/10_04___K_S_Sridhar.pdf.

Steffen et al. 2011. The Anthropocene: From global change to planetary stewardship. AMBIO 40, 739-761.

Sundstrom, S.M., Angeler, D.G., Garmestani, A.S., Garcia, J.H. and Allen, C.R. 2014. Transdisciplinary application of cross-scale resilience. Sustainability 6, 6925-6948.

Tacoli, C. 1998. Rural-urban interactions: A guide to the literature. Environment and Urbanization 10, 147-166.

Taubenböck, H., Wegmann, M., Berger, C., Breunig, M., Roth, A. and Mehl, H. 2008. Spatiotemporal analysis of Indian mega cities. In: Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS). Vol. XXXVII. Part B2. Beijing 2008, 75-82.

UNDP (United Nations Development Programme) 2011. Human Development Report 2011. Availabe at: http://hdr.undp.org/en/media/HDR_2011_EN_Table3.pdf.

Vinayakam, K. and Sekar, S.P. 2013. Rural to urban migration in an Indian metropolis: A case study of Chennai City. Journal of Humanities and Social Science 6, 32-35.

WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen) 2011. Welt im Wandel – Gesellschaftsvertrag für eine Globale Transformation, Berlin. Available at: http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/jg2011/wbgu_jg2011.pdf.

Young, A. 2013. Inequality, the urban-rural gap, and migration. The Quarterly Journal of Economics 128, 1727-1785.

Zhang, K., Dearing, J.A., Dawson, T.P., Dong, X., Yang, X. and Zhang, W. 2015. Poverty alleviation strategies in eastern China lead to critical ecological dynamics. Science of the Total Environment 506/507, 164-181.

Indo-German project collaborations in FOR2432/1

Code	Indian Project	PIs	German co-project
A	**Intensification and efficiency of resource use in production systems**		
I-A01	Soil and water quality in agricultural systems along the rural-urban interface	V.R.R. Parama A. Bürkert B. Ludwig	Intensification effects on matter flows in rural-urban cropping systems
I-A02	Effects of agricultural water and nutrient management on farmers livelihoods	A. Sathish, B.K. Ramachandrappa S. Peth	Effects of land use intensification and soil management practices on field water cycles and water use efficiency
I-A03	Optimized use of feed resources for high lifetime productivity of dairy cows and consequences on enteric CH_4 release	R. Bhatta E. Schlecht S. König	The relevance of nutrient management and primary and functional traits for dairy production in an urbanising environment
B	**Ecology, economy, and service exchanges**		
I-B01	Plant and insect diversity in agro-eco-systems along the rural-urban interface and Mapping of bee species distribution in agriculture systems under transition	K.N. Ganeshaiah S. Devy K. Wiegand, T. Tscharntke I. Grass	Agricultural biodiversity and associated services across rural-urban landscapes – field and modelling studies
I-B02	Attitudes and decisions of agricultural households in the rural-urban interface: A survey and comparative analysis	M.S. Nataraju K.C. Lalitha M. Wollni O. Musshoff	Preferences, decision-making behaviour of households, and public good provision
I-B03	Effects of urbanization on value chains and livelihoods of farmers and other stakeholders	G.N. Nagaraja B.V.C. Reddy B. Brümmer	Economic efficiency of dairy production and marketing: A comprehensive value chain approach
C	**Patterns of land use, social fabric, and consumption**		
I-C01	Integrating air- and space borne spectroscopy and laser scanning to assess structural and functional characteristics of crops and field margin vegetation	R.R. Nidamanuri S. Nautiyal M. Wachendorf	Assessment of structural and functional characteristics of cropping systems using advanced terrestrial, air-, and space-borne remote sensing applications
I-C02	Spatio-temporal land use patterns and the relationship between green areas and biophysical and socio-economic features	B.N. Diwakara V.P. Tewari C. Kleinn	Spatio-temporal land use patterns in the rural-urban interface
I-C03	Ecosystem services, agricultural diversification and the smalholders' livelihood in Bangalore	S.Purushothaman S. Devy G.S. Cumming K. Wiegand S. von Cramon	Spatial modelling of individual service choices and their implications for social-ecological transitions
I-C04	Urbanization effects on consumption patterns, dietary diversification, and human nutritional status in Bangalore	D. Vijayalakshmi C. Dittrich	Sustainable food consumption practices of middle class consumers
I-C05	Food insecurity at different stages of urbanization	K.B. Umesh B.V.C. Reddy S. Klasen S. von Cramon	Patterns and determinants of nutrition and food security in the rural-urban interface
	I-Coordination	B.V.C. Reddy K.N. Ganeshaiah A. Bürkert S. von Cramon	Coordination