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

FOR2432 Seminar Series 2022

Online sessions via Zoom
Every other Friday, 09:30-11:30
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Regular format: 30 min talk plus 10 min discussion for Presenter 1, 30 min talk plus 10 min discussion for Presenter 2, plus 20 min overarching discussion

Contributions for each session will be announced and Zoom-links provided by round-mails three days prior to the meeting dates

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Agricultural biodiversity and associated functions and services across rural-urban landscapes

Gabriel Marcacci

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Urbanization is one of the greatest threats to biodiversity and food security, as expanding cities, especially in the Global South, increasingly compete with natural and agricultural lands. Yet, the impact of urban expansion on agricultural biodiversity and associated functions and services in tropical regions is overlooked. We studied the effects of urbanization on farmland birds and bees across three seasons in 36 conventional vegetable-producing farms spread along an urbanization gradient in Bengaluru, a South Indian megacity. We found that urbanization was a major driver of taxonomic and functional homogenization of farmland bird communities, with particular losses of functionally important groups such as insectivores of crop pests, potentially threatening important ecosystem services such as biological pest control. Moreover, urbanization reduced functional redundancy of bird communities, which may further weaken ecosystems resilience to future perturbations. Bee responses to urbanization were trait specific, with some contrasting results from studies conducted in temperate regions. Furthermore, agricultural management practices such as crop diversification and the preservation of semi-natural habitats (e.g., hedges, field margins with native flowering plants) promoted taxonomic and functional diversity of bee communities. This suggests that urban agriculture can support functionally diverse bee communities and, if managed in a sustainable manner, can be used to develop win-win solutions for biodiversity conservation of pollinators and food security in and around cities. These two studies demonstrate the importance to consider different taxonomic groups (e.g., birds and bees) as they can respond to urbanization in opposite ways.

Perceived importance of ecosystem services around green spaces in the rural-urban interface of Bengaluru, India

Pramila Thapa
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Urbanization is a major anthropogenic process with often irreversible impacts on wellbeing of a society. With the increasing trend of urbanization globally, there are ongoing discussions on roles of green infrastructure to solve societal challenges. Existence of green spaces mostly decreases with increasing degree of urbanity, and their degradation is even worse in megacities of the Global South such as in Bengaluru. In Bengaluru, many tree species have specific local purposes and meaning shaped by the cultural background and livelihood of the residents. However, dynamics of multiple ecosystem (dis)services provided by the green spaces along rural-urban gradients are less explored.

Using the five most common types of green spaces in Bengaluru (domestic tree space, farm tree space, street tree space, platform tree space and temple tree space), and considering three tree species per tree space that are commonly chosen for its design locally, we carried out a photo-elicitation survey to assess the relative importance of the different green spaces for ecosystem (dis)services supply as perceived by the local community. We used different sets of photographs depicting those green spaces with different tree species and surveyed 649 residents from 61 villages across two transects along the rural-urban gradient. When we asked if ecosystem (dis)services were perceived differently among the tree spaces, we found those differences were statistically significant ($p<0.001$). We also found that regulating and cultural services were more appreciated at the urban end of the gradient, provisioning services were more appreciated in transitional areas, and disservices were more reported in the rural region. As for the socio-cultural factors, we found that the respondents being females, of age group 30-59, illiterate or without formal education or having at least diploma degree, being from scheduled class or tribe, and having agriculture as an income source rated provisioning services higher than other categories of the social factors. Respondents being males, of age groups 30-59 and 19-29, formal education, being from scheduled class or tribe or Other Backward Class (OBC) and having agriculture as an income source rated regulating services higher than other categories of the social factors. Respondents being males, of age group 30-59, illiterate or without formal education or having at least diploma degree, being from scheduled class or tribe or from OBC, and having agriculture as an income source rated cultural services higher than other categories of the social factors. Respondents being males, from respondents up to 12th class or illiterate or without formal education, being from scheduled class or tribe, and not having agriculture as an income source rated disservices higher than other categories of the social factors. Our results contribute to a better understanding of the use of green spaces in rural-urban dynamics and may inform relevant policies. Understanding the differences in use of green spaces by different groups of people would facilitate inclusive management, policy making and governance of the green spaces.

Effects of heat stress across the rural-urban interface on phenotypic trait expressions of dairy cattle in a tropical savanna region

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Among all livestock systems in tropical regions, the dairy sector is facing huge challenges to sustain productivity under the rapidly changing climatic conditions. To date, there is a lack of knowledge on combined effects of climate, season, and farm location on trait responses in different cattle breeds. This study presents a novel approach to assess the impact of several climatic and geographical factors on production traits, energy efficiency indicators, as well as hygiene traits in dairy cattle reared across the rural-urban interface in the tropical savanna region of Bengaluru, a rising megacity in southern India. In total 96 cattle were selected across Bengaluru's rural urban interface, reflecting a broad variety of social-ecological systems. The traits considered included test day milk yield (MY), body condition score (BCS), body weight (BW), hock assessment score (HAS), udder hygiene score (UHS) and upper leg hygiene score (ULHS). Apart from the cow-related factors like breed, lactation stage, lactation number and milking frequency, the environmental classification variables season, farm location as expressed by the survey stratification index (SSI), and temperature humidity index (THI), significantly affected most of the traits, with some indications for breed by environment interactions. In particular, season significantly influenced the production and hygiene traits. Further, an evident breed variation was also observed for the seasonal influence on BW, wherein exotic cows had a higher BW than crossbreds during summer season. The distinct trend of SSI in its influence on most of the traits highlights that cows housed in urban areas had better trait expression than in rural areas, thereby revealing a predominant role of management. The THI had a significant effect on MY, BCS and HAS, and THI = 75 was identified as heat stress threshold. The results indicate the importance of considering ecological, social and climatic factors simultaneously, in order to improve primary and functional breed-specific traits of dairy cattle reared in challenging environments.

Modelling bird distributions for Bengaluru

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Knowing where species are is a key interest of ecologists, but field research on species distributions is limited by time and cost constraints. The recently developed *spectre* software (Simpkins et al., 2021) predicts species distributions from estimated α- and β-diversity, but was only tested with input data free from error. Bird data collected within two research transects in Bengaluru, India was utilized for two use cases. In a fist use case, we tested how uncertainty in *spectre-* inputs affected predicted bird occurrences. We linked the bird data to environmental predictors (land cover) derived from satellite imagery. One part of the bird data was used to parameterize the α- and β-diversity models, whereas the other part was used to evaluate the predictions made by the *spectre* software. In a second use case, the usefulness of the new software was demonstrated by predicting bird distributions for new sites located within both transects. Predictions were most sensitive to uncertainty in estimated β-diversity, and predictions for new sites indicated a decline of insectivore richness across the whole transects. Our study demonstrated the usefulness of the new *spectre* software as a tool to predict species distributions from sparse observational data for new areas.

08.04.2022
https://uni-kassel.zoom.us/j/91982916144?pwd=Rnh6NmVtdDJ4N2pjK0NkZ01hNjBDUT09
Meeting ID: 919 8291 6144 / Passcode: 535221

The status of Bengaluru's groundwater system as revealed through its borewells

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Over-exploitation of groundwater in India's fastest-growing metropolis, Bengaluru, has resulted in wells being bored to unprecedented depths in a crystalline-rock aquifer. However, key questions about the sustainability of this extraction process remain unaddressed due to the complexity of monitoring. Using primary surveys, this study traced the spatio-temporal evolution of the wells on a city scale, finding that catchments with deficient water infrastructure have deeper wells. To maintain yields, wells with depths >400 m are drilled, especially since 2000, leading to unsustainable groundwater extraction. Camera inspections in 54 wells at Electronic City in 2016 and 2017 revealed that water levels in the majority of the wells remained lower at depths <100 m, although some wells had deeper water levels at depths >250 m. Analysis of $\delta^{18}O$ and $\delta^{2}H$ signatures of groundwater samples at all depths followed the local meteoric water line indicating recent recharge, implying that drilling deeper only increases the borehole volume and does not tap into newer water sources. Water levels in deeper wells may stabilize at lower depths, and are subject to high spatial variability, density of drilling, and high connectivity in upper zones. Given the interconnectedness between shallow and deeper aquifers, our research shows that increasing borewell depths could be a good indicator for falling aquifer water levels. This study fills an important gap in peri-urban, intermediate-scale aquifer conceptualizations across different land uses and provides further evidence for the difficulties of reliable groundwater monitoring in the over-exploited hard-rock aquifers of Bengaluru city.

Covid-19 and agricultural management in the rural-urban interface of Bengaluru

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Lockdowns in response to the spread of the novel Corona virus caused major disruptions of agricultural and labour markets, with potentially devastating effects for the livelihoods of farm households in developing countries. At the same time, the number of reported Covid-19 infections during lockdown periods in many developing countries was very low and case numbers rose considerably only after the lockdowns were lifted. The implications of lockdowns and rising numbers of infections beyond the initial lockdown periods is so far little understood. We examine farm households' response to the Indian nationwide lockdown between March 25 and May 31, 2020, and to the first wave of Covid-19 infections in India between July and December 2020. We combine data collected in the rural-urban interface of the mega-city of Bengaluru during a face-to-face survey just before the lockdown (February 4 – March 10, 2020) with two datasets from telephone surveys. One telephone survey was administered in the last two weeks of the lockdown (May 18 – June 2, 2020) and a second one at the end of first wave of Covid-19 infections (December 2, 2020 – March 2, 2021).

We first examine changes in on-farm family labour supply of 351 farm households during the lockdown. We find that 66 percent of farm households reduced their on-farm family labour supply, by on average almost 40 percent compared to pre-lockdown levels. Changes in on-farm family labour supply differed by key pre-Covid-19 livelihood characteristics: Farm households that were engaged in crop marketing pre-lockdown decreased their on-farm family labour supply by on average 3–4 hours per day. In turn, farm households that relied on off-farm income increased their on-farm family labour supply by on average 3–4 hours per day. We then use data from 253 farm households to analyse the implications of the first wave of Covid-19 infections for agricultural management, i.e. farm input use and crop marketing. Descriptive findings largely indicate an increase in the use of farm inputs and crop marketing compared to pre-Covid-19. Employing correlated random effects panel models, we find that higher concern about an infection by the household's primary caregiver is positively associated with pesticides, irrigation and sustainable agricultural practices use, but negatively related to hiring labour. However, higher exposure to Covid-19 on the sub-district level is negatively related to male on-farm labour and crop marketing. Our findings suggest that the lockdown and the first wave of infections had differential implications, depending on pre-Covid household characteristics, concern about an infection and the level of exposure during the post-lockdown period. Our findings contribute to understanding and evaluating the implications of the early policy response to the Covid-19 pandemic in India. This is important in view of designing future policies that strengthen the functioning of agricultural supply chains and farm households' resilience to shocks.

17.06.2022
https://uni-kassel.zoom.us/j/97684221433?pwd=b2E0RDZXOEhZMUoyNHpHUllFV0lzZz09
Meeting-ID: 976 8422 1433 / Kenncode: 296887

Middle class consumption practices along rural-urban gradients in Bengaluru, India

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Our project addresses the food consumption practices of middle-class households along two rural-urban transects to the north and south of Bengaluru. Specifically, we compare the consumption habits of agricultural and non-agricultural households to assess sustainable food consumption practices. With the onset of the Covid-19 pandemic our research questions expanded to include the effects of the pandemic on perceptions of food safety and shifts in consumption practices. In the two years since the Covid-19 pandemic began, life in Bengaluru has largely returned to normal and the typical food shopping and consumption practices have resumed. However, we find that small changes have taken root among middle-class households due to the heightened attention to maintaining good health and the direct connection between food consumption habits and individual health. While it is still too early to determine which changes will last or be widely adopted; the results from our household survey indicate a food transitions in progress. Namely, a willingness to pay for organic and better-quality food. We also observe that some traditional ingredients and foods have gained an elevated status for being 'immune-boosting' and that their consumption increases in frequency in parallel with Covid-19 waves of infection. In this presentation I will share my research questions, methods, preliminary results and next steps.

Bridging actors and their role in co-managing lakes: Cases from Greater Bengaluru Metropolitan Region (GBMR)

Arvind Lakshmisha

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Co-management is seen as a means to effectively manage common-pool resources, especially collaborations based on sharing of roles and responsibilities between state and non-state actors. Collaborations depend on certain key intermediary bridging actors who facilitate and coordinate links between these actors. In this paper, we aim to understand the role of these bridging actors in shaping networks of co-management by developing a framework based on certain characteristics such as initiation, position, and facilitation of interactions whose application we illustrate for three lakes situated across a rural–urban gradient in Greater Bengaluru Metropolitan Region (GBMR). Drawing on concepts from co-management and social network analysis, we analyse data collected from documents, key informant interviews, and FGDs to identify that bridging actors play a critical role in resource gathering, enhancing mutual trust, and promoting innovation through information exchange irrespective of the social-ecological context. Beyond mere description, we highlight that state sponsorship plays an important role in establishment of bridging actors in urban and peri-urban areas due to heterogeneity in perceptions, actors, lack of trust and credibility in comparison to rural lakes where state sponsorship is less important and community engagement is stronger. We conclude that irrespective of the context, position of bridging actors plays an important role in facilitation of interactions within networks.

Validation of remote sensing-based crop management intensity models using independent data from on-farm experimental fields located on the transects of Bengaluru

Dr. Damian Schulze-Brüninghoff
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To investigate spatio-temporal dynamics on cropping systems along the rural-urban interface in Bengaluru, remote sensing methods have been developed at two experimental field layouts (irrigated and rainfed) at GKVK University of Agricultural Sciences in Bengaluru, India, over the primary agricultural season in 2018. Methods have been developed to model leaf area index, leaf chlorophyll concentration and canopy water content by spaceborne multispectral and unmanned aerial vehicle borne hyperspectral sensor data. Best study's outcome has been identified and validated on practical farms along the northern transect of Bengaluru with data collected in 2021. We revealed that model development on single year data from fields under controlled experimental management conditions is insufficient for transferring on practical fields and that additional calibration steps are necessary to increase model accuracies. We could show that multi-year data from experimental fields could increase model transferability and that additional training data from practical fields is highly important for accelerating model prediction performances.

15.07.2022
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Meeting-ID: 913 8000 4269 / Passcode: 219000

Analysis of characteristics and spatial patterns of agricultural landscape along an urban-rural gradient

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Urbanization is a multi-dimensional complex process which drives changes in the landscape. Globally, the agricultural landscape is the landscape most exposed to urbanization. Therefore, finding spatial and temporal patterns of changes in the agricultural landscape is essential for sustainable development. To address this information gap, this study developed a workflow: a) to map agricultural land-cover, b) to recognise the spatial pattern of the agricultural land-cover along the urban-rural gradient, and c) to discover agricultural landscape types in the urban-rural gradient around Bengaluru, one of the most populated cities in India. Pixel-based hierarchical supervised classification was employed to map agricultural land-cover using WorldView 3 satellite remote sensing data. Four herbaceous crops types (millet, maize, pulses, and cash crops) and woody plantations were mapped as agricultural land-cover. Landscape metrics-based values were utilised to identify spatial patterns of the mapped agricultural land-cover against the degree of urbanization using the survey stratification index (SSI). The data-driven, unsupervised clustering method was applied to determine the agricultural landscape types. Herbaceous crop type and woody plantation mapping resulted in 63.5 % and 89.2 % overall accuracy, respectively. Landscape pattern analysis indicated that the share of agricultural land increased from urban to rural areas, and diverse heterogeneous agricultural land-cover patterns appeared in transition regions. Moreover, field crops were dominant in rural areas, and cash crops were the primary crop type in urban regions. Woody plantation was the significant crop type in both urban and transition regions. Four agricultural landscape clusters were characterized, namely 1) A-field crop dominant, 2) B-diverse agriculture, 3) C-modest agriculture, and 4) D-few or no agriculture. As a case study, the findings suggest that urbanization in Bengaluru has an apparent effect on the agricultural landscape. Overall, the developed workflow can be repeatable and transferable to distinct areas and could help to find the temporal pattern and compare the characteristics of agricultural landscapes.

An investigation of the spatial influences and governance implications of social-ecological heterogeneity, connectivity, and scale on landscape change

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For the sustainable management of natural resources, institutional arrangements and governance structures should acknowledge and address the complex, emergent, and non-linear dynamics of social-ecological systems (SES). Current best practices for the governance of small-scale common pool resources, such as water and fisheries, are described by Ostrom's design principles. Researchers have explored the applicability of some of the design principles for larger, complex SES. However, the interpretation and application of the design principles in a large SES are not straightforward due to such systems' inherent complexity and scale. Although the design principles include the concepts of self-organization, local knowledge and participation, and feedbacks, there are gaps in understanding and the relevance of the design principles for large SES with high spatial heterogeneity. Our study aims to extend SES theory by exploring the relevance of the design principles for urbanizing, spatially heterogeneous landscapes.

Peri-urban SES are spatially dynamic landscapes experiencing degradation of natural resources and loss of related ecosystem goods and services. They are often characterized by multiple and conflicting resource use, overlap and gaps in policies, corroding institutions, actor heterogeneity, lack of social capital, and skewed power dynamics. Consequently, natural resource management is challenging in a peri-urban SES. Therefore, scholars have proposed commons-based approaches to manage resources in the SES.

We identified three research questions relating to the roles of space, scale, and connectivity in natural resource governance to explore the applicability of the design principles in a peri-urban SES. We addressed them using an exploratory dynamic simulation model based on Ostrom's SES framework. The model uses a modified reaction-diffusion equation and includes the concepts from game theory and land use change studies. We used a dataset of simulated landscapes (N=200), loosely based on urban peripheries of rapidly expanding tier-1 Indian cities.

First, We explored the applicability of design principle 2 for addressing the issue of institutional fit in dynamic landscapes. Design principle 2 asserts congruence between governance rules and local social-ecological conditions. However, little is known about how to achieve congruence in spatially dynamic SES, partly because the local conditions are constantly changing. Using the model, we explored social-ecological feedbacks between ecological patterns and landscape governance. We captured feedbacks by varying the spatial extent of decision making in the model from a regional to a local scale across landscapes for two different levels of spatial heterogeneity. We found that the rate of urbanization and urbanization trend differed significantly at the regional scale as compared to the local scale for highly heterogeneous landscapes. For low heterogeneity landscapes, the trend was similar for both regional and local scales. We extended and operationalized the design principle by

explicitly defining the term 'local' as relative rather than fixed, that is, as a spatial extent of decision-making based on landscape heterogeneity.

Second, we explored the influence of resistance among actors on effectiveness of design principle 3 for governing spatially dynamic landscapes. Design principle 3 emphasises the importance of collective participation by local actors in the rule making. In a peri-urban SES, urban actors appropriate land which often results in land fragmentation and affects the livelihood of rural inhabitants by reducing land availability for activities such as agriculture. Little is known about how rural actors resist or accept these impacts and whether the design principle is useful in this context. We simulated the consequences of individual rural and urban actor decisions on emerging land use patterns in the urban periphery. We used game theory to describe competition for land, and landscape metrics to quantify the impacts of increasing rural resistance on emerging landscape patterns. We found that landscape structure (number of patches, patch area, clumping of patches and edge density) had a non-linear response to resistance to urbanization. The responses of individual landscape structural elements varied for a given level of resistance. The non-linear response and presence of tipping points for ecological processes depending on connectivity or area can create significant challenges and opportunities for sustainable land use change in spatially dynamic SES. We conclude that efforts to use the design principles to manage complex landscapes must account for actor heterogeneity and the potential of actor resistance in achieving ecosystem sustainability.

Third, we explored the applicability of design principle 3 to situations where a group of actors have limited local knowledge. Design principle 3 stresses the importance of local knowledge and therefore, emphasizes including local actors in decision-making. In a peri-urban SES, however, urban actors have limited local knowledge of rural elements of the SES but wield strong influence over policymaking and landscape governance. In addition, it is known that local spatial conditions influence the decisions of actors. We hypothesized that urban actors can regulate the influence of existing landscape conditions on emerging landscape patterns by explicitly including local spatial information in decision-making. We explored the influence of varying levels of spatial neighbourhood information included in the decision-making on spatial composition and configuration of green spaces left after urbanization for high and low heterogeneity landscapes. We found that the change in patch area, which explained most of the variation in the outcomes, followed a sigmoidal curve in response to the varying level of neighbourhood information for both landscapes. For high heterogeneity landscapes, the change in patch area was higher than the low heterogeneity landscapes for the same level of neighbourhood information. As level of neighbourhood information increased in the decision making, the difference between the patch metrics for high and low heterogeneity reduced. The results show that urban actors can regulate the influence of existing landscape conditions on emerging landscape patterns by explicitly including local spatial information in the decision-making. Urban actors can compensate for lack of knowledge and contribute to integrated governance by making spatially conscious choices. Our work sheds new light on cross-scale interactions in spatially dynamic landscapes.

In sum, we operationalised design principle 2 and 3 for spatially dynamic SES by exploring feedbacks and cross-scale interactions in the SES. The study provides new insights into the spatial interplay between governance and landscape change and extends SES theory for spatially explicit SES and landscape governance for dynamic landscapes with multiple land use.

Soil respiration under different N fertilization and irrigation regimes in Bengaluru, India

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Rampant urbanization has led to different management intensities/practices in urban and peri-urban agriculture (UPA) which affects the soils' physical, chemical, and microbial properties. This study was conducted to investigate the effects of different levels of mineral nitrogen (N) fertilizer and irrigation on CO_2 fluxes in typical crops during the Kharif (wet) and Rabi (dry) season under the monsoonal climate of Bengaluru, South India.

To this end data were collected from Kharif 2017 to Rabi 2021 in a two-factorial split-plot, on-station experiment conducted under rainfed and irrigated conditions at University of Agricultural Sciences Bangalore (UASB). We studied the three rainfed crops maize (*Zea mays* L.), finger millet (*Eleusine coracana* Gaertn.), and lablab (*Lablab purpureus* L. Sweet) as well as irrigated cabbage (*Brassica oleracea* var. capitata), eggplant (*Solanum melongena* L.), and chili (*Capsicum annuum* L.). CO_2 emissions were determined using a Los Gatos Research (LGR) multi-gas analyzer (CO_2, CH_4, NH_3 and H_2O). Measurements were conducted from 7:00 am to 11:30 am and repeated from 1:00 pm to 6:00 pm.

Irrespective of irrigation, season and crops, afternoon hours' CO_2 flux rate was significantly higher than in the morning hours. In the irrigated field diurnal difference in emission ranged from 1.8-72% while in the rainfed field it ranged from 11.0 – 128.4 %. Effect of N fertilization on CO_2 flux was significantly higher on high N plots for all the crops. However, irrespective of crops the difference of CO_2 emission between high and low N plots in the rainfed field was 56.4 % whereas in the irrigated field it was 12.1% only. Applying linear mixed effect model on the data, it was found that N fertilization treatment had always a positive effect on CO_2 emission but it was highest in rainfed crops. Effect of soil moisture on the emission was positive in rainfed crops but negative in irrigated crops. Soil temperature at 5 cm depth had positive effects on CO_2 emission in both fields. The crop-specific CO_2 fluxes were independent of N fertilization under irrigation, but were remarkably consistent across years.

Does green infrastructure promote human wellbeing? A social--ecological systems assessment in urbanizing contexts of Bengaluru, India

Pramila Thapa

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Urban green infrastructure provides multiple benefits to urban dwellers and is often considered an important component of human wellbeing. But how exactly the green infrastructure influences the human wellbeing along a rural-urban gradient is still poorly understood. This study assesses the distribution of green infrastructure in the rural-urban interface of Bengaluru, India, and its association with human wellbeing by combining remote sensing data with results from a household survey. Based on high resolution satellite images, we calculated the tree cover percentage around 1200 households in 61 villages within the northern and southern transects of Bengaluru at two concentric radii of 60 and 300m. We used the household survey socio-economic data reported by the household decision makers and classified them into eight categories: stable ecosystems, social relationships, agency and political voice, work and leisure, education, mental health, and physical and economic security. With these data sets (tree cover and socio-economic data), we run a fractional regression to identify the association between these two parameters. The results of such a linkage of social-ecological and spatial data to assess green infrastructure in the rural-urban continuum would help regional planners and decision makers visualize and plan for livable environments.