# Global mapping of urban–rural catchment areas reveals unequal access to services

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**Using travel time to cities of different sizes, we map populations across an urban–rural continuum to improve on the standard dichotomous representations of urban–rural interactions. We extend existing approaches by 1) building on central place theory to capture the urban hierarchy in access to services and employment opportunities provided by urban centers of different sizes, 2) defining urban–rural catchment areas (URCAs) expressing the interconnection between urban centers and their surrounding rural areas, and 3) adopting a global gridded approach comparable across countries. We find that one-fourth of the global population lives in periurban areas of intermediate and smaller cities and towns, which challenges the centrality of large cities in development. In low-income countries, 64% of the population lives either in small cities and towns or within their catchment areas, which has major implications for access to services and employment opportunities. Intermediate and small cities appear to provide catchment areas for proportionately more people gravitating around them than larger cities. This could indicate that, for countries transitioning to middle income, policies and investments strengthening economic linkages between urban centers and their surrounding rural areas may be as important as investing in urbanization or the rural hinterlands. The dataset provided can support national economic planning and territorial development strategies by enabling policy makers to focus more in depth on urban–rural interactions.**

rural–urban continuum | city–region systems | territorial development | economic geography | functional urban areas

> For a rural society, separate from the urban social community, does not exist at the present time [. . .] except, perhaps, in the thoughts of dreamers. – Max Weber (1904) (ref. 1, p. 363)

The concepts of rural and urban date as far back as classical Roman times and have acquired particular cultural and moral associations (2). This dichotomy, while expedient to classify population, has long been recognized as inadequate in many disciplines, including demography, geography, economics, sociology, and public health (3–8). For example, when it comes to employment opportunities or access to services, rural is often equated with a more disadvantaged situation, but someone living in a rural area an hour away from a large city probably has better access to services and opportunities than someone living in a remote town. Neither the urban hierarchy, in terms of services provided by cities of different sizes, nor the travel time needed to access services are captured in the traditional urban–rural breakdown; hence, key aspects of urban–rural interactions are overlooked. Our approach leverages new global datasets (9) to provide a spatial representation of urban centers and their catchment areas, emphasizing the interconnection between them. The partitioning we obtain is consistent, exhaustive in terms of location and population, and yields results that can be superimposed on a country's administrative layers. When combined with population data, aggregating across catchment areas at a regional or national level provides a representation of how a population is distributed along a rural–urban continuum.

## The Rural–Urban Continuum: A Century in the Making

Starting in the early twentieth century, in response to the limitations of the rural–urban dichotomy, the idea of a continuum from a remote rural condition to an urban setting began to take shape in the social sciences. For example, up to the 1960s, rural sociology often relied on the framework of the rural–urban continuum codified by Sorokin and Zimmerman (3) in the late 1920s, and further propelled to prominence by a seminal paper by Louis Wirth (1938) (10), who stated that "city and the country may be regarded as two poles in reference to one or the other of which all human settlements tend to arrange themselves." Halfacree (2009) (11) notes that this approach, by mixing sociology and geography, would play a defining role in sociological research. At the time, the adoption of the rural–urban continuum aimed to explain the nature of social relationships by reference to settlement patterns along a one-dimensional scale between rural and urban. Not until the mid-1960s was it generally accepted that this intention was not fruitful on both empirical and theoretical grounds (12–14). The idea that social organization is a function of variation in human communities along the rural–urban continuum was abandoned. Evidence accumulated that population density, population size, and the general social and physical environment did not coordinate any specific form of society.

Despite sociologists concluding the rural–urban continuum was of limited use, the idea of a continuum proved highly influential in

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### Significance

Physical access to services and employment opportunities shapes the lives of people everywhere. For 3.4 billion people living in rural locations, the size of nearby urban centers and the associated travel time affect the breadth of services and opportunities available and their accessibility. We identify catchment areas of urban centers of different sizes and how many people gravitate toward each city or town, providing a full spatial representation of the connection between rural areas and urban centers and fresh insights on the diversity of urban–rural systems. The global dataset opens the door to applied research in various disciplines—such as poverty reduction, food systems, health, and education—where a person's place of residence is an important factor.

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other fields as the basis for a classification that permitted a more nuanced picture of rural–urban contexts. One relevant example is how the concept became encoded in the Rural–Urban Continuum Codes (RUCCs) produced by the US Department of Agrciulture (USDA) in the 1970s to classify counties in the United States (15). These categorized "metropolitan" counties by population size and "non-metropolitan" counties by population in incorporated "urban" municipalities and proximity to metropolitan areas to produce a ninefold classification. The RUCC generated broad multidisciplinary interest in empirical analyses using the rural–urban continuum as a concept. The codes have been used extensively in contexts of analyzing variation along the rural–urban continuum of obesity and physical activity (16, 17), epidemiological studies (18–21), voting patterns (22), ethnoracial diversity (23), disaster resilience (24), food insecurity (25), and access to education (26, 27).

The usefulness of a rural–urban classification system will depend on the empirical application for which it is being used. For this reason, the USDA supplemented the RUCC with additional classification systems, including Urban Influence Codes (UIC) (which differ from the RUCC primarily in distinguishing between large and small metropolitan areas) and Rural–Urban Commuting Area Codes (RUCAs) to focus specifically on labor markets and Frontier and Remote Codes (FARs) to identify challenges in access to services in remote rural areas [Cromartie (28)].

The different rural–urban classification schemes available in the United States highlight how different approaches can be taken depending on the objective of the classification. This becomes even more evident looking at classifications in other countries. Woods and Heley (2) and Hopkins and Copus (29) provide an overview of characteristics considered in several countries that have moved beyond a pure rural–urban dichotomy. They provide examples of countries that distinguish multiple types of urban areas (Austria, Canada, New Zealand, Northern Ireland, and Scotland) and those that have emphasized the rural dimension (Belgium, Chile, Czech Republic, England, Hungary, India, Indonesia, Scotland, Spain, Turkey, and Wales). For some of these countries, both the urban and rural dimensions are disaggregated as part of a more detailed typology; this is the case for Scotland, which distinguishes between urban areas with a population above or below 125,000 people and categorizes rural areas and small towns based on driving time to the urban areas.

Accessibility to urban areas plays a role in multiple classifications that revolve around access to services and employment opportunities. Hopkins and Copus (29) provide examples of typologies that identify urban areas along with their surrounding areas with which they have strong economic links (examples are France, Switzerland, and Mexico).

One of the challenges posed by all these different definitions is that they are not comparable across countries. Interest in the comparative analysis of the socioeconomic condition of rural regions and evaluation of rural development programs has prompted the cross-national comparison of rural–urban typologies employed in different states and the formulation of new transnational typologies. To this end, the Organisation for Economic Cooperation and Development (OECD) introduced a typology that uses primarily population density to categorize regions as predominantly rural regions, predominantly intermediate regions, and predominantly urban regions (30). The European Union (EU) has developed a new typology as a modification of the OECD model. While still employing the same categories as the OECD, the new methodology uses grid cells as its base rather than Local Administrative Units (LAUs) since LAUs tend to vary substantially in size across EU countries (31). Finally, an accessibility dimension has been added to nuance OECD's typology by specifying whether predominantly intermediate or predominantly rural regions are remote in the sense that at least half of the population lives an hour or more from a city of 50,000 people or more.

The innovations in transnational typologies tend to reflect what has worked in national classifications, allowing for the data limitations facing an international effort, namely the use of a gridded system and the introduction of accessibility to urban centers as a relevant variable for rural areas. However, the important experiences of the United States and Scotland of taking into consideration the size of urban centers of reference for rural areas have yet to be adopted in a transnational typology. Incorporating urban hierarchy was raised as a priority for future work at a National Academy of Sciences workshop in 2016 on how to improve rural–urban classifications (ref. 32, pp. 77–78).

## The Planner's Perspective—Combining Urban and Rural into Functional Areas

From a different standpoint, the idea of a continuum developed also within regional science with the concept of the urban–rural gradient, which similarly envisages a continuous transition from urban to rural extremes, attempting to capture urban–rural connections and interdependencies. The overarching framework for this approach is central place theory (CPT) developed by Christaller (33) in 1933, which defines regions as an area of a certain market size distributed around a central place, representing a common catchment area for goods and services available in the central place. CPT was a breakthrough in predicting and understanding the hierarchical development of settlements in terms of size and functions, where each level of the hierarchy provides different and distinctive services.

Although hugely influential, CPT can be challenging to apply empirically as it is essentially about estimating a system of central places for different goods and services. Empirical applications from urban studies used the simpler concept of the urban field to describe the areas extending around individual towns and cities in which there are intensive interactions between the urban center and rural periphery: for instance, in daily commuting, use of services, and economic transactions [for example, Friedmann and Miller (34)].

More recently, the literature refers to these approaches that represent the area of influence of an urban center as Functional Areas, Functional Economic Areas, Functional Economic Regions, City–Regions, Functional Urban Regions, Local Labor Market Areas, Travel-to-Work Areas, and Functional Territories (35). There is no global coverage for these different approaches, although there has been work on a subset of advanced economies (36). With a few rare exceptions (35, 37), the rural–urban distinction is lost in these approaches aiming to define one unitary functional area; a location is either "in or out" without specifying whether it is at the core or periphery of the functional area. This is useful in planning for cities and regions (36, 38, 39) but is very limited when compared with empirical use of the RUCC since each functional area is considered unique. One can attribute variables, such as metro area size, to compare performance across functional areas (39), but this is rarely done.

Functional area approaches are typically used in ad hoc studies for local planning and cover only the population in larger cities and their immediate surroundings, inevitably omitting vulnerable groups that cannot access services and ignoring the numerous medium and small cities providing important regional services. So far, this approach has been applied mostly to advanced economies in the high- or upper-middle–income per capita categories (36, 39, 40).

To overcome some of the limitations of the current functional area approaches, we argue for revisiting CPT with tools that were not available when the approach was first developed and applied, such as detailed geospatial data and the computational means to analyze them. The motivation is that the CPT framework has already proven useful for policy makers and other actors in functional economic regions to cooperate in public service delivery, infrastructure provision, and economic development (41).

The starting point for our argument is the key concept in Christaller's approach that the upper limit to the reach of a central place is ideally the maximum distance over which a good will be demanded but that in the case where there is another central place nearby that offers the same good, then there is a point at which it becomes cheaper for the purchaser to go to the other center. That point defines the real range of a good (42). We exploit this intuition by using travel time to locations as a proxy for cost and adopting an urban hierarchy based on city size to classify rural locations as gravitating around a specific urban center as advocated by Partridge and coauthors (43). This allows us to determine functional areas endogenously and in an exhaustive manner.

## Moving Forward: A Global, Flexible, Gridded Classification That Builds on Existing Approaches

Both the rural–urban continuum and the functional areas proved useful in practical terms (in overcoming the rural–urban dichotomy) when they superseded the notion of the rural–urban continuum being on a one-dimensional scale. Case in point, the most influential implementation of the rural–urban continuum remains the US RUCC that distinguishes the size of metropolitan areas, size of the urban population outside of metro areas, and adjacency to a metro area. Similarly, with a functional area, it is the relationship between the urban center and its surrounding areas that is prioritized. Jones and Woods (44) view this perspective as a shift from an absolutist view of "rural" and urban as discrete spaces to a more relativist position in which space is understood as continual and connected, which may be divided into territories or localities but where the boundaries of these units are porous and contingent such that different places are interconnected with each other.

The notion of relative space emphasizes the interconnections between spaces and places, such that "localities are identified by their cores, not their edges, and are not necessarily consistent with formal administrative geographies" (44). In this respect, the new EU rural–urban typology, with its gridded approach, shows the potential of geographic information systems and georeferenced data. Specifically, it frees the classification from adhering to local government or census tract areas with the possibility of then aggregating upward. This aspect, alongside the need to maintain a multidimensional framework, is central to the approach being presented in our paper.

In moving forward, we build on past experiences that focused on the interconnections between rural and urban areas. The US experience is particularly useful as it has defined multiple indicators to classify rural–urban systems. For example, the Urban Influence Codes remedy the fact that the RUCCs do not report the size of the metro area to which a rural county is adjacent, while the Rural–Urban Commuter Areas capture the more functional aspects and whether people in rural counties gravitate to a metro area as commuters. Finally, the FARs capture the remoteness of a location. Ideally, one would like to construct one multidimensional indicator that can capture all these different aspects. Our proposed approach is inspired by this goal and discussion on rural–urban area classifications held at the aforementioned National Academy of Sciences workshop (32).

Based on these experiences, we innovate in several respects: 1) we build on CPT to capture the urban hierarchy that exists between urban centers of different sizes in terms of access to services and employment opportunities from rural locations; 2) we define urban–rural catchment areas (URCAs) expressing the interconnection between urban centers (of different sizes) and their surrounding rural areas; and 3) we adopt a gridded approach that is easily comparable across countries, developing a dataset for the whole world.

In so doing, we provide a coherent framework in which, based on proximity and an urban hierarchy of cities of different sizes, locations are characterized in terms of access to services provided by their urban center of reference (*Materials and Methods*). In our approach, we refer to results obtained by spatially aggregating URCAs as an urban–rural continuum (as opposed to the rural–urban continuum commonly used) since what drives our classification of rural populations is the location of cities of different sizes. The multidimensional representation of the urban–rural continuum captures how location affects access to services and opportunities, as expressed in the time needed to travel to urban centers of different sizes. Incorporating functional aspects into the urban–rural continuum allows analysis to identify the extent to which development and poverty reduction effects on rural areas emanate from large cities or towns—a current focus of the development community (45–49).

The data identifying URCAs are sufficient to obtain subindicators that convey the kind of information contained in the different indicators available in the United States (RUCC, UIC, RUCA, and FAR). On the opposite front, when comparing with functional areas, a drawback we overcome by introducing URCAs is that functional areas and territories typically focus only on a subset of urban centers in a country and their immediate surroundings. This means that there can be a substantial share of the national population that is not taken into account in these analyses. This is not the case with the URCA approach. For example, Berdegué et al. (35), with their thorough and innovative approach, report that for the functional areas they identify in Colombia, coverage ranges between 60 and 86% of the population, depending on the parameter thresholds used. In our URCA approach, 99% of Colombia's population is directly linked to an urban center of reference. The other advantage of the URCAs is that zonal statistics can be used to identify, within each administrative unit, the share of population that falls in a specific category of the continuum (e.g., the rural population in a county that gravitates around intermediate cities and is within 2- to 3-h travel time of their urban center of reference).

Another characteristic of our approach is that by providing a gradient of travel times, it bypasses the need for commuting data used in functional area approaches, which is often not available in many countries or for smaller cities. It also bypasses the need for arbitrary thresholds, such as in commuting rates, which typically define what locations are included in a functional area. The urban–rural continuum is less about a specific labor market—where a location is either in or out—and more about what would be the urban center of reference for a given location. The travel time gradient is useful in differentiating between those who may be commuting to the urban center and those who would access services on a more sporadic basis. It is also useful for understanding the implications of any infrastructure investments within a broader national context.

To conclude, the prioritization algorithm based on the primacy of larger urban centers for a same travel time category is at the core of determining URCAs. The approach is inspired by CPT—where we assume city size is a proxy for the breadth of services and opportunities provided by an urban center. The approach taken captures empirical phenomena such as the one observed by Woods (50) in 2011, where smaller urban centers relatively close to larger cities may retain a fairly high provision of local services but are also largely bypassed by residents from surrounding rural communities who travel into the larger settlement for work and services. Recent applications of CPT, such as analyzing home-to-school distances (51) or access to innovation-related services (52), indicate that the theory is still relevant. However, the focus here is not to test the theory in so much as constructing indicators that can put in relation urban centers of different sizes with their areas of influence by classifying rural locations as gravitating around a specific urban center. As Mulligan et al. (41) note, CPT offers planners a powerful way of understanding the fabric of urbanization and making decisions—including transportation investments, allocating land use, and more—affecting the overall functionality of the regions in which they operate. One of the aims of this paper is to readily provide the functionality of CPT to planners around the world where in-depth CPT analyses may not be available. The other aim is to provide—as a global public good—a consistent, exhaustive, and multidimensional representation of the urban–rural continuum.

## Results

Fig. 1 shows locations within the catchment areas of large cities (gray), intermediate cities (blue), small cities and towns (orange), and the rural hinterland (green) with travel times of less than 1 h (periurban), 1 to 3 h (perirural), or over 3 h (hinterland). For our purposes, urban centers are defined by a continuous grid with a density of at least 1,500 inhabitants per kilometer$^2$ or a density of built up greater than 50% and a minimum of 20,000 inhabitants. This follows the Global Human Settlements Layer definition (53) and does not have any correspondence with what may be classified as urban in a country or considered urban based on local social norms. Rural locations are distinguished between periurban, perirural, and hinterland depending on travel time to their urban center of reference. The rationale for these choices is that the focus here is about capturing access to services and providing a classification system that is comparable across countries. The terms urban, periurban, perirural, and hinterland are to facilitate discussion of results; however, the terms can be dropped and just referred to as travel time as is done in Figs. 1 and 2. The latter approach is closer in spirit to functional areas with the distinction that information is maintained about the extent to which a location is in the core or the periphery of a functional area.

Results from the estimated catchment areas (Fig. 1) indicate there are clear differences across regions. Small cities and towns dominate large parts of the Americas, Europe, and sub-Saharan Africa, whereas larger cities are more prominent in the densely populated regions of Asia, such as India and eastern China. In Fig. 1, the darker the color of a given rural location, the more easily connected it is to an urban center, which may imply better infrastructure, as in the United States, where the catchment areas of smaller cities extend far outward or many cities close together, as in India.

Fig. 2 presents the population distribution across the urban–rural continuum for broad country income and regional categories. The urban–rural continuum obtained by aggregating across catchment areas yields five key insights about regions and territories and stimulates the formulation of hypotheses to be tested in future work.

First, less than 1% of the global population lives in the rural hinterland, more than 3 h from an urban settlement of 20,000 people or more. Although Max Weber's quote in the opening of this article referred specifically to modernized societies at the beginning of the twentieth century, the notion that rural society is not separate from the urban social community would now seem to apply across regions and country income levels. Even at the national level, among countries with a population of at least 10 million, only three—Madagascar, Niger, and Zimbabwe—have more than 5% of their population living in the rural hinterland (Dataset S1). If we consider countries with populations of 1 million or more, the number increases to 11 countries (of 158).

Second, there is a large share of people living in periurban areas, not just of large cities but also, intermediate and smaller cities and towns. This is especially the case in low-income countries where nearly 30% of the population lives in a periurban area of an intermediate or smaller city/town of at least 20,000 people.

Third, rural populations tend to gravitate less than proportionally around large cities. The catchment areas of urban

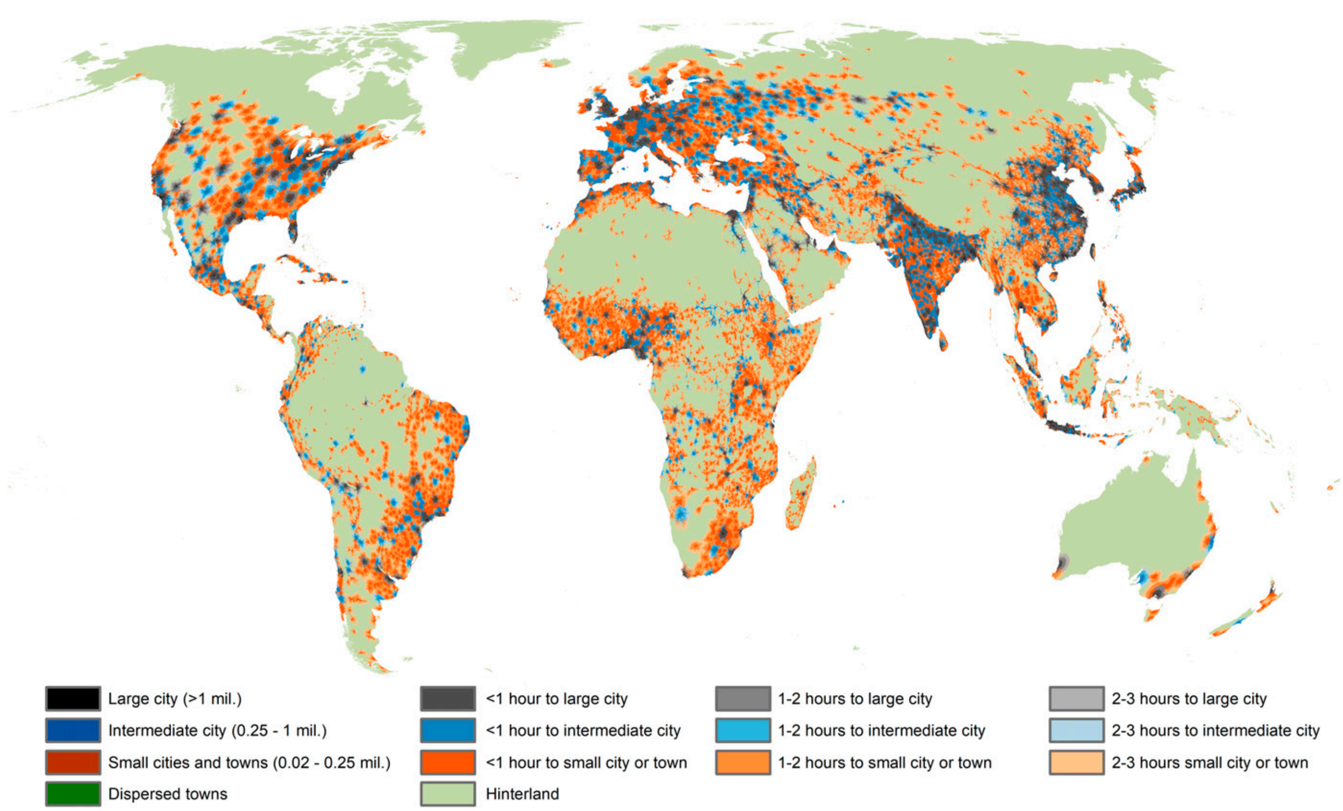


**Fig. 1.** Global map of URCAs in 2015 at a spatial resolution of 1 km$^2$, showing catchment areas of cities of different population sizes.

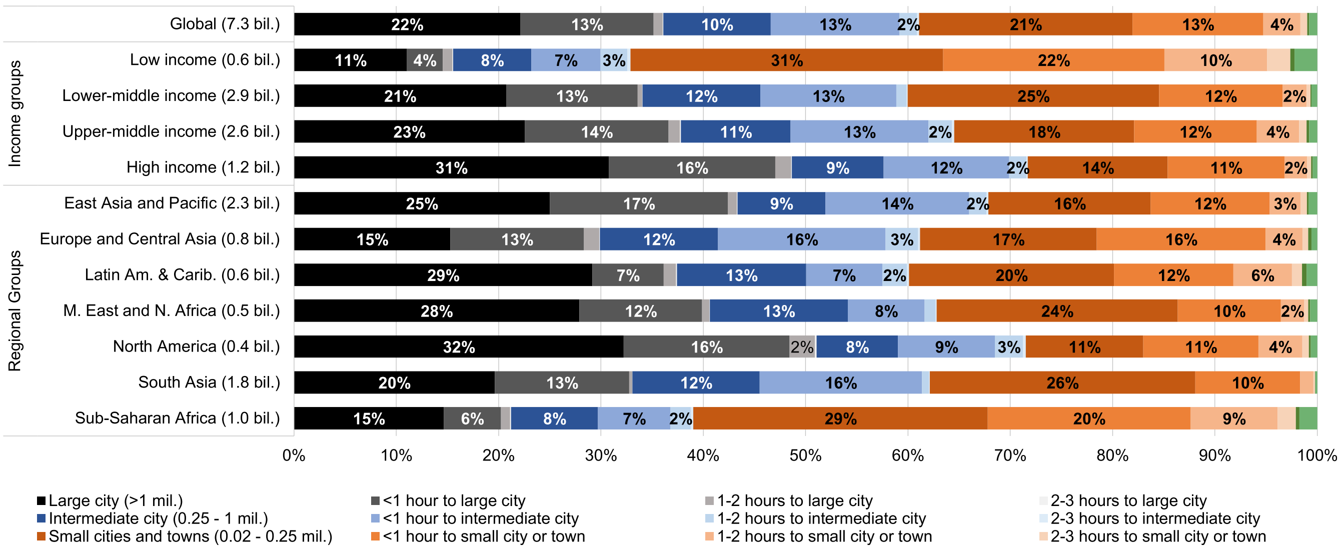


**Fig. 2.** Global population distribution across the urban–rural continuum in 2015 and by country income and regional groups. Percentage of total population in different city sizes or in proximate areas of different travel times to these cities was obtained by aggregating across catchment areas. Economic development is expressed as per capita gross national income. Latin Am. & Carib., Latin America and the Caribbean; M. East and N. Africa, Middle East and North Africa.



centers of different sizes each play a role in shaping the development of territories. What emerges globally is that small and intermediate cities play a prominent role. Although large cities are home to more than 40% of the world's urban population, less than one-third of the global rural population gravitates around large cities. This discrepancy between the magnitude of the urban population of large cities vis-à-vis the rural populations that gravitate around them is true across all regions (except south Asia) and income categories (compare *SI Appendix*, Figs. S1 and S2). It is particularly striking for Latin America and the Caribbean, where large cities dominate (nearly 50% of urban population), but less than one in four rural people gravitates around large cities. At a finer disaggregation of city size, we find the capacity—in relative terms—of the largest cities (>5 million) to engage a population in their surrounding territory is limited (*SI Appendix*, Fig. S3). This result is surprising, considering that the urban hierarchy adopted in our classification favors large cities in assigning a rural location to an urban center. The cause of this observed phenomenon warrants further investigation and could be tied to economic geography and the strategic location of smaller cities and towns relative to a central place such as a large city.

Fourth, for low-per capita income countries, the urban–rural profile is dominated by small cities and their rural catchment areas, which is not the case in richer countries. In low-income countries, 64% of the population either is in small cities and towns or within their catchment areas. However, this appears to be a specificity of low-income countries since lower-middle–income and higher countries exhibit a more balanced urban–rural profile across city sizes, with small cities and towns and their catchment areas accounting for between 28 and 39% of the population. This leads us to hypothesize that in the very early phases of development, urbanization and improvements in urban–rural connectivity are key as they create the conditions for access to services. Case in point, on average, for lower-middle–income countries (and higher), only 10% or less of the population is located more than an hour from an urban center of 20,000 or more, compared with nearly 20% for low-income countries. This has significant implications for access to off-farm employment opportunities, education, and health services.

Fifth, in high-income countries, more people live in low-population density areas than in high-density settlements in the rural catchment; the reverse applies in lower- and middle-income countries. The proportion of the rural population living in high-density rural areas is 8% in high-income countries, compared with 26% in upper-middle–income, 43% in lower-middle–income, and 55% in low-income economies (data for Dataset S1, *iii* and *SI Appendix*, Fig. S3). This may reflect high-income countries' tendency toward suburbanization around cities where low-density housing is the preferred option, which is consistent with findings by Veneri (36). These patterns raise concerns about pressure on food systems if lower-income countries replicate land use trajectories followed by high-income countries, toward lower-density suburbs.

Fig. 2 can be generated for any level of spatial aggregation, such as national or subnational. In *SI Appendix*, we provide the breakdown of the urban–rural continuum for 260 countries and territories, which highlights the diversity of urban–rural systems even within the same region or income category (Dataset S1).

## Discussion

We have portrayed the diversity of urban–rural systems and the limitations of existing approaches to capture urban–rural connectivity. Using recently published data (9), we provide the tools to operationalize an urban–rural continuum that incorporates functional aspects of territories by identifying URCAs. The approach is based on CPT, assuming city size as a proxy for the breadth of services and opportunities offered, and travel time as a measure of the cost of reaching those services and opportunities from a rural location. The approach yields three important preliminary insights into the distribution of the global population and the relationship between urbanization and economic development. First, the near totality of people around the world lives in URCAs—defined here as living within 3 h of an urban settlement with a population of 20,000 or more—thus highlighting the interconnection between rural areas and urban centers. Second, there is a large share of people living in periurban areas not just of large cities but also, of intermediate and smaller cities and towns. Third, intermediate and small cities appear to provide catchment areas for proportionately more people gravitating around them than larger cities. These insights have strong policy implications,


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ranging from access to health services to organizing city–region food systems and facilitating a mobility transition toward more commuting and less migration.

The challenge posed by the prominence of periurban areas is that these tend to be overlooked within both urban and rural policies. Municipal governments usually focus on the well-being of residents within their administrative boundaries, and authorities governing rural areas may not differentiate between periurban and more remote populations. The latter is evident in how agriculture dominates rural policy in many countries. Differentiated rural policies and greater coordination between urban and rural governments are needed to help periurban households leverage their proximity to towns and cities.

The third insight, on the importance of small and intermediate cities for rural populations, is typically not adequately reflected within the policies of developing countries; instead, governments tend to focus on and invest more resources in larger cities. Urban policies should be broadened to better reflect the role and needs of small and intermediate cities to benefit not only their urban residents but also, the large rural populations living nearby. In many countries, economic planning and development policy need to move toward a more territorial perspective that takes account of interlinkages between cities of different sizes as well as with their surrounding rural areas.

Insights from a continuum approach have strong policy implications, as demonstrated by the use of the US RUCCs in policy-relevant research (16–27). Overlaying administrative units on the spatial urban–rural continuum provided here yields an RUCC-type representation for any country in the world. This will be more nuanced and detailed than the US RUCC because it provides the percentage population in an administrative unit per category of the urban–rural continuum (as in Fig. 2), which is particularly important for large administrative units. In general, the multidimensional nature of the classification used to delineate URCAs, alongside the gridded representation, provides enough flexibility to allow users to define indicators at the administrative level that are salient both for planning and as explanatory variables for research in several disciplines.

Thanks to the hierarchical approach inspired by CPT, another policy-relevant area for future investigation comes from endogenously identifying functional areas around urban centers of reference without the need to set commuting thresholds. This type of analysis can help bring to the surface systems of cities and their hierarchical relationship in terms of provision of services. We expect that the datasets made available here will inform policy makers and enable research on the relationship between city size and rural poverty reduction (45–49), currently possible in only a few countries.

Despite the advances provided in this paper, there are aspects not addressed here that will require further research. For example, currently, the URCA approach is not particularly well suited for capturing the relationship of rural areas with polycentric urban systems. These are systems where population, services, and employment are not concentrated in one center, but rather, there are two or more urban centers that functionally organize their surrounding territory. Although URCAs can capture the morphological aspects of a polycentric system, a rural location is associated with only one center of the system. This issue could be resolved by modifying the classification algorithm to identify a primary and secondary urban center of reference.

Another area that may need consideration is linked to what we consider the strength of our approach, namely that the classification algorithm is driven by the urban hierarchy and not by arbitrary thresholds. For example, the choice made in this paper is that a location that is less than 1 h from a center of 50,000 people will gravitate around that center, even if it happens to be just an hour and a half from a city of more than a million people. If a researcher believes that cities of a million or more should be given priority over a city of 50,000 people, even if they are a little further away, the algorithm can be revised to reflect that by changing the order in the hierarchy of agglomerations. The hierarchy we adopted in the paper was, in our view, the most intuitive and transparent; however, it is just one among several options.

Finally, the approach presented here is not intended to substitute well-established approaches such as the RUCC in the United States or the functional urban areas analyzed at OECD based on commuting data. The intention here is to make something available for countries that do not have these approaches in place and often do not have the data to implement them. In this respect, the proposed approach and associated dataset could be part of a toolbox to help countries reach their target for the Sustainable Development Goals (SDGs). This applies directly to SDG11.a on supporting positive economic, social, and environmental links between urban, periurban, and rural areas by strengthening national and regional development planning. It also applies indirectly to SDG1 (no poverty) and SDG2 (zero hunger) by informing the debate on rural vs. urban poverty and food insecurity, as well as SDG3 (good health and well-being) and SDG4 (quality education) by representing challenges and opportunities in access to basic services.

## Materials and Methods

Our proposed approach identifies catchment areas of urban centers and classifies the global population, allocating rural populations around differently sized cities. The classification is based on four dimensions: urban center location, population distribution, population density, and travel time to urban centers, all of which can be mapped globally and consistently and then aggregated as administrative unit statistics to define an urban–rural continuum at the specified level of aggregation.

We identified urban centers and computed population distribution and density for the URCAs using spatial datasets from the Global Human Settlement Layer (54, 55). We matched all rural populations to their urban center of reference based on the time needed to reach these urban centers using the least-cost-path algorithm presented in the Global Map of Access to Cities in 2015 by Weiss et al. (56) at a spatial resolution of ∼1 km. The least-cost-path algorithm determines the time required to travel from one location to another by finding the fastest route over a cost surface. The cost surface is derived from spatial datasets that represent the surface transport network—roads, railroads, navigable rivers, and other surfaces traversed by foot—derived from land cover data, elevation and slope; and international borders that act as delays. The characteristics of each dataset were used to estimate plausible travel speeds across different parts of the transport network, foot-based speeds over different types of land cover surfaces, speed adjustment factors associated with slope and extreme elevation, and delays at international border crossings. The resulting cost surface estimates the time required to cross each 1-km pixel of the world's surface. We use the most up-to-date estimates of travel times available based on Weiss et al. (57).

A hierarchy of urban centers by population size (largest to smallest) is used to determine which center is the point of reference for a given rural location: proximity to a larger center dominates over a smaller one in the same travel time category. The agglomerations range from large cities with 1) populations greater than 5 million and 2) between 1 and 5 million, intermediate cities with 3) 500,000 to 1 million and 4) 250,000 to 500,000 inhabitants, and small cities with populations 5) between 100,000 and 250,000 and 6) between 50,000 and 100,000 to 7) towns of between 20,000 and 50,000 people. This classification approach allocates each rural pixel to one defined category: less than 1-, 1-to-2-, and 2-to-3-h travel time to one of seven urban agglomeration sizes.

We identify the URCAs starting with the periurban population (facing less than 1-h travel to the edge of the urban agglomeration) for each agglomeration by identifying pixels under 1-h travel time to cities of 5 million or more. Next, we identify (among the remaining pixels) those in that same time range but to cities of 1 to 5 million people, and so on until towns of 20,000 to 50,000 people. The same procedure is then followed for the perirural population, living in rural pixels that are yet to be allocated, for longer travel times. The classification ends when all that is left are pixels that are more than 3 h away from any urban agglomeration of at least 20,000 people, which are considered as hinterland and not gravitating around any urban agglomeration. To further characterize the hinterland, we identify populations in "dispersed towns" defined as isolated towns of at least 5,000 inhabitants.

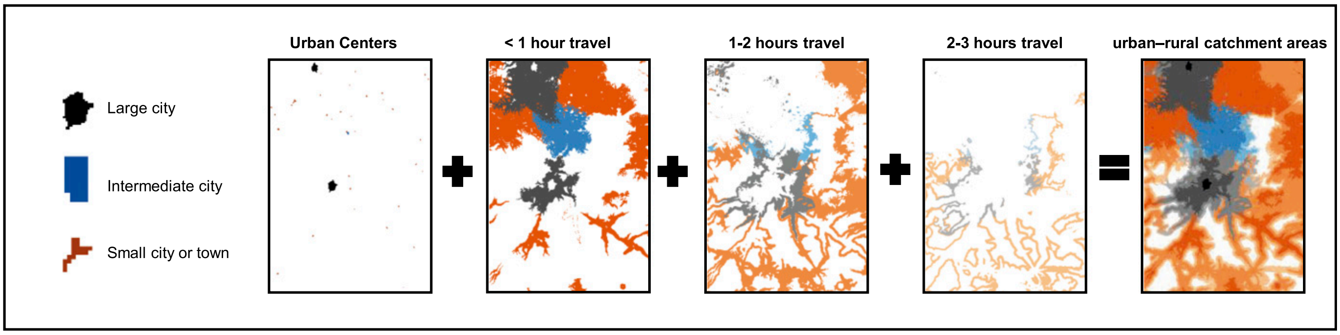


**Fig. 3.** Illustration of the urban–rural continuum classification of city sizes and catchment areas based on different minimum travel times to these cities.

For towns, the hierarchy deviates slightly from what is described above: for a rural location, being 1 to 2 h from a city of 50,000 or more takes precedence over being less than 1 h from a town of 20,000 to 50,000 people. This adjustment was done because the types of services provided by the smaller towns are assumed to be qualitatively different from those of larger centers, and we felt that people would be willing to travel the extra distance to a larger urban center (*SI Appendix* has a more detailed description).

For presentation purposes, we aggregate the seven urban categories into "large cities" (over 1 million people), "intermediate cities" (250,000 to 1 million), and "small cities and towns" (20,000 to 250,000). Fig. 3 illustrates graphically the steps involved for the aggregated urban categories.

Finally, to reflect the diversity of population density across the urban–rural continuum, we distinguished between high-density rural areas with over 1,500 inhabitants per kilometer$^2$ and lower-density areas (53). Unlike traditional functional area approaches, our approach does not define urban catchment areas by using thresholds, such as proportion of people commuting; instead, these emerge endogenously from our urban hierarchy and by calculating the shortest travel time. Data and metadata can be found at doi: 10.6084/m9.figshare.12579572.

**Data Availability.** Raster file (TIFF) data have been deposited in Figshare (DOI: 10.6084/m9.figshare.12579572). Map boundaries are based on the Global Administrative Unit Layers (GAUL) (58). Countries are grouped by income according to the World Bank classification for 2015 (59) and by the UN geographic region (60).

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