

Regional integration in the Horn of Africa through the lens of inter-city connectivity

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ARTICLE INFO

Keywords:

Connectivity
Horn of Africa
Borderlands
Regional integration
Infrastructure

ABSTRACT

Urban challenges are increasingly framed in the context of broader objectives of socio-economic development and macro-regional evolutions. Cities and the myriad networks in which they are embedded have thus been placed at the center of regional integration agendas. This paper benchmarks contemporary regional integration levels in the Horn of Africa by examining its cities' connectivities in transport networks. To this end, we specify a composite network consisting of air/train/road connectivity and analyze cities' eigenvector and betweenness centralities within these networks. We find that the importance of national spaces for inter-city connectivity is much more evident in the Horn of Africa than in other parts of the world, which is also visible in the peripheralization of cities in borderlands. We argue that the region's connectivity needs to be understood from a multiscalar and multimodal perspective and provide a baseline against which the impact of future interventions aimed at enhancing city connectivity/regional integration can be examined.

1. Introduction

In recent decades, the World Bank's urban policies have become increasingly geared towards developing contexts. Jones and Ward (1994) noted that changes in the World Bank's policy paradigms were often discursive rather than formative, but lauded the increasing attention for situating urban development assistance in the context of broader socio-economic development objectives and macro-regional evolutions. In the Horn of Africa, arguably one of the least researched areas in the world in general and in terms of its cities in particular (Kanai et al., 2018), a major recent evolution has been the increased importance of regional integration. For example, in late 2019, five countries in the Horn of Africa – Djibouti, Somalia, Kenya, Ethiopia, and Eritrea – launched the Horn of Africa Initiative, highlighting the importance of regional partnerships and stressing the importance of cooperation and concerted action to address common challenges.

Continuing the trend first observed by Jones and Ward (1994), World Bank-led policy research on the Horn of Africa (HoA) Initiative

frames urban challenges in the context of broader objectives of socio-economic development and macro-regional evolutions. A crucial component has been to position cities and the myriad networks in which they are embedded at the center of the regional integration agenda. For example, poor inter-city connectivity across national borders has emerged as one of the main signals of weak regional integration. As a result, regional dialogue in the HoA Initiative is placing a premium on interventions that enhance regional inter-city connectivity because of the broad range of socio-economic benefits allegedly associated with it. For example, there is ample empirical evidence that the goods, services, and knowledge provided by well-connected urban contexts are more abundant, more diverse, and lower in cost (Cattaneo et al., 2021). Furthermore, well-connected cities also provide more direct access to medical services and education and have the potential to promote social interaction between people with different ethnic, national, and linguistic backgrounds (Weiss et al., 2020).

Against this backdrop, in this paper, we report on a World Bank-funded policy research project that attempts to provide a baseline of

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<https://doi.org/10.1016/j.apgeog.2022.102754>

Received 30 November 2021; Received in revised form 29 May 2022; Accepted 21 June 2022

Available online 6 July 2022

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the level of regional integration in the HoA. Using a network-analytical framework, we benchmark contemporary levels of regional connectivity of HoA cities by measuring and interpreting the topological position of cities in transport networks. In doing so, we contribute to the literature in three complementary ways. First, the paper has an empirical objective: we extend urban research on what continues to be one of the least-researched regions of the world (Kanai et al., 2018), and this in spite of fast-paced urban developments in the HoA (Güneralp et al., 2018). Second, the paper has a methodological objective: we explore how the lack of comparable and up-to-date urban data on the HoA can be overcome by drawing on a combination of emerging data sources (Carr-Hill, 2013). Third, the paper also has a policy objective: by benchmarking the regional connectivity of HoA cities, we provide a baseline against which the impact of future interventions aimed at enhancing city connectivity/regional integration can be examined, both on its own terms and in terms of broader objectives of socio-economic development within the region at large. Although given ongoing tensions in Tigray much of the thinking and discourse on HoA regional integration needs to be (re)cast and critically (re)examined, we hope our approach, framework, and results remain of relevance in the years to come.

The remainder of this paper is organized as follows: Section 2 outlines the rationale for an analysis of inter-city connectivity and its linkages to address the broader topic of regional integration in the HoA; Section 3 discusses our analytical framework; Section 4 provides an overview of our results; Section 5 extends the discussion of results by reviewing some of the main implications, after which the paper is concluded in Section 6 with an overview of our main findings and some avenues for further research.

2. Conceptual framework: intercity connectivity and regional integration in the HoA

Research on the impacts of city connectivity can be framed within broader scientific debates on the impacts of transport infrastructure provision on socio-economic processes in general and its role in promoting regional integration by causing, reinforcing, or tackling spatial inequality in particular. It is widely accepted that transport infrastructures have the potential to impact the development of cities as well as the welfare of their population (e.g., Limão & Venables, 2001; Yin et al., 2015; Glaeser et al., 2016). This extensively documented impact is discursively reinforced by policy narratives: many transport expansion or improvement projects are justified because of their alleged ability to bolster socio-economic development in the broadest sense (Banister & Berechman, 2001; Button & Yuan, 2013; Zhao et al., 2017). The notion of urban connectivity is, however, much more specific than mere transport provision. Camagni (1993) and later Capello (2000) extended the concept of 'network externalities', initially coined in economics (Katz & Shapiro, 1985), into 'city network externalities' to refer to the benefits associated with inter-city connections. They advance a club good perspective on city network externalities (van Meeteren et al., 2016), emphasizing the benefits accruing on the level of the urban production function because connections deliver beneficial synergies and complementarities (Camagni et al., 2013).

In its most basic guise, city connectivity refers to the pattern of linkages between cities that can be examined using graph theory tools.

Although interest in 'city networks' dates back to at least the 1960s (e.g., Nystuen & Dacey, 1961), there has been a surge in interest in this field since the early 2000s (Neal et al., 2021). Crucially, city connectivity entails much more than a city's stock of transport infrastructures¹: it refers to the directness, diversity, topology, and density of a city's connections with other cities. For example, the presence of a sizable airport alone does not make a city a well-connected node, as this also depends on the nature and variety of its direct connections and several other connectivity characteristics. In addition, a city's connectivity may change because of changes that are not directly related to that city: creating additional air transport connectivity in a proximate city with which it has good road connectivity may also change a city's connectivity.

It is clear that HoA cities are very unequally connected in transport networks (e.g., Rammelt and Leung (2017)). For example, the Kenyan city of El Wak and the Ethiopian city of Tepi are separated by a Euclidean distance of about 780 km. However, given the lack of well-developed transport corridors, this entails 1250 km of driving that takes 24 h at best. Furthermore, there are no clear-cut options to significantly shorten this connection (for example, by air), making it hard to conceive meaningful interactions between both urban economies. Overall, regional, national, and international connectivity is clearly concentrated in the HoA's major cities, especially its capital cities. Meanwhile, relatively smaller and/or peripherally located cities are often poorly connected to these major nodes and transport corridors. Furthermore, regional integration in the HoA is in many ways uneven. On the one hand, HoA was one of the pioneering African regions experimenting with regional cooperation in the 1990s. On the other hand, the results of such experiments were mixed, with often more conflict than cooperation emerging (El-Affendi, 2009). One of the many reasons for the uneven regional integration is that some of the territories in HoA states consist of *de facto* ungoverned spaces, undermining the establishment of an overarching governance structure within the region (Kabandula & Shaw, 2018).

Most previous research on HoA integration has been based on qualitative analysis, often drawing on ethnographic methods applied to case studies (e.g., Harbeson (1978); Feyissa et al. (2010); Mengisteb and Bereketeab (2012)). Here, we complement this research with a large-scale analysis of transport network data. In particular, we formalize the notion of the unequal connectivity of cities in the region based on a network analysis of HoA cities' connectivity in the ensemble of regional transport networks. The following section outlines the analytical framework of our study.

3. Analytical framework

3.1. Selection of cities

One of the recurring challenges in urban research is the formal and consistent identification of cities (Parr, 2007). Measures of cities often rely on national definitions, which vary considerably and limit comparability and integrated analysis. Over the past years, there have been several efforts to develop harmonized indicators. One of the most consistent frameworks in this context is the Degree of Urbanization (DoU), which is based on the Global Human Settlement Layer developed

¹ Although this paper is cast in the language of a 'connectivity' analysis, in practice our analytical framework consists of a mixed connectivity/accessibility setup. The sometimes-subtle difference between both concepts can be summarized as follows: in infrastructural terms, connectivity refers to the actual interaction between cities, while accessibility refers to the potential capacity or ease with which other cities can be reached. The distinction between both concepts is sometimes blurry: the number of weekly flights between two cities can clearly be seen as a measure of both connectivity and accessibility; large values point to a large potential accessibility of and large *de facto* connections.

in the context of a European Union-initiated project (<https://ghsl.jrc.ec.europa.eu/degurba.php>). This entails developing a spatial raster dataset depicting the global distribution of population, after which population densities are used as the input to an algorithm assigning territories to different classes based on spatial contiguities of similar raster cells. ‘Cities’ are identified as contiguous sets of grid cells with a density of at least 1,500 inhabitants per km² that collectively have a population of at least 50,000. Gaps within this collection of grid cells are filled, after which the edges are smoothed.

A total of 84 centers in the Horn of Africa are identified as ‘cities’ in the DoU classification, two of which are cross-border cities (i.e., Mandera at the Kenya/Somalia border and Moyale at the Kenya/Ethiopia border). With the exceptions of Djibouti (Djibouti) and Asmara (Eritrea), all cities are located in Kenya, Ethiopia, and Somalia. To make the analysis regionally more inclusive, additional cities with a population below 50,000 were selected for Djibouti (4) and Eritrea (5) using population data from the City Population database (<http://www.citypopulation.de>). This produces 92 cities, with at least five cities in each country (Fig. 1).

3.2. Data sources and specification of connections

Our analysis is based on a combination of three transport networks: road, air, and train. In recent literature, such a combination has been widely applied to develop a comprehensive view of inter-city connectivity (e.g., Zhu et al., 2018; Zhu et al., 2019). Although air transport and train networks are increasingly important connectivity providers within the region at large, the connectivity they provide is presently restricted to specific parts of the population and specific HoA cities and corridors: most inter-city connections in the HoA are provided via road. Furthermore, the road network is also a major potential ‘feeder’ of air transport connectivity, especially for cities located in the relative vicinity of major air transport hubs (e.g., Athi River near Nairobi and Debre Zeit near Addis Ababa): depending on the distance and road quality, these cities can also draw on the air transport connectivity nominally associated with their capital cities. More recently, Bertazzini (2021) highlighted the importance of the road network built across the HoA region, as it could have a long-term impact on the region’s spatial distribution of economic activities. In light of this, we specify a network that combines all three networks but assigns a larger weight to the road network.

Road connectivity is based on measures of driving time (in minutes) and distance (in kilometers) for the fastest routes given by Google Maps between all $92 \times (92-1) / 2 = 4,186$ pairs of cities. In reality, many potential factors may affect the actual driving time within the HoA. One of the most prominent factors is perhaps border-crossings. The exact spent on each border-crossing trip in HoA is highly idiosyncratic – sometimes it takes no extra time; sometimes it can take several hours if not days. Nevertheless, for modeling purposes, we have to add a universal ‘penalty’ of (extra) travel time to all international connections to reflect this nature, which is also a common practice in transport studies (e.g., Zhu et al., 2018; Zhu et al., 2019). We added a conservative 20-min penalty to all international connections to account for time lost at border-crossings, which may nonetheless underestimate the time to cross borders in the region but is aligned with ongoing efforts (e.g., at Moyale) to smoothen the process.² Road connectivity is, however, much subtler than mere potential average speed: it is also defined by the distance that needs to be covered (reflecting time and potentially capital ‘lost’ when making the connection) and population size effects (reflecting the magnitude of the benefits offered by a high-quality connection). We therefore specify a road connectivity measure that

² We conducted a suite of robustness checks by specifying the time lost at border-crossings as 10 min, 20 min, 30 min, 40 min, 1 h, 1.5 h, and 2 h. The pairwise correlation coefficients of the total travel time from any two treatments are higher than 0.999.

draws on a spatial interaction approach (Fotheringham, 1983; Wu et al., 2021): it jointly considers the population sizes of the cities and the road quality. As to not overestimate the effects of larger population sizes and shorter driving distances and times, we use logarithms, producing the following road connectivity measure:

$$\text{Road}_{a-b} = \frac{\log(\text{Pop}_a) * \log(\text{Pop}_b)}{\log(\text{Distance}_{a-b}) * \log(\text{TravelTime}_{a-b})} \quad (1)$$

The strongest national connections are between (very) proximate cities, e.g., between Dese and Tita in Ethiopia and between Nairobi and Ndenderu in Kenya. Note, however, that as per Equation (1), road connectivity is not a mere matter of distance. For example, although being located in relative proximity, Ndenderu and Athi River in Kenya are not that strongly connected because it takes on average 73 min to cover the 46 km separating these medium-size cities in light of the congestion around Nairobi.

Air connectivity is measured by recording the number of weekly direct flights. This information was derived from Google searches, after which it was cross-referenced with secondary online data sources such as Skyscanner (globally one of the largest metasearch travel engines) and details of operations at the different airports. Using the logarithm of weekly flights as not to inflate the importance of the few sizable air transport links in the HoA produces the following air connectivity measure:

$$\text{Air}_{a-b} = \log(\# \text{ of weekly direct flights}_{a-b} + 1) \quad (2)$$

Finally, train connectivity is measured by recording the number of weekly trains, drawing on national railway enterprise websites, most notably for Kenya (e.g., <https://metickets.krc.co.ke/>) and Ethiopia (e.g., <http://www.erc.gov.et/>). Results were cross-referenced with online searches of operations in specific cities. Again, using the logarithm of weekly trains produces our train connectivity measure:

$$\text{Train}_{a-b} = \log(\# \text{ of weekly direct trains}_{a-b} + 1) \quad (3)$$

The strongest air connections are Nairobi-Mombasa and Nairobi-Kisumu, with a total of 169 and 85 weekly direct flights, respectively. This is followed by a range of connections between Addis Ababa and major cities in northern and eastern Ethiopia (Bahir Dar, Dire Dawa, Jijiga, Gondar, and Mekelle). The strongest international connection is between Nairobi and Addis Ababa, with 38 weekly direct flights. The most substantial train connection is again Nairobi-Mombasa, with a total of 21 weekly trains. Although most of the – presently scarce – railway corridors in the HoA are national, there is an international corridor: the Addis Ababa-Djibouti Railway, a new standard gauge international railway that serves as one of the backbones of the new Ethiopian National Railway Network. It also connects Nazret and Dire Dawa (Ethiopia) and Ali Sabieh (Djibouti) on a near-daily basis and provides landlocked Ethiopia with access to the Gulf of Aden and the Red Sea via Djibouti.

3.3. Network analysis

3.3.1. Network specification

This specification of the inter-city connections outlined in the previous sub-section produces three networks: a fully connected road network (Fig. 2a), a sparse air transport network (Fig. 2b), and an even sparser train network (Fig. 2c). The three networks are aggregated in two steps.

First, the three sub-networks are combined into a composite network (Fig. 2d). To this end, we standardize all three measures given by Equations (1)–(3) by applying a min-max normalization, producing distributions between 0 (minimum connectivity) and 1 (maximum connectivity). These normalized connectivity scores are then combined into an overall connectivity score between each pair of cities by combining the three scores. The road connectivity network is assigned

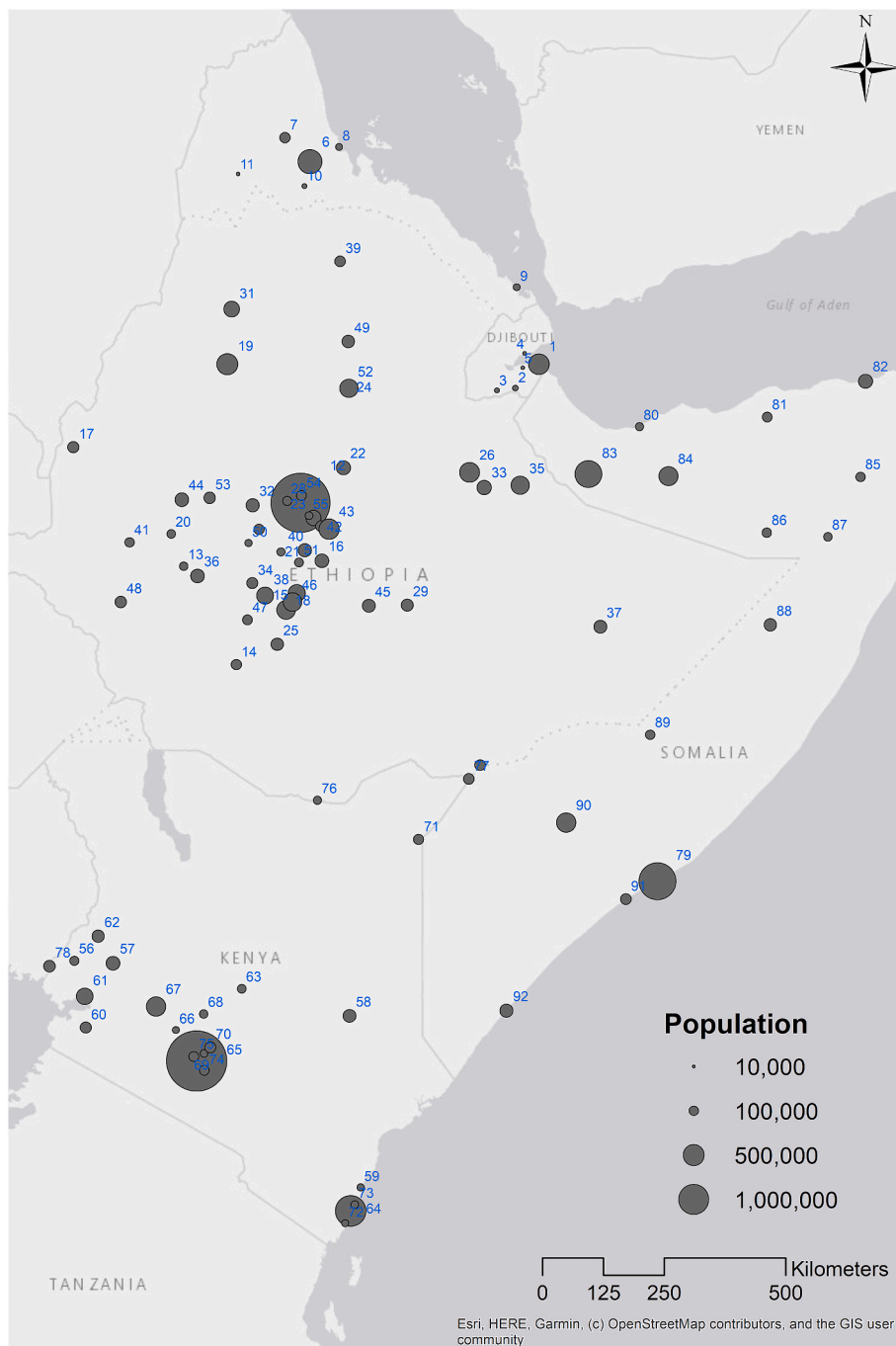


Fig. 1. ‘Cities’ in the HoA based on the Degree of Urbanization methodology (<https://ghsl.jrc.ec.europa.eu/degurba.php>, and <http://www.citypopulation.de> for cities in Eritrea and Djibouti beyond the capital). City codes can be found in Appendix 1.

the most significant weight because of its great importance and full connectedness (see Fig. 2a). Within the air transport and train networks, the former was given a larger weight than the latter, given more pairs of cities connected via flights than trains (see Fig. 2b vs. Fig. 2c). Therefore, we operationalized the following weight assignment as 3/6 for road, 2/6 for air, and 1/6 for train in Eq. (4):

$$\text{Connectivity}_{a-b} = \text{Road}_{a-b}/2 + \text{Air}_{a-b}/3 + \text{Train}_{a-b}/6 \quad (4)$$

Second, we remove non-significant connections. In principle, the network specified in Equation (1) (Fig. 2a) and subsequently Equation (4) (Fig. 2d) is fully connected: the distribution produced by Equation (1) has a theoretical minimum of 0, but in practice infinitesimally converges upon 0. The latter values are associated with relatively small

cities divided by extremely long driving distances and/or times: it is always possible to connect any pair of cities no matter how feasible this turns out to be. To remove these conceptually meaningless connections, we imposed a threshold. To decide on the cutoff point, starting with the poorest connection (between Barentu in Eritrea and Ukunda in Kenya), we eliminated connections stepwise. After each elimination, we calculated the Pearson correlation coefficient between the original, fully connected network and the newly derived network to assess how strongly they resemble each other. Ultimately, we decided on a cutoff point of $\text{Connectivity}_{a-b} = 0.08$. This produces a network with a very sizable correlation of 0.91 with the original network but only retains 248 of the 4,278 (6%) original city pairs. Each city has at least one connection and is therefore connected to the network at large. The

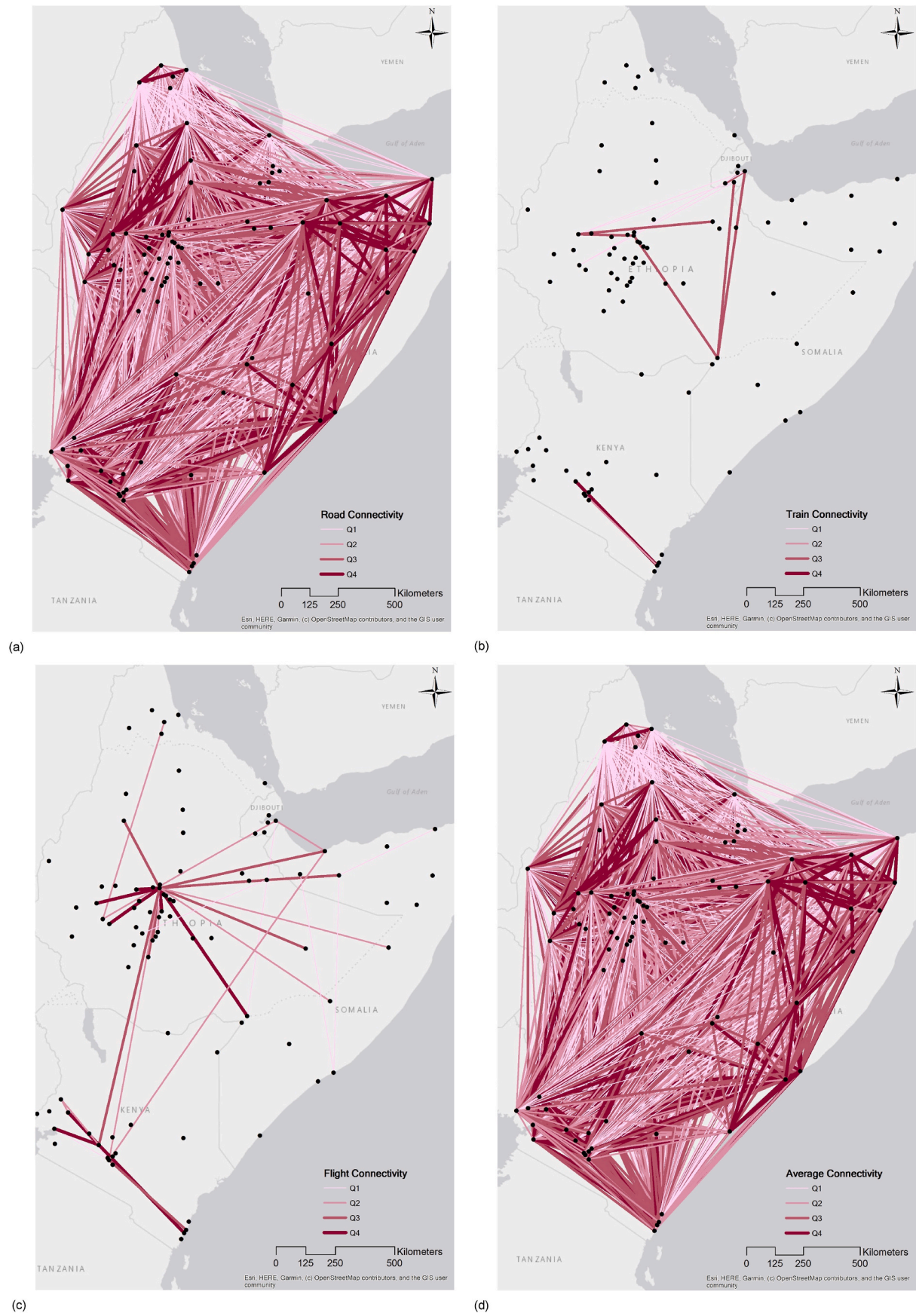


Fig. 2. Inter-city transport networks in the HoA: (a) Road, (b) Air, (c) Train, and (d) Composite. The relative strength of connections is shown through both shades and thickness utilizing quartiles (Q1 = the first quartile; Q2 = the second quartile; Q3 = the third quartile; Q4 = the fourth quartile).

resulting network is shown in Fig. 3: this much-sparser network closely resembles the original network structure (Fig. 2d) but with a density that allows for a more meaningful analysis of its topology and structure.

3.3.2. Formal network analysis of connectivity matrix

Network analysis offers the opportunity for a systematic appraisal of connectivity in city networks (Derudder, 2021; Zhang et al., 2019). In our research, we implement two complementary centrality measures that inform our understanding of the position of individual cities within the HoA's infrastructure networks: eigenvector centrality (EC) and betweenness centrality (BC). As two of those most classic centrality measures, both EC and BC have been widely applied in transport studies and applied geography (e.g., Cheung et al., 2020; Wang et al., 2020). The application of centrality measures implies adopting a graph-theoretical conceptualization in which a node is a 'vertex,' and a connection is an 'edge'. The formal mathematical specification of this is that a network $G(\mathcal{V}, \mathcal{E})$ is constructed with each of the $N = |\mathcal{V}|$ nodes representing a city, with the connections between them being encoded in the set of links \mathcal{E} . This network is fully described by the non-negative adjacency matrix $W \equiv \{w_{ij}\}$. An element w_{ij} of W is different from zero if there is a connection between two cities i and j , while $i \neq j$.

EC accounts for the strategic nature of a node's connections: it foregrounds cities that are on average well connected to well-connected cities. Instead of using the simplest, but not necessarily very informative,

centrality measure – degree centrality (DC), which is a 'local' measure accounting for the total strength of a node's connections – EC is a 'global measure' looking specifically beyond first-order neighbors. EC can be cast as a generalization of DC in that it is given by:

$$EC(i) = u_{1,i} \tag{5}$$

with $u_{1,i}$ representing the i th component u_1 , the eigenvector associated with the eigenvalue λ_1 of A , so that it satisfies:

$$Au_1 = \lambda_1 u_1 \tag{6}$$

In this case $A \equiv \{a_{ij}\}$ is the adjacency matrix of G , whose non-zero elements denote the presence of a connection between cities i and j . In our research, EC will above all foreground major transport hubs (e.g., Addis Ababa) and smaller cities located near them. In addition, it also identifies the privileged position of cities located along major transport corridors because of the externalities associated with having access to multiple nodes that are in turn also inter-connected. In contrast, cities that have above all connections with poorly connected cities will have small EC.

BC, in turn, accounts for a node serving as the most efficient gateway for otherwise unconnected nodes. For each city $i \in \mathcal{V}$, BC can be computed from W as follows:

$$BC(i) = \sum_{a \neq i \neq b \in V} \frac{\sigma_{ab}(i)}{\sigma_{ab}} \tag{7}$$

where σ_{ab} is the total number of shortest paths between nodes a and b , and $\sigma_{ab}(i)$ is the number of those paths that pass through i . In our research, BC will foreground cities with several near-exclusive connections that cities can use to make otherwise unfeasible connections. In doing so, these cities serve the most efficient gateways for accessing the remainder of the city network. Like EC, this is a 'global' measure in that it looks beyond nodes' first-order neighbors. More concretely, cities combining air transport connections with strong road connections to otherwise not very well-connected cities will have large BC. However, BC can be more subtle, with cities along long road corridors acting as the most efficient gateway for entire network parts that would otherwise be unconnected (Neal, 2014). This also implies that cities with limited connections can have sizable BC if one of their connections links other cities to the remainder of the network. BC is typically much more skewed than EC, as only a limited number of nodes often perform this role.

4. Results: city connectivity in the HoA

We organize the discussion of our results in two sub-sections. First, we focus on the overall regional integration in the HoA through the lens of inter-city connections. Second, we present the results of the centrality analysis, zooming in on the most significant patterns.

4.1. Regional integration in the HoA

The most obvious starting point is a discussion of the HoA's strongest connections. Table 1 shows the ten strongest connections at large (top part) and the ten strongest international connections (bottom part). The national imprint of city connectivity patterns is immediately apparent in that there is no overlap between both rankings: the ten strongest connections at large are all intra-national, with the strongest international connection (Addis Ababa-Djibouti) ranked 13th overall.

Nairobi-Mombasa is the most connected city-dyad in the HoA: it has both the strongest air and train connections alongside a moderate level of road connectivity via the (often-congested) A109. The importance of road connectivity as put forward in our analytical framework shows from the second strongest connection not being a multimodal connection between major cities, but rather a road connection between two

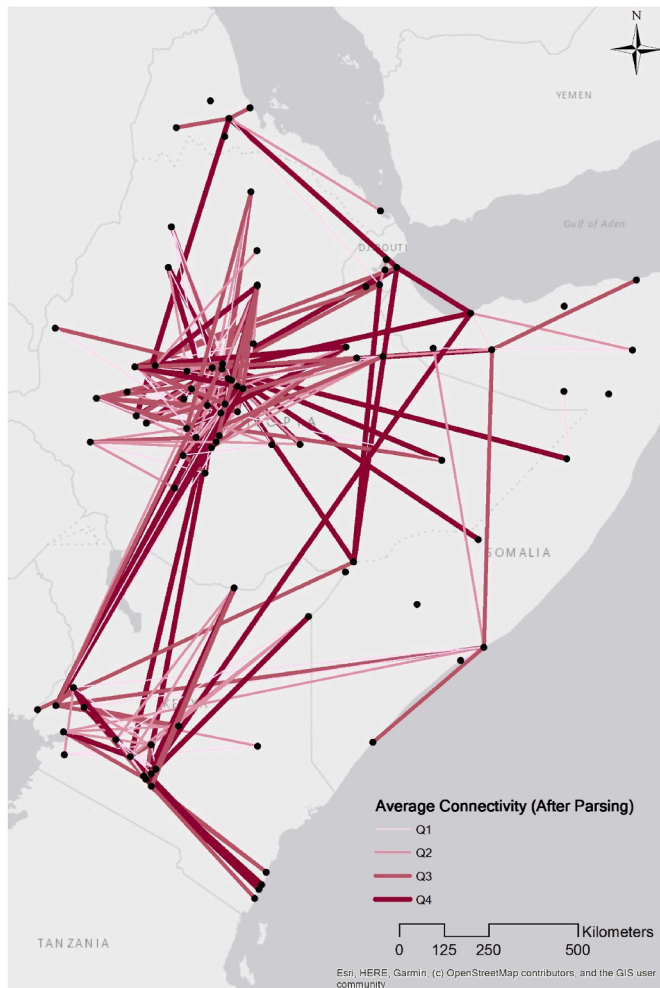


Fig. 3. Inter-city transport networks in the HoA after network parsing. The relative strength of connections is shown through both shades and thickness through quartiles (Q1 = the first quartile; Q2 = the second quartile; Q3 = the third quartile; Q4 = the fourth quartile).

Table 1
10 strongest connections (a) and international connections (b) in the Horn of Africa.

(a) All connections				
City a	Country	City b	Country	Connectivity _{a-b}
Mombasa	Kenya	Nairobi	Kenya	0.588
Dese	Ethiopia	Tita	Ethiopia	0.500
Addis Ababa	Ethiopia	Dire Dawa	Ethiopia	0.477
Nairobi	Kenya	Ruiru	Kenya	0.424
Nairobi	Kenya	Ndenderu	Kenya	0.381
Kisumu	Kenya	Nairobi	Kenya	0.378
Nairobi	Kenya	Atthi River	Kenya	0.376
Mombasa	Kenya	Ukunda	Kenya	0.374
Addis Ababa	Ethiopia	Bahir Dar	Ethiopia	0.368
Debre Zeyit	Ethiopia	Dukem	Ethiopia	0.336
(b) International connections				
City a	Country	City b	Country	Connectivity _{a-b}
Djibouti	Djibouti	Addis Ababa	Ethiopia	0.309
Addis Ababa	Ethiopia	Nairobi	Kenya	0.299
Djibouti	Djibouti	Dire Dawa	Ethiopia	0.298
Addis Ababa	Ethiopia	Hargeysa	Somalia	0.264
Addis Ababa	Ethiopia	Muqdisho	Somalia	0.262
Nairobi	Kenya	Muqdisho	Somalia	0.231
Addis Ababa	Ethiopia	Mombasa	Kenya	0.223
Djibouti	Djibouti	Muqdisho	Somalia	0.204
Ali Sabieh	Djibouti	Dire Dawa	Ethiopia	0.183
Asmera	Eritrea	Addis Ababa	Ethiopia	0.181

smaller yet adjacent settlements: Dese and Tita in Ethiopia are only 10 km separated from each other along Ethiopia’s A2 highway. The remainder of the top 10 combines both patterns, i.e., either city connected by multiple modes or nearby cities connected via major roads.

The most important international connections are a combination of city-dyads connected by relatively strong air linkages (Nairobi-Addis Ababa and Mogadishu-Addis Ababa) and a range of city-dyads in the corridor running from Addis Ababa to Djibouti. In this west-east corridor, a number of cities are linked by more than one mode: Addis Ababa-Djibouti and Dire Dawa-Djibouti by all three modes, and Djibouti-Nazret, Dire Dawa-Ali Sabieh, Nazret-Ali Sabieh, and Addis Ababa-Ali Sabieh by both train and road.

Fig. 4 shows all international connections where Connectivity_{a-b} > 0. When read alongside the bottom half of Table 1, the map accentuates that the strongest international connections are between capital cities or between cities along the broadly defined Addis Ababa-Djibouti corridor. Some of the strongest connections, for example, Addis Ababa-Burco and Nazret-Hargeisa, connect central Ethiopia to Djibouti and northern Somalia. This west-east corridor fans out east of Awash and Dire Dawa, respectively. In Awash, the A1 highway branches off to Djibouti in a northeasterly direction, while there is also road and train connectivity further to the east in the direction of Dire Dawa.³ In Dire Dawa, the train connection branches off to Djibouti in a northerly direction, with road connectivity continuing east into Somalia. East of Dire Dawa, connectivity is less strong and more fragmented; however, it combines air transport connections such as Addis Ababa-Hargeisa and moderates yet viable road connections between Dire Dawa and Jijiga in Ethiopia on the one hand and Hargeisa and Berbera in Somalia on the other hand. The relative strength of connectivity along this broadly defined east-west corridor compared to a possible north-south corridor between Addis Ababa and Nairobi via Moyale can in large part be explained by the importance of access to ports for landlocked Ethiopia.

Although fewer international road connections are running from north to south, there are some connections between Asmara on the one hand and northern Ethiopian cities on the other hand (Bahir Dar, Tita, and Gonder). Proposed road upgrades and negotiations on a rail corridor

³ The planned rail link between Awash and Weldiya will further strengthen the road-based connectivity along this corridor.

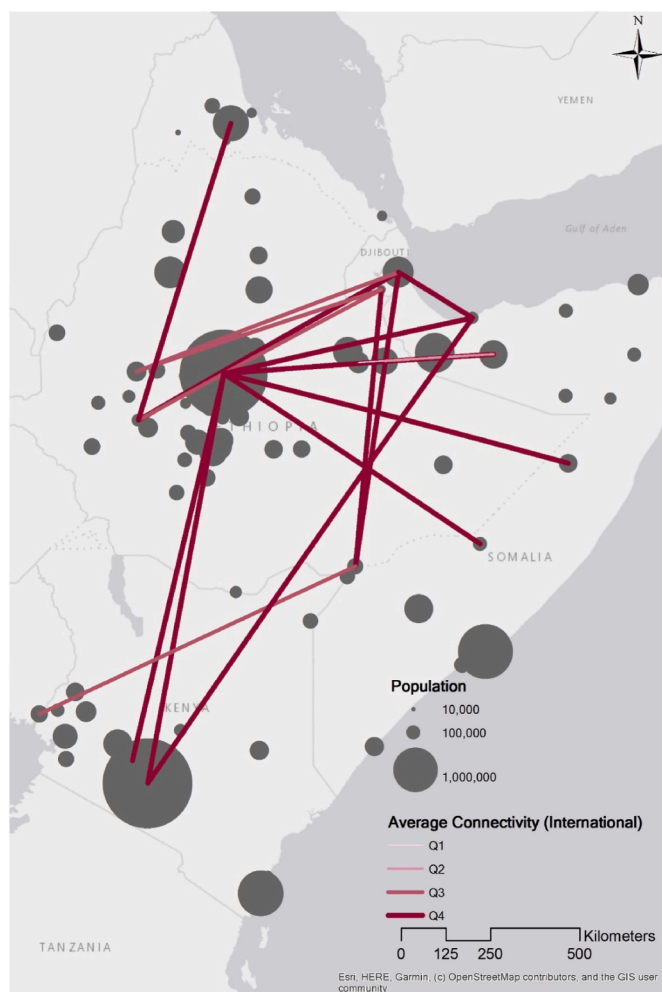


Fig. 4. International connections with average connectivity > 0. The relative strength of connections is shown through both shades and thickness through quartiles (Q1 = the first quartile; Q2 = the second quartile; Q3 = the third quartile; Q4 = the fourth quartile).

connecting northern Ethiopia via Mekelle and Asmara to Massawa’s port could strengthen this potential. The strongest north-south connection is that between Addis Ababa and Nairobi, reflecting the size of both cities and – by the standards of the HoA – reasonable connectivity along the A2 (Kenya) and A7 (Ethiopia) via Moyale. On the one hand, this shows that previous road upgrades have paid off: when not factoring in the Moyale border-crossing time, our data suggest a possible average speed of up to 1.3 km/min. Besides, the opening up of a border facility at Moyale easing the flow of goods and people allows capitalizing on this potential. This shows that upgrades to road connectivity also require upgrades to border services and facilities, which in the Nairobi-Addis Ababa link has been well understood. Another long-distance transborder connection is between Nairobi and Kismayo along the A3, an important artery from Nairobi to the east that is in relatively good condition for most of the way.

The weakest connections – defined here as the shortest distances without a viable road link – are found in the borderlands between Ethiopia, Djibouti, and Eritrea. Table 2 shows the shortest distances where Connectivity_{a-b} = 0. This is, to some degree, a physical-geographical artifact with the Gulf of Tadjourah acting as a barrier. However, it nonetheless shows that the connectivity between Ethiopia and Djibouti is presently not extended into southern Eritrea. In the face of poor intra-Eritrea connections between Assab and the major centers in northern Eritrea, Assab is presently isolated on all possible fronts,

Table 2
10 international connections with shortest Euclidean distance but connectivity = 0.

City a	Country (city a)	City b	Country (city b)	Euclidean distance (km)
Tadjoura	Djibouti	Assab	Eritrea	136.8
El Wak	Kenya	Mandera	Somalia	161.4
Djibouti	Djibouti	Assab	Eritrea	164.6
Arta	Djibouti	Assab	Eritrea	165.9
Mendefera	Eritrea	Mekele	Ethiopia	170.3
Dikhil	Djibouti	Dire Dawa	Ethiopia	177.4
Dolo	Ethiopia	El Wak	Kenya	197.9
Ali Sabieh	Djibouti	Jijiga	Ethiopia	200.2
Dikhil	Djibouti	Jijiga	Ethiopia	200.7
Dikhil	Djibouti	Harer	Ethiopia	201.2

despite its potential importance as a port. To build a resilient and stronger network in this part of the HoA, a complementary strategy is needed. This will involve extending connections from Assab into Djibouti and Ethiopia, a national policy strengthening connectivity across the Eritrean coastline into Massawa and Asmara, and connecting this to the links coming in from northern Ethiopia. Given that connectivity in this part of the HoA will have a strong logistics dimension, this should ideally involve road and rail connections connected to wider networks that exist or are in the making.

Although transport connectivity is co-defined by distance decay and national functional spaces even in the economically most integrated regions, the lack of regional integration in the HoA is manifest. For example, unlike transnational infrastructure connectivity in Europe and across Asia (especially in the context of the Belt and Road Initiative), HoA connectivity can first and foremost be described as a collection of 'national spaces'. This can be seen in Table 3, which shows the average values of Connectivity_{a-b} for country-pairs. Intra-country connectivities (0.034530) are 29 times larger than the average value of inter-country connectivities (0.001211), which cannot be solely explained by distance decay alone. In short, the lack of regional economic integration results in, and also results from, the lack of connectivity between the HoA's major cities. Indeed, the five largest values are uniformly for intra-country connections, with Djibouti being unsurprisingly given its small size compared with other countries and features the strongest connections. The connections between the Djibouti-Ethiopia-Somalia triad form a second block, with most connections emanating from the border-crossing connections by road and train in the Djibouti-Dire Dawa-Hargeisa triangle. Given the strategic importance of the Djibouti, Berbera, and Bossaso ports for landlocked Ethiopia, further developing connectivity in this corridor will prove important.

There are minor connections between Djibouti and Eritrea, Ethiopia and Eritrea, Kenya and Somalia, and Kenya and Ethiopia. The small

Table 3
Average connectivities at the level of countries.

Country 1	Country 2	Average connectivity
Djibouti	Djibouti	0.067987
Kenya	Kenya	0.044773
Eritrea	Eritrea	0.026542
Ethiopia	Ethiopia	0.022497
Somalia	Somalia	0.010849
Djibouti	Ethiopia	0.005470
Djibouti	Somalia	0.002908
Ethiopia	Somalia	0.001699
Kenya	Somalia	0.000787
Eritrea	Ethiopia	0.000684
Ethiopia	Kenya	0.000565
Djibouti	Eritrea	0.000000
Djibouti	Kenya	0.000000
Eritrea	Kenya	0.000000
Eritrea	Somalia	0.000000

value for the connectivity between Kenya and Ethiopia is an artifact of both countries' size, with no major connections between Ethiopia's north and Kenya's south. However, the low average connectivities between cities in the region's two largest economies are notable. Indeed, beyond (1) the flights between Addis Ababa on the one hand and Nairobi and Mombasa on the other hand and (2) the Addis Ababa-Nairobi road link via Moyale, there are as good as no viable connections between both countries. Finally, there are no connections between Djibouti and Kenya, Eritrea and Kenya, and Somalia and Eritrea.

4.2. Centralities

The centrality analysis allows translating the structural ensemble of inter-city connections into evaluations of the role of individual cities. Figs. 5 and 6 map the distribution of eigenvector and betweenness centrality, respectively.

The cities with the largest values for eigenvector centrality (EC) are a combination of, first, the HoA's capital cities/main economic centers and, second, cities with a privileged position along major transport corridors. First, Addis Ababa and Nairobi have a much larger EC than the other capital cities in the HoA. This reflects both the size of their national economies and the diverse ways both cities are connected with many cities. Despite having less EC than Addis Ababa and Nairobi, the importance of capital cities shows from Djibouti (13th), Mogadishu

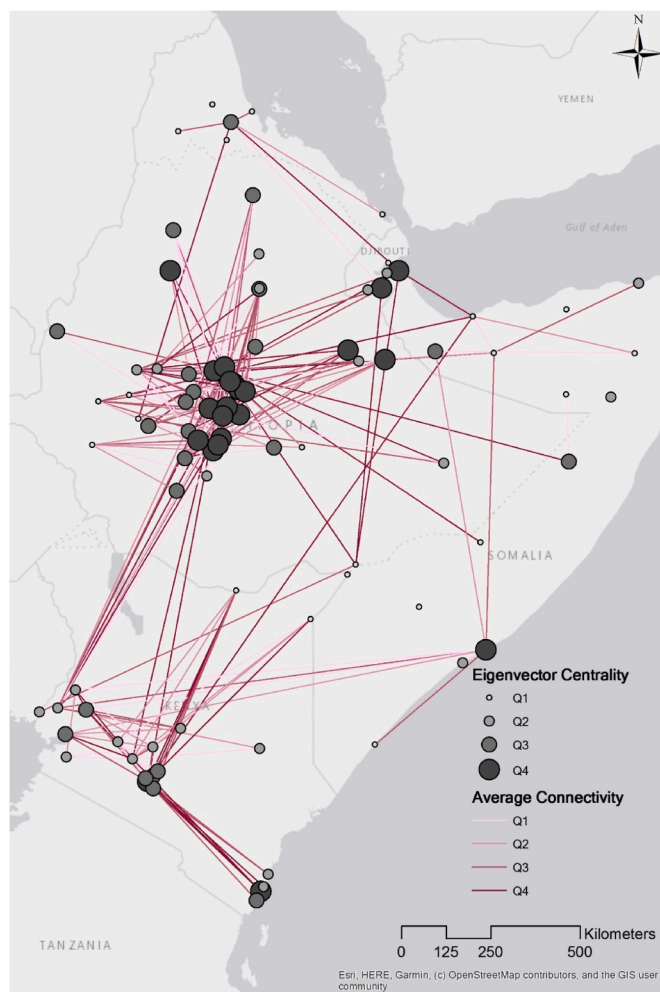


Fig. 5. Eigenvector centrality (EC) of HoA cities. The relative size of EC is shown through both shades and thickness through quartiles (Q1 = the first quartile; Q2 = the second quartile; Q3 = the third quartile; Q4 = the fourth quartile).

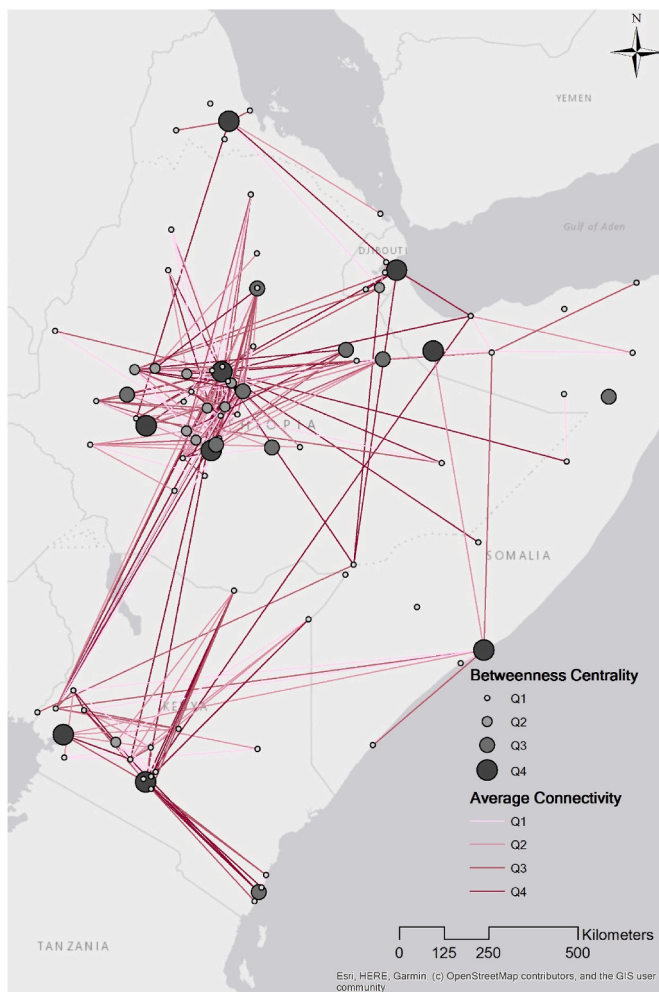


Fig. 6. Betweenness centrality (BC) of HoA cities. The relative size of BC is shown through both shades and thickness through quartiles (Q1 = the first quartile; Q2 = the second quartile; Q3 = the third quartile; Q4 = the fourth quartile).

(19th), and Asmara (44th), which are by far the most connected cities in their respective countries. Second, EC map foregrounds cities located along major transport corridors: this allows them to connect with cities with sizable air transport connectivity and/or with many other cities located along these corridors. Prominent examples are cities with strong connections with Addis Ababa: Nazret (2nd) and Dire Dawa (7th) by rail and road, and Debre Zeyit (also known as Bishoftu, 4th) and Dukem (10th) along the expressway to Adama. A similar interpretation holds for Ali Sabieh (23rd) in Djibouti. The EC perspective also emphasizes the strategic importance of having a major direct air service to the HoA's major gateways, bringing other key centers in closer reach.

Weak EC connectivities are associated with peripheral cities in their national context: Ceerigaabo in Somalia, Assab in Eritrea, Tadjourah in Djibouti, Tepi in Ethiopia, and El Wak in Kenya are clear examples here. These are invariably cities without a commercial airport, are not located along major road corridors, often lack well-developed inter-city road infrastructure at large, and are relatively far removed from other cities. Even though these cities often function as major trading centers for their respective regions, their very modest connectivities within the HoA reflect and reproduce patterns of peripheralization. The culmination of these patterns can be found in border cities, most prominently in the Kenyan-Ethiopian-Somalian border regions: Dolo (Ethiopia/Somalia), Mandera (Kenya/Ethiopia/Somalia), and Moyale (Kenya/Ethiopia) are among the weakest connected nodes in terms of EC, even if in the case of

the latter city there have been ongoing efforts to better connect the city as part of the Addis Ababa-Nairobi link.

The lowest values are for Somalian and Eritrean cities, reflecting a combination of the lack of non-road-based transport infrastructure, average or sometimes even poor road infrastructure, and – above all, in Somalia – large distances between the different cities. An obvious example is Beledweyne, located in central Somalia. Although a relatively large city, it is only connected to the HoA's broader transport networks via road. It has no formal connections into Ethiopia, with the Ferfer border post being defunct. Although located along the north-south road axis connecting Mogadishu with northern Somalia via Garowe, these are the only viable connections that cover large distances at limited speeds. A broadly similar situation can be observed in Eritrea, although the somewhat denser cluster of cities around Asmara pushes these cities' EC somewhat up in the ranking. Nonetheless, for a city such as Barentu, located in western Eritrea, the situation is comparable to that of Beledweyne in Somalia: it has no possible connections into Ethiopia and only low-speed road connections with Mendefera, Keren, and Asmara in Eritrea.

The importance of air connectivity, no matter how small, shows from the example of Boosaaso in Somalia, which is ranked 61st. Although it is one of the least important cities in the HoA in terms of its overall level of connections, its direct link with Mogadishu allows for potentially faster access to the other major cities in the HoA could be expected on the strength of its connections alone. This logic also applies to road connectivity, with Moyale's links in Kenya along the A2 highway to Nairobi, bringing it somewhat 'closer' to other major cities in the HoA compared with other peripheral cities such as El Wak, Ceerigaabo, Mandera, and Dolo.

As expected, the distribution of BC is much more skewed, with only 28 cities having a value > 0. The BC ranking brings the regional dominance of Addis Ababa and Nairobi even more to the fore. Both cities act as the HoA's regional gateways to complement their broader international gateway function (Bassens et al., 2012). Despite not having that many connections, Asmara (4th) and Mogadishu (8th) are now ranked much higher, reflecting their crucial role in connecting other cities in their country to the rest of the HoA network, most crucially via the air links they offer. Awasa in Ethiopia (ranked 3rd) also emerges as a major gateway. It connects secondary Ethiopian cities located in the south to the rest of the network via its strategic location along the A8 highway (the Cairo-Cape Town link) and its direct air connection with Addis Ababa. Finally, several HoA cities that are (relatively) weakly connected appear on the BC map. Examples are Kisumu (Kenya, 5th), Hargeisa (Somalia, 7th), and Robe (Ethiopia, 14th). What sets these cities apart from Bahir Dar and Gondar in Ethiopia is that they can also be 'used' by other cities to connect to the HoA network at large.

5. Discussion: policy perspectives on connectivity for the HoA

The previous section gave a straightforward overview of our results. In this section, we review some of the broader implications of the different tables and maps. Three sets of implications stand out.

First, the importance of national spaces for inter-city connectivity is perhaps much more evident in the HoA than in other parts of the world (Githaiga et al., 2019; Zhang, 2020; Brenton et al., 2021). There are several reasons for this, ranging from the development context to evolving geopolitical and geoeconomic tensions. As a result, connectivity provision has often followed a logic that promotes national cohesion rather than regional integration. This is very clear in Ethiopia, where connectivity provision has been oriented centrally located in Addis Ababa. Although a degree of national coordination is reasonable and even desirable, the relative lack of regional integration in the HoA in terms of inter-urban connectivity is striking. In addition to the plans being drawn up in the HoA Initiative context, several exceptions are already in place. Prime examples include the rail and road connectivity on the west-east corridor running from Addis Ababa on the one hand to

Djibouti and cities in northwestern Somalia on the other hand, as well as the Addis Ababa-Nairobi road link via Moyale. Future regional patterns of connectivity could include connections between landlocked Ethiopia and a range of Red Sea ports, the Liboi-Kismayo Road facilitating connectivity between Nairobi and southern Somalia, and aligning upgrades to Eritrean infrastructure with connections into northern Ethiopia. Importantly, each of these examples clearly shows that national and regional initiatives are not at odds with each other: targeted national city connectivity provision interventions can have regional effects, and vice versa.

Second, these thick borders also result in the peripheralization of borderlands. The debilitating effect of national borders on intra-regional connectivity in the HoA is nowhere more manifest than in its border cities, which tend to suffer from national development policies' 'borderland blindness' (cf. Trémolières & Walther, 2019). Border cities find themselves at the bottom of the centrality rankings because they suffer from the combined effects of limited infrastructure provision (often only road connectivity) and long distances to other cities via poor roads. The market town of Mendera (in the border region between Kenya, Ethiopia, and Somalia) and Dolo (at the Ethiopia-Somalia border) are arguably the most striking examples. However, there is a broader logic here, with peripheral cities often being deprived of connectivity (e.g., El Wak in Kenya, Tepi in Ethiopia, Assab in Eritrea, Tadjourah in Djibouti, and Beledweyne in Somalia). This is a relevant observation in its own right. However, there is a further debilitating effect here because border cities benefit the most from connectivity investments to promote regional integration: they are often veritable *trans*-border agglomerations with a high potential for social and commercial exchanges. For example, Dolo is an Ethiopian market town at the Somali border extended with refugee camps created around 2010. According to UNHCR registration data (United Nations High Commissioner for Refugees (UNHCR), 2021), these camps now host around 220,000, almost exclusively Somali refugees, so that refugees outnumber the host population. The lack of health facilities at the Somali side of the border and regional tensions in Somalia does not preclude that, according to a recent report by the University of Oxford Refugee Studies Centre (2020), Dolo can only be fully understood as part of a cross-border economy, interconnected to the national economy of Somalia. However, the current state of infrastructure does not reflect this as the nearest tarmac road is more than 300 km in every direction. Thus, and as shown by the example of Moyale, a second observation is that enhancing regional connectivity crucially depends on facilitating, regulating, and further developing existing exchanges across borders.

Third, connectivity needs to be understood from a multiscalar and multimodal perspective. This is very evident in ongoing discussions on the opening up of new ports such as Assab in southern Eritrea as gateways for the HoA at large, of crucial importance for landlocked Ethiopia in particular. Port competitiveness is increasingly tied to developing trade corridors, integrating the port in a multimodal transportation network to improve market access, fluidity of trade, and the integration of emerging industrial networks. From this perspective, a port is an interface between maritime trade, economic activities of ports, and inland terminals that provide intermodal structures and connections with the vast hinterlands (Merk & Notteboom, 2015). Conversely, the amplification capacity of transport corridors may allow the expansion of trade via the port. These bonds of mutual causality are key to understanding connectivity to port cities: the quality and capacity of hinterland modalities, roads, and relays are essential to any expansion of trade. In the HoA, this crucially requires coordination between national, bilateral, region-wide, and border city connectivity plans. The case of the border region between Eritrea, Ethiopia, and Djibouti serves to illustrate: to fully unleash the potential of the strategic Eritrean port city of Assab will require (1) action on the Eritrean side (better connections by road and rail to Asmara), (2) coordination between Eritrea, Ethiopia and Djibouti to (re)open cross-border road connections and possibly develop rail links, and (3) integration with plans for expanding the

Ethiopian railway system.

6. Conclusions

There is often friction associated with covering vast distances between cities. Investment in trade and transport corridors seek to reduce this friction: it can ensure increased inter-city connectivity, facilitating the mobility of goods, people, capital, and ideas, and subsequently further unleashing the economic and societal potential within cities/regions. In this paper, we have formalized such an approach through a benchmark analysis of the position of HoA cities in regional transport networks.

Overall, and unsurprisingly given the broader development context, inter-city connectivity in the HoA is not as well-developed as in other regions. For example, even though Addis Ababa and Nairobi are reasonably well connected, road connectivity between both cities falls short of their rising economic and demographic potential (and that of southern Ethiopia and northern Kenya more generally). For example, it is anticipated that 22 h and 25 min are needed to cover the 1,556 km between both cities, which is much higher than the time needed to connect major economic centers in other parts of the world that are also separated by a border and a similar distance, e.g., Paris-Warsaw (15 h and 47 min), Vancouver-San Francisco (14 h and 43 min), and Bangkok-Kuala Lumpur (17 h and 59 min). Although the road upgrades and the efforts at the Moyale border crossing often serve as an exemplar, there is clear scope for further improvements, especially when considering that Moyale is the only authorized/formal gateway between both countries.

The creation or deepening of transport corridors in the HoA implies the stepwise evolution from a set of poorly connected cities to a much more integrated, region-wide network connecting all cities in the HoA. The spatial concentration of flows in cities along these axes turns them into privileged sites in the broader region. One of the key objectives of the Horn of Africa (HoA) infrastructure investments is to develop such an integrated regional transport system anchored in its cities. Importantly, enhancing regional connectivity depends on facilitating, regulating, and further developing existing exchanges across borders.

Nevertheless, analyzing specific sets of cities within a regional urban system often suffers from oversimplified explanations (e.g., Muller, 1977). Such analyses should consider both functional and locational variations among the centers or the changing conditions of regional development. Future research could use the baseline developed in this paper to better theorize and understand the functional and locational variations across the HoA. Further research could also explore the potential of multimodal and topological resilience of port access from a network perspective, opening up the discussion beyond the HoA, given that Port Sudan provides an alternative for landlocked Ethiopia.

Notes

The boundaries, colors, denominations, and other information shown on any map in this paper do not imply any judgment on the part of the authors concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

Funding information

The research on which this paper is based was carried out in the context of a World Bank-funded project on regional integration in the Horn of Africa. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent. This paper was also supported by the University of Glasgow Reinvigorating Research funding (No. 201644-20) and the University of Glasgow Early Career Mobility Scheme (No. 143108-01).

CRediT authorship contribution statement

Mingshu Wang: Methodology, Formal analysis, Investigation, Writing – original draft, Visualization, Writing – review & editing. **Ben**

Derudder: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing. **Charles Kunaka:** Conceptualization, Writing – review & editing. **Xingjian Liu:** Methodology, Investigation, Writing – review & editing.

Appendix 1. City code of all cities in the Horn of Africa (Fig. 1)

Code	City	Country	Code	City	Country	Code	City	Country
1	Djibouti	Djibouti	32	Hagere Hiywet	Ethiopia	63	Meru	Kenya
2	Ali sabieh	Djibouti	33	Harer	Ethiopia	64	Mombasa	Kenya
3	Dikhil	Djibouti	34	Hosaina	Ethiopia	65	Nairobi	Kenya
4	Tadjoura	Djibouti	35	Jijiga	Ethiopia	66	Naivasha	Kenya
5	Arta	Djibouti	36	Jima	Ethiopia	67	Nakuru	Kenya
6	Asmera	Eritrea	37	Keabri Dehar	Ethiopia	68	Nyeri	Kenya
7	Keren	Eritrea	38	K'olito	Ethiopia	69	Ruiru	Kenya
8	Massawa	Eritrea	39	Mekele	Ethiopia	70	Thika	Kenya
9	Assab	Eritrea	40	Mek'i	Ethiopia	71	El Wak	Kenya
10	Mendefera	Eritrea	41	Metu	Ethiopia	72	Ukunda	Kenya
11	Barentu	Eritrea	42	Mojo	Ethiopia	73	Utange	Kenya
12	Adis Abeba	Ethiopia	43	Nazret	Ethiopia	74	Athi River	Kenya
13	Agaro	Ethiopia	44	Nekemte	Ethiopia	75	Ndenderu	Kenya
14	Arba Minch	Ethiopia	45	Robe	Ethiopia	76	Moyale	Kenya & Ethiopia
15	Arsi Negele	Ethiopia	46	Shashemene	Ethiopia	77	Mandera	Kenya & Somalia
16	Asela	Ethiopia	47	Sodo	Ethiopia	78	Busia	Kenya
17	Asosa	Ethiopia	48	Tepi	Ethiopia	79	Muqdisho	Somalia
18	Awasa	Ethiopia	49	Weldiya	Ethiopia	80	Berbera	Somalia
19	Bahir Dar	Ethiopia	50	Welkite	Ethiopia	81	Ceerigaabo	Somalia
20	Bedele	Ethiopia	51	Ziway	Ethiopia	82	Boosaaso	Somalia
21	Butajira	Ethiopia	52	Tita	Ethiopia	83	Hargeysa	Somalia
22	Debre Birhan	Ethiopia	53	Baco	Ethiopia	84	Burco	Somalia
23	Debre Zeyit	Ethiopia	54	Sululta	Ethiopia	85	Qardho	Somalia
24	Dese	Ethiopia	55	Dukem	Ethiopia	86	Laascaanood	Somalia
25	Dila	Ethiopia	56	Bungoma	Kenya	87	Garoowe	Somalia
26	Dire Dawa	Ethiopia	57	Eldoret	Kenya	88	Gaalkacyo	Somalia
27	Dolo	Ethiopia	58	Garissa	Kenya	89	Beledweyne	Somalia
28	Genet	Ethiopia	59	Kilifi	Kenya	90	Baydhabo	Somalia
29	Ginir	Ethiopia	60	Kisii	Kenya	91	Merca	Somalia
30	Giyon	Ethiopia	61	Kisumu	Kenya	92	Kismaayo	Somalia
31	Gonder	Ethiopia	62	Kitale	Kenya			

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