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THE SPATIAL ORGANIZATION OF ACCESSIBILITY AND FUNCTIONAL HIERARCHY AT THE LOCAL, REGIONAL AND NATIONAL SCALES – THE CASE OF ISRAEL

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ABSTRACT

Accessibility is a well-known basic term in spatial science and planning and is inherently related to functional aspects of places and geographical systems. Therefore, accessibility analysis is considered to be an important tool for defining and explaining regional divisions, as well as for enhancing spatial planning policy. However, as Batty (2009, p. 192) has indicated there are differences between accessibility potential of places and the actual distribution of performance or activities of people and these differences can vary with changes in scale. However, previous studies have examined functional systems and spatial accessibility with little attention to the association among them across geographical scales. Our study attempts to fill this gap and to explore the emergence of spatial accessibility and how relates to the formation of a functional system.

The aim of this study is to achieve a better understanding of how spatial accessibility relates to the formation of functional systems at different spatial scales of national systems. Using the space syntax methodology, spatial accessibility was analyzed for the entire national road network of Israel across different geographic scales – from local culminating in the national scale. The analysis was based on angular segment analyses of the road center-line network. Following this, the correlation between spatial accessibility across scale and functional regions was examined, as defined by employment and commuting flows.

Exploration of the relationship resulted in a spatial organization connected to the functional systems in Israel. This shows significant correspondence and exposes transitions between local, regional and national spatio-functional systems, as follows. First, a significant correlation between local (2km radius) accessibility levels of settlements with the number of employees and commuters. Second, the regional (15-20km radius) accessibility is highly correlated to the emergence of the main employment centers. As part of those centers, particularly noticeable is the functional dominance of the four metropolitan areas. Third, the main metropolitan areas are integrated at higher scale (from 30km radius) and form together a core region characterized by high accessibility, with a clear distinction from this outer region characterized by relatively low accessibility. This spatial structure conforms to the center-periphery structure at the national level of Israel. Additionally, the commuting flow patterns reveal that the core region is relatively well connected, especially the Tel Aviv metropolitan area, which is also characterized by dominant accessibility. In contrast, no substantial commuting flows were found within the periphery, as well as between periphery-core as would be expected from the low accessibility of the area. It seems that the core region functions at multiple scales (local-regional-national) while the periphery functions only at a local scale. The national accessibility reflects well the separation between the two spatio-functional systems.

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These findings indicate a close relationship with functional performance across geographical scales and accessibility potentials. They also reinforce the importance of accessibility analysis as an indicator for defining and explaining the functional organization of the entire road network at the urban, regional and national scales.

KEYWORDS

Accessibility, National Network Model, Center- Periphery, Space Syntax, Israel.

1. INTRODUCTION

Accessibility is a well-known basic term in physical and urban planning and many definitions have been proposed (e.g., Hansen, 1959; Markovich, 2013; Handy and Niemeier, 1997; Geurs and van Wee, 2004). A simple definition refers to the *"relative nearness or proximity of one place or person to all other places and persons"* (Batty, 2009, p. 191) where the term of *places* also includes opportunities and activities. Accessibility of a place has enormous association to its functional, economic and social aspects (Erkut & Özgen, 2003; Geurs & van Wee, 2004; Spiekermann & Neubauer, 2002) with significant potential effects on future potential development (Hansen, 1959; Wachs & Kumagai, 1973).

Road networks are the basic elements that allow accessibility connecting places from the small scale (neighborhood/settlement) through the medium (cities) to the regional and national scales (Parham, Law, & Versluis, 2017; Serra & Pinho, 2013). Previously, studies have analyzed accessibility in specific contexts or for a specific area, usually up to the city or to the metropolitan level (e.g., Benenson et al., 2011; Curtis, 2011; Hansen, 1959) without explicit reference to the larger context as part of the national system. However, cities are indeed an integral and critical part of regional and national contexts which greatly affect their functional potential (Law & Versluis, 2015; Serra, Hillier, & Karimi, 2015). For example, it has been found that even metropolitan regions is unsuitable for functional analysis due to the strong linkages with their surrounding environs (Bar-El & Parr, 2003a; Pain, 2008).

Accessibility analysis at regional or country scales is not new, returning to the classical *Locational Theories* from the mid-19th century which called to supplement space into economic models by examining existing settlement patterns according economic and physical considerations. They emphasized that location and size of settlements in a given space is significantly affected by proximity to other places by geographic location, distance and size of the neighboring populated centers (Portugali, 2011, p. 17-37), specifically, a city's relative accessibility. However, in contrast to the early studies which suffered from coarse definitions considering their limited information and lack of knowledge, technologies and resolution, the advantages of current state-of-the-art geographic information (GI) technologies allow the rapid analysis of accessibility at a national context with greater resolution and finer granularity.

Indeed, several recent studies investigated accessibility at an unprecedented national scale, based on road network analysis, up to the street segment level (Law & Versluis, 2015; Parham et al., 2017; Serra et al., 2015). However, these studies were conducted only in the United Kingdom, without explicit reference to the transitions among different functional systems across multiple scales. These studies also gave little attention for the national spatial context.

It has been suggested that economic activities organize and divide the national space into core (center) and peripheral regions according to the *agglomeration principle* (Weber, 1929, p. 124-172). Briefly, increasing returns and scale-of-economies are stronger when transportation costs are low and, therefore, it is expected that a concentration of economic activity in a core region will lead to concentration of population around this area. Consequently, the rest of the space (periphery) is less dense and more diffuse with concomitantly lower economic activity. This process is expected to continue through a circular causality of positive feedback (Krugman, 1991, 1999). In general, it can be argued that this creates a simple spatial division between center and periphery, with the center characterized by high accessibility to activities (such as work, shopping or leisure) and opportunities (such as markets or jobs) and the periphery region being characterized by low accessibility to those features (Schürmann & Talaat, 2000; Spiekermann & Neubauer, 2002).

However, this simple dichotomy between core-periphery is unsuitable for all countries (e.g., Bar-El and Parr, 2003b) and distinctions between center and periphery may be more complex. For example, there may be multiple concentrations of economic activity in more than one region (Krugman, 1999) with other attractors distributed in space (e.g., education, health and commercial services). These then produce changes in the spatial population distributions thereby leading to feedback circular causation processes (Bar-El & Parr, 2003b). Also, policy interventions at multiple levels of governance may structurally modify conditions at a national level. Differential taxes or rapid transit infrastructure may, for instance, significantly reduce the locational disadvantages of peripheral regions (Copus, 2001; Lanaspa, Pueyo, & Sanz, 2001). These aspects are reinforced by findings indicating that the center-periphery structure can be envisioned from a monocentric into a polycentric structure (Copus, 2001). A similar phenomenon can be observed in urban-metropolitan regions (Hall & Pain, 2006; Pain, 2008; Zhong et al., 2017). Noteworthy is the possibility of intermediate structures between them (M. Burger & Meijers, 2012; De Goei, Burger, Van Oort, & Kitson, 2010). Accordingly, it may be assumed here that a comprehensive national scale analysis should be conducted from a multi-scale level perspective, from the small scale to larger ones, in order to understand the emergence of different spatio-functional systems.

Network analysis methodologies allow high-resolution spatial configuration analyses, when focusing on the relative centralities of each road segment and the correlation to different socio-economic and functional indicators. Indeed, network centralities have been found to be significantly correlated with a variety of functional phenomena at the urban and regional scale level, such as movement distribution (Omer, Rofè, & Lerman, 2015; Penn, Hillier, Banister, & Xu, 1998), land use patterns (Ozbil, Peponis, & Stone, 2011; Scoppa & Peponis, 2015), liveliness and regeneration of urban environment (Ortiz-Chao & Hillier, 2007; Vaughan, Jones, Griffiths, & Haklay, 2010). They were also shown to be a powerful tool for transportation and urban planning (Karimi, 2012; Lerman, Rofè, & Omer, 2014), including assessment of planning interventions at the urban scale (Cooper, Harvey, Orford, & Chiaradia, 2018; Marcus, Ståhle, & Dahlhielm, 2010; Raford & Ragland, 2006). Usually, at the national scale, most studies focus on modeling vehicular movement with little attention to the functional context (Jiang, Zhao, & Yin, 2008; Serra & Hillier, 2018).

Recently, several studies aimed to demonstrate the associations of national spatial configuration with several types of functional and socio-economic aspects (Serra et al., 2015), commuting patterns (Law & Versluis, 2015) and the growth potential of cities (Parham et al., 2017). These studies were based on the Space Syntax methodological framework, a set of theories and techniques for topo-geometric analysis of spatial configurations across various geographical scales (Al Sayed, Turner, Hillier, Iida, & Penn, 2014). Based on centrality analysis of the road network, a complex relationship was exposed between the spatial structure to functional and social-economic indicators across different spatial scales. For example, spatial accessibility (i.e., integration measures) was found to be highly correlated with population density (R^2=0.83 at radius of 5km), workplace density (R^2=0.81 at radius of 5km), the number of commuters (R^2=0.51 at radius of 10km) (Law & Versluis, 2015), working population density (R^2=0.56 at radius of 2km) and movement volume (R^2=0.47-0.68 in radius of 10-20km) (Serra et al., 2015). However, little attention was given to the spatio-functional hierarchy resulting from the relationships and structuration between spatial accessibility and functional distribution at different scales. A first step in this direction, though at a regional level, has shown that the spatial patterns of accessibility of Oporto's metropolitan region are linked to the general spatial division of neighborhood, city and region (Serra & Pinho, 2013).

Another proposition that may be termed as a functional approach, argues that different functional aspects operate over multiple scales and levels (M. J. Burger, van der Knaap, & Wall, 2014; Pain, 2008) and the functional linkage between areas (i.e., functional areas) is mainly determined by flows of people between regions and not determined merely by a physical connection (M. Burger & Meijers, 2012; Hall, 2009; Razin & Charney, 2015). Indeed, a high correlation was found between accessibility of an area and the number of commuters (Law & Versluis, 2015). Yet, these kind of analyses were conducted mainly at urban (Roth, Kang, Batty, & Barthélemy, 2011; Zhong et al., 2016) and regional scales (Adrienko & Adrienko, 2011; M. J. Burger et al., 2014). National scale analysis is usually limited to coarse regional divisions (e.g., Givoni, 2017). Furthermore, the reliance on "commuting sheds" or population flows to define functional area boundaries may lead to substantially different regional boundaries (Schleith, Widener, Kim, & Liu, 2018). Therefore, the analysis of functional structures (or boundaries) with respect to the accessibility-based spatial configuration is actually combines between both approaches.

As described above, intensive work has been done on spatial systems and on functional systems, nevertheless, an integrative spatial-functional approach is lacking and not examined properly, especially at the national scale. This study attempts to fill this gap. Based on the assumption that *"accessibility is perhaps the most important concept in defining and explaining regional form and function*" (Wachs & Kumagai, 1973), our study analyzes *spatial accessibility* in order *to capture the emergence of distinct spatial accessibility systems and their relation to the formation of particular functional systems, from local levels up to the national scale.* Such an integrative approach suggested here is consistent with the necessity to explicitly associate functional activity with the physical infrastructure while emphasizing the relevance of spatial scales for analysis (Batty, 2009).

2. DATASETS AND METHODS

A spatio-functional national analysis should consider four main aspects. First, characterization of the hierarchical structure of different spatial accessibility systems. Second, characterization of the functional structure. Third, an examination of the associations between spatial to functional systems across scale. Fourth, detection of the transitions between the different functional systems based on different spatial scales. Therefore, the methodological framework implemented in this paper includes data collection and analysis in two directions: the first aimed to expose accessibility potential at different scale, while the second aimed to reveal functional divisions (figure 1). Then, comparative examinations were performed in order to characterize the hierarchical structure of different spatio-functional systems and detect the transitions of scale between those systems.

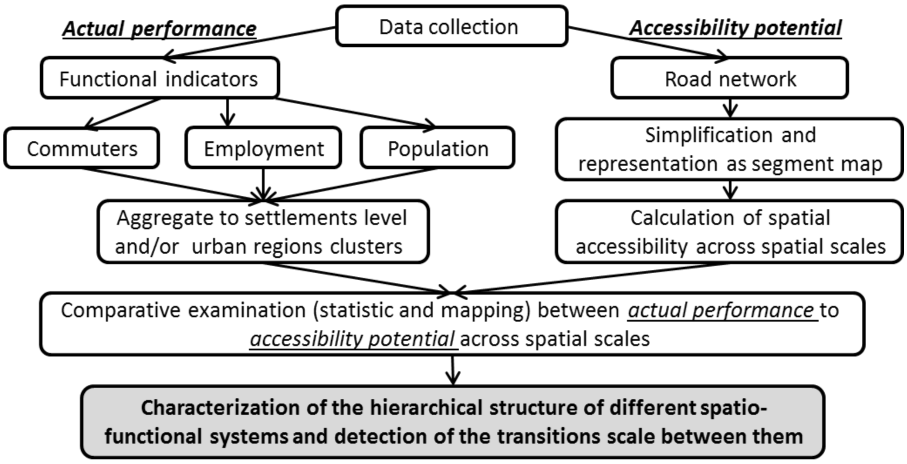

Figure 1. Methodological framework.

2.1. Case study

Israel is a small country (size of 22,072 km^2, 8,797,900 citizens), densely populated (387/km^2 in all land area and 7,117/km^2 in the built-up area) with a developed economy characterized by high urbanization levels and a rapid history of development (Israel Central Bureau of Statistics, "ICBS", 2018). Policies of population dispersal have been implemented throughout the 20th century, beginning with geopolitical considerations and later for reducing the evolutionary processes of *gravity cities* (Portugali, 2011, p. 32-34), *agglomeration* (Weber, 1929, p. 124-172) and *core-periphery* (Krugman, 1991, 1999) organization of space. Those actions have generally been unsuccessful, especially referring to the inequalities between center and periphery (Asif, Golan, Porat, & Polinov, 2014; Bystrov, 2008). The concentration in the core region, increased by sprawl processes three decades ago (Frenkel & Ashkenazi, 2008) has led policy makers to support spatial development of four metropolitan centers: Tel Aviv, Haifa, Jerusalem and Be'er Sheva (Asif et al., 2014). Yet, the dominance of the Tel Aviv metropolitan gradually percolated outward to overshadow other metropolitan areas. Ideas of improving transportation infrastructure to allow functional integration of periphery regions to the metropolitan labor market have not yet been achieved (Razin & Charney, 2015). Investments in long-distance transport infrastructure in Israel have been found to actually increase the dependency of the periphery on the center while increasing core-periphery disparities (Givoni, 2017; Rotem-Mindali & Geffen, 2014).

Center-periphery relations in Israel are strongly associated with socio-economic gaps and lack of opportunities in the periphery versus the center (e.g., Bystrov, 2008; Shokeid, 2011). Other essential questions in this context concern the center's carrying capacity (transport, land, garbage, sewage etc.) due to the accelerated development, especially in the Tel Aviv region (Bystrov, 2008; Soffer &

Bystrov, 2006). These fundamental issues are primarily related to strategic spatial planning initiatives (Asif et al., 2014). The national perspective, along with attention to regional divisions (Bar-El & Parr, 2003b) and the necessity to engage local development of the periphery (Bystrov, 2008; Rotem-Mindali & Geffen, 2014), require a multi-scale view of the national space, in a manner that has not yet been examined in Israel. A nationwide spatio-functional examination is a vital step towards long-term strategic planning efforts for Israel.

This study proposes to examine the relationships of spatial structure (section 2.2) and functional structure (section 2.3) in Israel, giving a countrywide spatio-functional perspective. The investigation was based on two main data sources: (i) GIS layers of the Israel road network obtained from GISrael (a geographic information database in Israel, a product of the Mapa Company) and (ii) the most updated available official data on population, employees and commuters (ICBS, 2008).

2.2. National road network model

The mobility modes (i.e., mode split of journeys) to work in Israel are clearly based on usage of the road networks: ~57% by private car, ~18% by public bus, ~11% by foot, ~9% by workplace transportation, 0.6% by train, and 4% by other modes (ICBS, 2008c). These figures reinforce the applicability of road network accessibility for the Israel national scale analysis.

The road network in Israel is disconnected, a kind of "island state", without continuity to surrounding countries. The national road network model used in this study is based on the entire Israel paved road network (Figure 2a). Road representation is skeletal where the original road network was transformed into Road Center-Lines (RCL) based on different road types. Following this, their geometries were simplified in order to reduce unnecessary complexity, as suggested by Krenz (2017) and have been performed in similar ways for several national-scale studies (Parham et al., 2017; Serra & Hillier, 2018). This process transformed the road network into a road segment which was found to be consistent with the results of the "traditional" segment line model of Space Syntax (Krenz, 2017). The final national road network model included of 333,303 nodes (road segments). These steps of processing were done in the ArcGIS (ver. 10.3) software.

Subsequently, we analyzed the spatial configuration of Israel's road network based on angular segment analysis (the cumulative angular changes made along a route), which has been found most suitable for detecting spatial patterns at the urban, regional and national scales (Hillier, Yang, & Turner, 2012; Serra et al., 2015; Serra & Pinho, 2013). In order to examine the spatial accessibility in Israel, we use the centrality measure of *Integration*, which corresponds to the graph-based *Closeness* centrality measure (Hillier & Iida, 2005). This measure describes how close a given node (road segment) is to all other nodes and represents the degree of accessibility for each road segment in the network at the entire road network (radius N) (Jiang, 2009; Omer and Jiang, 2015). Formally, the closeness measure is defined by:

$$(1) \qquad Closeness\,(Vi) = \frac{n-1}{\sum_{k=1}^{n} d\,(Vi, Vk)}$$

where *n* is the total number of segments (nodes) within a road network and *d* is the shortest angular distance from a given road segment (*Vi*) to every other road segments (node *Vk*) in the segment map.

The integration measure was calculated for spatial scales with radii of 1, 2, 5, 10, 15, 30, 50, 75, 100 and 150 km, in order to reveal the emergence of different spatial systems. Closeness represents the *to-movement* potential, i.e., the potential of a given location to be a destination or origin for movement within the network for defined radius (Hillier & Iida, 2005) and, therefore, it is suitable for examining differences between aggregated movement (journeys to work) and movement potential over different spatial scales. The calculation of integration centralities was done using Depthmap software (version 10.3, UCL).

2.3. Functional indicators

In order to examine the functional aspect in Israel we used several variables of the labor market. The first data source (ICBS, 2008d) includes data for 2,800,440 employees and their workplace location at the settlement level (figure 2c), referring to employees having a permanent and known workplace. Data for 185,110 employees with unknown workplace and those without a permanent workplace (45,320, 139,790, respectively) are not included here. Also, data was unavailable for small settlement with less than 30 employees, subject to governmental privacy policy of the ICBS (2008). Further, at the settlement level, this privacy limitation reduces the total number of settlements in the study from 1218 to 953. The population distribution of 953 settlements (98% of population) can be classified according to the ICBS into *rural settlements* (<2k residents, n=733), *urban settlements* (2k-20k residents, n=145), *small cities* (20k-100k residents, n=61), *medium cities* (100k-200k residents, n=8), and *major cities* (>200k residents, n=6) (figure 2b).

The second dataset (ICBS, 2008a,d) includes data on the number of commuters at the settlement level (figure 2e). This variable was calculated from the number of employees in the locality (figure 2c) not including the number of employees with residence in the locality (figure 2d). According to the ICBS privacy policy the data includes fewer records and contains information on 411 settlements.

The third dataset aimed to expose the continuity of employment areas regardless to municipal boundaries. The ICBS (2008a) implemented an Inverse Distance Weighted (IDW) model for spatial interpolation of the distribution of employees in localities. Regions with more than 2,500 employees were then aggregated into employment regions (figure 2f). This resulted in 53 employment areas containing 87% of the total employees and among them 11 main employment centers were selected by the researchers. To develop a more "natural" definition we reanalyzed the data by adopting a cutoff of >20k employees who also gave 11 areas with 77% from the total employees in Israel[4]. Latter, for intensive examination we used commuting flow patterns obtained from the ICBS dataset (2008a) (figure 6). Based on limitations imposed by the privacy policy, the data is limited to commuting among main employment centers or from large settlements to the main employment centers. Nevertheless, the main commuting patterns constitute 95% of the commuters to the main employment centers, and therefore reflect the main commuting patterns in Israel, i.e., there are no other significant commuting patterns.

[4] These main centers differ from the original analysis done by the ICBS (2008a) that refer to areas size. We chose to refer to the employment size, i.e. the 11 largest employment centers.

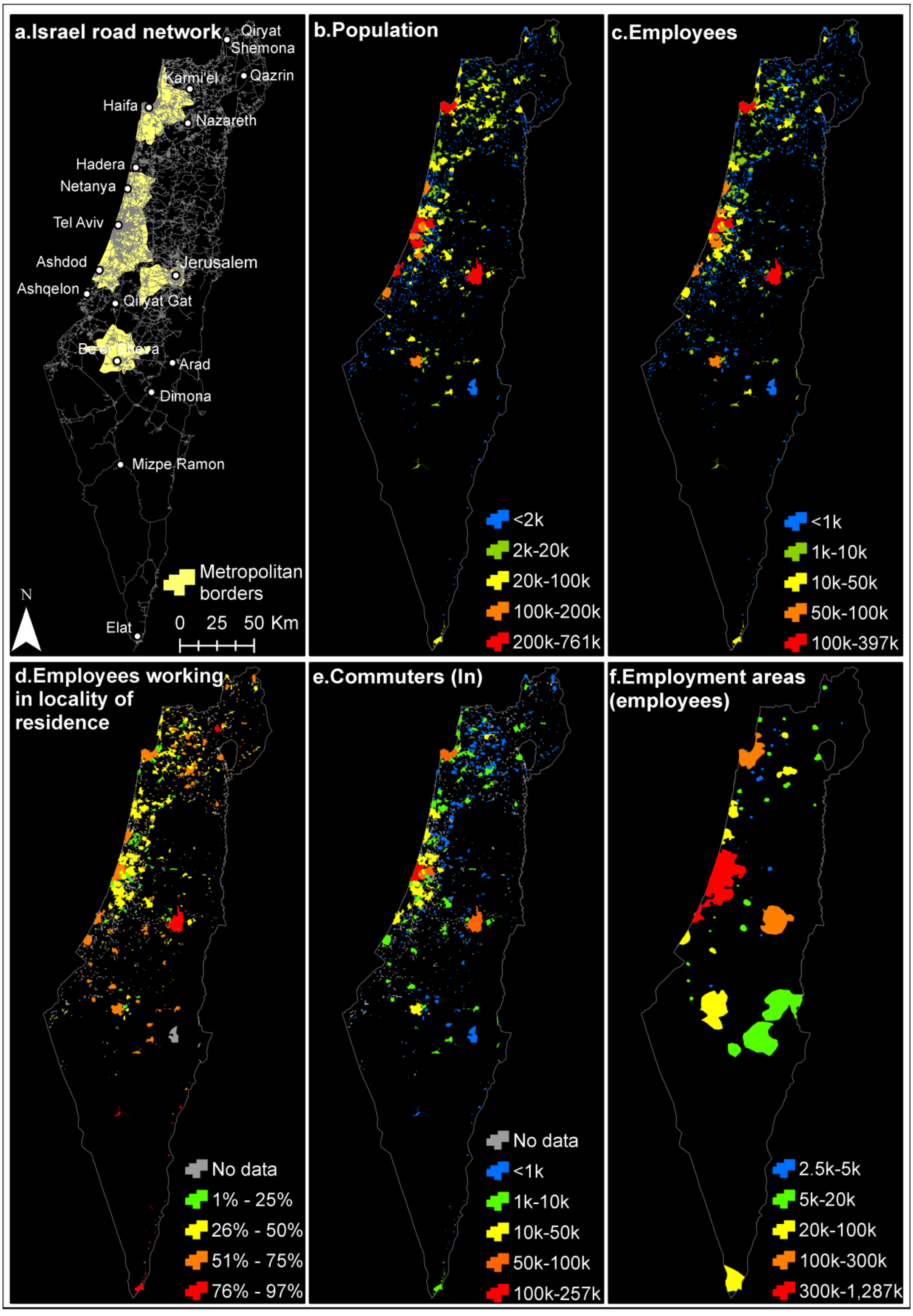

Figure 2. Israel case study. a. Israel road network; b. population at the settlement level; c. employees at the settlement level; d. employees (%) working in locality of residence; e. commuters (in) at the settlement level; f. employment areas with more than 2500 employees. The 11 main employment centers (>20k employees) are marked by yellow, orange and red colors according to their size.

2.4. Statistical methods

In order to reveal the emergence of different spatial accessibility systems and their relation to the formation of different functional systems we regressed the data of road network accessibility to the functional divisions. Similar to other studies (Law & Versluis, 2015; Serra et al., 2015), the average Integration value for each settlement and for each employment area (figure 2c,f) was calculated by taking the mean Integration value of all road segments in each settlement or in each employment area (respectively). Mean integration was calculated for all spatial radii chosen (see Section 2.2 above). Because the functional indicators and the spatial accessibility of settlements and employment areas are characterized by long-tail distributions, we log-transformed the variables to stabilize the variance. This allows the use of Pearson correlation and linear regression to examine the associations between several functional indicators to accessibility level at different spatial scales.

3. RESULTS

3.1. The emergence of spatial accessibility systems

The Integration centrality measure exposes eleven patterns of accessibility levels across various spatial scales (figure 3), revealing a complex spatial structure. This allows a high resolution examination of the spatial configuration of Israel. In general, the formation of several spatial systems is indicated with the increase of scale to the national scale (radius N). At lower scales, a patchy structure of high accessibility is exhibited and this corresponds very well to the municipality boundaries of urban settlements (see also figure 2b). As the scale increases, by increasing the radius of the analysis, some "hotspots" disappear while others remain distinct and conforming to the municipal boundaries of medium and large cities smaller communities in denser areas begin to merge into larger clusters of urban regions. Ultimately, the four metropolitan areas in Israel are revealed by this methodology (figure 1a). At larger scales integration between the main metropolitan areas forms a core region (center) with a clear distinction from the unintegrated region (periphery) according to accessibility levels.

More explicitly, three main spatial accessibility systems are identified: the *local*, the *regional* and the *national scales*. The *local* spatial system appears in the radius of 1 and 2 km (up to 3 km) (figure 3a,b) and emphasizes in the medium level of accessibility most of the urban settlement in Israel while in the higher level of accessibility highlights the cities (see also figure 2b). Conversely, the rural settlements are not sufficiently connected in order to create a high accessibility potential which means there is an inability to generate significant to-movement potential (potential to be a destination). The *regional* spatial system appears from 5 km up to 15 km (figure 3c-e) and is characterized by clusters of highly accessible urban regions in dense areas (especially in the central and coastal Tel Aviv area) while medium cities with medium levels of accessibility are highlighted in isolated regions. From the range of 10 km there is a tendency to formation the four metropolitan areas (see also figure 2a) which are prominent from medium accessibility levels within the radius of 15 km. The next spatial system, the *national*, begins to form by integration of the inter-metropolitan space, which completed in 30 km radius (figure 3f), and continues to grow into one apparent core region (center). At the larger radius of analysis (>75 km, figure 3h-k) the national core-periphery structure is clearly distinguishable by accessibility levels: high accessibility level of the core region (center), low accessibility level of the periphery region, and some buffer zone between them characterized by medium accessibility.

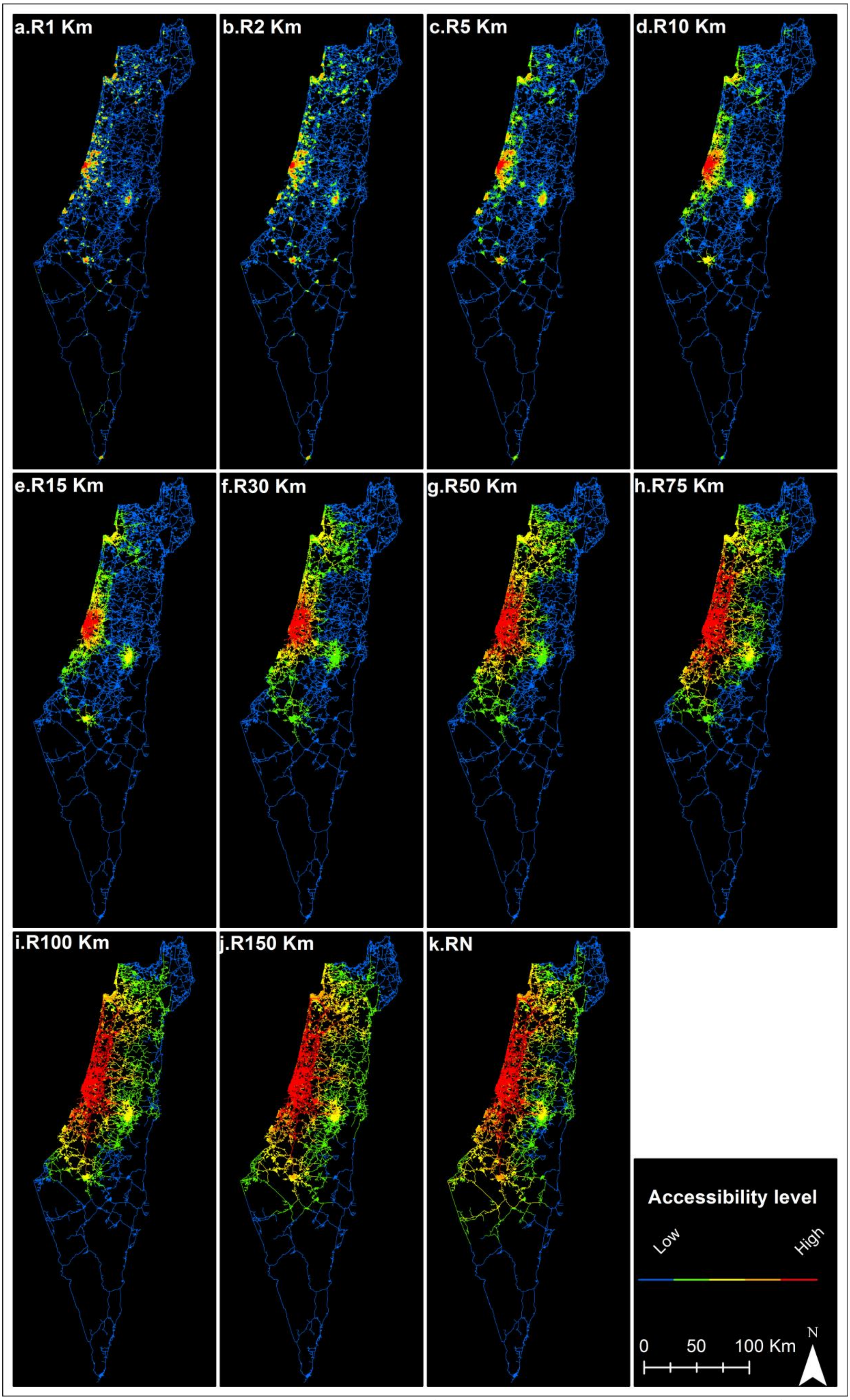

Figure 3. Accessibility level (Integration centrality) at Radius of: a. 1 Km; b. 2 Km; c. 5 Km; d. 10 Km; e. 15 Km; f. 30 Km; g. 50 Km; h. 75 Km; i. 100 Km; j. 150 Km; k. N (global accessibility).

The detection of the three spatial accessibility systems is supported by inspecting the correlation between accessibility levels across spatial scales. Figure 4 presents the results of correlation matrix analysis between integration values across scales. The graph highlights a clear trend of three distinct clusters corresponding to the three spatial accessibility systems observed above: local, regional, and national (marked by green, blue and red, respectively). Indeed, high correlations are obtained within each cluster: at the local system ($r>0.90$), at the regional system ($r>0.85$) and within the national system ($r>0.80$) all of which are significant ($p<0.01$), while the relationships between the clusters were not statistically significant. This clearly illustrates the main transition zones between the spatial systems at the intersections between the systems (marked by black circles), between 2 to 5 km from local to regional and between 15 to 30 km from regional to national. Overall, the results indicate three spatial accessibility systems with similarities within each system and, on the other hand, dissimilarities between the systems and especially between local-regional to national system.

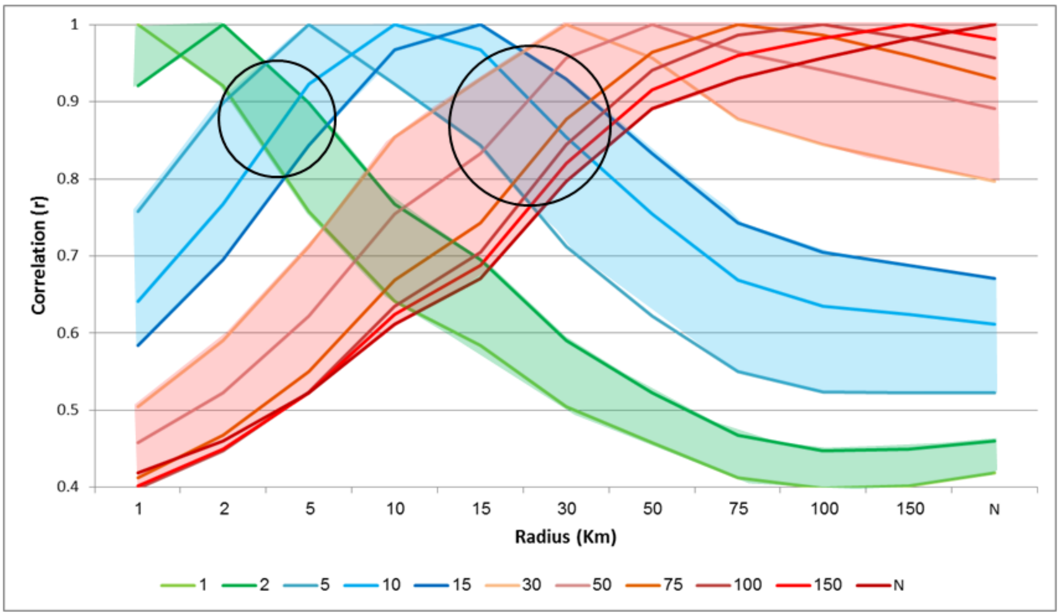

Figure 4. Correlations between the Integration values across spatial scales (Km). Clustering of local (*green*), regional (*blue*) and national (*red*) radii are highlighted. The black circles remark the transition zones between the spatial systems. All correlations are significant ($p<0.01$).

Within these three spatial systems, the Tel Aviv metropolitan area dominantes all others, from the context of accessibility. From the smaller scale, especially from 5 km radius (figure 3), Tel Aviv is prominent with notable attraction due to its high level of accessibility potential, which expands across multiple scales. This aspect will be discussed later in the functional context in section 3.2. In addition, it should be noted that a demarcation between center and periphery is observed with the accessibility being stable from a radius of 75 km and above (figure 3h-k) as also indicted by the high correlation ($r>0.92$, $p<0.01$) between the accessibility levels in those radii (figure 4). This is a particularly salient quality of the high accessibility of the core region. This exemplifies the strength and stability of the core region on the national scale.

The following section aims to reveal the relationships between Israel spatial structures shown above to Israel functional aspects.

3.2. From spatial systems to functional structures

As noted in section 2.3, the examination of the functional aspect in Israel is based on data of the labor market at: (i) the settlement level (figure 3c-e, n=953), (ii) continuous employment areas with more than 2,500 employees (figure 3f, n=53), (iii) continuous areas with more than 20,000 employees, i.e., the main employment centers (figure 3f, n=11) (additional details in section 2.3). Therefore, we obtained *three levels of functional divisions*. Then we examined the correspondence between the spatial accessibility systems (section 3.1) to those functional divisions.

Figure 5 presents the coefficient of determination (R^2) between accessibility level across spatial scales to employments and numbers of commuters, according to the three functional divisions noted above.

This reveals several points. In all functional divisions employments and the commuters are correlated to accessibility level (R^2>0.55 and R^2>0.57, respectively), especially for the main employment centers (R^2=0.81). However, no correlations are identified above 30 km. This may indicate a bound on accessibility to work. Likewise, correlations differ between accessibility in relation to different radii and from different functional divisions, meaning that the functional divisions perform at different levels of spatial scales and the relevant spatial radius of accessibility for each functional division can be detected.

Actually, it is noticeable that the highest correlation between spatial accessibility and local employment at the settlement level is at a radius of approximately 2 km (figure 5a). The highest correlations between spatial accessibility and the spatial distribution employment areas begin from at 5 km (figure 5b), while the radius of 10-15 km (and perhaps even increasing to 20 km), constitutes the dominant radius of accessibility for the main employment centers (figure 5c). The local and the regional functional scales correspond to the local and regional spatial accessibility systems revealed in section 3.1. These consistencies are also confirmed by visual comparison between: (i) settlements with more than 1,000 employees (figure 2c) and/or more than 1,000 commuters (figure 2e) to medium and high accessibility levels at radius 2 km (figure 3b); (ii) between employment areas (figure 2f) to medium and high accessibility levels at radius 5 km (figure 3c); and (iii) the main employment centers (figure 2f, >20k) to medium and high accessibility levels at radius 10-15 km (figure 3d,e).

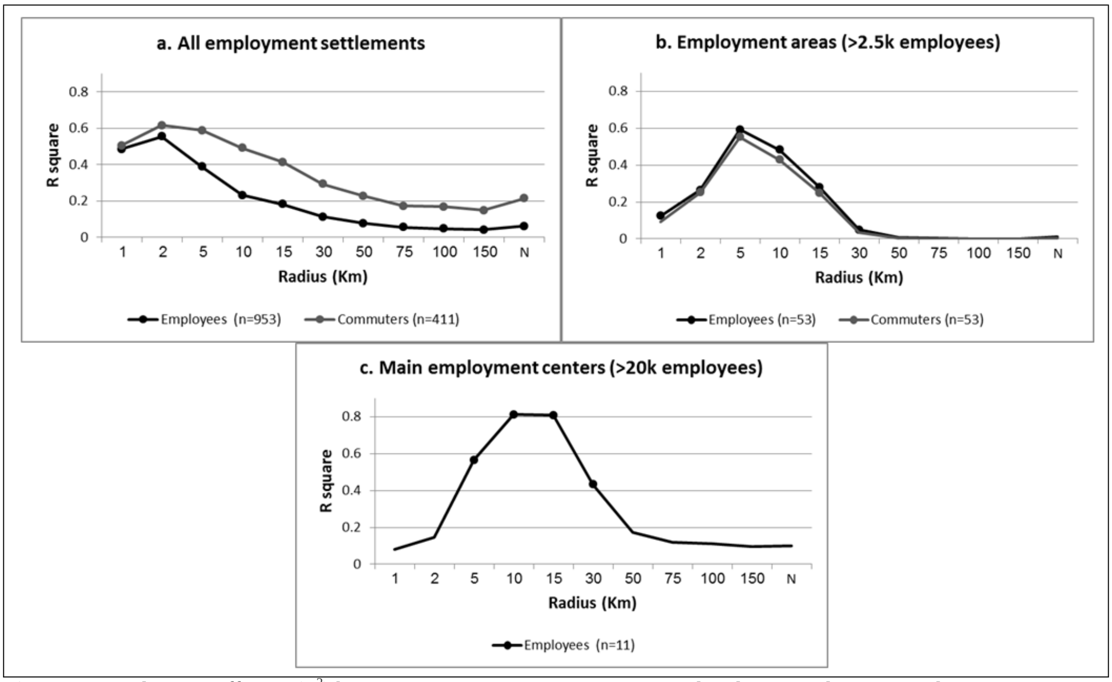

Figure 5. Correlation coefficient (R^2) between average Integration across spatial scales to employments and commuters at: a. settlements level; b. employment areas; c. main employment centers. The number of commuters to the main employment centers are not included because they contain most of their commuters in their territories (i.e., commuters that not included in their territories are very few). Only significant correlations ($p < 0.05$) are noted.

Low associations with respect to functional aspects are found for scales larger than 30 km. However, exploring commuting flows reveals that the core region is relatively well connected, especially the Tel Aviv metropolitan area (figure 6, see also figure 2a), which is also characterized by dominant accessibility across all spatial scales (figure 3). A nested structure was also observed in the metropolitan areas and, remarkably, in the metropolitan area of Tel Aviv (Razin and Charney, 2015; ICBS, 2008e). In contrast, no substantial commuting flows were found within the periphery as well as between periphery-core at the national scale (based on the governmental data). It seems that the isolated cities in the periphery (figure 2b,c) attract commuters (figure 2e) to a more limited extent, and most of the employed persons there (>50%) work in their city of residence (figure 2d). Therefore, while the core area is characterized by kind of polycentric commuting structure, the periphery suffers from weaker commuting flows.

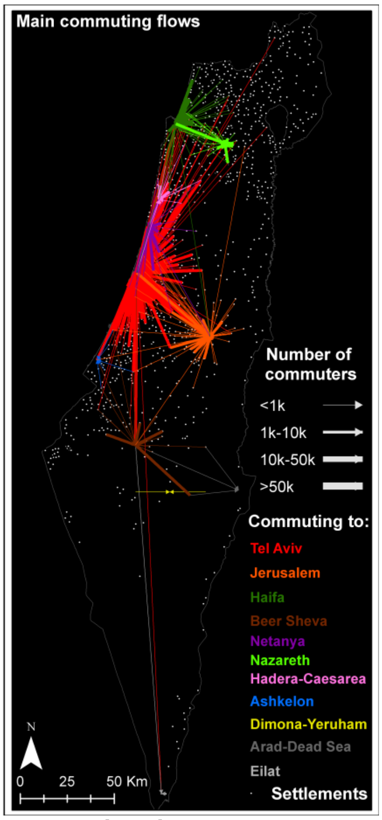

Figure 6. The main commuting flows patterns in Israel. See limitations in section 2.3

This difference between functional behavior in the center and functional behavior in the periphery raises a hypothesis regarding Israel's functional structure that works differentially in the center versus the periphery. Markedly, it seems that national accessibility is important as a separation between the two spatio-functional systems. In order to examine this hypothesis, it is necessary to use multi-scale examination in order expose if the core functional system functions at multiple scales (local-regional-national) while the periphery only functions at a local scale. This analysis may also provide insight about the relevance of scale and more specifically, which scale is more important, local, regional, national or some combination of them.

The stability of accessibility across scales was then investigated using local (2 km), regional (15 km) and national (N) accessibility values for the settlement level. We use an analysis based on the principle of high/low clusters to characterize the level of accessibility of a settlement (high/ low) over a set of combinations of multi-scale pairs (local-regional; regional-national; local-national). Since accessibility levels of settlements for local and regional scales are characterized by heavy-tailed distributions, we apply the principle of the *head/tail break classification* that deals with a heavy-tailed distribution and categorize the data into "head" (values above mean) and "tail" (values below mean) (Jiang, 2013, 2015). We applied this algorithm for each accessibility value (local, regional and national) which resulted in two groups for each scale: the *head*- settlements with accessibility level above the mean, and the *tail*- settlements with accessibility level below the mean. Then, based on the results for each settlement we classified the settlements by clusters of "*head-head", "tail-tail", "head-tail"*, and "*tail-head*" according to the scale groups of "local-regional", "regional-national" and "local-national"[5]. Later, we also examined the correlation of the obtained clustering with employees, population and commuters at the settlement level.

The spatial analysis of the *"head-tail"* clusters are presented in figure 7, and their relationships to employees, commuters and population are presented in figure 8. The spatial-groups and the clusters

[5] For example, for the group of "local-regional", the classification groups are *"head-head*" (head local- head regional), "*tail-tail*" (tail local- tail regional), "*head-tail*" (head local- tail regional), and *"tail-head*" (tail local- head regional).

color are corresponding between both figures. The analysis exposes several essential points. The red clusters (“head-head”) located in the center remain stable in the vast majority of cases according to their geographic patterns, i.e., the center is characterized by multi-scale high accessibility. Most of the small settlements in the periphery (population <3000) are unable to create sufficient accessibility at any scale (“tail-tail”), while peripheral cities and local councils (population >3000) are able to provide significantly higher local accessibility (“head local- tail regional/national”). The peripheral cities are limited to low regional and national accessibility, and therefore, function only at local scales (figure 7b,8b). Figures 7c and 8c provide a good picture for Israel's functional structure, when most of the cities in the center are characterized by “head-head” levels of accessibility with large population sizes, employees and commuters, with cities in the periphery having “head-tail” levels of accessibility and medium population sizes, employees and commuters. In contrast, small settlements in the center remain to the “tail-head” group and have small size of population, employees and commuters and their counterparts in the periphery belong to the “tail-tail” group as a result of low accessibility.

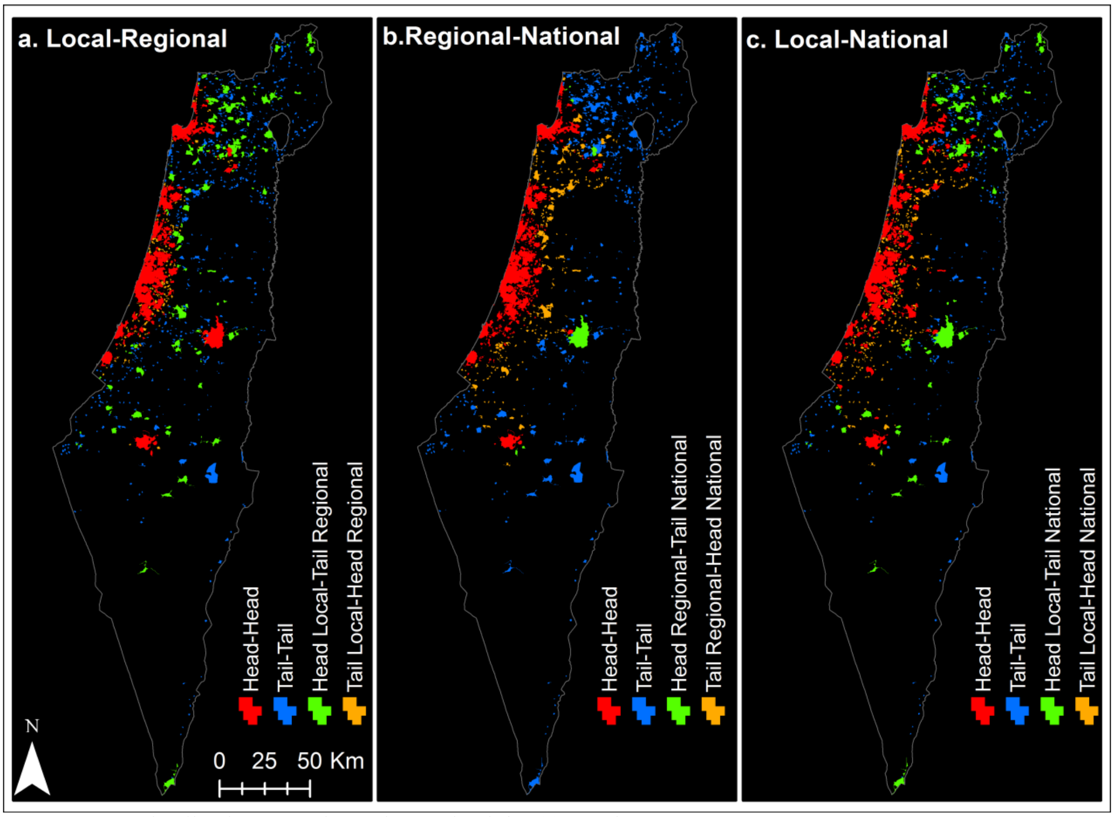

Figure 7. “Head-Tail” clusters at the settlement level for (a) Local-Regional scale; (b) Regional-National scale; and (c) National-Local scale. The spatial-groups and the clusters color are corresponding to figure 8.

The *“head-tail”* analysis in figure 8 reveals a hierarchal scaling effect with accessibility providing a base for functional activity at the local scale which constitutes the critical mass to enable potential functional activities. The consequence of which is that without local accessibility it is almost impossible to reach high levels of functional activity. However, low national accessibility limits the level of functional activity observed for medium and large cities are mainly characterized with high national accessibility.

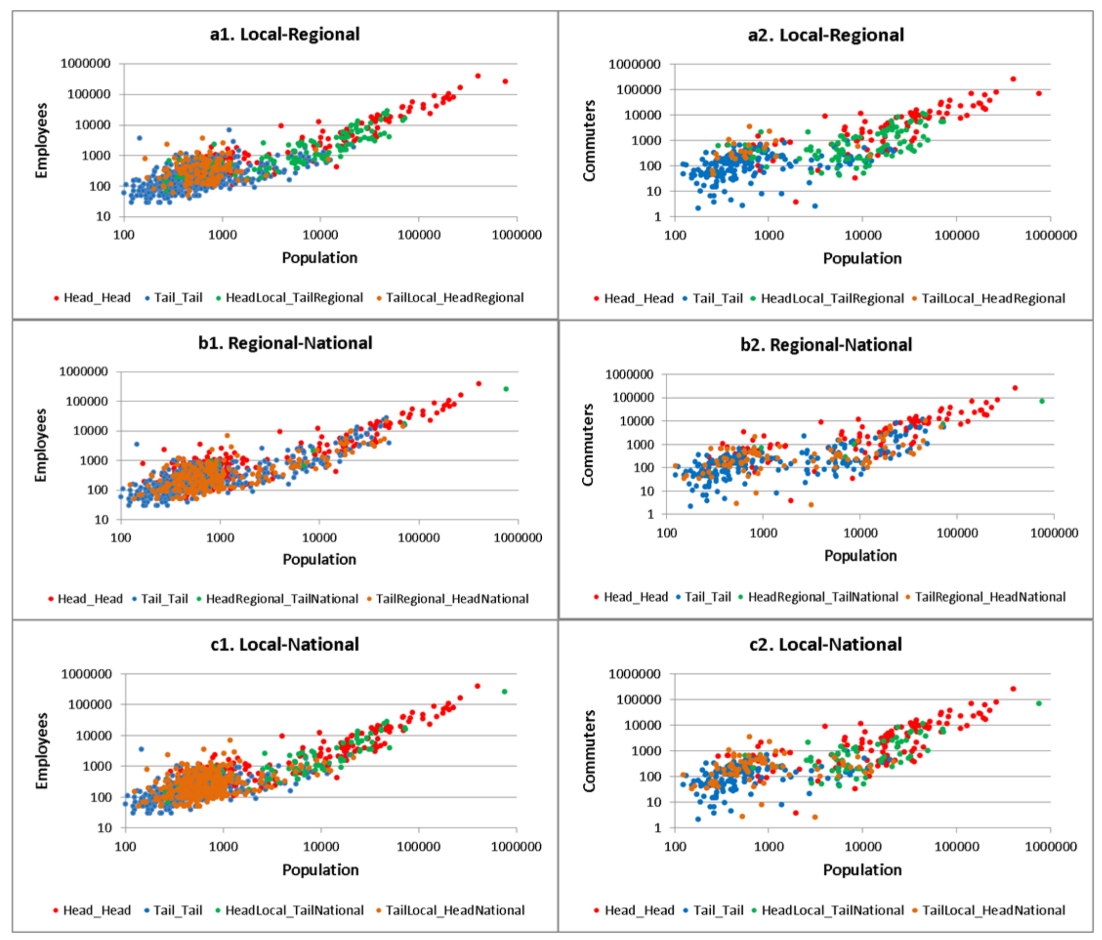

Figure 8. "Head-Tail" clusters at the settlement level for (a1,2) Local-Regional scale; (b1,2) Regional-National scale; and (c1,2) Local-National scale; and their correlation to: population and employees (1) and population and commuters (2). The spatial-groups and the clusters color are corresponding to figure 7.

4. CONCLUSIONS

This study aimed to reveal the emergence of distinct spatial accessibility systems and their relation to the spatial distribution of functional systems, from local levels up to the national scale. Using angular segment analysis based on the Space Syntax methodology, we analyzed the spatial accessibility (integration measures) of the entire paved road network of Israel at various of spatial scales. Also the functional aspect in Israel was analyzed with several variables of the labor market (population size, employees, commuters and main commuter's flows). Subsequently, the associations between spatial accessibility and functional indicators across different spatial scales were examined.

The results presented here expose three spatial accessibility systems of local (1-3 km), regional (5-20 km) and national scale (>30 km). Further, a significant correspondence exposes transitions between local and regional spatio-functional systems. A significant correlation between local (2km radius) accessibility levels of settlements with the number of employees and commuters and the regional (15-20 km radius) accessibility is highly correspondence to the emergence of the main employment centers. As part of those centers, particularly noticeable the dominant functional system of the four metropolitan areas. A detailed examination of the main commuting flow patterns reveals that the core region is relatively well connected, especially, around the metropolitan's centers. This is particularly appropriate concerning the Tel Aviv metropolitan area, which is also characterized by dominant accessibility. In contrast, no substantial commuting flows were found within the peripheral areas as well as between periphery-core. It seems that the core region functions at multiple scales (local-regional-national) while the periphery functions only at a local scale. The national accessibility reflects well the separation between the two spatio-functional systems.

These findings reinforce the importance of accessibility analysis as an indicator for defining and explaining the functional organization at the urban, regional and of national scales as well as the abilities of space syntax methodology as a powerful tool in this respect. Various aspects discussed indicate the importance of countrywide spatio-functional analysis for assist long-term strategic planning for Israel.

Further work is needed in order to expand the examination of accessibility at national scales. First, the effects of rail transportation should be considered[6] (Lerman & Lebendiger, 2017). Second, changes in accessibility across time (Kwok & Yeh, 2004) should be also examined to test the stability or the changes in these measures of accessibility. Another use case for this methodology of centrality measures and spatial structure could detect and define the emergent boundaries communities (Fortunato, 2010) and core-periphery (Rombach, Porter, Fowler, & Mucha, 2014) as defined by network accessibility. Third, it is also necessary to use commuting flows data with higher resolution, at least at the city scale level, will improve our ability to conduct accurate analysis concerning the accessibility-employment relations.

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[6] It should be note again that in Israel only 0.6% from the journeys to work in 2008 carried out by the train. In 2016, 3.4% from the journeys to work carried out by the train (Bank of Israel, 2018)

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