Social Networks 64 (2021) 181–193

Contents lists available at ScienceDirect

Social Networks

journal homepage: www.elsevier.com/locate/socnet

Exploratory social-spatial network analysis of global migration structure

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ARTICLE INFO

Keywords:
Network analysis
International migration structure
Migratory ties
Migration patterns

ABSTRACT

At the global level, international migration can be considered as a network of migration exchanges between different countries. Employing an exploratory network analysis of the international migration structure, the present paper examines the structural characteristics of this network and the status of the countries. The analysis is done using the socio-spatial approach. Results show that as the severity of network ties grow, the number of ties reduce significantly and ties are asymmetric. Most of the migrations in the international migration structure have also taken place outside the near and neighboring countries. The network analysis showed two migration patterns of "International Migratory Highways" and "Migratory Clusters". In the first migration pattern, migrations are largely asymmetric and towards the major centers of immigration, while in the second one, migrations are mostly symmetric and within specific geographical areas.

Introduction

Ever since the issue of migration was raised by Adam Smith, many studies have been conducted to investigate the causes and consequences of migration flows (Aleskerov et al., 2017: 3) and it has attracted many theoretical and empirical considerations. According to some analyses, the rate of international migration has increased in the recent years. According to UN estimates, in 2015, the number of international migrants and refugees has increased to 71 million compared to 41 million in 2000 (United Nations, 2015; Özden et al., 2011).

However, other studies show that the international migration flow has declined in the recent years. According to Abel and Shender's estimates, the rate of international migration declined from 41.4 million (0.75 % of world population) during 1990–1995, to 34.2 million (0.57 % of world population) during 1995–2000 (Abel & Sander, 2014: 1521). Migration is one of the fundamental processes of change in the world that has many effects on societies and shapes the world population (Aleskerov et al., 2017: 3) and it is a "self-perpetuating process" (Massey, 1990).

Migration studies show that the approaches used in this area of research are largely based on quantitative and qualitative analyses on the causes and consequences of migration in the countries of origin or destination countries (see Jennissen, 2007), and there are less studies on the structure of international migration.

Social networks analysis and migration

Migration theories have been largely based on migration flows across a country, or, at best, the level of country-to-country flows (dyadic level) (Tranos et al., 2015) as well as focusing on migrants in origin or destination areas (Fazito and Soares, 2015: 186). There is, however, a growing agreement that the movement of people between each pair of countries is better understood in the context of broader groups or networks of movements (Salt, 1989). Migration researchers have long recognized that migratory processes do not occur in a vacuum; rather, they are embedded in social networks (Bilecen et al., 2018; Gold, 2001) and migration is structured by social networks (Fazito and Soares, 2015). Network analysis is a method to control the embeddedness of dyads into the surrounding network structure (Windzio, 2018). In fact, the structure of the migration network is the distribution of points of origin and destination and their connections that may determine migration onset, pace and volume (Fazito and Soares, 2015).

Despite the strength of network analyses in examining migration structures, the network analysis approach has not been widely used by migration researchers (Ryan and D'Angelo, 2018; Ryan, 2011). Using the network analysis approach, research shows that in the issues of migration, two categories of studies have used this approach. First, there are the researchers who examined the migrants network in one country or the country of origin and destination of migrations at the individual analysis level (see Vacca et al., 2018; Ryan and D'Angelo, 2018; Verdery et al., 2018; Fazito and Soares, 2015; Cachia and Maya, 2018; Bojarczuk and Mühlau, 2017; Popielarz and Cserpes, 2018; Garip and Asad, 2016;

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https://doi.org/10.1016/j.socnet.2020.09.007

Available online 15 October 2020

Massey and Espinosa, 1997; Lubbers et al., 2007; Lubbers et al., 2009; Brandes et al., 2010; Bolíbar et al., 2015).

The use of the analysis of personal networks of migrants (see McCarty, 2002) and its related methods in migration studies have been expanding in the recent years. According to these studies, the nature of personal network studies have made important contributions to understanding immigrants' personal communities and adaptation patterns (Vacca et al., 2018; Gold, 2005; Boyd, 1989).

The second category is the macro-level studies that analyze the international migration network (see Danchev & Porter, 2018; Windzio, 2018; Tranos et al., 2015; Aleskerov et al., 2017; Abel and Sander, 2014; Sander et al., 2014; Fagiolo and Mastrorillo, 2012). The main focus of these analyses is on large-scale real-world networks and their universal, structural and statistical properties (Newman, 2003; Tranos et al., 2015). In this method, all the countries involved in international migration are represented in a graph (Aleskerov et al., 2017). In the analysis of the international migration network, migration between two countries is considered as part of a set of nodes (countries) and arcs (directed arrows between nodes) (Windzio, 2018: 22). In the network analysis of the international migration structure, migration can be considered as a "social-spatial network". A social space network is a set of nodes (countries) located in geographic space and connected to each other via a set of edges associated with length (Barthelemy, 2011; Danchev and Porter, 2018).

The present paper attempts to draw a comprehensive picture of the international migration network by combining network analysis and spatial analysis and determining migration patterns internationally. It also seeks to identify the share of continents and geographic regions as migratory groupings through moving beyond national levels.

Method

In this study, an exploratory network analysis method is used to study the international migrations structure. Exploratory network analysis provides the fundamentals in order to approach international migration as a global network (Tranos et al., 2015).

The visualization method was used to illustrate the international migration structure. Drawing the networks and showing them through a visualization such as a sociograms have resulted in mapping a single 'snap shot in time' (Conway, 2014: 111). The visualization of global migration flows allows for the visual quantification of directional gross migration flows and the identification of their spatial patterns (Abel and Sander, 2014: 1521). Using graphs such as the sociograms (Windzio, 2018), GIS maps (Danchev and Porter, 2018) and Circular Plots (Abel and Sander, 2014; Sander et al., 2014) in network analysis is the main method of the visualization of ties in the network of international migration.

Drawing upong the definition provided by Danchev and Porter (2018)—migration as a social-spatial network—, we used two methods to analyze the international migration structure. Network analysis graphs were employed in the form of a sociogram to map the migration ties between nodes (countries) and GIS maps were used to map out migration flows in the world. Sociograms offer a structured, integrated view of relationships that would not be immediately perceivable just from qualitative analyses (such as interviews) and quantitative analyses (such as statistical tables) (Ryan and D'Angelo, 2018)

Also, paying attention to the geographical and spatial aspects of migration in order to determine the main migration paths and examine the local or global aspects of migration can help clarify the international migrations structure[1] .

Along with the use of visualization, Network-related indicators were also used. Network analysis indicators, especially centrality degree, have been used to analyze the position of nodes (countries). Centrality degree characterizes the number of countries connected with the given country through migration flows (Aleskerov et al., 2017:9).

As for the network analysis, Pajek and R softwares were used. Pajek software provides the possibility of analyzing large matrix data and extracting *network-level* and *nodes-level* properties (Nooy et al., 2005). R software provides a variety of clustering and graphical displays of them and extracts the particular network indicators. ARC / GIS software was also used to show the international population movements between the countries of origin and destination countries on the world map. To this end, for each tie, the geographical coordinates of the country of origin and destination country were determined and, finally, using the *XY To Line analysis*, the international migrations network was displayed on the map. Additionally, *Density Line Analysis* was used to determine the density of migration paths and *Kernel Density Analysis* to display the spatial distribution of the "in" – "out" centrality degree of countries on the map.

Data

The current research method uses existing data based on global data. International migration studies use two types of data, migration flows data and stock data. Migration flows data capture the number of migrants entering and leaving (inflow and outflow) a country over the course of a specific period, such as one year (United Nations Department for Economic and Social Affairs Statistical Division (UN SD, 2017). Stock data, measured at a given point in time as the number of people living in a country other than the one in which they were born (Abel and Sander, 2014: 1520). Flow data are only available for 45 countries worldwide (United Nations Department of Economic and Social Affairs (UN DESA, 2015) or were estimated by some researchers based on the data on migrant stocks (Abel and Sander, 2014; Raymer et al., 2013). Therefore, these data are not able to determine the share of demographic changes such as mortality and birth of migrants in the destination country. Also, the results of migration flow data are sensitive to rapid changes such as short-term political crises and differences in definitions and methods for calculating migration flows over the same period poses difficulties in comparing these statistics.

Stock data, on the other hand, can date back decades in history. These data depend on the demographic characteristics of the sending country. Also stock data do not reflect the dynamic changes in the international migration process and are more stable even after huge crises.[2]

Therefore, it can be seen that both types of data have weaknesses but migrant stocks data are widely available and significantly easier to measure across countries (Abel and Sander, 2014: 1520). Also aggregate migration stocks can overlook differences among types of migration (e.g., labour or education) or dynamic forms of migration (Danchev and Porter, 2016: 23). So migration stocks represent the long-term effects of migration and thus a more stable component of global migration structure (Bilsborrow and Zlotnik, 1994: 66).

Also this data shows how countries are linked to each other by migration.Therefore, since the purpose of the present study is to identify the structure of international migrations rather than migration flows, migrant stocks data have been used for analysis.

For this purpose, data from the United Nations Global Migration Database (UNGMD) have been used. These data show the total number of migrants during the years 1990–2017. These data are provided based on surveys and other official statistical sources and presented in a matrix of 232 countries and territories. The data of 2017 are used in this paper. The total number of migrants in 2017 is 257,715,425, out of which 95.4 % was provided in the form of 232 countries matrix, and 4.6 % of migrants was not classified among these countries. Therefore, the paper is

[1] . To study the relationship between geography and migration, refer to the review of the records provided by Danchev and Porter (2018).

[2] . Based on the suggestions and comments of the reviewers

based on the total number of migrants and on 95.4 % of international migrants and does not provide any analysis for the 4.6 % of the remaining data.

The weight of the ties was used to examine the status of countries in the structure of international migration more closely. The strength of a migration edge is a local property as it captures the intensity of migration between two countries (Danchev and Porter, 2018). International migration patterns are usually analyzed by simple measures as the number of migrant inflows and outflows, net and gross migration flows (Aleskerov et al., 2017). A review of past studies shows that two sets of measures have been used as weights of the ties. In some studies, raw data on the number of migrants (Danchev and Porter, 2018; Abel and Sander, 2014; Sander et al., 2014; Sekulić et al., 2018) and in some other studies the normalization of number of migrants by the population of the country of origin or destination country (Aleskerov et al., 2017; see Tranos et al., 2015; Sander et al., 2014) have been used.

In the present study, two measures are used to weigh the migration ties between countries. First, the percentage of migrants per tie relative to the total number of international migrants was used to examine the contribution of countries to the structure of international migrations. As noted, the most recent studies have used the raw number of immigrants for this purpose. But in order to interpret and understand countries' migration patterns more accurately, the use of the proportion of immigrants in each country relative to the total number of immigrants has been suggested and used. This index particularly allows for a higher level of analysis of, i.e. continents, geographical areas and country clusters. In this analysis, weighted in-degree centrality is the percentage of immigrants and weighted out-degree is the percentage of emigrants for each country or one group of countries relative to the total number of international migrants. Therefore, the interpretation of the results is easier. In this analysis, each country, regardless of its population size, will be equally treated as a vertex in the network (Abel and Sander, 2014).

In this study, the ratio of the number of immigrants in a country to the population of the country of destination of immigration was used to evaluate the *influence of immigration flow on the country of destination*. Aleskerov et al. (2017) have proposed a 0.1 % level for the "critical level of migrant inflow" between the two countries. Based on this level, if the migration flow from country A to country B does not reach 0.1 % of the population of country B, then country A does not directly influence country B through migration flows. (Aleskerov et al., 2017). In the present study, in addition to the 0.1 % level, the 1% level of influence in the destination country is also examined. In this analysis, the weighted in-degree centrality is a percentage of the population of the country of destination country relative to the total population of the country.

Community detection

community detection requires the partition of a network into communities of strongly connected nodes, with the nodes belonging to different communities only sparsely connected (Blondel et al., 2008). Community detection methods provide a rich and growing set of tools for working with relational data that can be used to understand the structure of complex networks (Fortunato, 2010). Various methods such as Walktrap community structure algorithm (Abel et al., 2020) and Louvain Community Detection have been suggested for community detection (Tranos et al., 2015) in international migrations studies.

In this paper, clValid package in R software was used for cluster validation (Brock et al., 2008). To this end, in the first step, the internal measures of the network were investigated through three indices: Silhouette Width, Dunn, and Connectivity Index. The results show that based on the indices, the optimal number of clusters for the present network is 2, which is not of analytical value for the present study. In the next step, the indices were calculated for the number of clusters derived from 5 clustering algorithms. The number of clusters and the indices used for evaluating the number of clusters in the hierarchical method are listed in Table 1.

Table 1
Internal validation of the number of clusters of clustering algorithms.

Method	Clusters numbers	Internal validation indices		
		Connectivity	Dunn	Silhouette
Label Propagation	12	34.2016	0.406	0.6807
Fast Greedy	9	24.3607	0.5476	0.7603
Infomap	21	69.5611	0.1531	0.6189
Louvai	9	24.3607	0.5476	0.7603
Walktrap	14	44.0746	0.3459	0.6712

As the results of the table show, the best performance of the indices is for the 9 clusters, which is obtained through Fast Greedy and Louvain methods. Therefore, in the present study, Louvain method, among the clustering algorithms available, was used based on previous studies and clustering validation indices.

The Louvain method, which was developed by Blondel et al. (2008) and is the most widely-used method (Tranos et al., 2015; Danchev and Porter, 2018; Sekulić et al., 2018; Thomas et al., 2017), aims to maximize modularity in a network. This is an indication of the quality of the derived communities, measuring the density of the links inside the community in comparison to these outside the community. The outcome of Louvain method reveals familiar structures. (Tranos et al., 2015, Blondel et al., 2008). One advantage of this community detection algorithm is the ability to use link weights (Sekulić et al., 2018). Therefore, the present paper uses this method of community detection for clustering countries.

Findings

General characteristics of the global migration network

An examination of the global migration network shows that out of 26,796 possible ties, there are 2834 mutual node pairs (mutual exchanges migrants), and 5322 asymmetric node pairs. There are also 18,640 pairs without migration. The network density is 0.30438, which indicates that there is about 30 % of migratory ties in the global migration network (Graph 1)

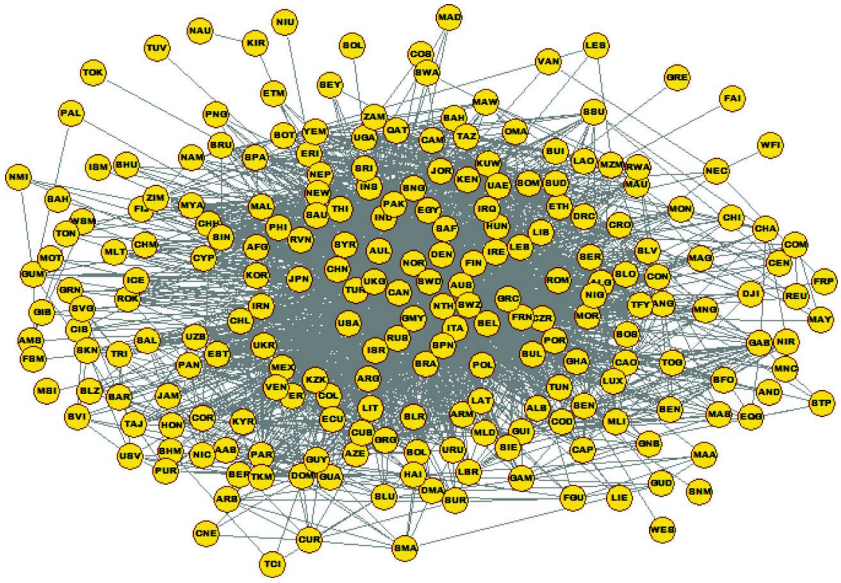
Of course, it should be noted that the number of migrants from one country to another may be small and, therefore, they will not play a crucial role in the international migrations structure. To investigate this, we are investigating the status of migration ties between countries based on the strength of ties, i.e., the share of each tie in international migrations. In order to determine the contribution of each tie in the international migration structure, the percentage of migrants per tie relative to the total number of international migrants was used. For this purpose, the ties with a ratio of more than 0.0.1 %, 0.01 %, 0.1 %, and 1% (approximately 257, 2570, 257,000 and 2,570,000 migrants respectively) were studied separately. Table 2 shows the results of the study of different strengths of ties.(Table 2)

As the table above shows, with the increase in the strength of ties (number of migrants) between the countries of origin and destination, the number of ties decrease considerably, as a result of which only 5 ties have strengths greater than 1% from the international migrations.

Asymmetric node pairs = MEX→USA (4.92 %), SYR→ TUR (1.27 %), (IND→UAE (1.28 %), BNG→IND (1.22 %)]

Mutual node pairs = RUS→UKR (1.28 %), UKR→RUS (1.27 %),

Edge density index in ties with a strength of higher than 0.001 % of total migrants was reduced to 8% of possible ties. Ties higher than 0.01%–3%, 0.1 % to 0.6 %, and 1% to 0.002 % of possible ties reduce too. Thus, it can be seen that most of the countries' ties in the structure of international migrations are of weak ties. The strength of these ties are less than 0.0.1 % (less than about 2570 migrants per ties) of



Graph 1. Global Migration Network (Full Network).

Table 2
Number of Mutual and Asymmetric ties on the strength of ties.

	Complete network	ties with a ratio greater than			
		0.001 %	0.01 %	0.1 %	1%
Mutual node pairs	2834	703	164	13	1
Asymmetric node pairs	5322	1655	720	153	4
Reciprocity (observed ties)	0.5157	0.459	0.3129	0.1452	0.3333
Reciprocity(total pairs)	0.1058	0.0262	0.0061	0.0005	0.0000
Edge density (total pairs)	0.3043	0.0879	0.0329	0.0062	0.0002

international migrations.

Meanwhile, the ratio of Mutual ties between countries reduced from about 10 % in the full network to close to zero percent in ties with a strength of more than 1 %. Reduction of Mutual ties, especially at 0.1 and 1 percent, is significant. Therefore, with the increase in the strength of ties, both the amount of ties and the amount of Mutual ties between different countries reduce significantly, with the networks being more asymmetric in nature.

An examination of the "in" and "out" centrality degree between the continents across the world, shows that Asian countries with “out” centrality degree of 41.16 have the highest number of emigrants. In other words, 41.16 % of international migrations are from Asian countries (regardless of intra-continental migration). European countries with an "out" centrality degree of 23.95 stand in the second highest position in the world. On the other hand, European countries with an "in" centrality degree of 29.81, Asian countries with 29.48, and North American countries with 21.45 have the highest share in the immigrants. (Fig. 1)

As can be seen, Asian and European countries have the largest share of immigrants and emigrants at the same time. The analysis of the spatial distribution of the "in" and "out" centrality degree to determine the geographical emigration and immigration regions in the world using *Kernel Density analysis* (Map 1) shows that the North American, Western European and Western-Asian regions focus more on the immigrants. Empirical data shows that the majority of the OCED countries are final destinations for the largest part of international migration (Tranos et al., 2015). According to spatial analysis, South Asia, Western Asia and Eastern Europe also have a greater focus on emigrants.

Centrality indicators of networks

The examination of countries’ centrality indicators in the structure of international migration indicates the central position of some countries in this process. The degree centrality indicates how well a node is connected in terms of direct connections, i.e., it keeps track of the degree of the node. (Rusinowska et al., 2011). The weighted in-degree (*WInDeg*) centrality represents the number of in-coming ties for each node with weights on them, i.e. the immigrant flow to the country. (Aleskerov et al., 2017). The study of the Weighted Input Degree (*WInDeg*) countries (degree of immigration) shows that the United States with a degree of

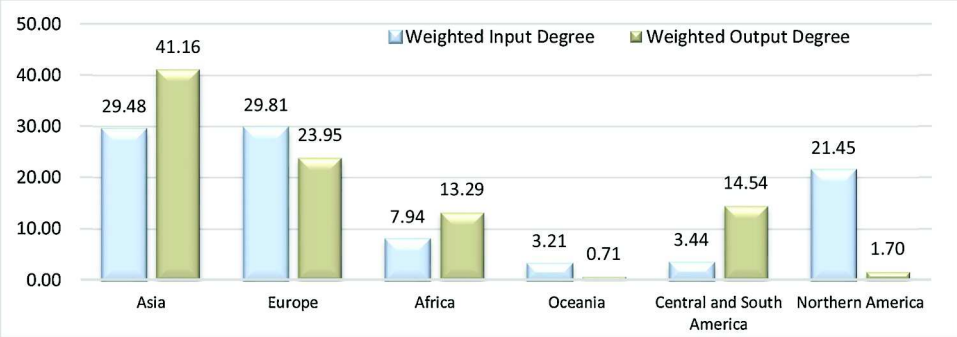
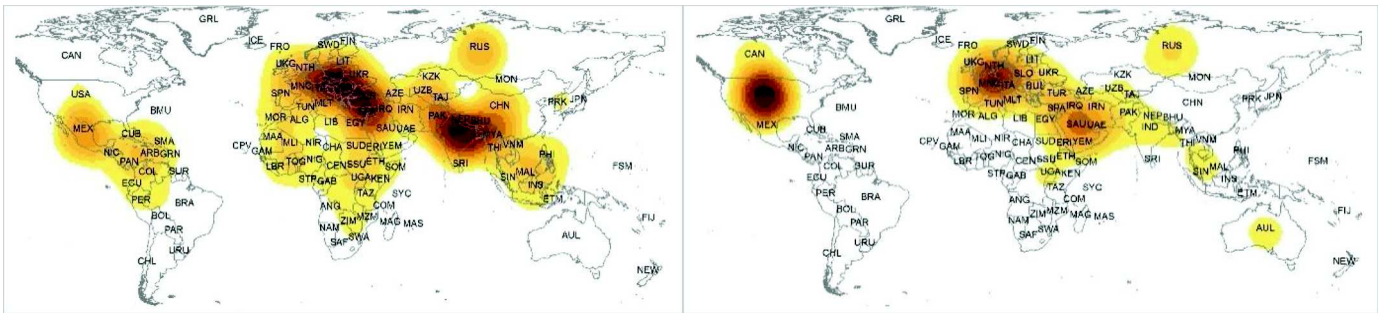


Fig. 1. The "in" and "out" centrality degree of the continents across the world. Weighted centrality degree represents the percentage of immigrants and emigrants in the countries of each continent.



Map 1. Spatial distribution of the most important immigrants and emigrants regions based on the "in" (right map) and "out" (left map) centrality degrees using Kernel Density analysis in ARC/GIS.

18,397 is in a more central position than other countries. In other words, 18.4 % of the international migration was to the United States. Germany, Saudi Arabia and Russia rank second to fourth. On the other hand, Weighted out-degree (WOutDeg) is the number of out-going links for each node and accordingly relates to the number of emigrants. (Aleskerov et al., 2017). the highest Weighted Output Degree (*WOutDeg*) of countries (degree of emigration) is for India with a degree of 6.433 and Mexico with 5.03 and Russia with 4.12.The status of the first 20 countries is presented.

In-degree centralization is highly and positively correlated with all other (binary and weighted) centrality indicators in the international migration network (i.e. eigenvector-based indicators, betweenness centrality, etc.). (Giorgio and Marina, 2014). Examination of the Eigenvector centrality (*InEige*) shows that the countries of the Russian Federation, the United States, Ukraine, Kazakhstan and Germany have the highest degree of Eigenvector. Eigenvector centrality ranks nodes based on the centrality of nodes that they are connected to. A high-ranked county is connected to other high-ranked counties with incoming or outgoing migration (Charyyev and Gunes, 2019). Eigenvector centrality is based on the idea that a particular node has a high importance if its adjacent nodes have a high importance. In international migration network these indices highlight the countries – "centers of international immigration", and the countries which are directly linked with them through migration flows (Aleskerov et al., 2017). Also The Russian Federation, Ukraine, Kazakhstan, Uzbekistan and Belarus have the highest degrees of eigenvector Output centrality(*OutEig*) (Table 3).

The betweenness centrality is defined as the sum of the fraction of all shortest paths in the network that pass that edge. Edges that are involved in a large number of shortest paths gain higher betweenness centrality scores. Edge-betweenness centrality measures the extent to which an edge contributes to the global connectivity of the world migration network. (Danchev and Porter, 2016., see Everett and Borgatti, 2005). The betweenness centrality is based on how important a nodeis in terms of connecting other nodes. (Rusinowska et al., 2011). The nodeis [countries] with a maximum score are assumed to be more important for a network to remain interconnected (Peres et al., 2016). In international migration network counties that are on the pathways of most migrations will be ranked highest(Charyyev and Gunes, 2019). Also proximity prestige is based on the idea that a node's importance is determined by the importance of its neighbors (Rusinowska et al., 2011). Maximum proximity prestige is achieved if a node [country] is directly chosen by all other nodes [countries](Nooy et al., 2011). In other words, a country is chosen as a destination for immigrants from other countries. The results showed the USA, Canada, United Kingdom, France, Germany and Australia have the highest degrees of Proximity Prestige (*InPre*) and Betweenness (*Betw*) (Table 3).

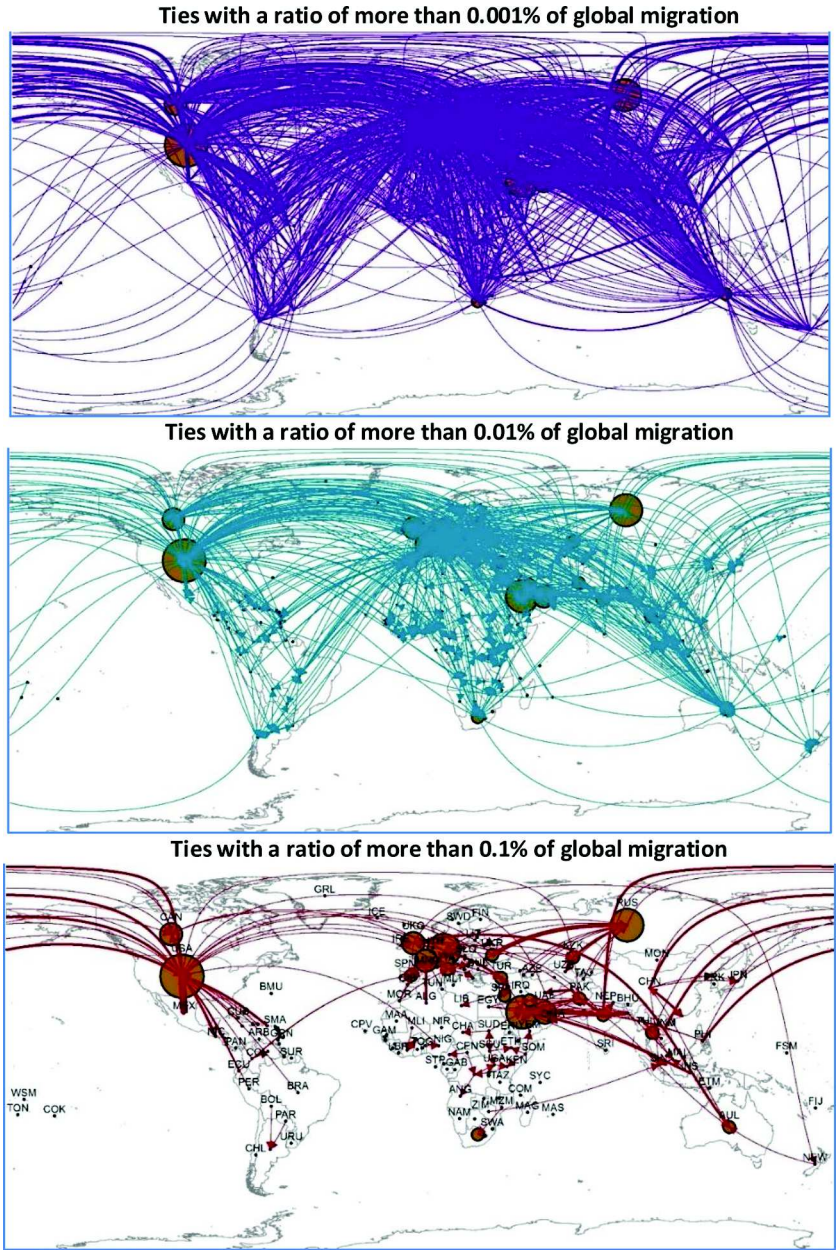
Migration within and between regions: a local-global duality[3]

One of the important issues in the study of international migration is the sphere of influence of migrations. In other words, migration is more local or international and transnational. Major studies confirm that the

Table 3
20 Countries with the highest "in" and "out" centrality degrees.

	WInDeg	InEige	InPre	Betw		WOutDeg	OutEig	OutPre	Betw
United States of America	18.397	0.777	0.6981	0.1703	India	6.433	0.014	0.5600	0.1703
Germany	4.679	0.519	0.6331	0.0582	Mexico	5.03	0.033	0.5110	0.0328
Saudi Arabia	4.569	0.011	0.3432	0.0020	Russian Federation	4.126	1	0.4254	0.0047
Russian Federation	4.511	1	0.4785	0.0265	China	3.857	0.027	0.4932	0.0265
United Kingdom	3.408	0.121	0.6887	0.1293	Bangladesh	2.907	0.011	0.5259	0.0208
United Arab Emirates	3.13	0.016	0.4730	0.0024	Syrian Arab Republic	2.659	0.028	0.4516	0.0044
France	3.061	0.086	0.6410	0.1301	Pakistan	2.317	0.007	0.4589	0.0004
Canada	3.041	0.145	0.7005	0.0522	Ukraine	2.3	0.781	0.4687	0.0019
Australia	2.71	0.1	0.6410	0.0437	Philippines	2.201	0.008	0.4495	0.0060
Spain	2.297	0.086	0.5791	0.0290	United Kingdom	1.906	0.006	0.4589	0.0091
Italy	2.289	0.112	0.6067	0.0382	Afghanistan	1.87	0.008	0.5329	0.1293
India	1.975	0.009	0.4500	0.0328	Poland	1.818	0.042	0.4485	0.0004
Turkey	1.852	0.05	0.4996	0.0138	Indonesia	1.641	0.002	0.4425	0.0018
Ukraine	1.762	0.766	0.4337	0.0060	Germany	1.632	0.068	0.4610	0.0114
Kazakhstan	1.41	0.619	0.3966	0.0022	Kazakhstan	1.579	0.61	0.5083	0.0582
Thailand	1.392	0.002	0.4643	0.0049	State of Palestine	1.472	0.005	0.4376	0.0022
Pakistan	1.317	0.004	0.3089	0.0019	Romania	1.384	0.014	0.3949	0.0068
Jordan	1.249	0.002	0.4265	0.0014	Turkey	1.322	0.036	0.4425	0.0018
Kuwait	1.164	0.006	0.4654	0.0020	Egypt	1.322	0.001	0.4589	0.0131
South Africa	1.112	0.022	0.5480	0.0232	Italy	1.172	0.009	0.4485	0.0138

[3] . For more precise description, the America continent was divided into two parts of North America and Central - South America.



Map 2. The international migrations by strength of ties greater than 0.0.1 %, 0.01 %, and 0.1 %. The maps are set according to the geographical coordinates of the country of origin and country of destination of each tie and according to the middle point of each country. The maps are drawn using the ARC/GIS. The size of the lines per tie is based on the number of migrants and circles based on the "Weighted Input Degree" centrality.

largest flows occurred within regions or to neighboring regions (Abel and Sander, 2014: 1522). Geographic distance and regional boundaries play important roles in demarcating the structure of more than half of the international migration communities (Danchev and Porter, 2018).

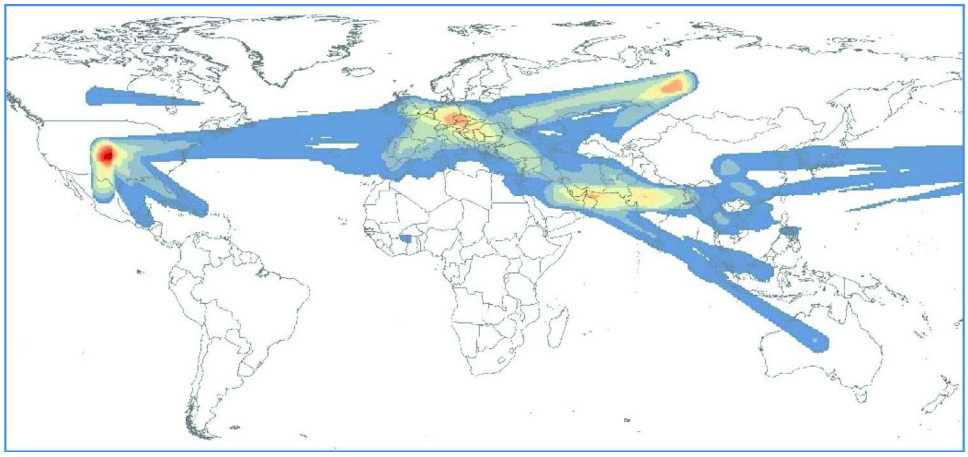
Basically, nodes that are closer to one another are more likely to be connected to each other (Barthelemy, 2011) and these networks are geographically concentrated (Abel et al. 2016: 1). Spatial proximity might facilitate back-and-forth migration. Also, travel time, monetary costs and cultural differences increase with an increase in spatial distance (Windzio, 2018: 21).

On the other hand, analyzing international migration, some scholars are considering the concept of "glocal" for both local and global aspects of migration (Danchev and Porter, 2018). Wellman instead of "Little Boxes" (densely-knit, linking people door-to-door) used the term "Glocalized" networks (sparsely-knit but with clusters, linking households both locally and globally) to refer to the simultaneous presence of strong local relationships and weak relationships that are global in geographic scope (Wellman, 2002).

Spatial analysis of international migration paths

Understanding the issue of local or global relations and taking into account about 8150 existing binary relations between countries illustrates the complexity of migration relations. This complexity is well illustrated in the maps of the migration paths. The study of the international migrations network paths represents a specific pattern of migration and focus on specific paths in the world. These paths are significantly reduced by increasing the strength of ties (the number of international migrants in each paths). The maps show the global migration paths in 2017 (Map 2).

As the maps show, there are many migratory relationships across the world countries and beyond local migrations. This Trans-regional aspect



Map 3. Density Line Analysis in paths with strength of ties greater than 0.001 % of the international migrations. The map is drawn using Arc/GIS.

Table 4
Intra-and inter-continental migration (ratio of total international migrations).

	Asia	Europe	Africa	Oceania	Central and South America	Northern America
Asia	24.51	8.14	0.47	1.23	0.11	6.70
Europe	2.84	15.55	0.92	1.20	0.48	2.95
Africa	1.73	3.85	6.51	0.20	0.02	0.98
Oceania	0.03	0.13	0.01	0.43	0.00	0.11
Central and South America	0.18	1.75	0.01	0.06	2.30	10.24
Northern America	0.19	0.40	0.02	0.09	0.52	0.47

Table 5
Percentage of intra and inter-continental migration relative to the total number of migrants from each continent and the total international migrations.

	Asia	Europe	Africa	Oceania	Central and South America	Northern America
Asia	59.54	19.77	1.15	2.98	0.28	16.28
Europe	11.85	64.93	3.85	5.02	2.02	12.33
Africa	13.05	28.97	49.00	1.51	0.12	7.34
Oceania	4.77	18.09	0.98	60.59	0.00	15.57
Central and South America	1.22	12.05	0.07	0.41	15.85	70.41
Northern America	11.37	23.45	1.30	5.24	30.82	27.81

of international migrations is more pronounced in the mainstream migration paths of the world.

A study on the analysis of the density of migration paths using *Density Line analysis* shows that most of the international migrations are on the paths between Central America and Caribbean with North America, North America with Western Europe and South-Europe, between Eastern Europe and Central Asia with Russia, between Southern Asia with Western Asia, between Australia / New Zealand and Western Europe, and between East Asia and North America. And most international migrants have migrated from these paths. Map 3 shows the major migration paths using Density Line analysis

As the results suggest, along with local migration, there are major migration paths to some of the international migration centers that represent the Trans-regional dimension of international migrations.

Due to the complexity of migration relations in the structure of international migration, we analyzed international migrations based on two geographical criteria: the continents and geographical areas (external criteria) and a clustering criterion (internal criteria). Table 4 shows the percentage of intra and intercontinental migration. As the table shows, 49.77 % of international migrations were intracontinental migrations and 50.23 % were intercontinental ones. Of the international migrations, 24.51 % were within Asia, 15.55 % were within Europe, 6.51 % within Africa, 0.43 % within Oceania, 2.30 % within Central and South America, and 0.47 % within North America.

Also, according to, Table 5 64.93 % of European migrants migrated to other European countries and 59.54 % of Asian migrants also migrated to other Asian countries. The lowest intra-continental migration is in South America with only 15.85 % of migrants migrating to their own region. The highest proportion of intercontinental migration is in Central and South America in which 70.41 % of the migrants migrated to North America (Table 5).

Therefore, as it was seen on the continental levels in Europe, Asia and the Pacific, most of the migrations occurred intra-continental, and most of the migrations out of the continent were in the Central and South America, North America and Africa. Thus, on the continental level, about half of the migrations were intercontinental and the other half had an intercontinental aspect.

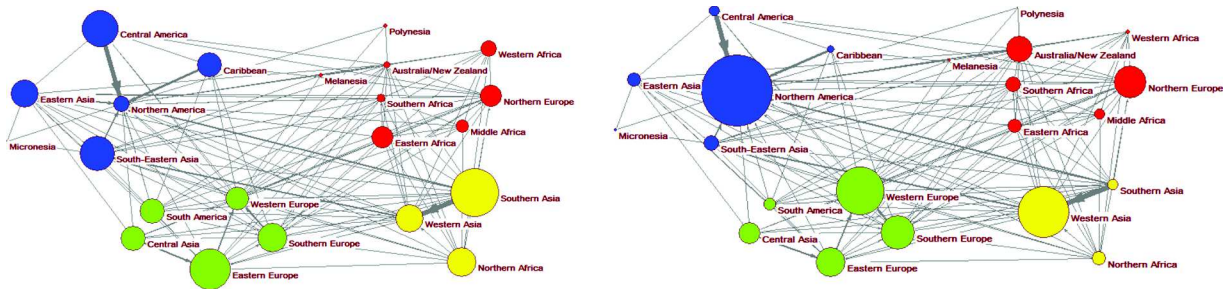
As the geographic regions are reduced to geographically more congruent regions, it can be seen that a complex network of relationships is created between smaller geographic units. The results show that according to 22 geographic regions, 65.81 % of migrations (169,602,521 people) were taken out of geographical areas and 29.59 % of migrations (76,257,994 people) occurred within these areas. Thus, it can be seen that intra-continental migration has also been largely out of the geographical areas. In Asia, as Table 6 shows, 71 % of South Asian migrants have migrated out of this region, accounting for 10.89 % of international migrants. Also, 67.6 % of Southeast Asian migrants have migrated out of the region, accounting for 5.53 % of international migrations. In Western Asia, 57.3 percent of migration occurred within the region, but in Central Asia, more migrants, 93.6 percent to be specific, migrated out of Central Asia, accounting for 2.76 percent of international migrations. In East Asia, 63.8 % of migrations has taken place outside the region. Therefore, in different geographical regions of Asia, the majority of migrants have migrated out of their areas.

In Africa, two groups of regions can be identified. In North Africa, most migrations have occurred outside the region. To be more specific, 98.6 % of migrants have migrated outside of northern Africa, accounting for 4.17 % of international migrations. Also, in sub-Saharan Africa, 57.1 percent of migrations occurred in middle Africa with 57.1 percent, East Africa with 53.1 percent, and South Africa with 54.8 percent. Most migrations in North Africa were outside the geographical area, while in West Africa, 66.2 % of migrations occurred within the region (Table 6).

In Europe, inter-regional migration is more than in-migration, with

Table 6
Percentage of intra and inter-regional migrations relative to the total number of migrants from each region and the total international migrations.

	Number of migrants of region countries		Percentage of migrants of region countries		Percentage of total international migrants	
	Out of the region	Within the region	Out of the region	Within the region	Out of the region	Within the region
Southern Asia	28,065,210	11,442,565	71.0	29.0	10.9	4.4
South-Eastern Asia	14,251,663	6,829,459	67.6	32.4	5.5	2.7
Western Asia	9,638,557	12,937,314	42.7	57.3	3.7	5.0
Central Asia	7,112,946	489,659	93.6	6.4	2.8	0.2
Eastern Asia	9,303,527	5,283,166	63.8	36.2	3.6	2.1
Northern Africa	10,746,733	154,629	98.6	1.4	4.2	0.1
Middle Africa	2,293,667	1,726,693	57.1	42.9	0.9	0.7
Western Africa	2,963,727	5,798,597	33.8	66.2	1.2	2.3
Eastern Africa	5,540,882	4,896,593	53.1	46.9	2.2	1.9
Southern Africa	876,232	721,603	54.8	45.2	0.3	0.3
Southern Europe	10,076,673	3,041,042	76.8	23.2	3.9	1.2
Western Europe	6,391,343	2,912,184	68.7	31.3	2.5	1.1
Northern Europe	5,978,998	1,984,409	75.1	24.9	2.3	0.8
Eastern Europe	20,076,032	10,489,018	65.7	34.3	7.8	4.1
South America	7,783,006	4,200,761	64.9	35.1	3.0	1.6
Central America	16,674,188	644,289	96.3	3.7	6.5	0.3
Northern America	3,195,671	1,211,262	72.5	27.5	1.2	0.5
Caribbean	7,551,062	695,832	91.6	8.4	2.9	0.3
Australia/New Zealand	618,517	747,375	45.3	54.7	0.2	0.3
Polynesia	206,172	25,772	88.9	11.1	0.1	0.0
Melanesia	231,944	0	100.0	0.0	0.1	0.0
Micronesia	25,772	25,772	50.0	50.0	0.0	0.0
Total	169,602,521	76,257,994			65.81	29.59



Graph 2. Clustering of 22 geographic regions using Louvain Community Detection. The size of the circles in the right graph is based on the in-degree centrality (immigrants) and the size in left graph based on the out-degree centrality (emigrants).

76.8 % of South-European migrants, 68.7 % of Western European migrants, 75.1 % of North-East migrants and 65.7 % of Eastern European migrants migrating outside their geographic areas.

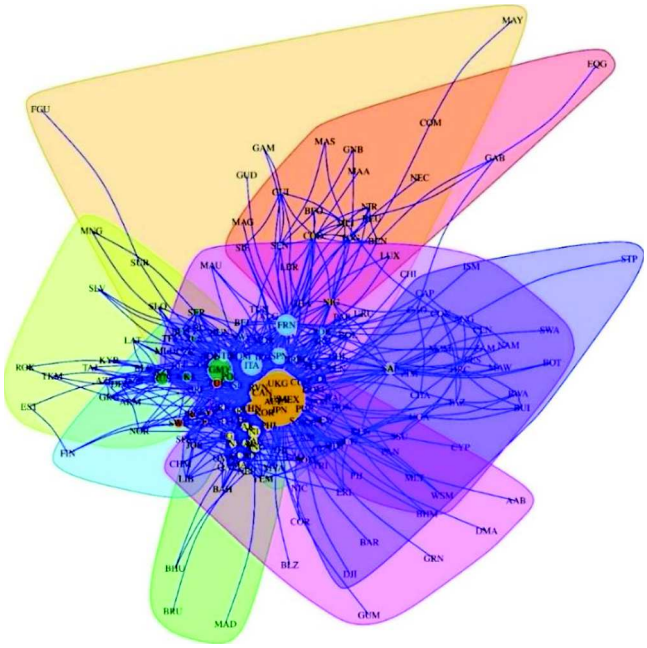
The countries located in North America, Central and South America also have migrations mainly occurring outside their area. In particular, in the Central American region, 96.3 % of migrants have migrated outside their area. This ratio is 64.9 percent for South America and 72.5 percent for North America. In Australia and New Zealand, 57.3 percent of migrations occurred within this range, but in the Polynesia, Melanesia, and Micronesia areas, migrations have been out of the region. Thus, it can be seen that with the smaller units of geography, migration takes on an inter-regional character.

Based on the Louvain Community Detection analysis, the community-based analysis of these 22 geographic areas has identified four clusters of geographic regions based on inter-regional ties. Graph 2 shows the status of these four clusters along with the relationships among them.

As the graph shows, the regions of Australia / New Zealand, Polynesia, Melanesia, South Africa, Eastern Africa and Central Africa and Northern Europe comprise cluster 1 (Red); South Asia, Western Asia, and North Africa are part of cluster 2 (Yellow); Central America, The Caribbean, North America, Micronesia, East Asia, and Southeast Asia are located in cluster 3 (Blue); and southern Europe, Eastern Europe, Western Europe, Central Asia and South America are in cluster 4 (Green).

These clusters represent the formation of some kind of Trans-regional migratory ties between geographically connected areas. Based on the nature (existence, direction and strength) of the ties, the clustering of countries in the international migrations network by using the "Louvain community detection" method with the R software specified nine clusters. An international migration community is a tightly-knit group of countries with dense internal migration connections (relative to a null model which describes random connections for a given distance range) but sparse connections to and from other countries in a network (Danchev and Porter, 2018) (Graph 3).

As Map 4 shows, the countries of South Asia, West Asia and Southeast Asia are in cluster 1. The cluster represents one of the most important migration paths from South and Southeast Asia, especially India, Bangladesh, Indonesia and Nepal to the Persian Gulf states, especially Saudi Arabia and the United Arab Emirates. Countries from Eastern Europe, Western Europe and Southern Europe along with Northwest Africa and South America are in cluster 2. This cluster is mainly based on the immigration exchange between European countries and the continuation of post-colonial relations between the countries of South America and North West Africa and France, Italy, Spain and Portugal. Countries from south of Africa in addition to countries from Oceania, Britain and Ireland are in cluster 3. This cluster corresponds to a large part of the British colonial empire. The migration flows in this cluster follow the colonial relationships between these countries with the British centrality. Eastern and Central African countries are in cluster 4; North and Central America along with East Asian countries and some Southeast Asian countries are in cluster 5; Countries from Eastern



Graph 3. Display clustering of countries using the cluster Louvain_method in software R. Each color specifies the scope of a cluster.

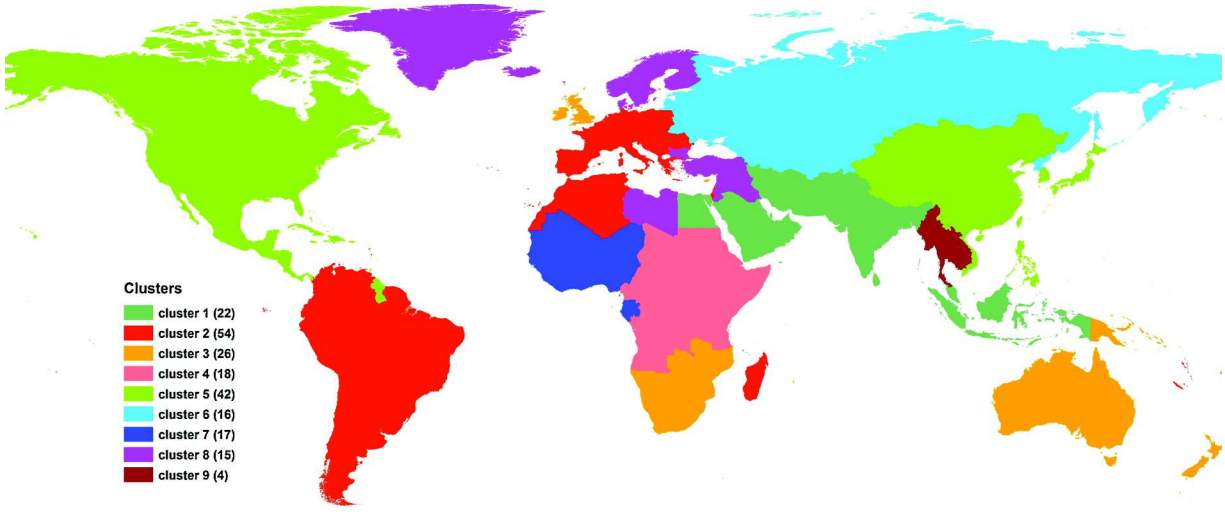
European, along with Central Asia and the Caucasus, are in cluster 6. In this cluster the CIS countries with a communist heritage are found. The countries of West Africa are in cluster 7. Countries from Western Asia and Northern Europe are in cluster 8. In this cluster, the fact that refugees flee from internal or inter-state political conflicts, especially the Palestinian and Syria Crisis plays a major role. Also, there are four Southeast Asian countries in cluster 9, which shows strong regional ties between these countries.

In addition to geographic units, clustering of countries may illustrate their migration paths better due to their inherent nature. As Table 7 shows, 68.3 percent (175,991,287) of international migrations were within clusters and 27.05 percent (69,712,022) among clusters.

According to the table, 14.90 percent of international migrations occurred within cluster 1, 5.01 percent of international migrations took place from cluster 1 to other clusters. In this cluster, 74.83 % of migrations were within the cluster. While 13.23 % of international migrations occurred within cluster 2, 6.3 % of these migrations were from this cluster to other clusters. Thus, 67.73 % of the migrations of this cluster occurred within the cluster.

In cluster 3, 65.11 % of migrations occurred within the cluster, 2.98 % of international migrations occurred within this cluster, and 1.6 % of migrants migrated to other clusters from this cluster. In cluster 4, similar to cluster 3, 65.49 % of migrations occurred within the cluster. The cluster made 3.44 percent of the international migrations within it and 1.81 percent moved to other clusters.

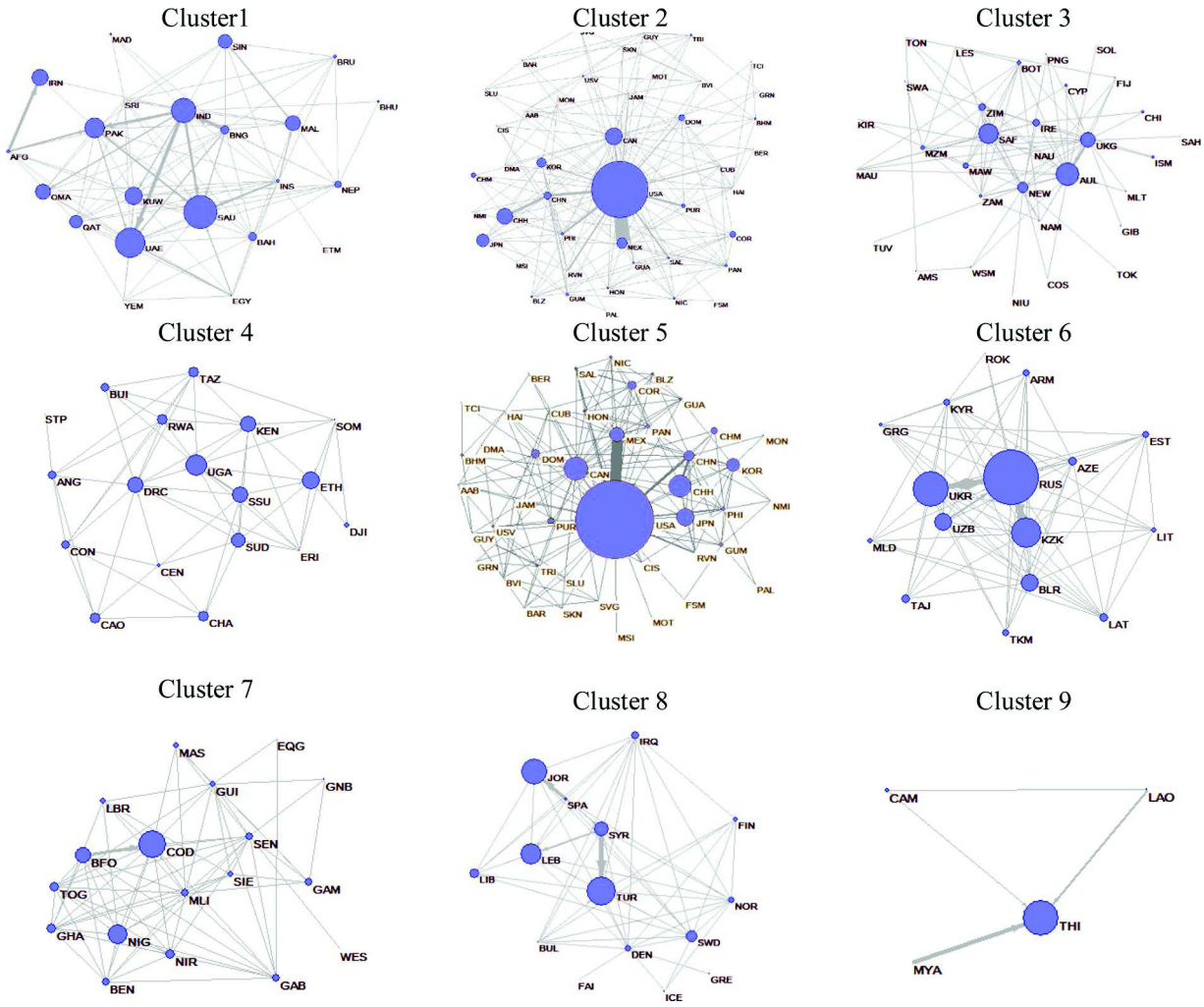
Cluster 5 has the highest intra-cluster migrations. 16.74 percent of international migrations has been done within this cluster, and 3.91 percent of the migrations has been made to other clusters. In this cluster, 81.04 % of migrations have occurred within the cluster. In cluster 6,



Map 4. Membership of countries in clusters of international migrations.

Table 7
Percentage of migrations within and between clusters relative to the total number of migrants from each region and the total international migrations.

	Number of migrants of cluster countries		Percentage of migrants of cluster countries		Percentage of total international migrants	
	Out of the cluster	Within the cluster	Out the of cluster	Within the cluster	Out of the cluster	Within the cluster
Cluster 1	12,916,697	38,407,330	25.17	74.83	5.01	14.90
Cluster 2	16,246,380	34,100,905	32.27	67.73	6.30	13.23
Cluster 3	4,110,561	7,672,188	34.89	65.11	1.60	2.98
Cluster 4	4,669,804	8,862,833	34.51	65.49	1.81	3.44
Cluster 5	10,076,673	43,146,716	18.93	81.07	3.91	16.74
Cluster 6	7,847,435	22,934,096	25.49	74.51	3.05	8.90
Cluster 7	2,669,932	6,048,581	30.62	69.38	1.04	2.35
Cluster 8	8,496,878	11,344,633	42.82	57.18	3.30	4.40
Cluster 9	2,677,663	3,474,004	43.53	56.47	1.04	1.35
Total	69,712,022	175,991,287			27.05	68.3



Graph 4. Migration ties between countries in nine clusters. The size of the circles shows the in-degree of each region and the size of the lines indicates the amount of displacement of migrants in different countries.

74.51 % of migrations occurred within the cluster countries, 8.9 % of international migrations occurred within this cluster. Also, 3.05 percent of international migrants have moved to other clusters. 2.35 %, 4.40 % and 1.35 % of international migrations occurred within clusters 7, 8, and 9 respectively. Also, 1.04 %, 3.30 % and 1.04 % of international migrations took place from these clusters to other clusters.

As can be seen, with the clustering of countries, it became clear that most of the international migrations are within these clusters. Graph 4 illustrates the ties between countries in each cluster.

Influence of international migrations on the countries

Based on the findings of the study, the weighted in-degree centrality or degree of influence of international migrations on the countries indicates that the UAE, Kuwait, Qatar, Bahrain, Oman, Singapore, Hong Kong, Saudi Arabia and Jordan have the highest percentage of immigrant population relative to resident population. According to the table, the UAE with a weighted in-degree centrality of 84.95 has the highest dependency on international migrations. Nearly 85 percent of its population is made up of immigrants. According to the findings, 24 countries make up more than 0.1 percent and 10 countries over 1 percent of the UAE population (Table 8).

Thus, with the normalization of the number of immigrants in the population of the destination country, the central countries of the international migration structure changed. The countries affected by international migration are not necessarily the countries with the highest percentage of immigrants in the world. Graph 5 shows the international migration network based on the influence of international migration structure.

Conclusion: international migration patterns

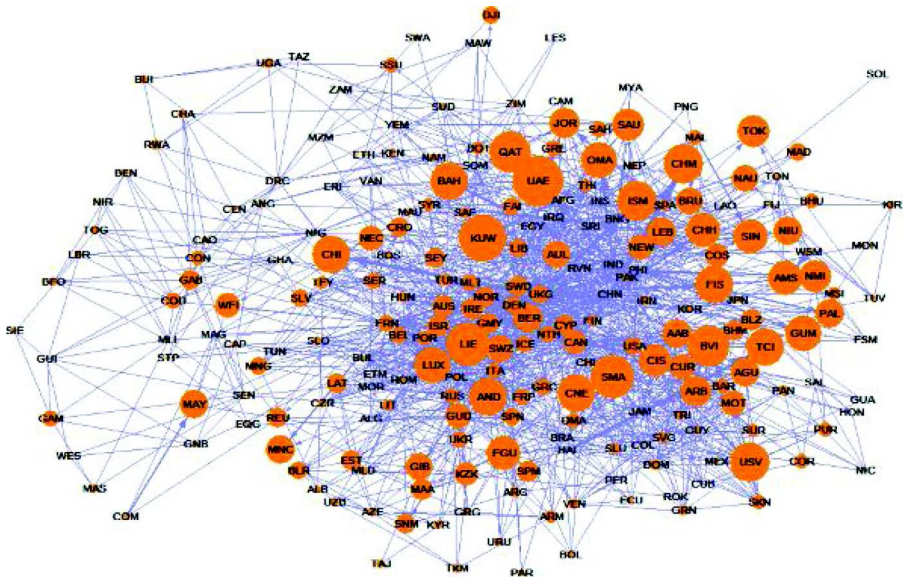
The study of structure of international migration using the exploratory network analysis approach showed that the international migration network has a network structure with complex relationships. Almost all countries have contributed to this network as the origin or destination of migration although the intensity, direction and number of ties vary widely among countries. Migration relations between countries of the world are largely asymmetric in this network. Particularly, with the increase in the tie intensity, the ties are largely asymmetric.

As the results showed, Asian and European countries have the largest share of immigrants and emigrants. Although OECD countries are the destination of many international migrants, the Middle East is also among the main centers of immigration.

Although many studies have shown that international migrations mainly occur in neighborhood and nearer countries, the analysis in the present paper showed that on the continental level, nearly half of the migrations took place outside the continents and at the geographical area level, and nearly two thirds of the migrations occurred outside the geographic areas. Therefore, it can be said that most of the international

Table 8
20 countries which are most influenced by international migration relative to their population.

rank	countries	Population of 2017	weighted in-degree centrality	The Influence of International Migration			
				Ties higher than 0.1 %		Ties higher than 1 %	
				The number of influencing countries	The mean of being influenced	The number of influencing countries	The mean of being influenced
1	United Arab Emirates	9,487,203	84.95	24	3.52	10	8.02
2	Kuwait	4,056,099	73.93	22	3.33	9	7.63
3	Qatar	2,724,728	61.95	19	3.22	10	5.87
4	Bahrain	1,494,076	47.83	21	2.25	7	6.11
5	Oman	4,665,928	42.63	12	3.54	5	7.88
6	Singapore	5,708,041	40.85	13	3.13	7	5.57
7	China, Hong Kong SAR	7,306,322	39.02	16	2.42	3	11.86
8	Saudi Arabia	33,101,179	35.57	16	2.22	12	2.77
9	Jordan	9,785,843	33.01	10	3.26	4	7.86
10	Australia	24,584,620	28.51	47	0.55	4	2.96
11	Lebanon	6,819,373	28.41	4	7.03	4	7.03*
12	Switzerland	8,455,804	28.23	40	0.63	6	2.53
13	New Zealand	4,702,034	21.81	28	0.73	7	2.05
14	Canada	36,732,095	21.37	40	0.44	4	1.68
15	Kazakhstan	18,080,019	20.11	10	1.97	4	4.52
16	Austria	8,819,901	18.82	30	0.57	4	2.37
17	Ireland	4,753,279	16.97	25	0.63	2	4.37
18	Israel	8,243,848	16.63	31	0.50	4	1.53
19	Sweden	9,904,896	16.16	36	0.37	3	1.31
20	Cyprus	1,179,678	15.87	22	0.65	4	2.02



Graph 5. Network of influence of immigrations on the countries. (Ties with higher than 0.1 % influence).

migrations have occurred outside the geographic area of the neighboring countries

The results of the exploratory social-spatial network analysis of international migrations structure showed that two patterns of migration are globally recognizable:

1) The analysis of migration paths showed that international migrations on a global scale have focused on specific paths to the centers of immigration in the world. Therefore, international migration is a phenomenon that is channelized into specific migrations paths, for which I use the term "*International Migratory Highways*". Major international migrations are concentrated on these highways. Most of the international migrations go beyond the geographical areas of these highways. The nature of these migrations is more asymmetric.

The term "highways" refers to a flow of migration at different times between the origins and main destinations of the migrations taking place in the world. In other words, the term reflects the paths that form migration flows beyond geographical proximity. According to this model, the immigrants from country A to country B at time 1 should enhance immigration at time 2. In other words, migrations stock a country at t1 might be a cause of migration at t2 from the same country. In a systems theory approach to migration, sending information, especially positive and favorable feedbacks from migrants to the source of migration, can create patterns of organized migration flows between specific origins and destinations of migration through a further amplification of migrations (Mabogunje, 1970: 12–13). Also the need to understand migration as an intrinsic part of much broader relationships between societies. Migratory movements generally arise from the existence of prior links between countries based on colonization, political influence, trade, investment or cultural ties. Although largescale migration between two countries tends to boost trade, capital flows,

Table 9
Matrix correlation of migrants stocks network between 1990 and 2017.

	1990	1995	2000	2005	2010	2015	2017
1990	1	0.937	0.86	0.79	0.741	0.717	0.707
1995		1	0.953	0.883	0.817	0.792	0.784
2000			1	0.933	0.863	0.84	0.836
2005				1	0.948	0.923	0.919
2010					1	0.98	0.977
2015						1	0.998
2017							1

investment, travel and tourism between the same countries (Castles et al., 2014: 3544)

Thus, according to migration systems theory, both prior ties and sending positive reinforcing feedbacks can create organized patterns of migration within the structure of international migrations between particular countries over time.

Therefore, changes in the number of immigrants in different countries based on the origins of immigration should follow a similar pattern of increase or decrease over time. The covariation of migrants stocks between 1990 and 2017 reflects the continuation of international migrations on International Migratory Highways. The matrix correlation of network migrants stocks between 1990 and 2017 is shown in Table 9.

As the table shows, there is a high correlation between the migrants stocks in these years. This shows a similar increase pattern across years in the structure of international migration. Therefore, the performance of these migration paths follows a similar trend despite the changes that have taken place, especially in refugees in different years.

2) However, there is a kind of migration exchange within the geographical and clustered areas, and not just a local one, but between the countries of the world. In these areas, countries have higher levels of mutual exchanges. "*Migratory Clusters*" are non-localized, but have a certain geographic dimension. In these clusters, migrations are more intra-cluster than out of clusters.

According to the results, migratory clusters are able to grasp the organization of international migrations beyond geographical divisions. Investigating the nature of these clusters and the causes of intra- and inter-cluster migration will undoubtedly require further empirical investigations using explanatory variables, especially with the ERGM regression approach (see Windzio, 2018; Windzio et al., 2019). Also, studying the motivations of immigrants and previous ties between countries within each cluster can provide useful information on the structure of international migration in the form of “migratory clusters” and “migratory highways”.

Acknowledgements

The author gratefully acknowledge Prof. Luigi Solivetti (Sapienza University of Rome) for critically reading the initial manuscript. I sincerely appreciate Ms. Mahsa Sadeghi Nezhad for her help in implementing clValid package in R software. Also I would like to thank the anonymous reviewers for their insightful comments on the paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.socnet.2020.09.007.

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