Geographical Analysis of Foreign Immigration and Spatial Patterns in Urban Areas.
Density Estimation and Spatial Segregation

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**Abstract**. The paper is focused on the analysis of immigrant population with particular reference to their spatial distribution and the tendency to cluster in some parts of a city, with the risk of generating ethnic enclaves or ghettoes. Methods used in the past to measure segregation and other characteristics of immigrants have long been aspatial, therefore not considering relationships between people within a city. In this paper the attention is dedicated to methods to analyse the immigrant residential distribution spatially, with particular reference to density-based method. The analysis is focused on the Municipality of Trieste (Italy) as a case study to test different methods for the analysis of immigration, and particularly to compare traditional indices, as Location Quotients and the Index of Segregation, to different, spatial ones, both based on Kernel Density Estimation functions, as the S index and the first version of an Index of Diversity.
**Keywords:**GIS; Geographical Analysis; Foreign Immigration; Spatial Segregation; Density Estimation; Trieste (Italy)

1 On qualitative and quantitative methods for the analysis of immigrants at urban level

The analysis on migrations, as correctly observed by Krasna [1] can rely on a mixed combination of methods and tools, both quantitative and qualitative ones. The former ones benefit from the diffusion of spatial analytical instruments and information systems, as well as from the huge availability of digital data and computation power unthinkable since few years ago. That allows filtering data and preparing information for the evaluation to be performed by the scholar on the phenomenon under examination. We can remind Tobler’s first law of geography [2], stating that every phenomenon over space is linked to all the other ones, but closer phenomena are more related to each other than farther ones, and therefore understand that the geographical space is capable of being analyzed by means of such quantitative methods, but also that no universal rules can be established, given the different characteristics and peculiarities of places over the Earth’s surface. The scholars involved in migration research should therefore rely also on qualitative methods in order to integrate their studies, with the difficult task of interpreting correctly what is happening over space.

With reference to migration studies, and particularly when these are referred to the urban environment, several analyses have been carried out in recent years to examine their spatial distribution, the characteristics of settlements and, more recently, the phenomena of residential segregation and the impact of migrants over the job market and the economy as a whole,in parallel with the migrants’ rooting in space as a structural component of society and economy. Researchers have focused their attention on different indicators in order to examine the characters of the spatial distribution of migrant groups, particularly in order to highlight the trends towards concentration rather than dispersion or homogeneity, or, still, the preferences for central rather than peripheral areas. The attention however is in particular focused on the analysis of phenomena related to residential segregation, at risk particularly in areas where a too high concentration of a single immigrant group is present if compared to the local residents such that ghettoes or ‘ethnic islands’ take place.

Some authors, as recalled by Cristaldi [3], draw their attention on some aspects related to segregation, as particularly the level of residential concentration, the assimilation and encapsulation. The indices generally used in the international research concerning geographical mobility and widely applied are the segregation index, based on the dissimilarity index (*D*)developed by Duncan and Duncan [4], with its different declinations. Its applications generally deal with the possibilities of comparison of the distribution of national groups in the intra-metropolitan area, among cities or on a diachronic scale [5][[1]](#footnote-2), as the main characteristic of the index is of being aspatial, and therefore allowing a direct comparison with other areas but saying little about the internal aspects of dissimilarity or segregation. Although such index has been used for decades and its family actually dominates the literature [10], this is a serious limitation, as it does not provide any indication on the population mix between zones but just within them, thus producing results that depend also on the zoning system chosen [11]. As O’ Sullivan and Wong remarks in fact [11], summary indices are useful to portray the level of segregation of a region and for comparing the results obtained for different regions, but they say little about some spatial aspects of segregation, as the possible rise of non-uniformity at local level or the level of segregation across the study area, and do not provide a visualization of segregation inside a region. Another limitation of such an index, shared also by a wealth of other indices, is the use of census data, generally collected and aggregated using a zoning system and that usually consider the different characteristics of population within the zones with little attention to the relations among them. Furthermore, the use of different zoning systems can lead to different values for a same study region, as it will be evident in the case studied in this paper, and therefore the spatial partitioning system strongly affects the evaluation of segregation, with a resulting ‘scale effect’, causing“smaller statistical enumeration units producing higher measured segregation levels” [12]. This is also related to the fact that moving from a highly disaggregated partition of space into a more aggregated one can lead to a generalization that, although valid for a certain level of analysis, is not valid for another one [13].

2 Measures of segregation

The measures of segregations applied in the last decades are based on Duncan and Duncan’s index of dissimilarity *D*[4]. The index is expressed in equation 1,

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|  . | (**1**) |

*x*i and *y*i are the population counts for the two subgroups in the areal unit *i*, while X and Y are the total counts for the two groups in the study region. The index ranges from 0 to 1, representing respectively the highest dispersion and highest concentration. As noticed before, the results the index *D* can assume varies with the choice of a zoning system and therefore with the areas and shapes the areal units *i* will have [11]. Furthermore, the index assumes that people living in a certain areal unit do not mix or interact with other people in neighbouring ones.

Researchers and scholars in geography proposed different methods through years to insert the spatial component within the dissimilarity index or to couple the index with other ones more prone to spatial representation and analysis. Some authors, as Jakubs [14] and Morgan [15] proposed distance-based approaches, Morril [16] and Wong [17] tried to adjust the level of D by introducing a neighbourhood-interaction approach, introducing additional elements into the D equation to consider the interaction among subgroups in neighbouring units. Other authors have coupled the use of the segregation index with other indices to explore more in depth the spatial structure of immigrants, as the Location Quotient (*LQ*), used to facilitate the analysis of residential segregation in different subunits of an area and therefore allowing mapping the spatial distribution of migrants according to a more disaggregated zoning system of the study region [5].

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|  . | (**2**) |

*x*irepresents the number of residents of a national group in areal unit *i*, *X* the number of residents in the entire study area (i.e., a municipality), *y*ithe foreign population in areal unit *i*and *Y*the foreign overall population in the study region. The location quotient LQ = 1 if the analyzed group holds in the areal unit *i* the same characteristics of the study region; if LQ > 1 than it is overrepresented in areal unit *i,* and if LQ< 1 than it is underrepresented. Although the drawback still lies onto the zoning system chosen and therefore on the higher or lower levels of aggregation of data, it allows also a visual, geographical analysis of the results obtained.

In the last years a quite wide use have been done of different version of Kernel Density Estimation to analyze phenomena expressed as point patterns, both *per se*, providing a visual three-dimensional surface of the spatial distribution of the phenomenon under examination, and to model some other aspatial indicator into a spatial context. Kernel Density Estimation was developed to provide an estimate of a population probability density function from a sample as an alternative to histograms [18], afterwards being extended to the spatial case [19][20] [21].The function creates a density surface from point pattern in space, providing an estimate of the events’ distribution within its searching radius, according to the distance to the point where the intensity is being estimated [22].

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|  . | (**3**) |

provides an estimate of the intensity of the spatial distribution of events, measured at location *s*;*si*is theithevents, *k (.)* represents the kernel function and is the bandwidth, varying which it is possible to obtain more or less smoothed surfaces and to analyze the phenomenon at different scales. A wide bandwidth over-smoothes the estimate by including many distant events, while a narrow one tends to overemphasize local variations in the events’ distribution [11] [23]. Among the advantages of the function there is the spread of the function all over the study region, obtained by assigning the estimated values over a fine grid superimposed to the study region, which cells become the places where values are attributed. Another desirable property is represented by the possibility of express the results of the Kernel Density Estimation either as density values (i.e., events per square kilometer) or as probability estimates, with the sum of cell values over the study region integrating to unity [24] and therefore allowing a direct comparison with other distributions of events.

The applications of KDE span through Earth’s and social sciences, almost in every field where geographical data can be expressed as point events over a study region. In population related studies, Kernel Density Estimation has been widely used particularly in the recent years, from ‘pure’ analysis of population distribution [19] [23] [27], to the analysis of immigrant population in urban areas [9] [11] [25] [26].

In this latter case, the estimator can be used together with other, spatial or aspatial, indices to provide an immediate visualization of the phenomenon observed and observe the possible formation of ‘hot spots’ or clusters of particular ethnic groups, allowing the scholar to go and analyze more in depth those areas of interest for values higher – or lower – than expected. However, Kernel Density Estimator is also used for modeling other elements referred to a spatial extension, in order to allow more sophisticated and complex analyses and host indices in a spatial framework. This is the case of a series of indices being explored in the very last few years, where some aspatial index or qualitative analysis is modeled into the KDE framework.

3 Spatial indices of dissimilarity

Two indices are considered here to enhance the analysis on segregation from a more ‘spatial’ point of view. The attention is drawn on O’ Sullivan and Wong’s [11] segregation index *S* and the diversity index *IDiv* tested by Borruso and Donato [25].

O’ Sullivan and Wong presents a spatial modification of the Duncan’s index *D*, called *S*, basically comparing, at a very local level, the space deriving from the *intersection* of the extents occupied by two sub-groups of an overall population and the total extent of the *union* of such areas [28]. Operationally, the calculation of the index for the study region involves the computation of probability density functions by means of KDE for the different population sub-groups of interest. Each reference cell *i*is therefore assigned a probability value for each subgroup, and for each of the subgroups the probability value in that cell contributes to the integration to unity. The *S* index for the study region is then calculated as follows:

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|  . | (**4**) |

For each cell *i*minimum and maximum values are computed for the true probability of the two subgroups, *px*i and *py*i, these are summed for all the *i* cells, obtaining minimum and maximum values under the two surfaces, and their ratio is subtracted from unity to produce index *S*. The index obtained is aspatial as well, as it can be obtained for a study region, but the intermediate values, as the differences in maximum and minimum values, can be mapped, giving a disaggregate view of the contribution of each cell to the overall segregation, with lower values indicating areas with some degree of ethnic mixing. As the bandwidth in Kernel Density Estimation determines the level of smoothing, different values produce a decay of the index as bandwidth increases, thus reducing the segregation index overall the study region and still the differences of this behaviour in different regions or for different groups can be analyzed to explore dynamics proper of a territory or group, allowing an analysis not limited to a certain spatial extent but also observable at different distance scales.

The Kernel Density Estimation (KDE) has been also used to host *Index of diversity* to observe if characteristics of homogeneity or differentiation between ethnic groups rise in the urban space. the Index of Diversity (*IDiv*) [25] can be expressed as:

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|  . | (**5**) |

The index *IDivi* is referred to each sub-area *i*, this being either a census block or a grid cell, and*Ni*is the number of countries represented in sub-area *i*¸ *yi*the immigrant population in zone *i* and*xi*the overall resident population in sub-area *i*.The index is then processed by means of KDE to be transformed in a three-dimensional density surface to visualize its continuous variation over space. The index is not focused on the possibility of highlighting areas segregated or with high values of a single group’s concentration: the Index of Diversity must be seen as an effort to represent synthetically some of the differences and peculiarities of migration in the urban areas and to highlight some elements of potential union and cohabitation rather than segregation and division. The index is built starting from the census blocks, transformed in point elements for the further elaboration by means of the Kernel Density Estimator. The index is based on the computation of the number of countries represented in each census block. Then this value is multiplied by the percentage of foreign residents in the census block. The index therefore considers both the diversity of countries represented and the number of immigrants. High values of the index indicates the presence of several immigrants coming from different countries, while lower values represent a small number of immigrants and little diversity of countries. The index is not alternative to other indices but aimed at highlighting some qualitative characteristics of the spatial distribution of migrants in urban areas. Development of such indicators should move towards the implementation of entropy based methods [29] in order to consider, as a characteristic to map, the diversity and variety in the distribution of population, rather than focusing on elements of division and separation.

The different indices observed however present limitations deriving from the availability of census data and their level of detail. In both cases the indices require the use of point data to be processed by the Kernel Density Estimation. This is generally done mainly in an intermediate stage of the process, as data are generally aggregated at census blocks level, therefore adopting a certain zoning system. In fact, the higher is the level of disaggregation of data, the more refined can be the geographical analysis and minor the error propagation effect. On the contrary, a higher level of data aggregation leads to a dilution of the message linked to the data itself and more difficult is its transformation in true information for the researcher. The data available are not always so disaggregated - i.e. referred to address points, not always available for population data – but collected using areal spatial units as census blocks or enumeration districts, etc. Such areas generally present non homogeneous shapes and dimensions as well as being subject to possible re-aggregation and modification, what can lead to misinterpretations of the phenomena under examination, as a same measurement of the phenomenon can depend on the unit chosen.

These difficulties are partially minimized when a sufficiently fine zoning is used and these are then converted in geographical coordinate pairs, generally referred to areas’ centroids, that become point elements. This allow studying for instance the density of a phenomenon using homogeneous grouping methods or transforming the point dataset into a ‘density surface’ as in the kernel density analyses[[2]](#footnote-3). Still another issue, not yet completely tackled, lies in the multivariate nature of population data, that, other than being characterised by their geographical locations, consist also on qualitative and quantitative attributes, these including the ethnic group, gender, age, origin, therefore becoming also sometimes difficult to manage and analyze.

4 The spatial distribution of migrant population in Trieste

4.1 The data and the study area

The indices described above have been tested on the Municipality of Trieste as a study area on a selected set of ethnic groups, considering 2005 data referred to those people registered as residents in the city. The applications considered the more traditional, aspatial indices and the spatial ones, as well as the density based methods applied for the analysis of the distribution of the phenomenonand for incorporating other indices to portray spatially some of the characteristics of migration, as clustering, tendency to segregation and diversity.

Some considerations on the overall characteristics of migrants in the area however need to be done before the quantitative analysis by means of the indices examined.

The immigrant population as a whole, thus not considering residents coming from advanced developed countries seems to present elements of uniformity when observed as a scatter plot at address point level over the municipality of Trieste, however presenting a preference for central areas. A unique pattern of the spatial distribution of population however cannot be highlighted, and the analysis of single ethnic groups can reveal the diversities in the structure of the resident population.

People coming from countries once belonging to former Yugoslavian were quite relevant in the past in shaping the population distribution of the city tend to concentrate historically in densely populated and ethnically diversified sub-areas of the city, not properly ‘central’ but located around the city centre. This trend of concentration of foreign groups into properly urban and central areas of a city was observed in different national contexts, given the higher attraction played by the city for new immigrants, in terms of job opportunities and housing market [8]. In the case of Trieste it is however necessary to separate the analysis on migration at different levels. On one side the migrants from highly developed countries tend to distribute in residential areas as the local one; on another side migrants from former Yugoslavia form a ‘backbone’ of the city itself, with migrations dating back from the 19th Century on, while a third group can be identified in the ‘new ethnic groups’ that characterize the city with higher numbers, although still low if compared to other historical groups,particularly in the last few years. These latter two groups tend to concentrate in the proper urban districts of the city[[3]](#footnote-4).

In the present analysis a selection of ethnic groups has been done, these including those groups of more recent migration in the history of the city itself. These are therefore the Albanian, the Chinese, the Romanian and the Senegalese ones. Their immigration in larger figures dates back in the recent past, and particularly for the extra-Europe groups, as Chinese and Senegalese ones, the tendency to concentration is more evident from previous research [25] [26].

4.2 Segregation Index

One of the first analyses carried on is therefore focused on the segregation index (*SI*), derived from *D* seen before, applied to the above mentioned ethnic groups. In this first version the index was computed using data aggregated by the census blocks of the Municipality of Trieste, considering a selection of the 929 blocks in the Municipality (Fig. 1)[[4]](#footnote-5). Such areas are among the smallest one in a zoning system at Municipality level. The index is not mapped as it derives from a sum of the values obtained for the single census blocks and allows a first exam on the segregation.



**Fig. 1.** Spatial distribution of population in the Municipality of Trieste. The map displays census blocks (gray boundary areas) and residents’ locations as address-point (black dots)

The results are portrayed in Fig. 2a. A general trend of high clustering of the different ethnic groups considered can be noticed, with particular reference to the extra-European groups as Chinese and Senegalese.

The index was also calculated aggregating data at municipal district level rather than using census blocks. As the district zoning system provides bigger areas, this caused a dramatic decrease in values of the segregation index as expected after the consideration drawn before. However, the Chinese group still maintains higher figures if compared to the other ones (Fig. 2b)

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| *a)* | *b)* |

**Fig. 2.** ‘Traditional’ Segregation Index calculated using census blocks (*a*) and urban districts (*b*) zoning systems for the Municipality of Trieste. Note that changing the scale and using wider administrative units (urban districts) the index decreases remarkably with reference to all the ethnic groups

4.3 Location Quotients

Location Quotients were also computed for the selected ethnic groups in order to provide a cartographic visualization of the phenomena of concentration or diffusion. Also in this case the quotient was computed using census blocks. Albanian and Romanian nationals are quite sparse over the urban area (Fig. 3a and c), with several census blocks were the location quotient is considerably higher than 2, therefore denoting a high level of concentration. On the contrary, both Chinese and Senegalese groups are more clustered in some parts of the central city blocks, covering approximately neighbouring and non-completely overlapping areas. An area characterized by high concentration of these two groups is the one close to the railway station and a part of the city centre characterized by a lower density of resident population and by economic activities carried on in daytime (CBD). For these two groups in any case the preferred areas are those close to the railway station and the city centre, as well as those close to the main access routes to these areas [25] [26].

The results obtained by the application of the Location Quotient to the different subgroups can be also confirmed by means of the Kernel Density Estimation.

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| --- | --- |
| *LQ_albania**a)* | *LQ_cina**b)* |
| *LQ_romania**c)* | *LQ_SENEGAL**d)* |

**Fig. 3.** Location Quotient computed on census blocks for different ethnic groups. Index computed for immigrant residents from Albania (*a*), China (*b*), Romania (*c*) and Senegal (*d*). Note that Chinese and Senegalese residents present a more clustered pattern of the index

4.4 Kernel Density Estimation

This method was applied to the different events’ distributions characterized by the spatial distribution of the four ethnic groups starting from their address-point locations (Fig. 4). The three-dimensional surfaces obtained allow confirming and better visualizing the information obtained with the location quotient. With particular reference to the locations of Chinese and Senegalese groups (Fig. 4b and d) it is possible to notice their clustering in different parts of the city and an almost overlapping area in one of the peaks in the two distributions, corresponding to the less populated central area of the city[[5]](#footnote-6).

Quartic Kernel Density Estimations have been performed using a 300-m bandwidthand 50-m cell size[[6]](#footnote-7).The other two national groups are more dispersed over the Municipal territory, presenting therefore lower values in terms of intensity in the area of their higher presence.

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| --- | --- |
| KDE_ALBANIAa) | KDE_CINAb) |
| KDE_ROMc) | KDE_SENd) |

**Fig. 4.**Kernel Density Estimation calculated for four selected national groups in the Municipality of Trieste: Albanese (*a*), Chinese (*b*), Romanian (*c*) and Senegalese (*d*). The function used is quartic with a 300-m bandwidth and a 50-m cell size and the resultsare expressed as probability density distributions. Map scale in meters

* 1. The *S* index of segregation

The index of segregation S was then again following O’ Sullivan and Wong [11] procedure, consisting on using a quartic Kernel Density Estimation over the study region with different bandwidths and summing the values obtained at grid cell size level. The index obtained is less dependent on the zoning system chosen, as it is based on aggregated values from uniform 50-m grid cells used as sampling locations. A difference with O’ Sullivan and Wong method is given by the data chosen for the analysis, as here the Kernel Density Estimation for the different ethnic groups was performed over data available at address-point level rather than on census blocks[[7]](#footnote-8). Table 1 shows the results obtained for the index *S* using different bandwidths.

**Table 1.** Segregation values measured in the Trieste Municipality for different ethnic groups. Note the different decreasing values of the index for different groups as bandwidth increases

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| --- | --- |
| Kernel Bandwidth (m) | Segregation, *S* |
| Albania | China | Romania | Senegal |
| 150 | 0.757 | 0.868 | 0.774 | 0.814 |
| 300 | 0.641 | 0.803 | 0.625 | 0.815 |
| 450 | 0.583 | 0.771 | 0.548 | 0.766 |
| 600 | 0.546 | 0.744 | 0.495 | 0.729 |
| 900 | 0.502 | 0.731 | 0.438 | 0.731 |

One element to be noticed is the starting values of the 150-m bandwidth, not dissimilar to those already observed in Fig. 2, ranking very similarly the four groups to each other. It can be also noticed that values decrease as the bandwidth is incremented, not an unexpected results as we already pointed out the higher distance tend to dilute the data into wider areas, similarly to what observed in the ‘traditional’ segregation index (Fig. 5).



**Fig. 5.**Variation of the Segregation values measured in the Municipality of Trieste for different ethnic groups as bandwidth increases

However, interestingly decay functions characterize the different groups, with Chinese and Senegalese presenting the higher initial values and with a smooth decrease of the index as the bandwidth increases, while both Albanian and Romanian present a sharper decrease in the index when bandwidth increase.This says something more about the characteristics of settling of the different nationals, with a higher possible mix for the European nationals considered here if compared to the Asian and African ones.

The computation of index *S* gives also the opportunity to produce intermediate maps, providing a disaggregated view of the local contribution of each cell of the grid covering the area to the overall segregation. Maps in Fig. 6 present the numerator of equation 4, showing maximum minus minimum probability density values for each location between Italians and the four other national groups analyzed in this paper. Darker areas are those with higher concentrations of immigrants from the different countries and these areas highly contribute to the overall segregation, while light-color regions are those more prone to showing a higher level of ethnic mix.

|  |  |
| --- | --- |
| ita_alb_max_mina) | ita_cina_max_minb) |
| ita_rom_max_minc) | ita_sen_max_mind) |

**Fig. 6.**Maps of maximum population proportions minus minimum population proportions for the four ethnic group considered in the Municipality of Trieste. Maps are derived from data as in Fig. 4 and the density analysis performed over Italian nationals (not portrayed in a map here) and present respectively the difference maps for Albanian (*a*), Chinese (*b*), Romanian (*c*) and Senegalese (*d*)groups. Dark areas are those that most contribute to the overall segregation white lighter ones can be interpreted as those presenting a higher population mix. Map scale in meters

4.6 The Index of Diversity

The last index implemented is the IDiv to test and represent synthetically some of the differences and characteristics of the immigration phenomenon as a whole and, instead of measuring the elements of separation it considers those potentially representing union and cohabitation as the cultural and ethnic mix. The index here is not limited to the four ethnic groups analyzed, but considers the overall foreign residents in the Municipality of Trieste, counting both the number of countries represented and the number of residents for each country. Fig. 7 portrays the results for the index of diversity computed over the data, according to equation 5, aggregated at census block level.

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| --- | --- |
| *kde_idiv_2nn_**a)* | *kde_idiv_5nn_**b)* |

**Fig. 7.** Maps of the Index of Diversity (*IDiv*) computed over the immigrant groups in the Municipality of Trieste. The index highlight dark areas with high number of countries represented and high presence of migrant population, while lighter ones have less countries and a lower number of foreign national as well. Map scale in meters

Two different bandwidths were analyzed, using nearest neighbor index over census blocks’ centroids to determine the different orders of medium average distance of blocks. A 177-bandwidth, corresponding to grade *k* = 2 (Fig. 7a) and a 281-m one, referred to *k* = 5 (Fig. 7b) were experimented to see the ethnic mixing at two different scales. It is interesting to notice the high value of the index in areas where some of the groups tend to cluster. This is also the more populated area, and the index helps in highlighting also a population diversity in terms of ethnic groups represented, therefore limiting some of the possible suspects of true segregation. Furthermore it can be noticed that also other areas where segregation values for some ethnic groups are high, still present some mix that, given the lower number of population living in it, can still be attributed to a noticeable presence of different ethnic groups in the area.

5 Conclusions and discussion

In this paper a summary of some of the most used indices for measuring segregation or diversity in the distribution of migrant groups at urban level have been proposed, considering in particular the spatial aspects of such indices and the need to examine more in depth the articulated structure and characteristics of the population. Some problems still need to be addressed. On one side limitations can be noticed in the availability of disaggregated data, as individual nationals from different countries are often aggregated according to some zoning system that can affect the results from further analyses. However, if the zoning system produces sufficiently small areas some analytical methods reduce such problem. With reference to the indices used, an issue is still concerned with the choice of the bandwidth or distances of observation, although efforts in this direction are under exam [11] [25]. Other issues concern the multi-group analysis, therefore not limiting this to two subgroups but to the overall variety of countries represented in a given study region.Furthermore, qualitative, multivariate attribute of population data should be considered. There is also the need to explore the opportunity to develop and implement entropy-based diversity indices, as well as to examining the relations between economic activities, residential locations and segregation [25] [31] [32] as emerging migration issues to analyse [33] [34].As a partial conclusion concerning the use of quantitative methods, and particularly those based on density or those based on a choice of distances, it is worth noting that these must be refined and that not ‘easy’ solutions of the problem at stake can be found, nevertheless they provide a good starting point for more in depth and local analysis by the researchers, that can focus their attention over a micro scale of analysis, going further than the administrative divisions of space and reducing the minimum distance of observation to examine locally the dynamics at urban scale.

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1. Few applications of segregation indices have been done to Italian cases, particularly referred to the cities of Turin, Genoa and Milan [6], Parma, Reggio Emilia [7] and Piacenza [8] and more recently to Rome [5] and Trieste [9]. These two latter cases propose also a disaggregated analysis of segregation at urban level. [↑](#footnote-ref-2)
2. However, in previous analysis on spatial distribution of population, very little difference on the overall pattern drawn by a Kernel Density Estimation was notices between applications on point data based on address-points and those considering census blocks’ centroids [26]. [↑](#footnote-ref-3)
3. This is confirmed by the slightly higher value of the percentage of immigrant residents in the urban districts than those registered in the Municipality as a whole. Urban districts present a 5.28 % and the Municipality displays a 5.06 % value (2005 data). [↑](#footnote-ref-4)
4. Census data were also available at street-number level and will be seen particularly in the *S* index and standard KDE computation for single ethnic groups. [↑](#footnote-ref-5)
5. It has been often suggested to test different bandwidths according to the data distribution, particularly on the size of the study area or the number of points, and according to a researcher’s aim and scale of observation [22].Recently some authors [30]tested a k-nearest neighbor approach, with the bandwidth related to the mean nearest neighbor distance for different orders of k. [↑](#footnote-ref-6)
6. With reference to the choice of the grid,generally a resolution substantially smaller than the bandwidth by a factor of 5 or more and minimally by a factor of 2 has little effect on the density estimate [11] [↑](#footnote-ref-7)
7. For the Municipality of Trieste the differences in the three-dimensional surfaces obtained from the two different spatial elements were minimal. On bandwidth’s choice, O’Sullivan and Wong [11] propose calculating the average nearest neighbour distances between census blocks. [↑](#footnote-ref-8)