

Demography and Urban Form: Understanding Latent Dynamics of Population Density in Italy

Gianluigi Salvucci¹, Ilaria Zambon² and Luca Salvati³

¹Italian National Institute of Statistics, Via C. Balbo 16, I-00185 Rome (Italy);
Email: gianluigi.salvucci@istat.it

² University of Tuscia, Department DAFNE, Via S. Camillo De Lellis snc, I-01100 Viterbo (Italy);
Email: ilaria.zambon@unitus.it

³ Council for Agricultural Research and Economics (CREA), Viale S. Margherita 80, I-52100 Arezzo (Italy);
Email: luca.salvati@crea.gov.it

ABSTRACT

Population density is a key variable assessing the relationship between a given area and its population. By partitioning any study area into small units (e.g. administrative regions, municipalities, functional districts), population density is a simple indicator that can be derived from the surface area and the absolute size of resident population. However, density estimation was sometimes carried out in a rough way, especially when comparing very large areas. Density is usually calculated as the ratio of population living in a given area based on administrative limits. An exercise proposing alternative calculation methodologies is illustrated here considering census data on resident population in the major urban contexts of Italy. The empirical results of this study indicate the key role of density indicators that consider increasingly concise and true 'urban boundaries' replacing administrative boundaries and reducing statistical errors and spatial misunderstandings. A reflection on the use of improved and dedicated approaches to a more precise estimation of population density over specific administrative domains is fundamental to demographic analysis and urban studies.

Keywords: demography; urban development; statistical data; Italy.

Mathematics Subject Classification: 91B76, 92A17

Journal of Economic Literature (JEL) classification: Q01, Q10, Q32, Q54, Q56, Q58.

1. INTRODUCTION

Analysis of spatial distribution of resident population is common to many disciplines, having complications that are mainly known with demographers, geographers or regional scientists (Duncan, 1957; Salvati et al., 2013, 2019). A step beyond the simple list or cartographic representation of absolute numbers of population by geographic sub-divisions is the calculation of the ratio of population residing in a given surface area. The latter indicator is known as population density and was commonly used as a primary indicator to identify urban areas and qualify their growth over time (Tanguay et al., 2010; Salvati et al., 2013; Cooke and Behrens, 2017; Li et al., 2017).

While some researchers, such as Ullman (1941), interpreted the "Christaller model" as the territorial transposition of a hierarchical model based on population density, one of the most representative

examples was provided by Clark (1951). The relationship between population density and the distance from the inner city was analyzed assuming that population density is one of the most effective indicators of urban development (Biasi et al., 2015; Colantoni et al., 2016; Cecchini et al., 2018). Although this rationale is theoretically correct, there are several difficulties when applying this framework to municipalities with different size and form (Berry, 1964; Antrop, 2000; Liu et al., 2008).

In this regard, population density sometimes provides a biased view of the urban development of a given region (Krehl et al., 2016; Guo et al., 2017; Crols et al., 2017). As a matter of fact, by dividing the study area into small units (e.g. administrative regions, municipalities, functional districts), a simple indicator of population density can be derived from two basic information: surface area and population size. Generally speaking, density implies a logical linkage between numerator and denominator indicating that, for the same surface area, a city has more inhabitants than the others.

Use of gross population density depends on municipal size and urban form, which may provide a biased estimation of population concentration in metropolitan areas (Ceccarelli et al., 2014; Colantoni et al., 2013, 2016; Mariani et al., 2018). At country scale, higher values of population density may derive from a smaller spatial partition. To have a better assessment of this assumption, a possible strategy is to consider weighted averages of density values measured for the populations involved (Abbate and Salvucci, 2012).

2. DATA AND RESULTS

The concept of population density is the starting point for exploring the relationship between a given area and its population. The present study provides a practical exercise derived from a quantitative analysis of population data from the national census of population and household held by Istat (Italian National Statistical Institute) in Italy. In detail, each city in Italy was classified according to surface area (km²), number of inhabitants and density (inhabitants/km²), resulting from the ISTAT database (2001). The first 10 Italian cities were ranked according to their population density (Table 1) and the absolute number of resident inhabitants (Table 2).

Table 1. Italian cities rank by population density.

Rank	City	Surface area (km ²)	Population	Density
1	Naples	117.27	1,004,500	8,565.70
2	Milan	182.07	1,256,211	6,899.60
3	Turin	130.17	865,263	6,647.17
4	Palermo	158.88	686,722	4,322.26
5	Monza	33.02	120,204	3,640.33
6	Florence	102.41	356,118	3,477.37
7	Pescara	33.62	116,286	3,458.83
8	Grugliasco	13.12	38,725	2,951.60
9	Bergamo	39.6	113,143	2,857.14
10	Bari	116.2	316,532	2,724.02

In Italy, Rome is known as the largest populated city and Milan is more important as far as the density of activities is concerned. However, Table 1 highlights that Rome does not rank among the top 10 positions. These findings could be interpreted as Grugliasco, a municipality close to Turin (Northern

Italy), is more important than Rome from a demographic point of view. Conversely, this result simply reflects the formulation of the density index and role of the variables that constitute it.

Table 2. Italian cities rank by population size.

Rank	City	Surface area (km ²)	Population	Density
1	Rome	1285.3	2,546,804	1,981.49
2	Milan	182.07	1,256,211	6,899.60
3	Naples	117.27	1,004,500	8,565.70
4	Turin	130.17	865,263	6,647.18
5	Palermo	158.88	686,722	4,322.27
6	Genova	243.60	610,307	2,505.37
7	Bologna	140.73	371,217	2,637.80
8	Florence	102.41	356,118	3,477.38
9	Bari	116.2	316,532	2,724.03
10	Catania	180.88	313,110	1,731.04

Considering population size (Table 2), Rome results more important with its 2.5 million of inhabitants than Grugliasco (with just 38,000 inhabitants). Considering larger cities, Cagliari and Brescia emerged with values of 1,920 inhabitants/km² and 2,068 inhabitants/km² respectively. The relationship between municipal surface area and inhabitants in Italy was shown in **Error! Not a valid bookmark self-reference.**, displaying a very low goodness of fit (adjusted R²).

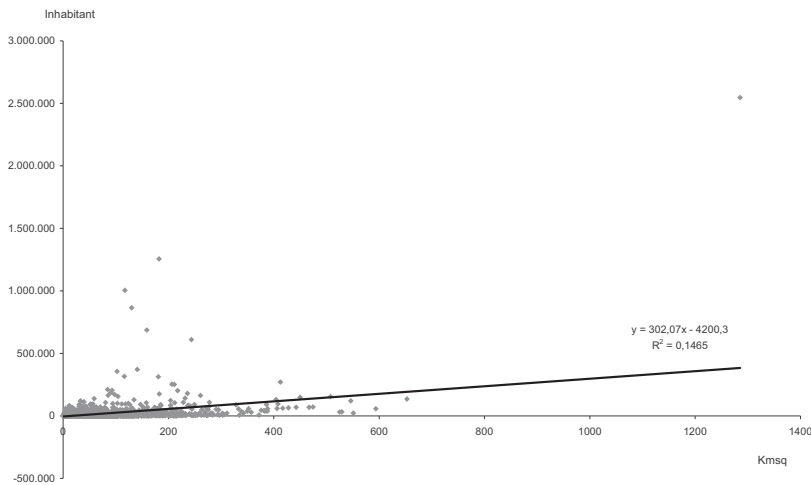


Figure 1. Relationship between population size (vertical axis) and population density (horizontal axis) in Italy (city level data).

Population density can be representative of the demographic and economic role of cities, controlling for the variance of urban areas, and considering low-resolution data, e.g. spatial domains such as districts/municipalities/functional areas. Considering results of a correlation analysis (Figure 2), a lowest variability of population moving from smaller domains (e.g. municipalities) to larger domains (e.g. regions or provinces) allows a higher representativeness of results from density analysis for different population sizes (Tables 3 and 4).

Table 3. Italian province rank by population density.

Rank	City	Surface area (km ²)	Population	Density
1	Naples	1,171.13	3,082,091	2,631.72
2	Milan	1,984.39	3,741,069	1,885.25
3	Trieste	211.82	242,598	1,145.30
4	Rome	5,351.81	3,783,193	706.90
5	Varese	1,198.71	814,411	679.41
6	Prato	365.26	229,776	629.08
7	Rimini	533.82	280,166	524.83
8	Genova	1,838.47	883,652	480.65
9	Como	1,288.07	537,737	417.47
10	Padua	2,141.59	867,608	405.12

Table 4. Italian province rank by population size.

Rank	City	Surface area (km ²)	Population	Density
1	Rome	5,351.81	3,783,193	706.90
2	Milan	1,984.39	3,741,069	1,885.25
3	Naples	1,171.13	3,082,091	2,631.72
4	Turin	6,830.25	2,172,518	318.07
5	Bari	5,138.3	1,551,333	301.92
6	Palermo	4,992.23	1,241,904	248.77
7	Brescia	4,784.36	1,115,376	233.13
8	Salerno	4,917.47	1,062,643	216.10
9	Catania	3,552.2	1,056,034	297.29
10	Bergamo	2,722.86	973,380	357.48

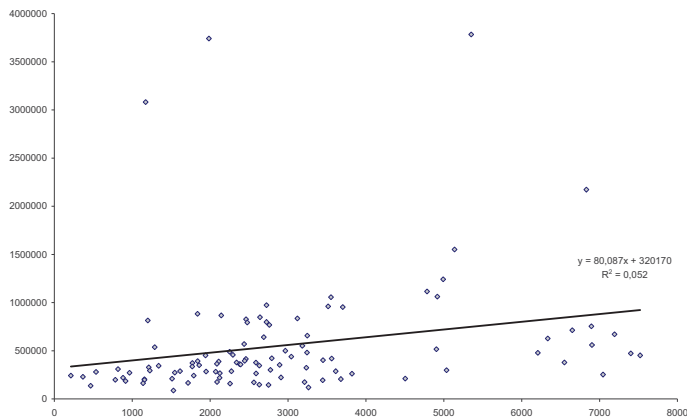


Figure 2. Relationship between population size (vertical axis) and population density (horizontal axis) in Italy (province level data).

3. BUILDING A REPRESENTATIVE INDICATOR OF NET POPULATION DENSITY

Intrinsic definitions of cities all imply the idea of dense urban fabric (Munafò et al., 2013; Morelli et al., 2014). By introducing an explicit analysis of land-use when investigating population density, the purpose of our exercise is to improve calculation of net population density for cities and urban areas. Demographic data at a disaggregated spatial resolution were collected from ISTAT population census referring to census blocks. By overlapping census sections to an updated Corine Land Cover map

provided by Land Copernicus European initiative, the predominant land-use for each census section was obtained aggregating all the areas with the aim to calculate a net indicator of population density by functional, homogeneous landscape matrices (Table 5). While population density in Italy is around 200 inhabitants per km², more than 3,000 people per km² resides on artificial fabric land-use, on average.

Table 5. Spatial distribution of resident population by land-use class.

Rank	City	km ²	Population	Density	Area (%)	Population (%)
1	Artificial fabric	12,262	43,694,310	3,563.5	5	79
2	Cropland	135,575	10,817,936	79.8	60	19
3	Forests	77,715	1,090,776	14.0	35	2

By tabulating the statistical distribution of selected indicators for major Italians cities and land-use, displays a divergent concentration of population residing in different cities, likely according to different land-use distribution. For instance, a strong divergence between Milan and Rome (or Naples) emerged from this analysis.

Table 6. Spatial distribution of population by city and land-use.

City	Area	Population	Density	Artificial Fabric	Population (%)	Agricultural Areas	Population (%)	Forest and semi natural areas	Population (%)	Other	Population (%)
Rome	1052.71	2546804	2,419.28	2390042	93.84%	155904	6.12%	786	0.03%	72	0.00%
Milan	164.52	1256211	7,635.61	1241329	98.82%	14847	1.18%	19	0.00%	16	0.00%
Naples	114.59	1004500	8,766.04	934861	93.07%	58762	5.85%	10877	1.08%	0	0.00%
Turin	124.11	865263	6,971.74	846791	97.87%	13317	1.54%	4621	0.53%	534	0.06%
Palermo	144.87	686722	4,740.26	669076	97.43%	12762	1.86%	4884	0.71%	0	0.00%

Building cost-effective indicators is a critical issue when linking demographic matters and assessment of contemporary landscapes, owing to the choice of different variables and the specific aggregation function – mainly the spatial selection of elementary domains. While gross population density is a simple ratio of two variables (population and surface area), we propose to calculate net population density as weighted mean of population densities under different land-use conditions in each city, in order to take account of local specificities in urban morphology. Considering n land use and population for each city, population density can be calculated as

$$\frac{\sum_{i=1}^n (pop_i p / area_i) \times area_i}{Area}$$

Different functions can be used to calculate this indicator. A representative mean treating high data heterogeneity is the entropy mean. By applying this function, a representative indicator of net population density was prepared (Table 7), providing a better representation of urban hierarchy in Italy. With this approach, Rome ranks as the first city in the Italian urban hierarchy, followed by Milan and Naples, respectively the second and the third cities in Italy as far as population size is concerned.

Table 7. Italian cities rank by net population density.

Rank	City	Area	Population	Density (entropy mean)	Density mean
1	Rome	1052.71	2,546,804.00	5,670.29	2,419.28
2	Milan	164.52	1,256,211.00	9,209.83	7,635.61
3	Naples	114.59	1,004,500.00	10,998.59	8,766.04
4	Turin	124.11	865,263.00	8,666.48	6,971.74
5	Palermo	144.87	686,722.00	7,699.19	4,740.26
6	Genova	213.24	610,307.00	7,205.80	2,862.07
7	Bologna	136.56	371,217.00	5,375.05	2,718.34
8	Florence	91.54	356,118.00	6,277.48	3,890.30
9	Bari	93.71	316,532.00	5,683.98	3,377.78
10	Catania	128.71	313,110.00	5,505.24	2,432.68

4. DISCUSSION AND CONCLUSIONS

Evaluation measures based on arbitrary (gross) population density endure the most generally applied methods to recognize dense or dispersed settlements (Craig, 1987; Hall et al., 2006; Hahs and McDonnell, 2006; Biasi et al., 2015). Population data are widely distributed through official statistics

on a satisfactory detailed spatial scale (Salvati et al., 2016; Zambon et al., 2019). Following Duncan (1957), most studies concerning population density evaluated the spatial variability of resident population over a defined region rather than the overall (or average) density in the whole area.

This contribution (i) provides a paradigmatic example of the bias derived from the elaboration of gross population density at fixed administrative spatial domains and (ii) introduces and discusses a possible solution to overcome this bias. The empirical exercise proposed in this study considering gross population density in Italy (municipal scale) indicates Rome, the Italian capital, as a less dense city than smaller and more concentrated cities. Trying to explain technical difficulties in the calculation of population density across a complex urban system like the Italian case, statistical tools likely overcoming such trouble were introduced and briefly discussed.

Population density by sub-areas can be easily calculated based on available statistical data. Assuming a population living in e.g. a neighborhood, a city or a metropolitan area, it can be divided by the total surface area relative to such settlements, taking account of the dominant land-use in order to correct gross density for the net extension of urban areas. In this way, it is possible to have a representative estimation of net population density, avoiding (or containing) biases derived from the use of arbitrary (and spatially heterogeneous) administrative units.

Whereas our methodology may work well in small areas with small variations in population density, it can lead to less stable outcomes for larger areas. Two basic issues with net population density approaches using average densities by land-use across heterogeneous areas include (i) the unpredictability of the impact of specific administrative boundaries; and (ii) the fact that average population density emphasizes densities at the plot scale. Although cities have legally defined spatial boundaries, the latter are selected by comparing such cities with the respective region or metropolitan area.

To conclude, our approach suggests the following steps: (i) analysis of the statistical distribution of population data, (ii) quantification of absolute values of the investigated variable, (iii) understanding the role of cities in their metropolitan region and then (iv) comparing estimations of gross and net population density derived from different methodologies. The empirical results of this study outline the need to use 'net' density indicators, considering different geographical partitions.

5. REFERENCES

- Abbate C., Salvucci G., 2012, *Analisi della densità abitativa nei quartieri della capitale: da città a bassa densità a quartieri sovrappopolati*, Memorie per il Prof. Spinelli, ISBN 978 88 555 3216-7, Roma.
- Antrop, M., 2000, Changing patterns in the urbanized countryside of Western Europe. *Landscape ecology*, **15**(3), 257-270.
- Berry, B. J., 1964, Cities as systems within systems of cities. *Papers in regional science*, **13**(1), 147-163.
- Biasi, R., Colantoni, A., Ferrara, C., Ranalli, F., Salvati, L., 2015, In-between sprawl and fires: long-term forest expansion and settlement dynamics at the wildland–urban interface in Rome, Italy. *International Journal of Sustainable Development World Ecology*, **22**(6), 467-475.

- Ceccarelli, T., Bajocco, S., Luigi Perini, L., Luca Salvati, L., 2014, Urbanisation and land take of high-quality agricultural soils-exploring long-term land use changes and land capability in Northern Italy. *International Journal of Environmental Research*, **8**(1), 181-192.
- Cecchini, M., Zambon, I., Pontrandolfi, A., Turco, R., Colantoni, A., Mavrakakis, A., Salvati, L. 2018, Urban sprawl and the 'olive'landscape: Sustainable land management for 'crisis' cities. *GeoJournal*, 1-19.
- Clark C., 1951, Urban population densities, *Journal of the Royal Statistical Society Series A (general)*, 490-496.
- Colantoni, A., Recanatani, F., Baldini, S., Felicetti, M., Romagnoli, M. 2013, Decision analysis for the determination of biomass in the territory Tuscia Romana by geographic information system and forest management plans. *Journal of Agricultural Engineering*, **44**(2s).
- Colantoni, A., Grigoriadis, E., Sateriano, A., Venanzoni, G., Salvati, L., 2016, Cities as selective land predators? A lesson on urban growth, deregulated planning and sprawl containment. *Science of the Total Environment*, **545**, 329-339.
- Cooke, S., Behrens, R., 2017, Correlation or cause? The limitations of population density as an indicator for public transport viability in the context of a rapidly growing developing city. *Transportation research procedia*, **25**, 3003-3016.
- Craig, J., 1987, An urban-rural categorisation for wards and local authorities. *Population Trends*, **47**, 6-11.
- Croels, T., Vanderhaegen, S., Canters, F., Engelen, G., Poelmans, L., Uljee, I., White, R., 2017, DOWDATING high-resolution population density maps using sealed surface cover time series. *Landscape and Urban Planning*, **160**, 96-106.
- Duncan, O. D. 1957, The measurement of population distribution. *Population Studies*, **11**(1), 27-45.
- Guo, C., Schwarz, N., Buchmann, C. M., 2017, Exploring the added value of population distribution indicators for studies of European urban form. *Applied spatial analysis and policy*, 1-25.
- Hahs, A. K., McDonnell, M. J., 2006, Selecting independent measures to quantify Melbourne's urban-rural gradient. *Landscape and urban planning*, **78**(4), 435-448.
- Hall, S. A., Kaufman, J. S., Ricketts, T. C., 2006, Defining urban and rural areas in US epidemiologic studies. *Journal of urban health*, **83**(2), 162-175.
- Hoover E., 1948, *The location of Economic Activity*, New York, Mc Graw Hill.
- Krehl, A., Siedentop, S., Taubenböck, H., Wurm, M., 2016, A comprehensive view on urban spatial structure: Urban density patterns of German city regions. *ISPRS International Journal of Geo-Information*, **5**(6), 76.
- Li, J., Fang, W., Wang, T., Qureshi, S., Alatalo, J., Bai, Y., 2017, Correlations between socioeconomic drivers and indicators of urban expansion: Evidence from the heavily urbanised shanghai metropolitan area, China. *Sustainability*, **9**(7), 1199.
- Liu, X. H., Kyriakidis, P. C., Goodchild, M. F., 2008, Population-density estimation using regression and area-to-point residual kriging. *International Journal of geographical information science*, **22**(4), 431-447.
- Marchetti, M., Vizzarri, M., Lasserre, B., Sallustio, L., Tavone, A., 2014, Natural capital and bioeconomy: challenges and opportunities for forestry. *Annals of Silvicultural Research*, **38**(2), 62-73.
- Mariani, F., Zambon, I., Salvati, L., 2018, Population Matters: Identifying Metropolitan Sub-Centers from Diachronic Density-Distance Curves, 1960–2010. *Sustainability*, **10**(12), 4653.
- Morelli, V. G., Rontos, K., Salvati, L., 2014, Between suburbanisation and re-urbanisation: Revisiting the urban life cycle in a Mediterranean compact city. *Urban Research Practice*, **7**(1), 74-88.
- Munafò, M., Salvati, L., Zitti, M., 2013, Estimating soil sealing rate at national level—Italy as a case study. *Ecological indicators*, **26**, 137-140.
- Salvati, L., Carlucci, M., Serra, P., Zambon, I., 2019, Demographic Transitions and Socioeconomic Development in Italy, 1862–2009: A Brief Overview. *Sustainability*, **11**(1), 242.

Salvati, L., Gemmiti, R., Perini, L., 2012, Land degradation in Mediterranean urban areas: an unexplored link with planning? *Area*, **44**(3), 317-325.

Salvati, L., Morelli, V. G., Rontos, K., Sabbi, A., 2013, Latent exurban development: City expansion along the rural-to-urban gradient in growing and declining regions of southern Europe. *Urban Geography*, **34**(3), 376-394.

Salvati, L., Sateriano, A., Rontos, K., 2016, Towards an indicator of urban centrality? Exploring changes in present and resident population (1991–2011) in Greece. *Ecological indicators*, **61**, 188-192.

Tanguay, G. A., Rajaonson, J., Lefebvre, J. F., Lanoie, P., 2010, Measuring the sustainability of cities: An analysis of the use of local indicators. *Ecological Indicators*, **10**(2), 407-418.

Ullmann E., 1941, A theory of location for cities, *American Journal of Sociology*, 853-865.

Zambon, I., Rontos, K., Serra, P., Colantoni, A., Salvati, L., 2019, Population Dynamics in Southern Europe: A Local-Scale Analysis, 1961–2011. *Sustainability*, **11**(1), 109.