Funnel plots and choropleth maps in cancer risk communication: a comparison of tools for disseminating population-based incidence data to stakeholders

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To cite: Mazzucco W, Cusimano R, Zarcone M, et al. Funnel plots and choropleth maps in cancer risk communication: a comparison of tools for disseminating population-based incidence data to stakeholders. BMJ Open 2017;7:e011502. doi:10.1136/bmjopen-2016-011502

ABSTRACT

Background: Population-based cancer registries provide epidemiological cancer information, but the indicators are often too complex to be interpreted by local authorities and communities, due to numeracy and literacy limitations. The aim of this paper is to compare the commonly used visual formats to funnel plots to enable local public health authorities and communities to access valid and understandable cancer incidence data obtained at the municipal level.

Methods: A funnel plot representation of standardised incidence ratio (SIR) was generated for the 82 municipalities of the Palermo Province with the 2003–2011 data from the Palermo Province Cancer Registry (Sicily, Italy). The properties of the funnel plot and choropleth map methodologies were compared within the context of disseminating epidemiological data to stakeholders.

Results: The SIRs of all the municipalities remained within the control limits, except for Palermo city area (SIR=1.12), which was sited outside the upper control limit line of 99.8%. The Palermo Province SIRs funnel plot representation was congruent with the choropleth map generated from the same data, but the former resulted more informative as shown by the comparisons of the weaknesses and strengths of the 2 visual formats.

Conclusions: Funnel plot should be used as a complementary valuable tool to communicate epidemiological data of cancer registries to communities and local authorities, visually conveying an efficient and simple way to interpret cancer incidence data.

BACKGROUND

Cancer is the second major cause of death in the developed countries.1 In the past few decades, the increasing burden of disease has caused major concerns in local communities, requiring local health authorities to develop risk communication plans that address cancer incidence, survival and the potential impact of environmental exposure.3 Apart from the presumed effects of lifestyle changes and environmental factors on cancer trends,3–6 the global increase in cancer prevalence could be largely attributable to a combination of improved cancer survival7 and ageing population.8 Local communities possess a variable degree of literacy and numeracy, which, in turn, influence their understanding of such demographical and epidemiological concepts.9, 10 Local public health and political authorities regularly engage in finding better ways to satisfy the growing demand for information on the
impact of cancer by the general public.\textsuperscript{11} In particular, citizens often question if they live in an area at high risk for environmental exposure.\textsuperscript{2}

The Centers for Diseases Control and Prevention (CDC) define public health surveillance as the “Ongoing, systematic collection, analysis, interpretation, and dissemination of data regarding a health-related event for use in public health action to reduce morbidity and mortality and to improve health.”\textsuperscript{12} Population-based cancer registries (PBCRs) carry out cancer surveillance by continuously collecting and classifying information on all new cancer cases within a defined population, and providing statistics on its occurrence for the purpose of assessing and controlling the impact of this disease on the community.\textsuperscript{13} The mission of PBCRs includes the translation and dissemination of evidences to enable informed decision-making and to empower the general population or other stakeholders, while preserving a rigorous methodological approach and facilitating a truthful interpretation of the data obtained. PBCR publications use validated and internationally shared measurement systems and employ terminology and visual formats that are easily understood by the scientific community, but often difficult to interpret for other stakeholders, particularly at the local level.\textsuperscript{14, 15}

The most commonly used format for reporting geographic comparisons of cancer epidemiological data is an atlas, which includes thematic maps, such as choropleth maps (CMs), representing cancer incidence rates (standardised rates, standardised ratios, etc) computed for specific areas.\textsuperscript{16, 17}

While data are available on how the context\textsuperscript{18} and the content of such communications influence individual risk perception,\textsuperscript{19} little is known about the effects of risk communications at a group level, particularly in small communities.\textsuperscript{20}

The Italian Association of Cancer Registries (AIRTum), a national network of 41 local PBCRs, including the Palermo Province Cancer Registry (PPCR), has greatly emphasised improving communication tools.\textsuperscript{21}

The aim of this paper is to propose the use of funnel plots (FPs) for reporting local cancer incidence data, as a complement to the more common visual formats employed by the PPCR to address local public health authorities and communities, in order to facilitate the dissemination and interpretation of measures of cancer statistics at the municipal level.

**METHODS**

The study population consists of the 51,951 new cancer cases, excluding non-melanoma skin cancers, registered between 2003 and 2011 by the PPCR among the 1244,289 residents of the 82 municipalities of the Palermo Province (PP; 679,850 inhabitants within the Palermo metropolitan area only).\textsuperscript{22} Cancer incidence in the PP municipalities was measured by using standardised incidence ratio (SIR), defined as the ratio between observed cases (Oi) and expected cases (Ei).\textsuperscript{23} The Oi were assumed to follow a homogeneous Poisson distribution with parameter \(\lambda=O_iE_i\). The Ei were estimated by indirect method,\textsuperscript{24} considering the entire population time under study (the PP) as the reference population, with \(\Sigma O_i=\Sigma E_i\).\textsuperscript{25} The resident population was reported using the intercensus estimates, provided by the Italian National Statistical Institute (ISTAT), also considering the annual municipal data on migration.\textsuperscript{22} For each SIR, the 95\% CI was calculated by using the normal approximation method.\textsuperscript{26}

Graphic FP representation\textsuperscript{26} was used to highlight any municipality with a higher cancer incidence compared with the reference population (entire PP population). The following elements were included to generate the FP (figure 1A): the SIRs of the 82 municipalities, on the y-axis; the target line (\(\theta_0=1\)), represented on the x-axis; the 95\% and 99.8\% CIs, calculated with the normal approximation method, defining the control limits.\textsuperscript{26} The two sets of control limit lines define three different areas within the graph (figure 1B): the ‘undercontrol’ area (in green), the ‘warning’ area (in yellow) and the ‘alert’ area (in red).\textsuperscript{27}

As the data distribution was not congruent with the underlying assumption (variance equal to the expected value), in order to check for any potential overdispersion\textsuperscript{28} both additive and multiplicative approaches were adopted. Overdispersion coefficients (\(\tau\) for the additive approach and \(\phi\) for the multiplicative approach) were calculated. Overdispersion was addressed by considering the winsorised estimates too.\textsuperscript{29} Moreover, Z-score,\textsuperscript{29} and the winsorisation method (by testing for different levels of Z-score quantiles\textsuperscript{28}) were applied for the direct selection of extreme values. Furthermore, to define the level of winsorisation, an R-script routine was developed to set a cut-off for the quantile between the acceptance and rejection of the overdispersion test (see online supplementary material).

The map representing the PP municipalities was generated by using the ISTAT Shapefile vector format,\textsuperscript{30} released in the ED50 (European Datum - 1950) UTM Zone 32N reference system, and converted in plane coordinates (decimal degrees), providing georeferenced data in addition to the coordinates of geographic objects and their borders (for polygons), also including the information on the location of each municipality. Although traditional geographical analyses use the centroids as geostatistical units, considering that some centroid could fall outside the municipal bounds, the coordinates of the city hall were used instead.\textsuperscript{31}

The PP cancer incidence variation was also shown in a CM,\textsuperscript{32} representing the SIRs of each municipality. To distinguish potential high-risk and low-risk areas, a central interval of 0.95–1.05 for the colour scale was fixed, irrespective of statistical significance. Values above 1.05 and below 0.95 were divided in tertiles.\textsuperscript{33}
Cluster analysis was performed by using the scan statistics obtained with Openshaw’s Geographical Analysis Machine (GAM), with varying radiuses, in order to detect potentials high-risk clusters and hot spot locations, setting the p value at 0.002. The analysis for hot spot research was performed using circles with a 3 km radius for each point of a grid, covering the study region by steps of 600 m (radius/5). The RStudio IDE (RStudio Team. RStudio: Integrated Development for R. 2015. http://www.rstudio.com/ (accessed 18 Jan 2016)) for the R software, V.3.1.0 (2014-04-10)—‘Spring Dance’ (R Core Team. R: A language and environment for statistical computing 2015. http://www.R-project.org/ (accessed 18 Jan 2016)), was used to perform statistical analysis.

Finally, the weaknesses and strengths of the FP and CM methodological approaches were compared using the available literature as reference.29 33 35 36

**Figure 1** (A) Funnel plot of the SIRs in the 82 Palermo Province municipalities (study period 2003–2011); (B) cancer attention areas: ‘undercontrol’ area (in green), ‘warning’ area (in yellow) and ‘alert’ area (in red). Ninety-five per cent CIs (‘blue’ control lines) and 99.8% CIs (‘red’ control lines); φ=overdispersion, calculated with multiplicative approach. SIR, standardised incidence ratio.
RESULTS

Figure 1A represents the FP of 82 municipality-specific SIRs, corrected for overdispersion (\(\phi=13.46\)) and adjusted using the multiplicative approach. All of the SIRs lay within the control limits, except for the Palermo city 1 (SIR=1.12), which resulted above the upper control limit line of 99.8%. Figure 1B identifies the three different cancer risk areas within the graph.

Overdispersion test results were concordant and the routine did not find out any valid value for winsorisation (see online supplementary material, section B).

Figure 2 displays the CM for cancer incidence in the 82 PP municipalities, generated by using the SIRs. The map highlights three different municipality areas (ISTAT code: 082042, 082053 and 082061; see table 1) with SIRs higher than 1.05.

Table 1 represents the expected cases (both men and women) and SIRs with 95% CIs in the 82 PP municipalities: most of the SIRs are lower than 1 and only six municipalities present SIRs higher than 1. Among them only Palermo had a statistically significant value higher than 1 (SIR=1.12; 95% CIs 1.11 to 1.14) while Isnello, the municipality showing the highest SIR, failed to meet the conventional criteria for statistical significance (SIR=1.22; 95% CI 0.99 to 1.45).

No clusters were identified by the GAM approach, while a hot spot corresponding to Palermo city was highlighted (figure 3).

Table 2 summarises a comparison of the weaknesses and strengths, as per the available literature, between the different visual formats explored within the context of disseminating epidemiological data to stakeholders.

As shown in the table 2, in terms of strengths, FP differed from CM in its ability to disseminate epidemiological data to stakeholders, in particular in the capability to show the scope of the phenomenon under investigation and the precision of estimates, and to highlight the significance of the estimates. On the other hand, CM, unlike FP, was able to define the spatial location of the risk and to locate the presence of any cluster. Both FP and CM were able to identify hot spots.
DISCUSSION

FPs are commonly used in process control and, in particular, in the healthcare field to compare institutional performance data; however, this format is used for survival and standardised mortality ratio in public health surveillance. We explored the use of FPs as a supplementary tool to local provide authorities and communities with synthetic access to valid and

| ISTAT code | Municipality       | Expected | SIR  | 95% CI        | ISTAT code | Municipality       | Expected | SIR  | 95% CI        |
|------------|--------------------|----------|------|----------------|------------|--------------------|----------|------|----------------|
| 082042     | Isnello            | 104.1    | 1.22 | 0.99 to 1.45  | 082031     | Cinisi             | 441.0    | 0.82 | 0.74 to 0.90  |
| 082053     | Palermo City       | 2737.14  | 1.12 | 1.11 to 1.14  | 082007     | Balestrate         | 292.4    | 0.81 | 0.72 to 0.91  |
| 082061     | Roccamena          | 81.4     | 1.06 | 0.83 to 1.29  | 082067     | Santa Flavia       | 414.6    | 0.81 | 0.73 to 0.89  |
| 082070     | Termini Imerese    | 1166.4   | 1.05 | 0.99 to 1.11  | 082059     | Pollina            | 148.0    | 0.81 | 0.68 to 0.94  |
| 082027     | Cefalù             | 685.3    | 1.01 | 0.93 to 1.08  | 082030     | Ciminna            | 209.5    | 0.81 | 0.70 to 0.92  |
| 082044     | Lascari            | 152.2    | 1.01 | 0.85 to 1.17  | 082064     | San Giuseppe Jato  | 379.0    | 0.81 | 0.73 to 0.89  |
| 082014     | Caccamo            | 396.1    | 0.98 | 0.88 to 1.07  | 082058     | Polizi Generosa    | 212.6    | 0.80 | 0.69 to 0.91  |
| 082035     | Ficarazzi          | 357.5    | 0.97 | 0.87 to 1.07  | 082036     | Gangi              | 406.6    | 0.80 | 0.72 to 0.87  |
| 082038     | Giardinello        | 84.1     | 0.96 | 0.76 to 1.17  | 082023     | Casteldaccia       | 416.4    | 0.79 | 0.72 to 0.89  |
| 082056     | Petralia Sottana    | 168.6    | 0.95 | 0.81 to 1.09  | 082004     | Attavilla Milicia  | 242.8    | 0.78 | 0.68 to 0.88  |
| 082012     | Bompietro          | 104.6    | 0.95 | 0.77 to 1.13  | 082005     | Attofente          | 379.8    | 0.78 | 0.70 to 0.86  |
| 082049     | Monreale           | 1319.0   | 0.94 | 0.89 to 0.99  | 082046     | Marineo           | 310.8    | 0.78 | 0.70 to 0.87  |
| 082052     | Palazzo Adriano    | 273.71   | 1.12 | 1.11 to 1.14  | 082025     | Castronovo di Sicilia | 175.4 | 0.78 | 0.67 to 0.90  |
| 082079     | Villabate          | 631.9    | 0.93 | 0.85 to 1.00  | 082050     | Montelepre         | 258.1    | 0.78 | 0.68 to 0.87  |
| 082008     | Baucina            | 102.0    | 0.95 | 0.77 to 1.06  | 082022     | Castel SCALE       | 416.4    | 0.79 | 0.72 to 0.89  |
| 082001     | Aliminusa          | 225.4    | 0.81 | 0.70 to 0.92  | 082002     | Alcostrucino       | 379.8    | 0.78 | 0.70 to 0.86  |
| 082043     | Isola delle Femmine| 235.3    | 0.88 | 0.77 to 0.99  | 082026     | Cefalà Diana       | 50.6     | 0.73 | 0.53 to 0.93  |
| 082032     | Collesano          | 220.9    | 0.88 | 0.77 to 0.99  | 082072     | Torretta           | 143.6    | 0.73 | 0.61 to 0.85  |
| 082024     | Castellana         | 200.3    | 0.87 | 0.75 to 0.99  | 082039     | Giuliana           | 121.2    | 0.72 | 0.59 to 0.85  |
| 082041     | Gratteri           | 65.2     | 0.87 | 0.66 to 1.09  | 082047     | Mezzojuslo         | 146.5    | 0.71 | 0.60 to 0.82  |
| 082060     | Prizzi             | 283.8    | 0.87 | 0.77 to 0.98  | 082055     | Petralia Soprania  | 201.3    | 0.71 | 0.61 to 0.81  |
| 082021     | Carini             | 1146.5   | 0.87 | 0.82 to 0.92  | 082062     | Roccapalumba       | 139.0    | 0.71 | 0.59 to 0.82  |
| 082029     | Chiusa Sclafani    | 181.4    | 0.86 | 0.73 to 0.99  | 082013     | Bottergo           | 261.3    | 0.70 | 0.62 to 0.79  |
| 082009     | Belmont            | 372.3    | 0.86 | 0.77 to 0.94  | 082037     | Geraci Siculo      | 112.7    | 0.69 | 0.56 to 0.82  |
| 082073     | Trabia             | 382.2    | 0.86 | 0.77 to 0.94  | 082066     | Santa Cristina Gela| 40.6     | 0.69 | 0.48 to 0.90  |
| 082057     | Plana degli Albanesi| 305.0  | 0.85 | 0.76 to 0.95  | 082018     | Campofiorito       | 74.2     | 0.67 | 0.52 to 0.83  |
| 082081     | Scilatto           | 36.6     | 0.85 | 0.57 to 1.12  | 082075     | Ustica             | 66.6     | 0.66 | 0.50 to 0.82  |
| 082015     | Caltavuturo        | 229.0    | 0.84 | 0.73 to 0.95  | 082033     | Contessa Entellina| 101.6    | 0.66 | 0.53 to 0.79  |
| 082080     | Vilafrati          | 166.2    | 0.84 | 0.71 to 0.96  | 082077     | Ventimiglia di Sicilia | 116.9 | 0.62 | 0.50 to 0.73  |
| 082022     | Castelbuono        | 469.4    | 0.83 | 0.76 to 0.91  | 082040     | Godrano            | 52.2     | 0.61 | 0.45 to 0.78  |
| 082068     | Sciarra            | 117.2    | 0.83 | 0.68 to 0.98  | 082069     | Sclafani Bagni     | 29.4     | 0.58 | 0.37 to 0.79  |
| 082011     | Bolognetta         | 162.6    | 0.82 | 0.70 to 0.95  | 082016     | Campofioro di Fitalia | 34.6    | 0.46 | 0.31 to 0.62  |

Bold typeface indicates a significant SIR value.

ISTAT, Italian National Statistical Institute; SIR, standardised incidence ratio; PP, Palermo Province.
understandable cancer incidence data (SIRs) obtained at the municipal level.

Given that SIR is an effective and well-established measure in the descriptive cancer epidemiology, we used this parameter to compare the use of FPs and the more common formats for reporting cancer epidemiological data.

Whereas scale-risk tables are easy to understand, readers do not usually take notice of the CI, which is a critically important measure of the precision of SIR estimates. By displaying sample statistics together with the corresponding sample size, in relation to the control limits, FPs allow visualising both information and precision levels without the need for processing several numeric values (in this study, we used 82 point estimates and 164 confidence boundaries).

Moreover, while it is common knowledge that the numeracy skills of the general public are limited, that this obviously reduces...
the general understanding of public health statistics, studies have also documented that understanding of the
CI is poor even among physicians, as heuristic reasoning
often prevails on sample size. Therefore, in order
to facilitate comprehension of the epidemiological
message, we have chosen the FP as a visual display
method to allow the reader to identify the SIR for each
municipality within the plot, and the different attention-
level areas (represented by different colours) under
which each location falls (figure 1B).

Reading a CM may be misleading for stakeholders
since the fear of being overexposed to environmental
and other risk factors may lead to misinterpretation of
the differences in colour scale, which do not properly
display the potential inaccuracy in the estimation of
cancer indicators (figure 2). On the other hand, the con-
servative choice of reporting only statistically signi-
cficant increased cancer risks, as shown for the Palermo city hot
spot (figure 3), excludes from the discussion the resi-
dents of most municipalities who would certainly be inter-
ested in knowing ‘what is going on in their back yard’.
The combination of FP and CM, supported by tabulation of
the numeric results, allows to identify locations where
cancer incidence may deserve further attention, such as
the municipality of Isnello, with a high SIR but a 95% CI
including the null value. Clear understanding by the rele-
vant stakeholders and their productive engagement may
clarify whether such borderline findings simply reflect
inadequate sample size, chance or a departure from the
expected incidence that deserves further investigation.

Within the context of the chosen sample population
and data, it has to be considered the presence of a
single area containing a large proportion of the entire
study population must be highlighted. This obviously
influences each SIR value, but its potential effects are
related to the study population used in the calculation of
SIRs, and do not influence the FP methodology itself.
Moreover, the graphic FP representation, differently
from the more commonly used visual formats, allows the
reader to observe, simultaneously, the situation of the
municipality of interest in relation to the entire study
population and to three specific areas (under control,
warning and alert) representing the different attention
levels. Moreover, it should also be kept in mind that the
SIR values have been standardised using the EU popula-
tion as external reference, allowing adjustment for age.
Finally, the presence of a single area with a substantial
population (Palermo city) implies an overestimation of
expected cases, but the epidemiological message did not
change even after the exclusion of the Palermo city area
from the analysis (data not shown).

Following the methodological approach proposed, rep-
resentation of the PP SIRs through FP seemed to be con-
gruent with CM generated using the same data, with the
former resulting more informative dealing with some of
the dimensions explored, as shown by the comparisons
of the weaknesses and strengths between the two visual
formats (table 2). In particular, with regard to the
strengths of the proposed visual format, FP shows the
scope of the phenomenon under investigation and the
precision and significance of estimates simultaneously, by
simply positioning the indicator of interest in one of the
time cancer attention areas; on the contrary, the more
commonly used CMs monodimensionally represent the
parameters of interest by using a different colour grad-
ation based on the frequency distribution of the values.

CONCLUSIONS

According to the proposed comparison between the two
explored methodological approaches, we concluded that
FP should be considered as a complement to the
current and commonly used graphical and visual
formats (CMs, tables, GAM maps) to effectively commu-
nicate cancer registry statistics, particularly incidence
rate, to communities and local authorities, visually con-
veying an efficient and simple to interpret cancer epi-
demiological data.

Future research on cancer risk communication should
concentrate on the presentation format and on the
framework in which the message is presented. From this
perspective, the FP could represent a useful tool for
empowering health communications to local communi-
ties and other stakeholders (patients’ associations, physi-
cians, pharmacists, local administration, etc).

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Mazzucco W, et al. BMJ Open 2017;7:e011502. doi:10.1136/bmjopen-2016-011502
Contributors
All individuals listed as authors have contributed substantially to designing, performing or reporting of the study and every specific contribution is indicated as follows. WM, RC, MZ and SM were involved in conception and design of the study. MZ and SM were involved in statistical analysis. WM, RC, MZ and SM were involved in interpretation of data. WM and RC were involved in manuscript writing and drafting. FV, WM and RC were involved in revision of the manuscript. WM, RC, MZ, SM and FV were involved in approval of the final version of the manuscript. The document has been reviewed and corrected by a native English speaker with extensive scientific editorial experience to ensure a high level of spelling, grammar and punctuation.

Funding
This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests
None declared.

Provenance and peer review
Not commissioned; externally peer reviewed.

Data sharing statement
Online supplementary data (results of overdispersion tests, R-script to detect the greatest cut-off for the winsorisation procedure) have been provided as an online supplementary file. Other statistical results are available by emailing walter.mazzucco@unipa.it.

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