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Noise annoyance mapping in urban environments as an advanced tool for the design of effective noise mitigation actions

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ABSTRACT

The design of noise mitigation actions, after strategic noise map evaluation of urban environments, is always a challenging task that normally relies on technology for the definition of proposals for noise prevention and control. Taking into account that the main objective of strategic noise maps and noise action planning in agglomerations is citizens' quality of life, comfort and health rather than just putting decibels down, the main effect of environmental noise on people living in urban areas, that is annoyance, must be taken into consideration when deciding about proposals for noise control and mitigation. Citizens' noise exposure comes as a direct result from strategic noise maps, both as percentage of people exposed to noise ranges, usually 5 dBA intervals, and as noise exposure mapping. In this work we focus on urban road traffic noise annoyance mapping, evaluated by means of recommended exposure-response relationship and recent WHO Europe revision formula, as a complementary tool to assist the design of effective noise mitigation actions that strengthens the advocacy of the person in the process of selecting proposals.

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1. INTRODUCTION

Environmental urban noise control and management by local administration has traditionally being accomplished by means of strategic noise maps (SNM) and local noise action plans (NAP). The city of Granada accumulates long tradition and experience managing local noise issues, counting on University of Granada researchers for help and expert assessment on environmental noise management and control by means of harmonised methods as demanded by law. The collaboration between Granada City Council and University of Granada has usually led to positive bidirectional synergies enriching both organisms and Granada 2008 SNM, subsequent 2013 NAP and latest 2016 SNM are great examples of this collaboration. These results are also proof of concern and commitment of the city of Granada with environmental noise management and control, not only according to law requirements but inspired by sustainable development criteria too, as promoted by Granada Local Agenda 21.

At present, Granada is undergoing a profound urban transformation inspired by the Smart City concept in order to enable the city progress and face new urban challenges. These challenges arise as a result of new local commitments that focus on reducing air contaminants (including noise), reduce greenhouse gases (GHG) emissions or increase energy savings and efficiency by boosting renewable energy sources. If we focus in noise and air issues, sharing emissions sources and demanding integral and integrated solutions, the city should start new and innovative approaches to manage and control air contamination and urban environmental noise from road traffic.

On the other hand, urban areas classified as “quiet areas” are a demand from EU regulations, but also from Spanish regulations and citizens claims. From previous studies in Granada (both strategic noise maps, noise action plan and noise annoyance studies in the city) it comes clear that noise management and control for a better quality of life turning urban areas into quiet areas is not just a matter of reducing decibels. Doing our best putting urban noise levels down will never, by itself, satisfy our sustainability commitments, not even by means of technology in a sensorized town under the Smart City concept. And this is so because the most important sensor has still not had the relevance it should have had in the development of urban strategies and action plans: the human sensor. And first effect on humans from noise exposure is annoyance and, at the same level of importance, disturbance on everyday activities.

2. NOISE EXPOSURE

The second strategic noise map of Granada came out later than it should have, as the city entered a complicated period of works on public roads because of under and over surface new metropolitan line, lasting until late 2015. When the urban panorama calmed down, results from Granada 2016 SNM [1] indicated that the city had experienced an overall positive evolution from 2008 SNM [2] It should be pointed out that strategic noise maps (SNM) and noise action plans (NAP) have only one purpose, that is prevent people from being exposed to noise levels over legal limits and prevent them as much as possible from unhealthy limits. So, percentages of citizens exposed to different noise ranges become the most important data to be analysed from SNM results. Tables 1 and 2 shows how these data have evolved in Granada from 2008 to 2016.

Table 1: Estimated persons exposed to road traffic noise in Granada. Taken from 2008 SNM results. Data in hundreds of persons.

Range (dBA)	L_{den}		L_d		L_e		L_n	
< 54	**583**	22,7%	**788**	30,7%	**834**	32,5%	**1.819**	70,9%
55 – 59	**589**	22,9%	**679**	26,5%	**699**	27,2%	**506**	19,7%
60 – 64	**719**	28,0%	**682**	26,6%	**632**	24,6%	**207**	8,1%
65 – 69	**481**	18,7%	**345**	13,4%	**306**	11,9%	**34**	1,3%
70 – 74	**178**	6,9%	**70**	2,7%	**93**	3,6%	**1**	0,04%
> 75	**17**	0,7%	**3**	0,1%	**3**	0,1%	**0**	0%
TOTAL	**2.567**	100%	**2.567**	100%	**2.567**	100%	**2.567**	100%

Table 2: Estimated persons exposed to road traffic noise in Granada. Taken from 2016 SNM results. Data in hundreds of persons.

Range (dBA)	L_{den}		L_d		L_e		L_n	
< 54	**468**	18,1%	**793**	30,7%	**1.041**	40,2%	**1.974**	76,3%
55 – 59	**860**	33,2%	**984**	38,0%	**964**	37,3%	**452**	17,5%
60 – 64	**818**	31,6%	**589**	22,8%	**451**	17,4%	**138**	5,3%
65 – 69	**333**	12,9%	**191**	7,4%	**115**	4,4%	**22**	0,9%
70 – 74	**97**	3,8%	**28**	1,1%	**17**	0,6%	**1**	0,04%
> 75	**12**	0,5%	**1**	0,1%	**0,3**	0,01%	**0**	0%
TOTAL	**2.587**	100%	**2.587**	100%	**2.587**	100%	**2.587**	100%

It can be seen how in 2016 the number of citizens within 55-59 Ld range have increased from 26,5% to 38,0% while they have decreased from 26,6% to 22,8% in the 60-64 Ld range or from 13,4% to 7,4% in the 65-69 Ld range. Similar results apply to other noise indicators, including Lden reaching an impressive 10% improvement too within the 55-59 range (from 22,9% to 33,2%) This overall positive evolution indicates that some noise control strategies have had the desired results over the time and that local administration has run an effective noise management system.

In order to face next challenges and make it better along the next decade, hot noise spots should be identified and corrected. Global figures do not give information on localised issues, on temporal and spatial distribution of noise problems around the city or information on best practice (what to do) which is highly connected to specific characteristic of urban design, architecture and public spaces distribution, soundscape climate, people exposure to noise around Granada and how they are affected and how they feel.

If we analyse information on people exposed to noise exposure as a function of the urban area where they live, we find that some urban areas are demanding preferent attention from local administration, as show in Table 3. Granada municipal territory is divided into five acoustic areas typified as "*Residential*" (R), "*Industrial*" (I), "*Sanitary, Educational and Cultural*" (SEC) and "*Tourist*" (T), each one with different acoustic quality objectives (AQO) assigned by law. As AQO are lower at SEC, more people live over exposed to noise in these areas, which determines a priority for noise control.

Table 3: Percentage of population over and under legal acoustic quality objectives (AQO) during day period, according to acoustic type areas in Granada.

Acoustic area type	AQO (Ld, dBA)	% population under AQO	% population over AQO
Residential	65	92	8
Industrial	75	93	7
Sanitary, Educational and Cultural - Centre	60	57	**43**
Sanitary, Educational and Cultural - South	60	49	**51**
Tourist	70	98	2

3. NOISE CONFLICT AREAS

Strategic noise maps comprise a lot of information, documents and data file and noise cartography is part of it. A revision of this cartography can give consultants a good overall view of the city acoustic situation, as shown in Figure 1 (left) for road traffic noise, the most important noise source in Granada [1] and Ld indicator.

First overall impression is that noise emerges from streets road traffic, being noise exposure greater around main streets and avenues. A close view gives detailed information about local distribution as shown on the right in Figure 1, representing the south east corner of the urban territory, SEC South territory, affected by ringway around the city.

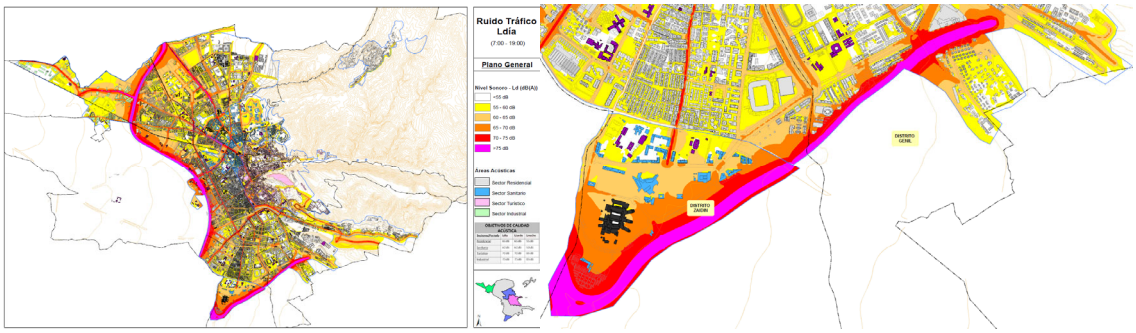

Figure 1: Granada 2016 SNM, road traffic noise source, Ld[left] and close view [right]

Environmental noise levels should not exceed AQO legal limits around the city and the areas where they do, indicate to local administration that they are conflict noise areas, mapped just like strategic noise maps in the so-called "noise conflict maps" (NCM) as shown in Figure 2 (left) in which green colour indicates "*no conflict*" and dark pink colour indicates exceedance of 20 dBA over legal limits.

The noise conflict distribution for the same close view area as in Figure 1 (SEC South territory) is shown on the right in Figure 2. Noise consultants may elaborate noise action plans from the analysis and interpretation of people exposed to noise and information extracted from these maps, as they clearly show the spatial and temporal distribution of conflict areas (similar maps for Le and Ln indicators).

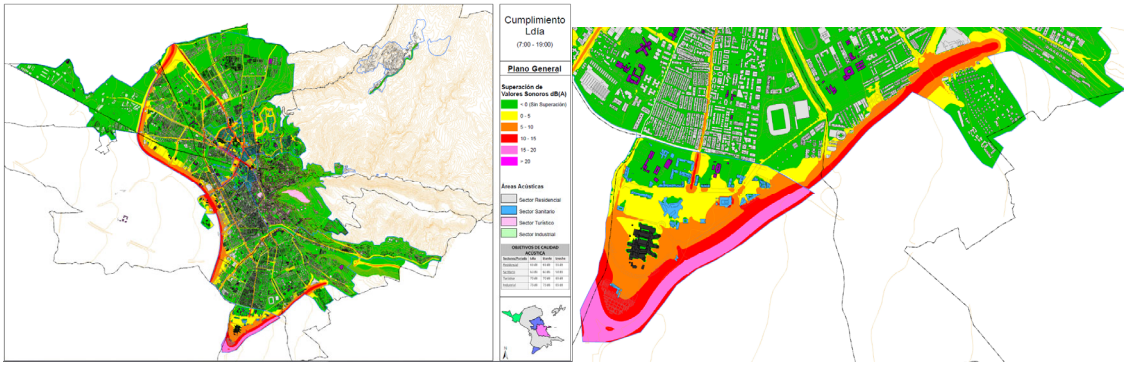

Figure 2: Granada 2016 SNM conflict noise map, Ld [left] and close view [right]

4. ADVANCED NAP DESIGN TOOLS

The noise conflict areas identification is important in order to have an overall idea of the context, where to act, where noise issues concentrate and what are the most important noise sources around. But taking a decision on the different alternatives and techniques for noise control to be included in a noise action plan (NAP) is a more complicated task that needs further assistance. We can find nowadays quite a good catalogue of proposals and solutions for noise control to assist policy makers and technicians (Smile project Handbook [3] just being an example) and recommendations that have emerged from a lot of research projects and demonstration initiatives starting in Harmonoise project, followed by Imagine and other projects like Smile, Heaven, Rotranomo, or Silvia EU funded R&D projects that can still be consulted at CORDIS [4] But successful policies for noise abatement require important investment decisions and objective analysis in order to decide best proposals and methods. Cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) take this into account and represent a must nowadays in NAP development, especially in road traffic noise control where new pavements and related actions always involve high expenses and high degree of citizens disturbances [5]. Among different methods and techniques for CBA and CEA, cost of noise calculation usually involves citizens noise exposure and noise annoyance estimations. The amount of people exposed to noise is normally included within SNM results. The estimation of annoyance is a quiet more difficult task as it relies on survey works, not always possible, and dose-response relationships, some of them still under development or testing work [6,7]

According to END [8] and its transposition to Spanish regulations, harmful noise effects should be assessed by means of dose-response relationships "*to be introduced"* (in the future) Similar statement as in END Annex III (literal quote "*Dose-effect relations should be used to assess the effect of noise on populations. The dose-effect relations introduced by future revisions of this Annex in accordance with Article 13(2)*…) END revision undertaken in 2015 [9] included CNOSSOS-EU model in Europe for common noise calculations but did not introduced aforementioned dose-effect relations. In this context, Miedema's et al. dose-response and dose-effect relationships are normally used [10,11] following EU recommendations [12,13] for noise annoyance and sleep disturbance estimations respectively. Noise annoyance studies have been carried out in Granada since 2005, when it was first undertaken by means of a standardized survey. At present, there is a good knowledge on community response to environmental noise in

Granada [14] that can be summarized as road traffic being the most important noise source in the city resulting in 51,9% of residents expressing annoyance and 22,5% high annoyance from this source considering the whole day period. If we consider day, evening and night periods, noise annoyance percentages show significant decrease from day (51,3%) to evening (44,6%) and night (38,9%) just as high annoyance that decreases from day period (25,9%) to evening (21,5%) and night period (18,0%). These numbers give local administration, again, an overall impression, really valuable information but, at the same time, clearly insufficient for NAP development.

The evaluation of citizens affected by noise and the impact of noise on sleep disturbance, annoyance and other effects is needed for the economic assessment of noise in terms of CBA and CEA and also for the estimation of priority indices for NAPs design [15]. In this context, exposure-response relationships provided by EU-position papers are reported to be valid and recommended by EEA [16] to calculate health impacts of noise in all kind of strategic noise studies such as NAPs as required by END. The challenge that we posed was gaining effectiveness in the decision-making support through the spatial visualization of that information as an advanced tool complementing numerical calculation of priority indices.

4.1 Most Exposed Urban Areas (MEUA)

First thing to do was the estimation of the most exposed urban areas (MEUA) within the noise conflict areas. According to Spanish regulations, ZPAE areas ("*Zonas de Protección Acústica Especial*") are urban territory over AQO during the whole day period (day, evening and night) Inversely, the urban territory under AQO during the whole day period constitutes the ZT areas ("*Zonas Tranquilas*"). This was done in GIS resulting the distribution shown on the left in Figure, in which areas of interest for NAP proposals are those delimited in pink (ZPAE). As ZPAE delimitation doesn't provide a priority hotspot criterion, the degree of the noise conflict was then calculated taking into consideration night noise conflict maps and noise annoyance of citizens exposed to night noise levels over 55 according to [5]. This was also done in GIS resulting in the determination of MEUA on the right in Figure 3.

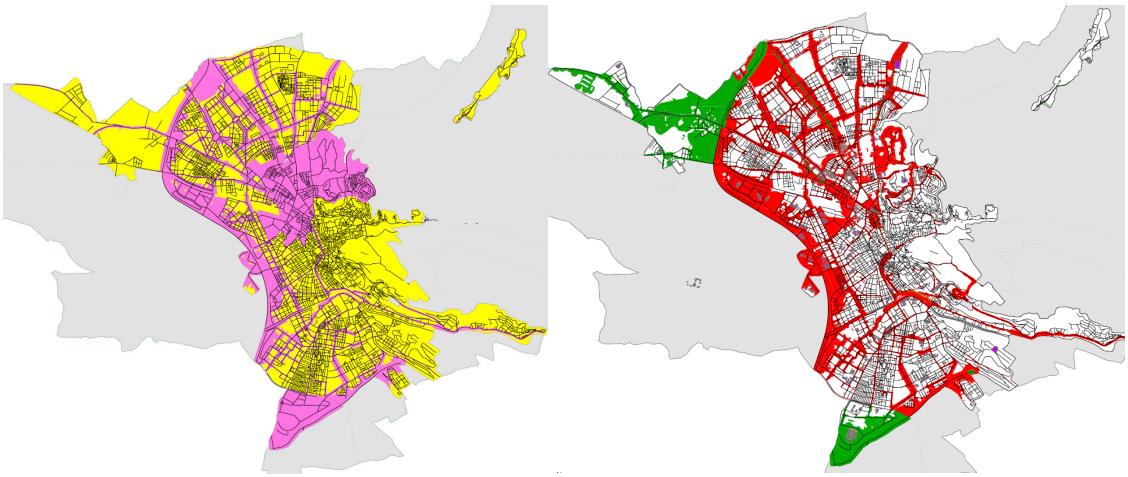

Figure 3: Granada noise conflict areas (ZPAE) – pink territory [left] and most exposed urban areas (MEUA) - high level noise conflict in red [right]

It can be seen that ZPAE designation give us partial information on noise conflicts that MEUA refines by more precisely delimiting preferent attention sites for NAP designers, as close view shows in Figure 4.

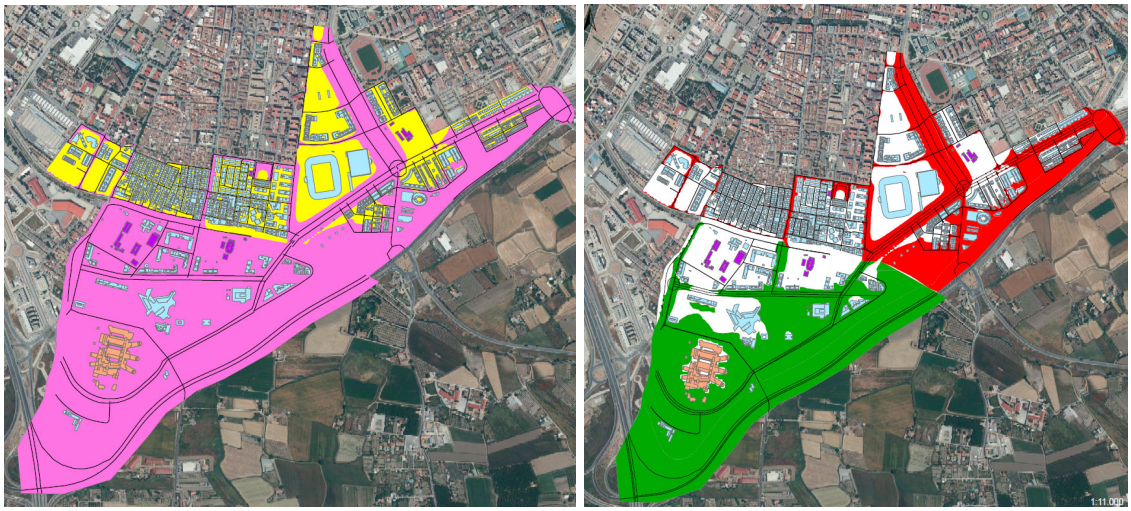

Figure 4: Close view of ZPAE area in pink (left); MEUA area identified in red (right)

4.2 Noise annoyance mapping

Noise annoyance mapping was then addressed in order to provide decision makers and NAP designers the complete view of citizens affected by road traffic noise in Granada, a vision that non-georeferenced data would never permit. An advanced complementary tool to know where to start the implementation of noise abatement measures and help with the best CBA/CEA ratios calculations. Percentage of persons annoyed (%A) and highly annoyed (%HA) have been estimated from [10] as recommended in [12]. Percentage of persons sleep disturbed (%SD) and highly sleep disturbed (%HSD) have been estimated from [11] as recommended in [13]. The percentage of persons highly noise annoyed has also been estimated by means of revised WHO dose-response relationship following [6], as well as the percentage of persons highly noise sleep disturbed by means of revised WHO dose-effect relationship following [7]. 2016 SNM noise levels data have been used as input in all cases. The "*Tourist*" acoustic area will be used to analyse the potential of this tool. A representation of (%SD) according to EU recommended dose-effect relationship can be seen in Figure 5.

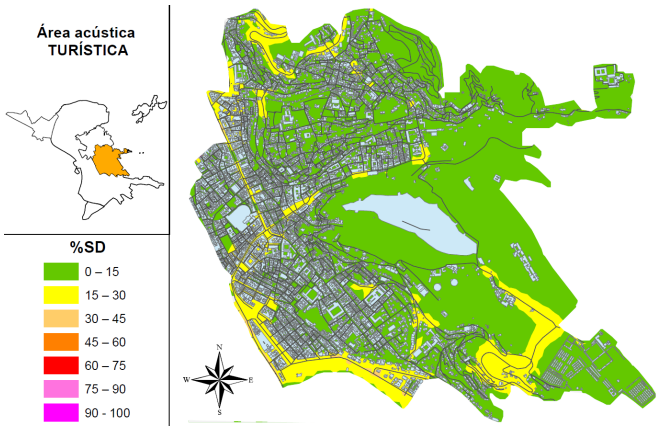

Figure 5: People sleep disturbed by road traffic noise (%SD) according to [13]

A close view of road traffic noise *strategic noise map* (SNM) for night period (Ln) and corresponding *noise conflict map* (NCM) is shown in Figure 6. Legal acoustic quality objective (AQO) for this area is Ld=65 dBA, so areas in orange in SNM (65 dBA or more) appear as yellow areas in NCM (an exceedance of 5 dBA over AQO).

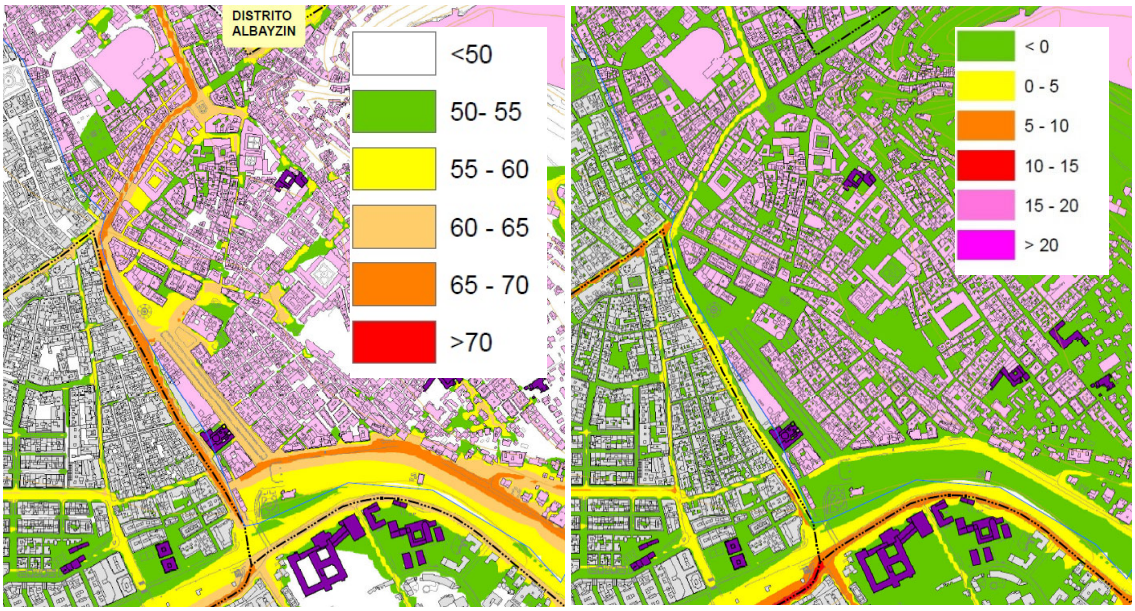

Figure 6: [Left] Close view "Tourist" acoustic area Ln SNM (dBA) for road traffic noise and [right] corresponding NCM

As commented before, strategic noise maps and noise conflict maps give information on where noise issues locate and how they temporally and spatially distribute, but decision-makers and NAP designers also need information on the magnitude of citizens noise exposure. If we take into consideration population data together with the exceedances data from NCM, we can estimate LKZ indicator as shown on the left in Figure 7.

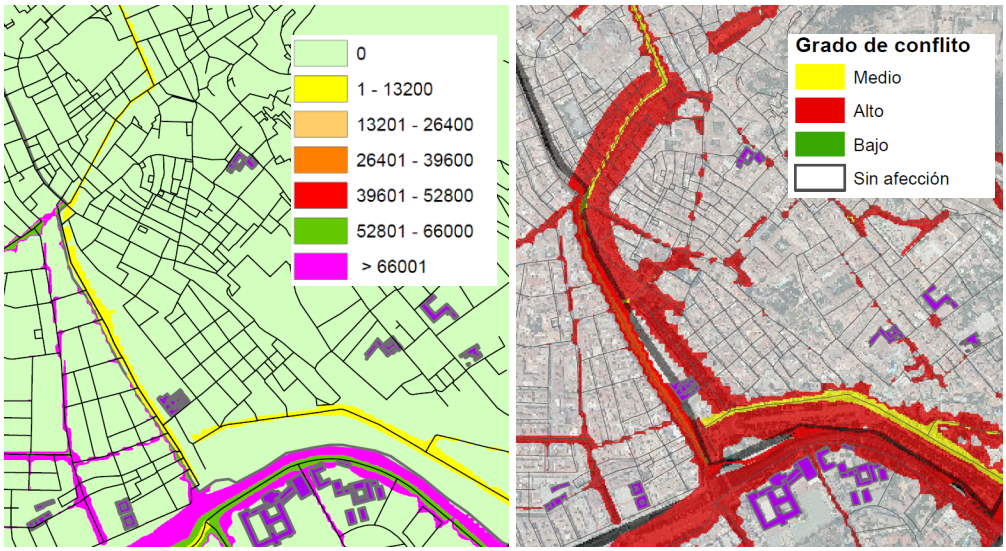

Figure 7: LKZ indicator (left) and MEUA (right) for close view area in Figure 6

High values of LKZ indicates a high degree of conflict with respect AQO that has been considered. As reported in [17], linear approaches like LKZ give results focusing on the number of people affected, but not on the most exposed areas which points out hotspots in the city as shown on the right in Figure 7 where MEUA indicates that there is a high degree of conflict (red colour, Figure 7 right) in areas that LKZ indicator doesn`t point as priority (yellow colour, Figure 7 left). Percentage of people sleep disturbed by noise as in Figure 5 can help decision-makers as detailed quantitative spatial information of noise effect can be used to clearly determine hotspots and evaluate different mitigation measures

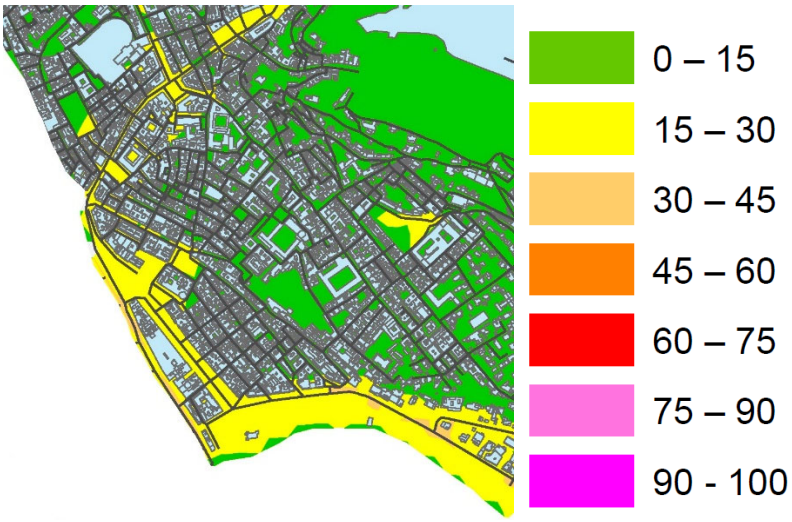

Figure 8: (%SD) Close view area in Figures 6 and 7, as shown in Figure 5

The potential of this tool also applies to noise annoyance and highly annoyance mapping estimated as recommended in [12] and shown in Figure 9 and 10. Having in mind that people highly annoyed (%HA) are included in people annoyed (%A) data, the comparative analysis of figures 9 and 10 let consultants a better characterisation of the degree of noise exposure for decision making purposes.

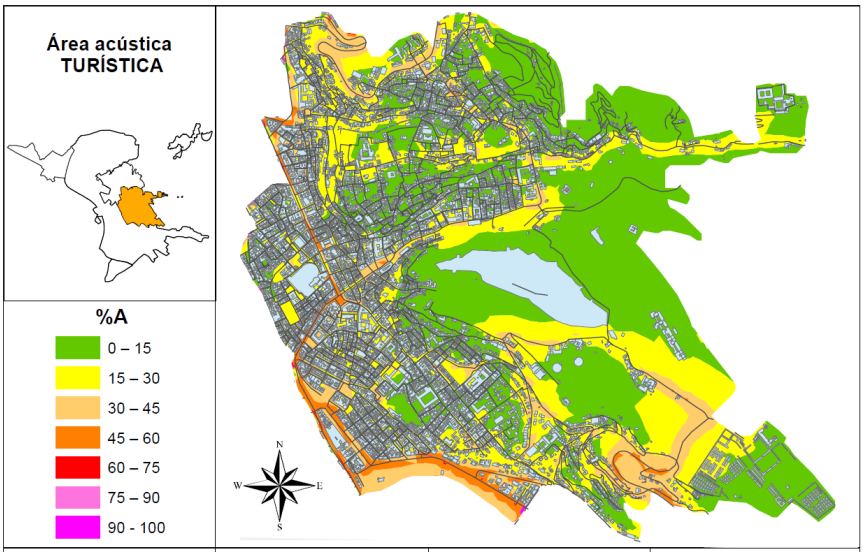

Figure 9: People road noise annoyed (%A),"Touristic" acoustic area according to [12]

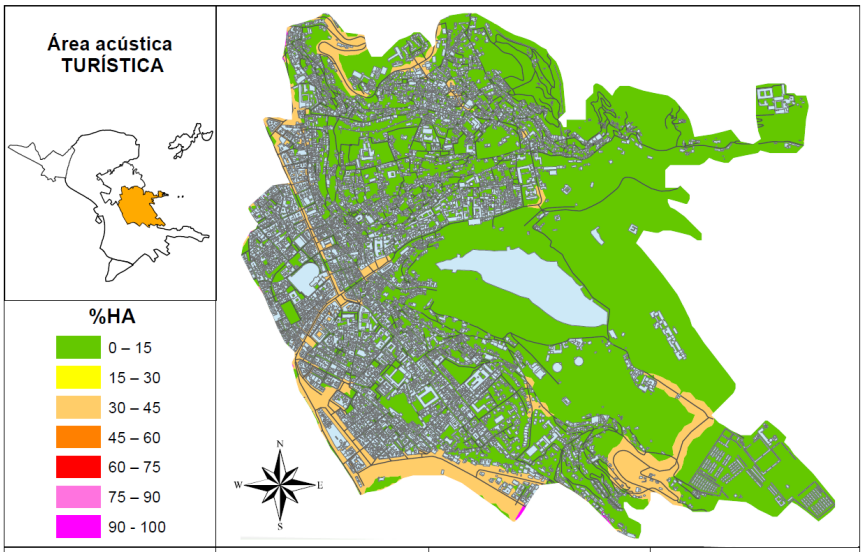

Figure 10: People highly annoyed (%HA) by road traffic noise within the "Touristic" acoustic area according to [12]

4.3 Revised WHO dose-response and dose-effect relationships

WHO revised dose-response relationship for %HA from road traffic noise as proposed by Guski et al [6] and dose-effect relationships for %HSD combined falling asleep and awakening effects as proposed by Basner and McGuire [7] have also been mapped. As stated in [6], our results show that %HA estimations are greater than EU recommended calculations especially at exposure levels from 40 to 65 dBA Lden, so %HA mapping can give quite different estimations than EU recommended formula depending on environmental noise levels distribution as shown in Figure 11 and 12. Environmental noise up to 65 dBA Lden gives greater annoyance now, which seem to us more realistic than previous results from EU recommended formulas. It can be seen in Figure 11 yellow areas indicating up to 30% people HA that in Figure 10 are drawn in green (up to 15% HA)

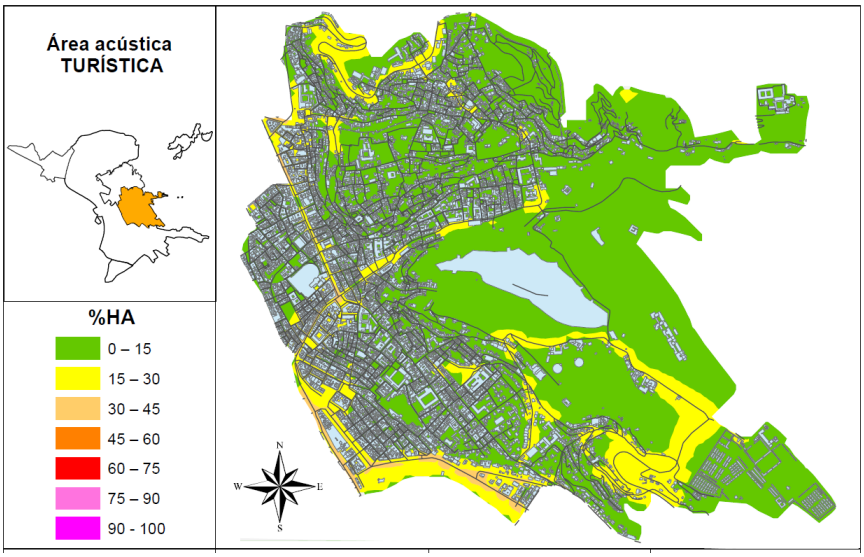

Figure 11: People highly annoyed (%HA) by road traffic noise within the "Touristic" acoustic area according to revised WHO dose-response relationship [6]

Similarly, noise from ringway generates lower HA around and centre areas in "*Residential*" territory shown Figure 12 appear clearly more affected with this revised formulation for %HA.

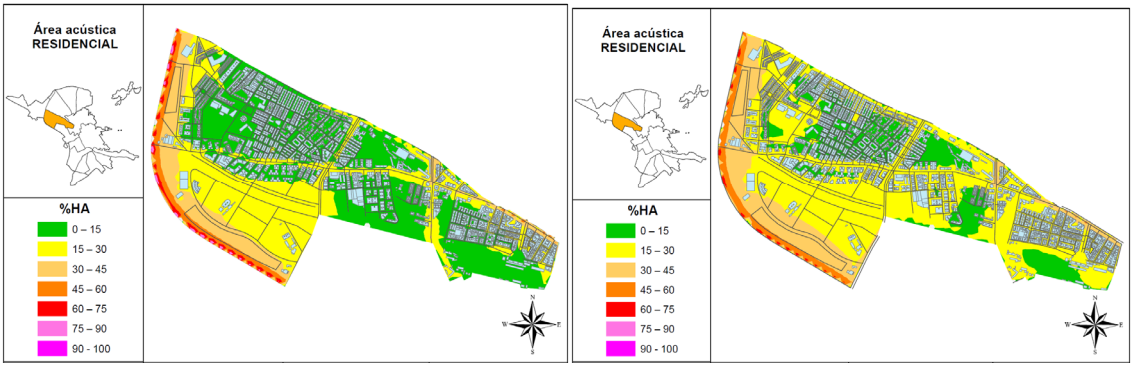

Figure 12: People highly annoyed (%HA) by road traffic noise, "Residential" acoustic area according to EU [12] (left) and revised WHO [6] (right)

That's not the case for %HSD, as revised relationship (valid por Ln range of 40-65 dB) systematically gives lower estimations of sleep disturbance than EU recommended formula as shown in Figure 13.

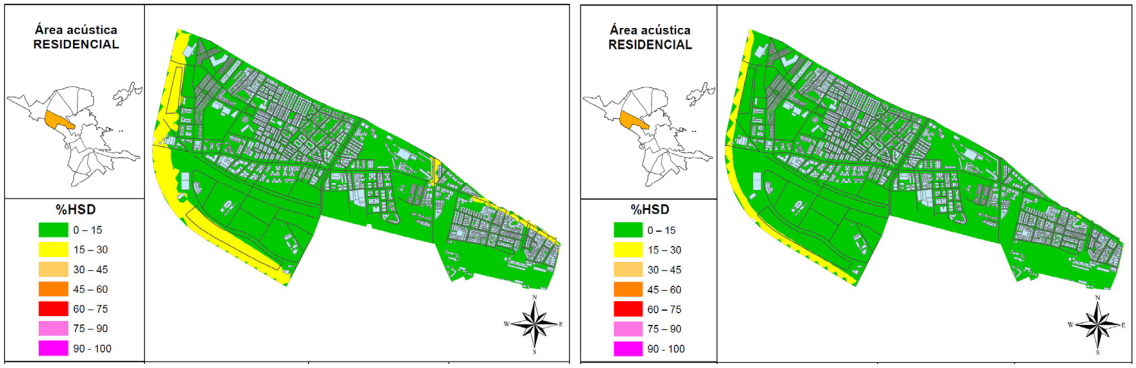

Figure 13: People highly sleep disturbed (%HSD) by road traffic noise, "Residential" acoustic area according to EU [13] (left) and revised WHO [7] (right)

Previous results show that EU recommended dose-response relationships underestimates people annoyed and highly annoyed by noise from road traffic noise [14] and further research has to be done in order to determine better fitting of data registered in Granada, including tests on WHO revised methodology by means of noise annoyance field data from our survey works.

6. CONCLUSIONS

Noise annoyance and sleep disturbance mapping is proposed as a supplementary tool for decision-makers and noise action plans designers in order to evaluate priorities and estimate best practice for noise management and control. It can also be a valuable tool for the evaluation of the effectiveness of noise reducing measures and the estimation of the economic assessment of noise that normally involves the calculus of citizens affected by noise, noise exposure scores or factors closely linked with estimated or expected noise annoyance.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. A. García, J. Martínez, C. López, M. Gutiérrez, R. Escobar, A. Olivares y J. Vida, "*Nuevo mapa estratégico de ruido de la ciudad de Granada*", SICA, Ministerio para la Transición Ecológica, (2016) http://sicaweb.cedex.es/ume-fase3.php?id=17
2. S. Serrano, O. Herrera, D.P. Ruiz y J. Vida "*Mapa estratégico de ruido de la ciudad de Granada*", SICA, Ministerio para la Transición Ecológica, (2008) *http://sicaweb.cedex.es/ume-fase1.php?id=259*
3. M. Kloth et al. "*SILENCE Practitioner Handbook on Local Noise Action Plans*", SILENCE EU Sixth Framework Programme Project (2009) *http://www.noiseineu.eu/fr/3527-a/homeindex/file?objectid=3161&objecttypeid=0*
4. CORDIS, Community Research and Development Information Service, European Commission. *https://cordis.europa.eu/project/rcn/70861/reporting/en*
5. CDER, "*State of the art in managing road traffic noise: cost-benefit analysis and cost-effectiveness analysis*", Technical Report 2017-03 (2017)
6. R. Guski, D. Schreckenberg and R. Schuemer, "*WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance*", Int. J. Env. Research and Pubic Health, 14, 1539 (2017)
7. M. Basner and S. McGuire, "*WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep*", Int. J. Env. Research and Pubic Health, 15, 519 (2018)
8. Directive 2002/49/EC of 25 June 2002 "*relating to the assessment and management of environmental noise"*, OJEC L189, 12-25 (2002)
9. Directive 2015/996 of 19 May 2015, "*establishing common noise assessment methods according to Directive 2002/49/EC*", OJEC L168, 1-823 (2015)
10. H.M. Miedema, C.G.M. Oudshoorn, "*Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals*", Environ Health Perspectives, 109(4), 409–16 (2001)
11. H.M. Miedema, W. Passchier and H. Vos, "*Elements for a position paper on night-time transportation noise and sleep disturbance"*, TNO Inro report 2002-59 (2003)
12. European Commision, WG2-Dose/Effect, "*Position paper on dose response relationships between transportation noise and annoyance*" (2002)
13. European Commision, WG Health and Socio-Economic Aspects, "*Position paper on dose-effect relationships for night time noise*" (2004)
14. J. Vida, J.A. Almagro and R. Quesada, "*Community response to environmental noise in Granada (Spain): an evaluation by means of a standardized social survey*" Internoise 2019 Proceedings (2019)
15. F. D'Alessandro and S. Schiavoni, "*A review and comparative analysis of European priority indices for noise action plans*", Science of the Total Environment (518-519), 290-301 (2015)
16. European Environment Agency, "*Good practice guide on noise exposure and potential health effects*", EEA EPoN Technical report Nº 11 (2010)
17. S. Eggers, "*Evaluation of noise mitigation measures: Common methods and a novel approach*", Proceedings Internoise 2016 (2016)