A Color Scheme for the Presentation of Sound Immission in Maps: Requirements and Principles for Design

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Summary
Sound immission is a spatial phenomenon. Therefore maps are especially suitable for the presentation of noise. In noise maps color is usually used for the representation of sound immission. If used appropriately, color facilitates an intuitive understanding of the distribution of traffic noise in a city, for example, and thus fosters map usability. However, color design of maps is complex because color is a physical stimulus that causes physiological as well as psychological reactions and thereby affects map interpretation. We therefore present a scheme that considers cartographic principles as well as perceptual issues. The scheme was tested in four user studies with a total of 232 participants. It consists of associative colors that can be matched to the ordered values and symbolize three levels of noise exposure. Additionally, it is suitable for color vision deficiencies.

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1. Introduction

Sound immission is a spatial phenomenon. Therefore maps are especially suitable for the presentation of noise. In maps phenomena are represented by the means of visual variables, such as size, shape, value, color, orientation, and texture [1]. For the representation of sound levels it is common to use the variables color and color value; color meaning color hue, e.g. red or blue, and color value representing the range from light to dark, e.g. light blue to dark blue.

Besides Bertin's variables concerning color there is a third variable that humans can perceive: saturation. It refers to the intensity of a color that is perceived and can be described as a color's difference to grey. Consequently, the appearance of a color depends on a combination of these three variables. In color design it is crucial to balance these perceptual variables looking at both the visualization's aim and the characteristics of the data.

Used properly, colors then have the power to reveal the structure within data. Due to aspects of color perception and cognition they can also contribute to misinterpretation, if used carelessly. In noise maps, color used appropriately facilitates an intuitive understanding of the distribution of traffic noise in a city, for example, and thus fosters map usability.

This paper introduces a color scheme, which takes into account cartographic rules, visual and cognitive perception as well as the characteristics of the presented phenomenon: sound immission. It is designed to be used for the areal presentation of noise, i.e. as filling of the equal-noise contours, and needs to be adapted if used for point or line data.

As a case study for the development of the color scheme we have chosen strategic noise maps according the Environmental Noise Directive (END) by the European Union (EU) [2].

In correspondence with the END, member states are requested to draw up noise maps for major roads, railways, airports and agglomerations every five years, starting in 2007. Each noise source, such as traffic, railway, airport and industrial noise, has to be presented in an individual map. The resulting maps are used for the assessment of noise in European cities, for informing the public and for formulating action plans. The maps present the harmonized noise indicators L_{den} (day-evening-night equivalent level) and L_{night} (night equivalent level) in dB as colored fillings of the equal-noise contours (isophones), resepctively.

It is crucial that maps are the major medium that is used for informing the public about noise and that they also serve as a discussion basis [3]. It implies a quality suitable for knowledge transfer [4]. As color is the most important design element for noise information, besides the base map, it is worthy of closer consideration.

2. Related work

2.1. Perceptual aspects of color design

Color design of maps is complex because color is a physical stimulus that causes physiological as well as psychological reactions. On the one hand, color is used for aesthetical reasons, to decorate, and on the other hand to imitate reality as well as to represent quantitative information [5], which is emphasized here. The latter is challenging because **color has an effect on map interpretation** [6]. This is due to **color perception** which is **subjective, context dependent, dependent on adjacent colors** [7] [8] [9] and **results from people's connotations** with colors. These are subjective, but also dependent on the cultural background [10] [11] [12]. Colors even **affect the perceived object size** [8] [13] [14], which is of concern if areal data is represented by means of colour, such as the isophones. Additionally, **color vision deficiencies** (CVD) (e.g., red-green color blindness) are a problem because red and green cannot be distinguished by 0.5 % of female and 8% of male users (cf. Fig. 1 and 3). Thus, these colors in combination should be avoided.
Because of the complexity of color perception and various effects many applications use color in a way that complicates map reading, leads to misinterpretation or, even worse, to manipulation.

2.2. Cartographic principles for color design

Cartographers have addressed the topic color design in depth [15] [16] [17] [18] [19]. *ColorBrewer* [20], a popular library for color schemes, is an example for the implementation of cartographic theory. It recommends single-hue schemes, e.g. light blue to dark blue, or schemes with no more than one hue-transition with a clear range from a light to dark, e.g. yellow to dark red, for scales with ordered values. However, for some applications, like noise mapping, the ready-made schemes are not suitable. Reasons for this are for example:

- Color specifications are never cast iron proof as color rendering, on screen or in print, varies [20]. The map maker cannot tell how a color will look like on the map users' screen or print out. This fact has to be considered when developing requirements for a scheme.
- Nature of data varies for different applications. How the logarithmic scale of the noise pressure level, for instance, can be reflected by means of color has not been subject to recommendations in cartography. However, it is important to understand this characteristic for data interpretation since higher values contribute more to a mean value and, therefore, have to be emphasized.

In respect thereof, we describe design guidelines that help to develop effective color schemes for specific use cases [21]:

1. Colors used to represent ordered data should build a **harmonical hierarchy** [22, p. 46] [23], i.e., lightness and saturation should increase or decrease systematically at one end of the scale. In multi-hue sequential schemes a hierarchy is achieved by using hues that have a perceivable order, like yellow to dark-red or yellow to purple. A scheme is harmonical if lightness and saturation is well balanced to ensure that single colors don't stand out. To achieve a balance sizes of the presented objects need to be taken into account and saturated colors in particular should be avoided for big objects, unless they are of critical importance.
2. **Match values or class distances and color distances**. To represent a big range of values, such as the logarithmic sound pressure level, we recommend to use a scheme that consists of different hues that are ordered on the basis of the principle mentioned above.
3. The **assurance of colors' consistency** on a variety of output devices is a major aim. Colors should be recognizable regardless of object size, adjacent colors, or device in use and enable a correct assignment of the object colors to the color patches in the legend. To facilitate this we recommend the use of different hues in a harmonical hierarchy and fewer lightness steps per hue.
4. To consider color vision deficiencies is crucial to facilitate the accessibility of digital maps. **Therefore, avoid colors that are not suitable for color vision deficiencies,** such as a combination of red and green.

In addition to these design guidelines, we advise to examine the users' tasks and to contemplate connotations with the presented phenomenon that should be reflected in color design. In case users are **looking up** individual values on the map, colors in particular have to be distinguishable. For **pattern identification** a hierarchy within the colors is

necessary that highlights one end of the scheme, puts low and high values in contrast, or highlights a critical value.
Since sound is no visible phenomenon, color is not used to imitate reality but to represent a physical value or a thread that emanates from the presented value, such as health risk or annoyance. Due to the fact that colors have psychological and emotional effects they have to be used carefully to avoid misinterpretation. A saturated warm color, like red, overemphasizes low values and signalizes a risk.

2.3. Existing schemes for noise maps

As Alberts and Alférez [24] point out ISO 1996:2 [25] defines a scheme for the representation of sound immission. However, in a subsequent revision color definitions have been left out [26]. Nonetheless in many European countries color definitions based on the ISO are still in use and stipulated by national legislation in Germany, as specified in the standard DIN 18005-2: 1991 [27] (Fig. 1).
The ISO/DIN-scheme is problematic for the following reasons:

- The colors cannot be ordered according to lightness and/or saturation and thus they cannot be matched to the dB-values without a map legend.
- There are big steps in saturation between the individual colors, which further counteracts the potential to bring the colors in a perceptive order. A systematical change of saturation is missing.
- Colors cannot be associated with the characteristic of the dB-values. Although the scheme is inspired by a traffic light system and uses green for lower values, the signal color red is used in the middle of the scheme, thus highlighting this sequence more than the higher, harmful values. These harmful values are presented in light blue, a cool color, which is counterintuitive.
- Red and green are used in combination. This hinders readability for users with color vision deficiencies.

The only advantage of this scheme is that the colors are easily distinguished from each other, which is achieved by abrupt changes of lightness. It is not suitable, though, for representing patterns in the data.
As an alternative, Alberts and Alférez [24] introduced a new scheme that shows a better balance of lightness than the ISO/DIN-scheme, emphasizing both ends of the scale with darker colors (Fig. 1). Nevertheless, saturation is not well balanced, the red class in the middle of the scheme is overemphasized. Additionally, red and green are used in combination which hinders readability for people with color vision deficiencies. We therefore present a scheme that considers all of the criticized aspects.

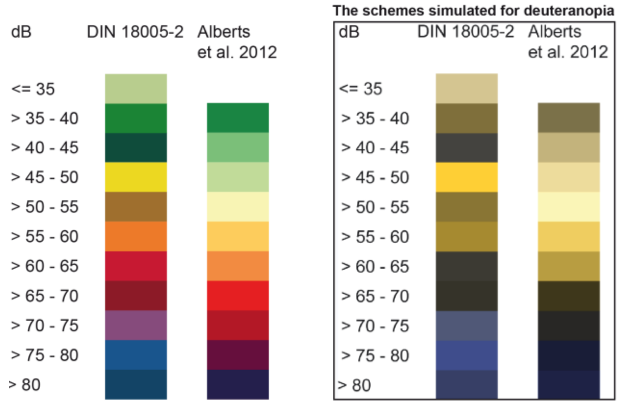

Figure 1: The ISO/DIN-scheme and the scheme proposed by [24]. The figure on the right shows the schemes as they appear for people with color vision deficiencies; red and green appears almost the same. (Simulated with the software *eye.syde*.)

3. Methodology for design and development

3.1. A user-centered design process

The scheme was developed in a user-centered design process. This is characterized by „early focus on users and tasks", "empirical measurement" and "iterative design" [28, p. 99]. Tasks and users were defined in a requirements analysis, looking especially at END noise maps. This requirements analysis looked at functional and non-functional requirements, such as cartographic design and color design. The information was gathered in a qualitative and a quantitative analysis of German noise maps, a workshop with practitioners and literature research. In the iterative design process four user studies with a total of 232 participants were conducted and provided insights for the design of the scheme. The user studies ensured that the aims and requirements were met.

3.2. Specific requirements on the scheme

Cartographic principles are too vage to define specific colors for specific cases of application. Hence requirements should be defined for each

application. These requirements depend on the map's objective and user group.
The priority of the presented color scheme was **distinguishability of colors** for all user groups, including users with color vision deficiency. Additionally, the colors should be **logically assignable to the characteristics of the noise data,** i.a. that noise levels are neither under- nor overestimated, hotspots and silent areas should be determined by the users without referring to the map legend and colors should facilitate an association with the categories of noise levels. The last requirement is that colors in the map can be **visually matched** with colors in the map legend.
To achieve results, that are applicable within the END, we defined the following prerequisites: 5 dB classes and the presentation of a range of values from over 35 dB to over 75 dB.

4. The new color scheme

To enhance recognizability, we retained some aspects of existing schemes: the use of green and warm colors to emphasize the contrast between positive and negative values, the use of red for 65 to 70 dB and the use of purple for high values. The dB-range, number of classes and class size was also maintained, since it is in line with the specifications in the END.
The resulting scheme was developed for digital use, CMYC were not tested extensively but can be found on the website www.coloringnoise.com (Fig. 2 and Tab. 1).

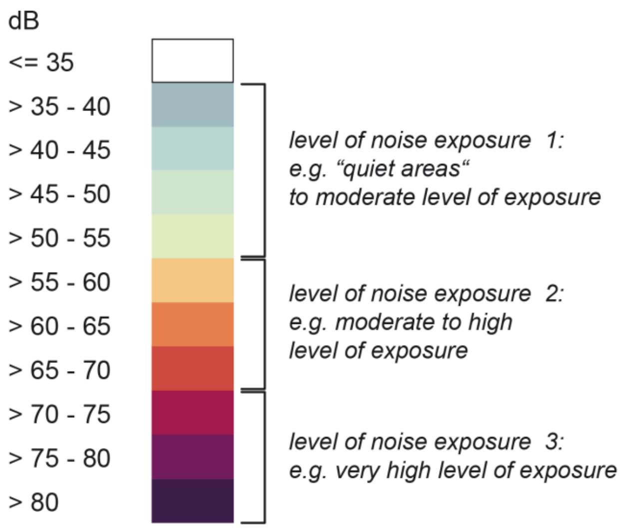

Figure 2: The colors of the new scheme. RGB values can be found in Tab.1.

Table I. RGB codes for the new scheme. CMYK values are available on www.coloringnoise.com.

dB	*R*	*G*	*B*	*Hex*
> 35-40	160	186	191	#A0BABF
> 40-45	184	214	209	#B8D6D1
> 45-50	206	228	204	#CEE4CC
> 50-55	226	242	191	#E2F2BF
> 55-60	243	198	131	#F3C683
> 60-65	232	126	77	#E87E4D
> 65-70	205	70	62	#CD463E
> 70-75	161	26	77	#A11A4D
> 75-80	117	8	92	#75085C
> 80	67	10	74	#430A4A

The scheme consists of ten colors and three color hues – blue-green, orange, and purple. They **symbolize three levels of noise exposure** and support recognition. A stronger color contrast for the classes 60 to 65 dB and 65 to 70 dB **indicates a higher high health risk**. A user study showed that colors with high color contrasts serve the aim to represent a big range of values better than similar colors with low contrast [29].

Figure 3: The ISO/DIN-scheme and the new scheme, both applied in a map. The new scheme on the right is suitable to present the distribuition of the values and highligts high values.

We aimed for a **systematic variation of lightness and saturation**: To highlight the positive end of the scale as well as the harmful (high) values, the lightest colors are in the middle of the scheme,

whereas saturation is highest for lowest and highest values (Fig. 3). The extreme increase of saturation for colors representing high values supports the representation of the noise pressure level's logarithmic scale. This scale has the effect that higher values contribute more to the energetic mean value.
Due to the systematic change of lightness, colors can be ordered according the rising dB-values – the logic of the represented dB-values is thus mirrored in the scheme.
The scheme is suitable for users with color vision deficiencies because pure green and red are not used in combination (Fig. 4). Nonetheless colors are intuitive, similar to a "traffic light scheme": The cool blue-green colors are associated with lower values in comparison to the saturated and warm orange and purple colors according to results from a user study [29].

Figure 4: Fig. 3 simulated for color vision deficiencies (deuteranopia). With the ISO/DIN scheme the class 40-45 dB can be mistaken for the classes 60-70 db. (Simulated with the software *eye.syde*.)

5. Conclusion and outlook

Color design is complex. In particular, this is due to perceptional aspects of color vision and a variety of connotations with colors. There is no magic recipe for color use in maps. Cartographic principles, such as a harmonic hierarchy for ordered values, a matching of data range and number of classes to color distances, an assurance of colors' consistency and a design for color vision deficiencies form the foundation.
To decide on a specific range of colors, the specific case of application has to be analyzed with regard to the user group, the user tasks, and the map makers' aim, such as to present an overview, or thresholds.
In Particular, the scheme is recommended for major roads in END noise maps, but according to the current state of research this is suitable for other types of sound immission. However, major points of discussion are the adaptability of the scheme for other class sizes than 5 dB, or for other value ranges than the applied > 35 to > 80 dB. This consideration is necessary when looking at the presentation of noise sources other than environmental noise.
The scheme was presented to the Acoustics, Noise Control and Vibration Engineering Standards Committee in DIN and VDI, of which the author is a member. The committee is currently revising DIN 45682:2002 "Themed maps in the domain of immission control" (NA 001-02-03-20 UA).

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Please bear in mind that colors are represented differently on diverse screens, devices, and prints.

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