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Accuracy of temporal samplings of environmental noise to estimate the long-term L_{den} value

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ABSTRACT

According to the European directive 2002/49/EC, the environmental noise descriptors L_{den} and L_{night} must be representative on annual term. Thus, the annual variation of the noise emission of the source and of meteorological parameters, wherever influencing the sound propagation, must be taken into account. As such a long term noise monitoring is not feasible, temporal sampling techniques are applied, by which the annual value of L_{den} and L_{night} are estimated from the measured valued on short periods chosen throughout the year. The accuracy of the estimated value depends on the ratio between the total measurement time and the long-term, as well as on the variability of the noise immission at the receiver which includes the temporal variability of source emission and influence of meteorological parameters on sound propagation.

The paper shows the results obtained from the statistical analysis of long-term L_{den} values estimated by some temporal samplings extracted from long-term continuous monitoring at 5 sites, selected for different time variability of noise sources (motorway, freeway, railway, residential area, small airport) and receiver distances (range 10-600 m). The obtained accuracies in estimating the long-term value of L_{den} are shown and compared one another.

1 INTRODUCTION

The European Environmental Noise Directive 2002/49/EC requires that the values of the acoustic parameters L_{den} and L_{night} are representative of a year. A continuous noise monitoring for such a long-term is cumbersome and quite expensive and in many cases the large resources involved are not justified in terms of better accuracy than that achievable by cheaper and feasible temporal samplings. Many experimental studies, mostly dealing with road traffic noise, were carried out to develop criteria for selection of temporal samplings appropriate to the variability of environmental noise in order to increase the accuracy of the estimated long-term value [1-6]. For instance, the ANSI S12.9-1992/Part 2 [7] states that for long-term noise monitoring strategies "measurements shall be taken for four distinctly different, entire days of the week. One day shall be chosen from each quarter of the year".

This paper would contribute to the above aim and describes the results obtained from the statistical analysis of long term L_{den} values estimated by some temporal samplings extracted from long term continuous monitoring at 5 sites, selected for different time variability of

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noise sources (motorway, freeway, railway, residential area, small airport) and receiver distances (range 10-600 m). The obtained accuracies in estimating the long-term value of L_{den} are shown and compared one another.

2 EXPERIMENTAL

The long-term day-evening-night level $L_{den,LT}$ can be determined by [8]:

$$L_{den,LT} = 10\lg\left[\frac{t_{day}}{24}10^{0.1L_{day}} + \frac{t_{evening}\cdot\sqrt{10}}{24}10^{0.1L_{evening}} + \frac{t_{night}\cdot 10}{24}10^{0.1L_{night}}\right] \quad dB(A) \qquad (1)$$

where, according to the implementation of the 2002/49/EC in Italy [9], $t_{day}=16$ (06-20h), $t_{evening}=2$ (20-22h), $t_{night}=8$ (22-06h) and L_{day}, $L_{evening}$, L_{night} are the A-weighted long-term equivalent levels $L_{Aeq,LT}$, each given by:

$$L_{Aeq,LT} = 10\lg\left[\frac{1}{LT}\sum_{i=1}^{LT}10^{0.1(L_{Aeq})_i}\right] \quad dB(A) \qquad (2)$$

where LT is the number of days or evenings or nights included in the long-term and $(L_{Aeq})_i$ is the i^{th} corresponding A-weighted equivalent level for the considered period.
According to the 2002/49/EC requirements $LT=365$, while using temporal sampling the total measurement time m is chosen to be $m << LT$ and, therefore, $L_{den,LT}$ is only estimated by $\hat{L}_{den,LT}$ with an error $\pm \varepsilon$:

$$L_{den,LT} = \hat{L}_{den,LT} \pm \varepsilon \quad dB(A) \qquad (3)$$

where $\hat{L}_{Aeq,LT} = L_{Aeq,m}$, being $L_{Aeq,m}$ the A-weighted equivalent level for the m measurement time.

2.1 Acoustic data sets

In the present study the acoustic data (overall L_{Aeq} and third octave band levels every 1 s) memorized by a sound monitoring system [10] installed at five different sites have been processed to get the hourly L_{Aeq} values. The sites, selected for different time variability of noise sources (motorway, freeway, railway, residential area, small airport) and receiver distances (range 10-600 m), are listed in Table 1 together with information on the prevailing sound sources and their distances from the monitoring microphone. For each site the number of 24 hour samples available for calculation of daily L_{den} and further data processing is also reported in Table 1.

Table 1: Sources and distances at each site and number of 24h samples.

Site	Sound sources and distance from monitoring microphone	N. of 24 hour samples
A	Motorway at 240 m	396
B	Freeway at 35 m and small industry at 25 m	276
C	Local road at 10 m and railway at 150 m	231
D	Residential area in small town	170
E	Small airport at 600 m	112

Figures from 1 to 5 show the daily pattern (blue lines) of the hourly L_{Aeq} values for each site. In the plots the long-term $L_{den,LT}$ value is reported together with the standard deviation of the daily L_{den}; the logarithmic (red line) and arithmetic mean (green line) values for each hour are also displayed. The small airport daily data set shows a great variability because of the sound events from the aircraft movements. In the distribution of the long-term hourly L_{Aeq}, given in Figure 6, two modes are observed corresponding to the aircraft noise (51 dB(A)) and the residual sound (39 dB(A)).

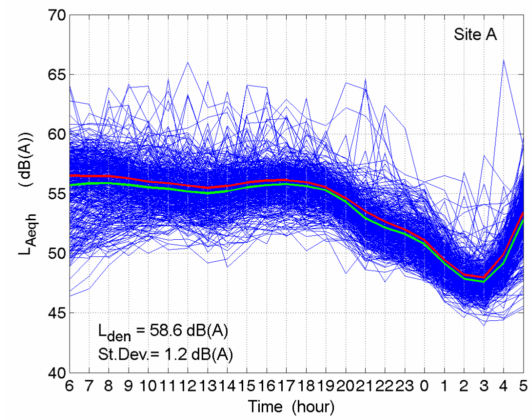

Figure 1: Motorway daily data set.

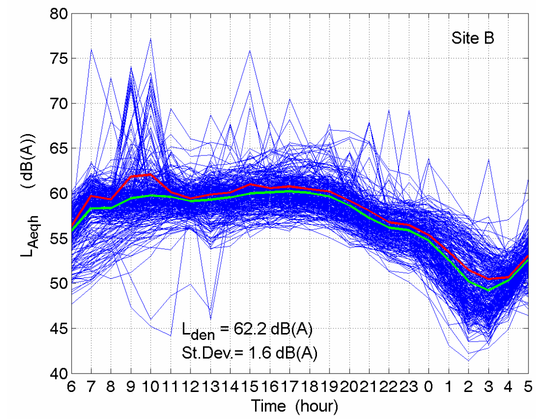

Figure 2: Freeway and small industry daily data set.

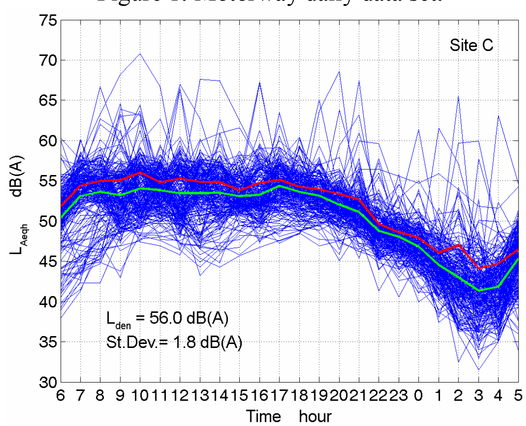

Figure 3: Local road and railway daily data set.

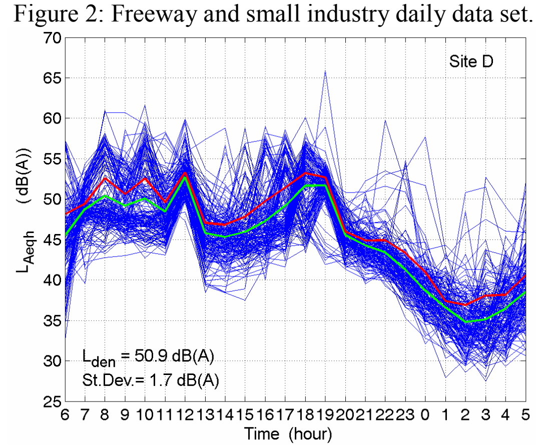

Figure 4: Residential area daily data set.

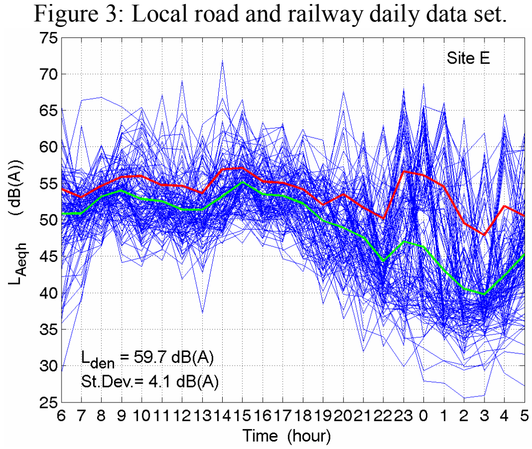

Figure 5: Small airport daily data set.

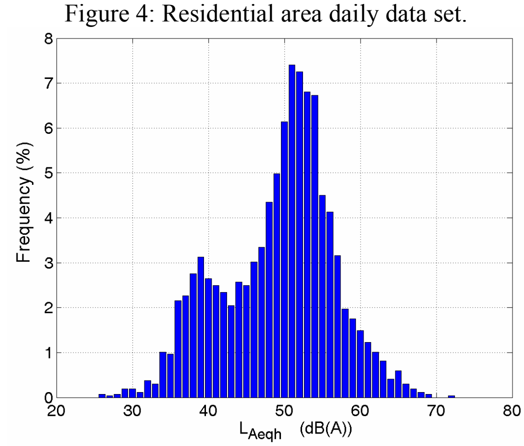

Figure 6: Distribution of hourly L_{Aeqh} long-term data set for the small airport.

2.2 Temporal samplings

Five temporal samplings have been considered, each formed by *m* days, and listed in Table 2 together with the corresponding available data subsets. For each site a *m*-dimensional subset has been randomly extracted from the entire data set without any requirement, excluding the chance, to extract consecutive days. This type of data subset has been chosen because it was already shown [4] that for a given value of *m* day sampling, random day strategy is preferable to the consecutive day strategy. In order to increase the number of subsets on which performing the statistical analysis, the extractions have been repeated 15 times (number of data subsets reported in brackets in Table 2).

Table 2: Temporal samplings and number of m-dimensional subsets available for processing; within ( ) those obtained by random extraction, repeated 15 times.

Temporal sampling		Site				
Duration	Code	A	B	C	D	E
1 day (*m*=1 day) (Sunday excluded)	1D	337 (5055)	239 (3585)	191 (2865)	146 (2190)	96 (1440)
5 weekdays (*m*=5 days) (Monday to Friday)	5D	55 (825)	37 (555)	27 (405)	23 (345)	15 (225)
1 week (*m*=7 days) (Monday to Sunday)	1W	55 (825)	37 (555)	27 (405)	23 (345)	15 (225)
2 weeks (*m*=14 days)	2W	27 (405)	18 (270)	13 (195)	11 (165)	7 (105)
3 weeks (*m*=21 days)	3W	18 (270)	12 (180)	9 (135)	7 (105)	---

The 1W sampling (1 week, *m=7*) has been chosen because required by the Italian legislation [11] as minimum measurement time for road traffic noise, while the 2W sampling (2 weeks, *m=14*) is reported in the literature [4, 12] as sufficiently representative of longer term variation of road traffic noise levels.

2.3 Sampled data analysis

A descriptive statistics of the error **ε**, being a random variable given by $\varepsilon = L_{den,LT} - \hat{L}_{den,LT}$, can provide useful information on how it varies with the temporal samplings. For instance, Figure 7 shows the box plot of the ε errors obtained for the examined temporal samplings at site C.

From a practical point of view it would be more interesting to know the probability of the error ε to be within a specified interval for a given temporal sampling. For instance, Figure 8 shows the results obtained at site A for each of the examined temporal samplings.

Another way to analyze the error ε is to compare the cumulative distribution F of the hourly L_{Aeqh} values for the long term with that F_m corresponding to a m-dimensional data subset given by the sampling. For cautiousness as descriptor of the differences between the two distributions the random variable **q** can be taken as follows:

$$\mathbf{q} = \max\left|F_m(L_{Aeqh}) - F(L_{Aeqh})\right| \tag{4}$$

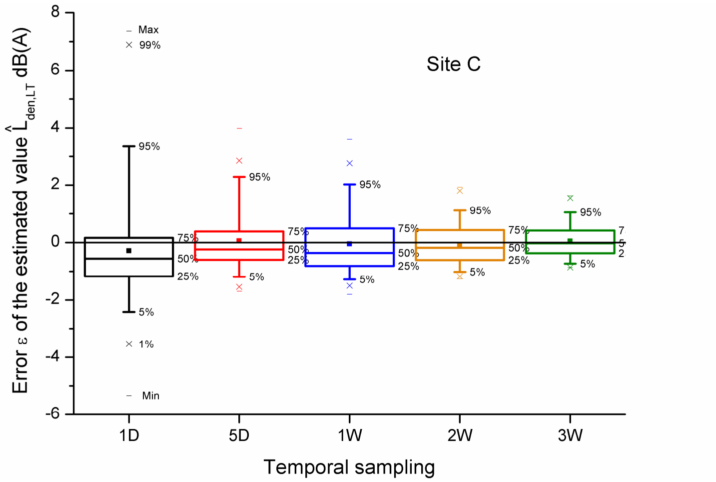

Figure 7: Box plot of the error ε of the estimated value $\hat{L}_{den,LT}$ for the examined temporal samplings.

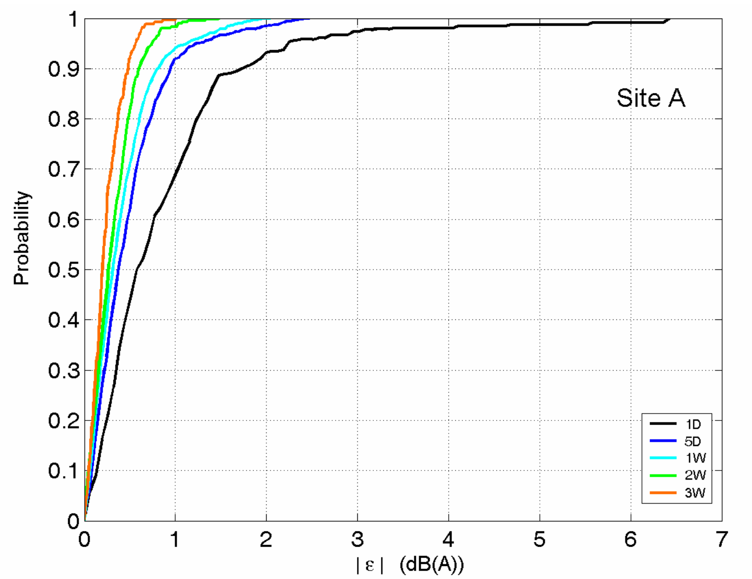

Figure 8: Probability of the module of error ε of $\hat{L}_{den,LT}$ to be within a specified interval.

As example, at site E (small airport) the observed differences between the long-term cumulative distribution (dots) and those corresponding to some temporal samplings are shown in Figure 9. The number of **q** values obtained are equal to the subsets available for processing for each site and any m-dimensional subset (Table 2). To summarize each of the **q** datasets by a single number, the value corresponding to 0.95 probability of the cumulative distribution was chosen (q_{95} in Figure 10). In the further analysis the interval $q_{95} \pm 0.05 \cdot q_{95}$ have been considered in order to increase the number of 24 hour time histories of hourly L_{Aeqh} showing a **q** value within the selected interval. Then the corresponding $\hat{L}_{den,LT}$ values have been calculated, as well as the average of |ε| and the standard deviation of ε.

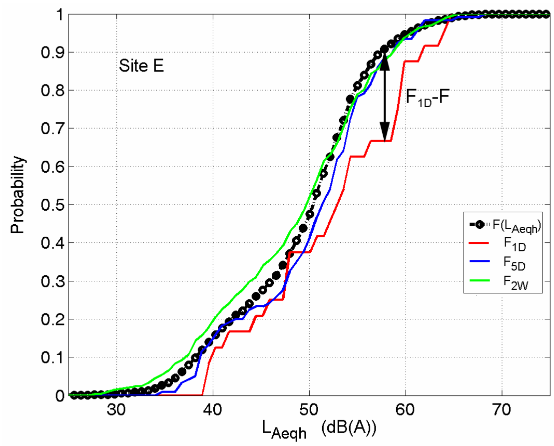

Figure 9: Cumulative distributions of hourly L_{Aeq} for long-term (F) and some temporal samplings (F_m).

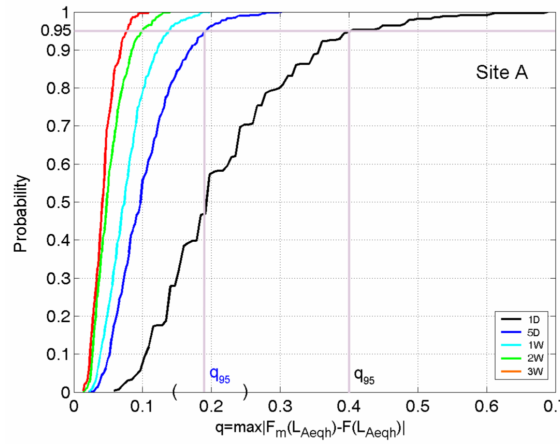

Figure 10: Cumulative distribution of **q** for each temporal samplings at site A.

3 RESULTS AND DISCUSSION

The descriptive statistics on the m subsets provides the mean value of the module of error ε and its standard deviation for each temporal sampling and site (Figure 11 and 12 respectively). As expected, both decrease with increasing the measurement time m and with the reduction of noise levels variability. This variability is represented by the standard deviation σ of the daily L_{den} values on the long-term for each site in Figure 11 and 12. However, the different size of subsets available should be taken into account in any comparison.

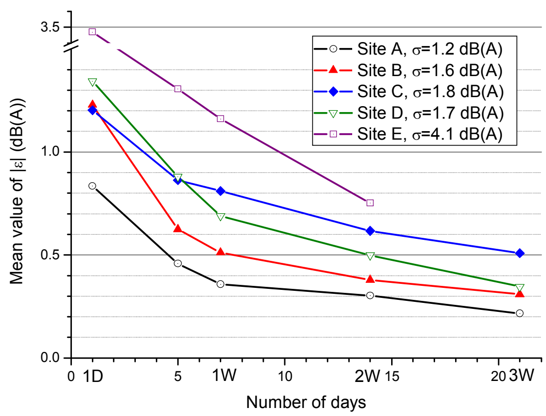

Figure 11: Mean value of the module of error ε for each temporal sampling and site. σ is the standard deviation of the daily L_{den} on the long-term.

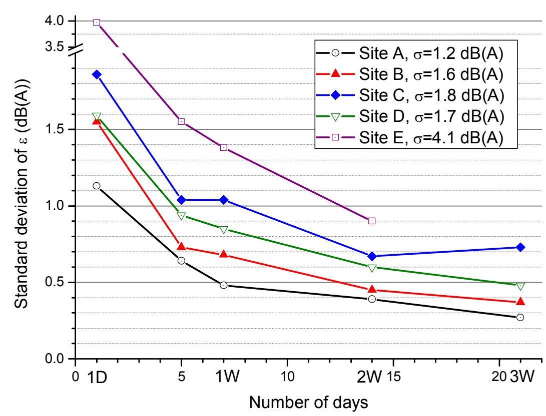

Figure 12: Standard deviation of error ε for each temporal sampling and site. σ is the standard deviation of the daily L_{den} on the long-term.

From the practical point of view, the data available to estimate ε are the number m of days of the temporal samplings and the measured standard deviation s of the hourly L_{Aeqh}. The data corresponding to the sites and the examined temporal samplings are reported in Figure 13 (on the left side) together with the corresponding module of the error ε (on the right side). Both the standard deviation s and the value of $|\varepsilon|$ are given at 95% confidence level.

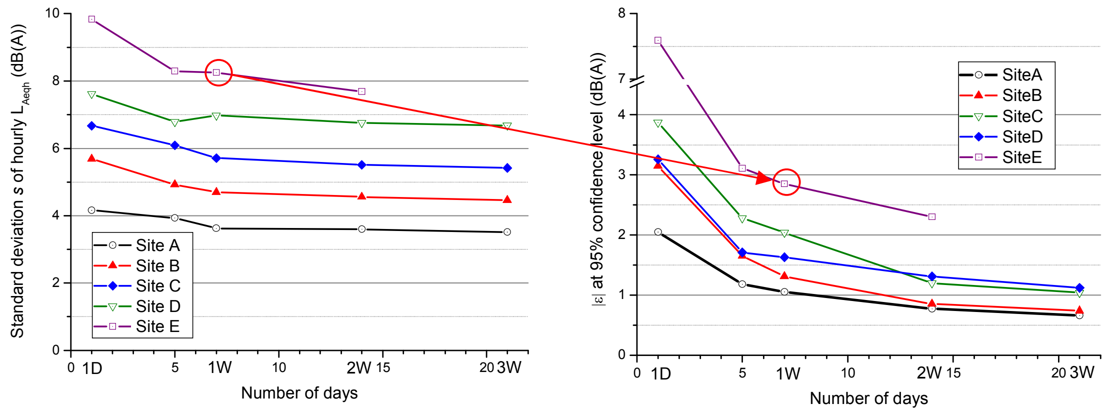

Figure 13: Length of temporal sampling vs. standard deviation s (left side) and module of error ε (right side), both at 95% confidence level for each site.

Looking at the differences between the long-term cumulative distribution F of the hourly L_{Aeqh} values and that F_m corresponding to a m-dimensional subset, Table 3 reports the number of the subsets having q values laying within the interval $q_{95} \pm 0.05 \cdot q_{95}$. Despite the variability of the interval width chosen to be directly proportional to q_{95}, the number of data subsets are not enough to have a robust statistics as obtained in the previous analyses. Thus, the plots in Figures 14 and 15 require cautiousness when compared to the others, especially Figures 11 and 12. However, the mean values of $|\varepsilon|$ related to q_{95} are 33% on average greater than those reported in Figure 11. This behavior could be due to the selection of subsets showing the largest differences between the cumulative distributions.

Table 3: Number of m-dimensional subsets within the interval $q_{95} \pm 0.05 \cdot q_{95}$.

Temporal sampling		Site				
Duration	Code	A	B	C	D	E
1 day (m=1 day)	1D	120	60	90	75	120
5 weekdays (m=5 days)	5D	21	12	14	12	11
1 week (m=7 days) (Monday to Sunday)	1W	24	15	11	14	9
2 weeks (m=14 days)	2W	12	8	6	2	7
3 weeks (m=21 days)	3W	6	3	7	3	---

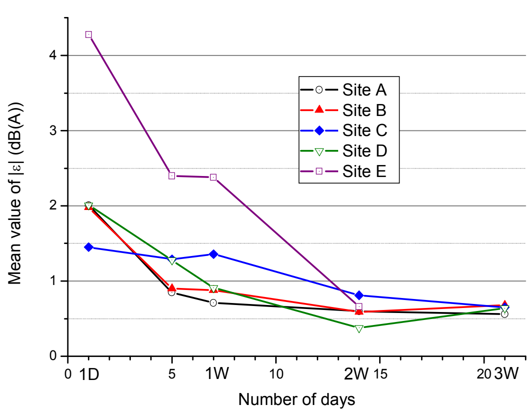

Figure 14: Mean value of the module of error ε for each temporal sampling and site.

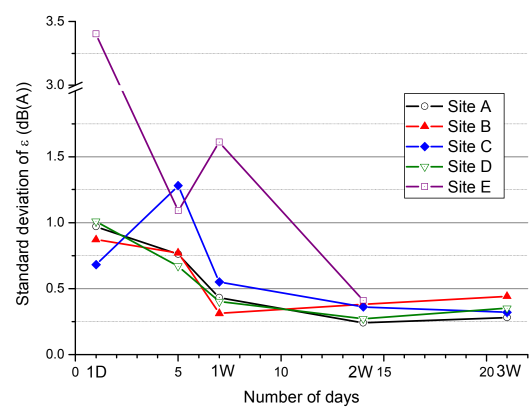

Figure 15: Standard deviation of error ε for each temporal sampling and site.

4 CONCLUSIONS

The large data set of 24 h continuous monitoring of hourly L_{Aeq} collected, even if limited to five sites, has enabled to perform statistical analyses on the accuracy of some temporal samplings in estimating the long-term value of L_{den}. The five temporal samplings examined were mostly formed by non-consecutive days. Three analyses have been carried out on the error ε in estimating the long-term value of L_{den}, that is:

i) descriptive statistics of the data subsets generated according to the temporal sampling rule;
ii) determination of the probability of the module of ε to be within a specified interval;
iii) statistics of the error ε produced by samplings showing the largest differences between the cumulative distributions of the long-term hourly L_{Aeq} and that corresponding to each temporal sampling (cautious approach).

The results show that a monitoring lasting 5-7 non-consecutive days seems a reasonable compromise between time saving and accuracy in estimating the long-term value of L_{den}, even when large variations of hourly L_{Aeq} occur. Moreover, the cautious approach provides values of the error ε, on average, 33% greater than those obtained by the i) analysis in the above list.

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