Air Pollution Investigated by Fluctuating Asymmetry of Leaves

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Abstract. Air pollution is an increasing threat in urban as well as rural areas. Particularly, motor vehicles and their exhaust gases cause considerable health risks. In addition to traditional air monitoring, we propose a new method by investigating morphological changes of leaves coming from trees that are located near streets or roads. Shape changes were measured by computing the already established fluctuating asymmetry index. Results of this study indicate that although air pollution may be lower in rural areas, the influence to the ecosystem can be quite comparable to urban areas.

1. Introduction

The environmental quality is largely determined by human pressure that generates great imbalances. Examples are soil degradation, the pollution of surface water, groundwater and landscape changes, which lead to the formation of special micro and mesoconditions. A feature specific to this impact is the fact that natural systems, increasingly modified by mankind, have a significant impact on life quality and population health. The aim of this study is to develop a methodological framework for quantifying human pressure on the natural environment.

The most accessible method of monitoring plants is the evaluation of morphometric changes. This method presents advantages, among which are rapidness and good accuracy. A major advantage is that the results fit to a statistical analysis of the plants’ reaction to the complex stress by the environment [1].

A promising approach for biomonitoring natural and human environments are evaluations based on morphogenetic monitoring or evaluations based on the stability of living organisms’ development [2; 3]. Furthermore, morphological shapes of organisms are strongly influenced by environmental boundary conditions. Particularly, the asymmetry of shapes, measured with the fluctuating asymmetry (FA) value, represents a reliable indicator [4].

FA measures small non-directional deviations from the usually strict bilateral symmetry and characterizes the morphogenetic homeostasis or stability as a result of the imperfections in the growth processes. Hence, FA is one of the most common and most available methods of analyzing random variabilities in living organisms [5].

For instance, in leaves, the environmental stress causes an ontogenetic change that is expressed by morphological changes such as asymmetric growth yielding higher FA values [6].

At the macroscopic level, the fluctuating asymmetry is proposed as an evaluation method for the stability of the organisms’ development [3, 5]. At the level of morphogenetic abnormalities, the value of FA is minimal only for certain optimal environmental conditions and it increases in a nonspecific
manner for all stress conditions. As a result, and because FA is useful for the stability evaluation, it has been approved by the Ministry of Natural Resources of the Russian Federation as a method of standard analysis [6].

Currently, the dominant factors which cause soil and air degradation in urban ecosystems are industrial pollution, transportation and other types of human activities. The most dangerous and intense source of urban atmospheric pollution is represented by road transport, characterized through the emissions of approximately 300 dangerous substances, among which are carbon monoxide (extremely dangerous), hydrocarbons (cancerous benzopyrene and benzantracene, formaldehyde, benzene), nitric oxides, smokes, lead, mercury, sulphur dioxide, and aldehydes. Several traffic induced negative effects on health and quality of life are already known. Recently, a large cohort study has investigated the incidence of dementia, Parkinson’s disease and multiple sclerosis [7]. Negative effects have been detected even for relatively short distinct distances to major roads of 50m or 100m.

Important research has been made in measuring leaf morphological parameters [8], in classification of leaves by shapes, color and texture features [9], and to classify leaves by their photos [10]. FA computations of leaves have also been made in works [6, 11, 12, 13].

Statistically significant differences were gained by computing a FA value of different leafs by Minakova et al. [14 - 17].

2. Materials and methods
For the determination of leaves ‘asymmetry, silver birch (Betula pendula Roth.) has been selected, a species which is largely spread in the Russian Federation. In addition, Betula pendula Roth tends to become the main target of toxic substances originated from techno-genetic pollution in an urban system (during its lifetime in a local region). Simultaneously, it is the species that is most influenced by the atmospheric and edaphic environments, thus reflecting very well the whole complex of human pressures on an ecosystem.

![Figure 1](image.png)

**Figure 1.** The geographical position of the study area – Kazan – Republic of Tatarstan, Russian Federation.
The locations for the study were in the Republic of Tatarstan (Fig. 1). In the center of Kazan 11 sites at a distance of 5-30m from the streets were chosen. In Raifa, which is part of the Volga-Kama Nature Reserve, five sites and additionally six sites along the federal highway A-295 near Raifa were chosen. In the period August-September 2014-2018 yrs., 100 leaves were collected at each site. Leaf processing was performed according to the method proposed by Minakova E. A. in 2014.

The Republic of Tatarstan is one of the most developed regions of the Russian Federation and has a high population density with large industrial and agricultural complexes, expansive real-estate and transport infrastructure, but also with a powerful scientific and education potential and the wide scope of social services. The city of Kazan, the capital of the Republic of Tatarstan, represents an important industrial center of the Russian Federation. The main pollutants in the ambient air from Kazan are volatile organic compounds, nitrogen oxides, carbon monoxide, hydrocarbons and sulfur dioxides. Kazan is the leader of the total emissions from stationary and mobile sources, the latter having the biggest impact on the environment of the Tatarstan (Fig. 2). The weight of road transport’s contribution to the total air pollution in Kazan is approximately 72% (74,77 thousand tons) [18].

Contrary, the Raifa region is part of a natural reserve and pollution is expected to be much lower than in Kazan.

3. Results
In Kazan, a heterogenic spatial distribution of the index FA was observed. In the largest part of the city, the quality of the environment is not corresponding to the conventional norm. The quality (Table 1) of the environment was described as being critical [16].

In Raifa (part of Volga-Kama Nature Reserve), as well as near Raifa along the influence of the traffic on the highway A-295 relatively high values of FA were observed (Table 2). Figure 6 shows average values for FA of the Kazan sites and for different groups of the Raifa sites. Values are always relatively high but any statistically relevant difference is visible. Although a minor difference between the site #10 in Kazan (average FA=0.048) and the site #6 in Raifa (average FA=0.05) for can be seen in Fig.7, statistical testing revealed that significance is not given (p=0.641, MannWhitney-U-Test).

All sampling sites were located near streets in the city center. The numbers in the first column correspond to the sampling sites shown in Tabl. 1. FA values are given as mean ± standard deviation.
Table 1. FA values of sites in Kazan.

| №  | Site of sampling                               | Average of FA for the period 2014-2018 | Level | Quality of environment                      |
|----|-----------------------------------------------|----------------------------------------|-------|---------------------------------------------|
| 1  | Vahitovskij district - station at Pavlyuhina street | 0.062±0.02                                | 5     | critical state                              |
| 2  | Volga district - station at Victory avenue     | 0.054±0.01                                | 4     | Substantial (significant) deviation from the norm |
| 3  | Volga district - station at Richard Sorge street | 0.057±0.01                                | 5     | critical state                              |
| 4  | Vahitovskij area - station near Chekhov market  | 0.064±0.02                                | 5     | critical state                              |
| 5  | Vahitovskij district - station at Tolstoy street | 0.064±0.02                                | 5     | critical state                              |
| 6  | Sovietskij district - station at Sovietskij Square area | 0.055±0.01                          | 5     | critical state                              |
| 7  | Sovietskij district - station near veterinary institute | 0.055±0.01                          | 5     | critical state                              |
| 8  | Novo - Savinovskij district - station at Gavrilova street | 0.054±0.02                                | 4     | Substantial (significant) deviation from the norm |
| 9  | Novo - Savinovskij district - station at Chuikova street | 0.054±0.01                                | 4     | Substantial (significant) deviation from the norm |
| 10 | Moscow District - station near youth center    | 0.051±0.01 and (0.048±0.01 by 2014)        | 3     | Middle level of deviation from the norm     |
| 11 | Kazanskij district - station at Gorky avenue   | 0.053±0.01                                | 4     | Substantial (significant) deviation from the norm |

All sampling sites were located in villages (part of Volga-Kama Nature Reserve) or near a federal highway. The numbers in the first column correspond to the sampling sites shown in Fig. 3. FA values are given as mean ± standard deviation.
Table 2. FA values of sites in Raifa and near Raifa.

| №  | Site of sampling                                      | FA            | Level | Quality of environment          |
|----|------------------------------------------------------|---------------|-------|---------------------------------|
|    | Public roads on the territory of rural settlement in Raifa                      |
| 1  | At the office of Volga-Kama state natural biosphere reservation (village Sadovaya) | 0.056±0.011   | 5     | critical state                  |
| 2  | Road from village Sadovaya                          | 0.054±0.013   | 4     | substantial (significant) deviation from the norm |
| 3  | Road to village Sadovaya                            | 0.055±0.012   | 5     | critical state                  |
| 4  | Along the road on the left (Raifa road, village Sadovaya) | 0.055±0.016   | 5     | critical state                  |
| 5  | Raifa Monastery                                      | 0.054±0.013   | 4     | substantial (significant) deviation from the norm |
|    | Sites in the zone of influence of the federal highway A-295 near Raifa |
| 6  | Raifa forest just at the federal highway A-295 (by 2014) | 0.055±0.013 (by 2014) | 5     | critical state                  |
| 7  | Village Novochuvatskij (road to Kazan)                | 0.06±0.014    | 5     | critical state                  |
| 8  | Village Novopol'sky (road to the Zelenodolsk City)   | 0.056±0.0095  | 5     | critical state                  |
| 9  | Village Urnyak (road to Kazan)                       | 0.056±0.011   | 4     | substantial (significant) deviation from the norm |
| 10 | Village Dubrovka (road to Zelenodolsk City)          | 0.055±0.012   | 5     | critical state                  |
| 11 | Village Dubrovka (road to Kazan)                     | 0.06±0.016    | 5     | critical state                  |

4. Discussion

In this study, we have used the fluctuating asymmetry of leaves. The results represent a starting point in the development of complex methodologies for assessing the pollution impact on ecosystems. The asymmetry on leaves topic is being discussed in many studies, but it is treated from different points of view. The analysis of the development instability, examined on two native herbs, across a gradient of mechanical soil disturbance, varies with species and the year. The disturbance level was also classified based upon the average level of plant disturbance instability [12]. Other studies [13] show that the values of repeatability and reproductivity between different assistants of different plant species of the same sets of leaves are much lower. That proves that occasional or random technical errors can be neglected.

In our study, we observed that traffic has an impact on the environmental quality in Raifa and surrounding areas under the influence of the federal highway A-295, despite the considerable distance from the city of Kazan and the availability of green areas that contribute to the dispersion of pollutants (special protection area of Volga-Kama Nature Reserve).

The main findings of this study are summarized below:
- FA offers valuable and precise information regarding the impact of the human activities on the morphogenesis of leaves. The reason is that FA can capture and describe irregular structures very well. Therefore, FA can be used for the evaluation of morphometric characteristics of leaves.
- FA proved to be a very useful index which shows how the asymmetry level for the right or for the left side of the leaves evolves under the impact of negative environmental quality modifications caused by human.

- The fluctuating asymmetry analysis have shown that the quality of the environment under the influence of the traffic on the federal highway A-295 near Raifa is low, despite of the considerable distance from the city of Kazan and of the availability of green areas which contribute to the dispersion of pollutants in the territory (Volga-Kama Nature Reserve).

- FA is a versatile method to detect manifestations of randomly varying developments of a living organism under the impact of the environmental quality.

It is particularly important to extend this research to other regions with different human pressures, with different climates, but also to other species of plants.

Furthermore, the model proposed could be used for the analysis of the asymmetry of hydrographic basins or for the spatial modelling of economic parameters.

5. Conclusions

Fluctuating asymmetry is proved to be versatile, precise and complementary methods for the determination of the symmetry modifications of leaves when exposed to different environmental factors. Along with already established methods, this approach may lead to scientific studies to assist pragmatic decision to a sustainable territorial management.

Air pollution of exhaust gases of automobile engines is an urgent environmental problem requiring urgent solutions. Exhaust gases of motor vehicles contain dozens of toxic substances that have a negative impact on roadside vegetation. This is manifested e.g. in altered morphological features of leaves of trees near highways. Residents of cities are usually exposed up to several hours every day, breathing in pollutants that are concentrated directly in the lungs. The quantitative measurement of air pollution is the basis for determining the state of the environment, since air pollution has the greatest impact on the population’s health.

6. References

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