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ECOLOGY

Impact of Technogenic Pollution of Urban Environment on Vitality Indicators of Urban Biota (Mollusk Fauna, Soil Mesofauna, Epiphytic Lichens)

N. V. Yorkina

Khmelnitsky Melitopol State Pedagogical University, Department of Chemistry and Biology, Melitopol, 72312 Ukraine
e-mail: nadeen777@mail.ru

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Abstract—The article presents results of ecological, chemical, and bioindication assessment of the urban ecosystem of an industrial city in the South of Ukraine. The dynamics of physical and chemical parameters of soil, surface water, and air in various functional areas of the city was analyzed. The complex pollution index for environmental components was determined. Bioindicative assessment of the ecological condition of the urban ecosystem was performed based on vitality parameters of epiphytic lichen flora, soil mesofauna, and freshwater mollusk fauna. Based on bioindicators' vitality, zones with different ecological conditions were demarcated. Toxic effects of various pollutants on living organisms and tolerance of some bioindicator species under anthropogenic pressure were analyzed. It was found that the amount of zoophages increases and homogenization of anamorphoscope composition of major mesopedobionts groups with the dominance of individual species is observed in anthropogenically transformed areas. In alkaline soils of functional areas of the urban ecosystem, prevalence of calcicole species—millipedes, pill bugs, and gastropods—was noted, which allows them to be used as soils' alkalization level indicators. The degree of correlation between the viability of bioindicator groups and complex pollution index of basic components of the urban environment was determined. For instance, an inverse correlation between the vitality of epiphytic lichen flora (G, %) and the complex atmospheric air environmental contamination index (P_a) (–0.80, $p < 0.05$); and a direct correlation between the decline in the vitality of soil mesofauna ($\bar{G}$,%) and complex soil contamination index (Z_s) (0.84, $p < 0.05$) were discovered. Therefore, biomorphs of epiphytic lichen flora and some groups of mesopedobionts can be used as pollution indicators for urban environments. Based on the study results, an algorithm for complex ecological, chemical, and bioindication assessment of ecological condition of an urban ecosystem in an industrial city was proposed.

Keywords: bioindication assessment, urban ecosystem, mollusk fauna, soil mesofauna, epiphytic lichens, ecological condition, vitality

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INTRODUCTION

Active urbanization processes and industrial development have led to significant pollution of soils, surface waters, and atmospheric air in cities. This caused a decrease of tolerance of living organisms—pedosphere dwellers, hydrobionts, and epiphytic lichens—and growth of the population incidence rate. Therefore, modern researches of urban environments are focused on identification of methods allowing one to assess the condition of urban air, soils, and waters quickly and accurately. However, classic approaches, based on ecological and chemical studies of urban environments, require considerable investments, while the commonly used techniques are often limited to identification of individual pollution sources for soil, atmosphere, and surface waters [1–5].

Bioindication is an effective and low-cost assessment method for an urban ecosystem; it is based on identification of most representative markers among flora and fauna species that have adapted to living conditions of the urban ecosystem [6]. Therefore, analysis of technogenic pollution impacts on urban biota vitality parameters and complex assessment of various functional urban areas becomes a primary objective of fundamental studies related to urban ecosystems.

MATERIALS AND METHODS

Experimental studies were performed in 2008–2012 in the city of Melitopol of the Zaporizhia oblast. The research program included ecological and chemical assessment of the city's urban ecosystem, bioindicative assessment of vitality parameters for epiphytic lichen flora, freshwater mollusk fauna, and soil mesofauna and determination of the ecological condition of the area.

The functional zones were demarcated using the urban zoning technique developed by Kalabekov [7]. The main units were: residential communities (six zones), industrial facilities (four zones), recreation areas (three zones), and areas located along motorways (three zones).

The following parameters were defined to characterize the ecological and chemical condition of the functional zones: complex atmosphere contamination index (P_a), complex water areas quality assessment index (P_w), and complex soil contamination index (Z_s). Results of the ecological and chemical assessments were correlated with vitality indicators (G) for the epiphytic lichen flora, hydrobionts, and mesopedobionts; the vitality indicators were calculated by multiplication of biodiversity W_i by the population density S of the indicator groups divided by their maximal values: $G = W_i/W_{\max}S_i/S_{\max}$ [6, 8].

Ecological and chemical assessment of the complex atmosphere contamination for the city of Melitopol included analysis of samples for the following pollutants: nitrogen dioxide, carbon monoxide, phenol, ammonia, sulfur dioxide, and suspended substances. Sampling was performed following the standard practice. M 822 and Taifun R–100 (B) aspirators were used to measure pollutant concentrations; Palladii-3M universal gas analyzer was used for carbon monoxide content measurement.

Water samples were collected along the Molochnaya River and the Peschanii and Kiziyarskii creeks. The following parameters were measured: pH; suspended substances (SS); chemical and biochemical oxygen consumption (COC; BOC); chlorides and sulfates concentration; active forms of Cd, Pb, Zn, and Cr. For sample collecting and analyzing, relevant analyzers were used. VARIAN AA240Z atomic absorption spectrometer was used for measurement of pollutant concentration in water objects; pH was measured by potentiometry using a pH–121 millivoltmeter pH-meter.

Soil samples were collected from the upper 10–20 cm horizon in soddy, mostly gleyed, sand and clay loam soils with low-humous sands; south solonetzic chernozems; and dark-chestnut permanent solonchak soils.

The following parameters were used to determine the ecological condition of soils in the Melitopol urban ecosystem: pH and concentration of active forms of biologically active heavy metals (Cd, Pb, Zn, and Cu). Acidity was measured by potentiometry using pH–121 millivoltmeter pH–meter. VARIAN AA240Z spectrometer was used to measure concentrations of active forms of heavy metals utilizing the atomic absorption technique. Active forms of heavy metals were extracted by ammonium–acetate buffer solution with pH 4.8.

Local (background) areas located outside the anthropogenically-affected areas, in the Forest Park recreation zone, were selected for comparison purposes to assess the urbanization impact on the soil pollution with heavy metals. The principle of geological and landscape–geochemical homogeneity of soils suggested by Yu.E. Saet was used in the selection of background areas.

Identification of lichen species was performed using identification keys by A.N. Oksner and S.Ya. Kondratyuk; freshwater and terrestrial mollusk species were identified using identification keys by N.V. Gural'-Sverlova and R.I. Gural' [9].

Microsoft Excel and STATISTICA–6.1 software products were used for processing and graphic presentation of the data. The studies were performed according to the algorithm for complex ecological, chemical, and bioindication assessment of ecological condition of an urban ecosystem (Fig. 1).

RESULTS AND DISCUSSION

Melitopol (46°50'00" N, 35°22'00" E) is a large regional-level city located in the southeast of the East European Plain on the border between the middle steppe and dry steppe subzones of the steppe zone. The total area is 49.66 km^2. The climate is moderate continental.

The city includes 78 industrial facilities whose operations affect the environment negatively.

A group of biophil metals—Cd, Pb, Zn, and Cu—that are highly toxic, resistant to decomposition, and accumulate in tissues of mesopedobionts were chosen for ecological and chemical assessment of the soil cover in the city. Stationery and mobile sources contaminate the Melitopol urban ecosystem with heavy metals; the major pollution sources are engineering and metalworking factories, vehicle emissions, domestic waste, and waste water.

According to foreign studies, the "key" functional groups of soil mesofauna are represented by ecosystem "engineers," microregulators and microsymbionts, saprophages, pathogenic organisms, and bacterial transformers [10].

In addition, soil invertebrates used as bioindicators must be numerous enough and resistant to small doses of toxicants, while the biodiagnostics results must be well reproducible [11].

It is known that bioindication assessment of ecological condition of the soil cover is based on vitality parameters of mesopedobionts, who can be arranged according to their sensitivity to heavy metals (from less vulnerable to most vulnerable) as follows: centipedes—arachnids—mollusks—earthworms—woodlouses [12].

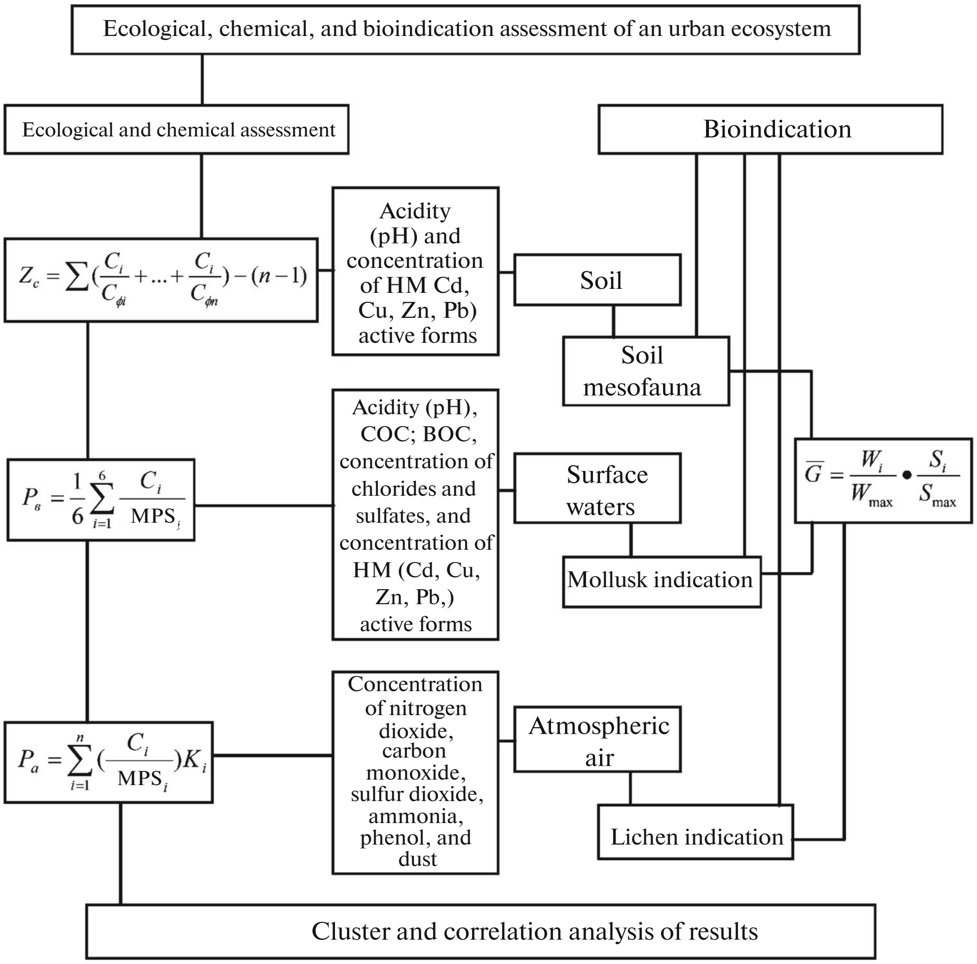


Fig. 1. Algorithm for complex assessment of ecological condition of an urban ecosystem.

All of the aforesaid was used as a basis for determination of impact of technogenic pollution of the urban environment on vitality parameters of the urban biota. Functional areas with different pollution levels were demarcated based on the bioindication assessment of the Melitopol urban ecosystem.

A favorable ecological condition was observed in the Forest Park recreation zone. The decline in vitality of soil mesopedobionts $\overline{G}$ (G_b of G_{max} = 60 units/m^2) was 9.5%. Phytophagans were the dominant trophic group in all parts of the recreation zone (68.3%). The range of hygromorphism among the mesopedobionts varied from ultrahygrophiles to xerophiles.

A stress ecological condition was detected, based on the vitality of soil mesopedobionts, in recreation zones as well: the City Park ($\overline{G}$ = 24.7%), the Institute of Irrigated Horticulture ($\overline{G}$ = 24.3%), and residential communities—Mikroraion ($\overline{G}$ = 22.5%) and Cottage District in the New Melitopol ($\overline{G}$ = 23.8%).

Areas with critical ecological condition included functional zones of residential areas (center, Aviagorodok) and motorways (TV Center). Decline in the mesofauna vitality in the city center was $\overline{G}$ = 50%, it was $\overline{G}$ = 40.2% in Aviagorodok, while it was $\overline{G}$ = 45.7% in TV Center.

A crisis ecological condition was detected in some parts of Peschanoe residential community ($\overline{G}$ = 58.2%) and motorways: the Berdianskii Bridge ($\overline{G}$ = 66.3%) and South Overpass ($\overline{G}$ = 78.3%).

Based on the urban ecosystem bioindicative assessment, four areas with catastrophic ecological condition were identified. These include areas of industrial facilities and Kiziyar residential community (the decline in mesofauna vitality exceeded 90%). An increase in the zoophages population and homogenization of anamorphoscope composition of major groups of mesopedobionts with the dominance of individual species were detected.

In alkaline soils of the Melitopol urban environment, prevalence of calcicole species—millipedes, pill bugs, and gastropods—was noted, which allows us to use them as soil alkalization level indicators.

The above results are confirmed by ecological and chemical assessment of the urban area. In functional zones with crisis and catastrophic condition, higher concentrations of Cd, Pb, Zn, and Cu active forms were detected. Industrial facilities and motor vehicle were main pollution sources for urban ecosystem edaphotopes.

A comparison of the ecological and chemical assessment of Melitopol urban ecosystem soils and bioindication assessment of them demonstrates a strong correlative relationship between the decline of vitality in bioindicator groups and the complex soil contamination index $Z_s = 0.84$ (the detected correlations are relevant at the $p < 0.05$ level).

β-mesosaprobic gastropods—*Lymnaea stagnalis* (Linnaeus, 1758), *Viviparus viviparus* (Linnaeus, 1758)—and a bivalve mollusk–oligosaprobiont *Anodonta anatina* (Linnaeus, 1758) were used as bioindicators of the ecological condition of water courses.

The dominance of β-mesosaprobic mollusk fauna demonstrated a moderate pollution level in the city water courses.

Functional zones with stress, crisis, and catastrophic condition of water bodies were identified based on mollusk bioindication of the Melitopol urban ecosystem.

A stressful ecological condition of the Molochnaya River was detected in the functional zone of Refma manufacturing facility. The decline in the vitality of freshwater mollusk fauna $\overline{G}$ in this functional zone (G_m = 69 units/m^2 in comparison with $G_{\max}$ = 91 units/m^2) was 24%. All the hydrobiont groups (oligo– and mesosaprobionts) were found in the studied area.

A crisis ecological condition of surface waters was detected, based on the decline in hydrobiont vitality, in the Forest Park recreation area ($\overline{G}$ = 67%) and Peschanoe residential community ($\overline{G}$ = 72%). Only β-mesosaprobic mollusk species were found in these functional zones.

A catastrophic ecological condition of water bodies was identified, based on mollusk fauna assessment, in most areas. In residential communities, the declines in hydrobiont vitality were as follows: Peschanoe residential community ($\overline{G}$ = 93%), New Melitopol (($\overline{G}$ = 95%), and Aviagorodok ($\overline{G}$ = 96%).

Therefore, the mollusk fauna bioindication assessment demonstrates predominance of functional zones with crisis and catastrophic ecological condition of water bodies.

Foliose and crustaceous nitrophytes and acidophytes predominated in the epiphytic lichen flora of Melitopol. In particular, it included *Xanthoria parietina* (L.) Th. Fr.*, Physcia stellaris* (L.) Nyl.*, Scoliciosporum chlorococcum* (Stenh.) Vezda*,* and *Hypogymnia physodes* (L.) Nyl. The epiphytes preferred eutrophic substrates, rich with mineral nutrients, and were found on very dusted bark of phorophytes [13].

Fruticose and foliose lichen species (*Ramalina fraxinea* (L.) Ach.*, Evernia Prunastri* (L.) Ach.*, Parmelia sulcata* Tayl.*,* and *Pleurosticta acetabulum* (Neck.) Elix et Lumbsch) were found in recreation zones. A visible increase in poliotolerant species resistant to technogenic air pollution— *Physcia stellaris*, *Xanthoria parietina*, and *Scoliciosporum chlorococcum*—was observed in all areas.

A quantitative analysis of epiphytes showed that leafy species were preferred substrates: field maple (*Acer campestre L.*), black locust (*Robinia pseudoacacia L.*), poplars (*Populus nigra L., Populus alba L.*), maple ash (*Acer negundo L.*), etc.

Zones with different ecological condition were demarcated based on the complex environmental contamination index (P_a) and vitality parameter of the epiphytic lichen flora (G).

A crisis ecological condition of the area was identified in the vicinity of Refma manufacturing facility (G_{cl} = 8%) and Kiziyar residential community (G_{cl} = 9%).

Functional zones of New Melitopol, Mikroraion, and Peschanoe residential communities, as well as Melitopol Plant of Tractor Hydraulics industrial facility, were defined as areas with critical ecological condition. The highest vitality of foliose lichen flora was observed in the City Park recreation area (G = 48%); the lowest vitality was observed in the vicinity of the TV Center motorway (G = 14%). A satisfactory ecological condition was identified in the South Overpass industrial zone (G_f = 35%) and Aviagorodok residential community (G_f = 45%).

The Forest Park recreation zone demonstrated favorable ecological condition (G = 80%).

The main pollutants of Melitopol functional zones are: sulfur dioxide, nitrogen dioxide, and suspended substances. An increase in their concentration was observed both in zones of industrial facilities and motorways and zones of residential communities. A comparison of ecological and chemical assessment and lichen indication assessment of the atmospheric air condition in the Melitopol urban ecosystem reveals a strong inverse correlation between the vitality of epiphytic lichen flora and the complex technogenic air contamination index (P_a = –0.80 ($p < 0.05$, N = 11).

Lichen indication assessment results matched against average annual atmospheric air pollution indexes are shown below (Fig. 2).

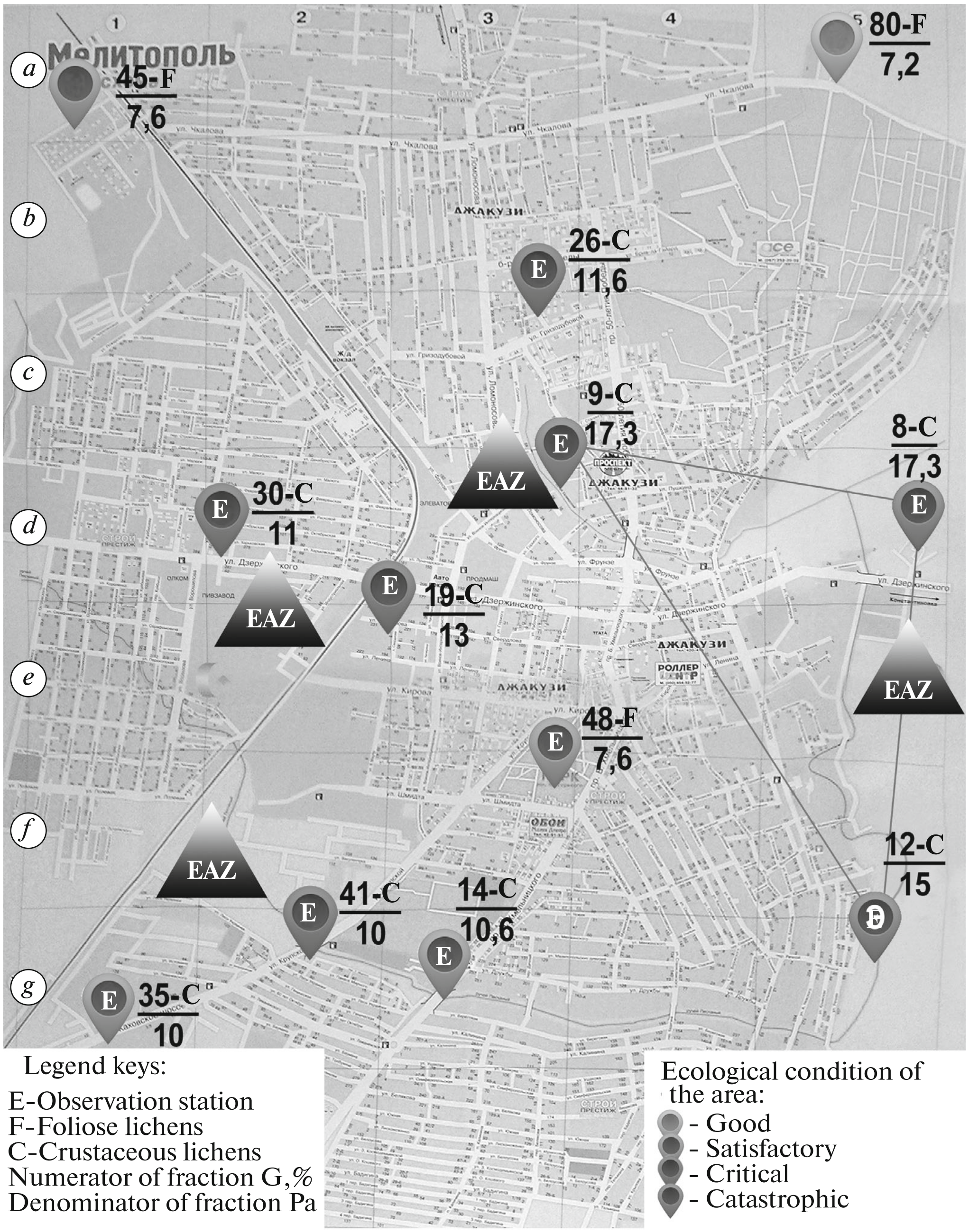


Fig. 2. Lichen indication map of technogenic air pollution of the city of Melitopol.

Bioindication assessment of the ecological condition of the Melitopol urban ecosystem was performed using cluster analysis (Fig. 3).

Based on cluster analysis results for the soil contamination data, Melitopol functional zones are ranged as follows:

(1) Catastrophic ecological condition of the area: T-1, T-2, T-3, and T-5;

(2) Crisis ecological condition of the area: T-11, T-12, and T-13;

(3) Critical ecological condition of the area: T-8, T-10, and T-14;

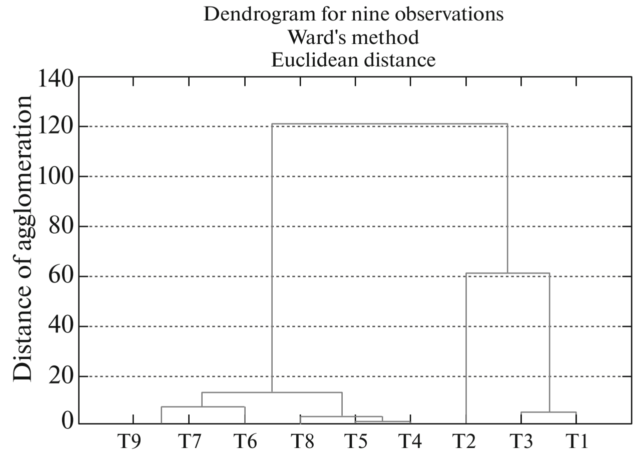
(4) Stress ecological condition of the area: T-4, T-6, T-17, and T-9;

(5) Favorable ecological condition of the area: T-15.

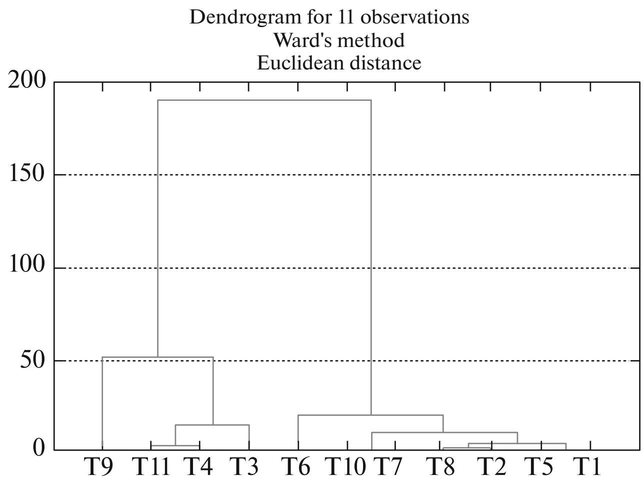
Based on cluster analysis results for the mollusk indication assessment, functional zones are ranged by the ecological condition of water courses as follows:

(1) Catastrophic condition: T-4, T-5, T-6, T-7, T-8, and T-9;

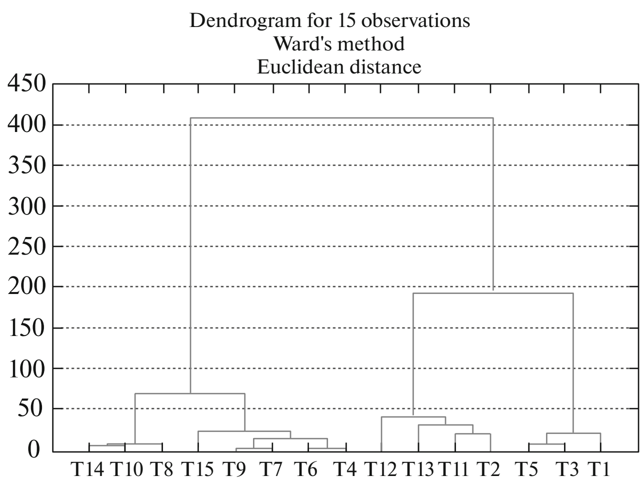
(2) Crisis condition: T-1 and T-3;



Cluster analysis results for surface waters pollution data for 2008–2012



Cluster analysis results for atmospheric air pollution data for 2008–2012



Cluster analysis results for soil cover pollution data for 2008–2012

Fig. 3. Cluster analysis results for soil, surface waters, and atmospheric air pollution data.

(3) Stress condition: T-2.

Figure 3 also shows cluster analysis results for technogenic air pollution data of the Melitopol urban ecosystem. According to these results, the functional zones are ranged as follows:

(1) Crisis ecological condition: T-7 and T-10;

(2) Critical ecological condition: T-1, T-2, T-5, and T-8;

(3) Satisfactory ecological condition: T-3, T-4, T-6; and T-11;

(4) Favorable ecological condition: T-9.

Therefore, based on ecological and chemical assessment of Melitopol urban soils, differences in the soil condition for various functional zones were established based on acidity (pH) and concentration of active forms of heavy metals. A strong direct correlation between the decline in the vitality of soil mesofauna and the complex soil contamination index (0.84, $p < 0.05$) and an inverse correlation between the vitality of epiphytic lichen flora and the complex technogenic air contamination index (–0.80, $p < 0.05$) were discovered.

A comparative analysis of the bioindication assessment and ecological and chemical assessment demonstrates that vitality parameters of epiphytic lichen flora, soil mesofauna, and hydrobionts can be used as an operative and low-cost method to research the ecological condition of similar urban ecosystems and for timely detection of adverse environmental signs in urban areas.

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