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AIR QUALITY COMPLEX INDEX FOR ESTIMATION OF AIR POLLUTION SITUATIONS

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To improve the regional system for assessment and management of the ambient air quality in the North-East Estonian region of oil shale mining and processing, as well as natural areas, the corresponding Air Quality Complex Index (AQI) has been elaborated. This method enables to generalize a large number of measured numerical values of concentrations of pollutants in case of multicomponential pollution fields and makes the results more easily understandable. The AQI is suitable for the real-time monitoring as well as for prediction of air quality values and pollution situations by calculated data.

Introduction

The natural and residential areas in the north-eastern Estonia (NE Estonia) are affected by multicomponent aerotechnogenic influxes, the individual ingredients of which have different hazardous characteristics in respect to health and plants. The simultaneous presence of 8-10 or more pollutants in the ambient air is typical for general pollution situation, especially in the neighbourhood of the oil shale processing plants. On all territory of NE Estonia the fly ash and sulphur dioxide, first of all, and other pollutants from burning oil shale in the power plants (PP) have been discovered.

In such conditions the need to describe air quality in a simplified form becomes actual. One way is to make use of special criteria - the Air Quality Index which permits the presentation of actual or prognostic pollution situation data in such a way that makes prevailing conditions more easily understandable than when using concentration data as such for many components in the air [1-4]. Principally, such index is a

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convenient tool for systematization and generalization of overground concentrations of pollutants by effects to ecosystems and inhabitants. The amount of information about concentrations of contaminants and real situation in the different regions of the landscape can be concentrated in the index form (index number), depending on the corresponding calculation method.

The present paper deals with elaboration and practical use of the integrated Air Quality Complex Index (AQI) for multicomponential pollution fields, which takes into account the short-term and long-time concentrations of pollutants in the ambient air in respect of health and nature, different dangerous effects of pollutants and combines the advantages of earlier described methods.

Historical Trends of Air Quality Index

Practically, the use of various index-systems in order to describe the air quality and pollution situations has been well-known long ago and has merited attention by many scientists working in the field of environment protection and air quality management.

The simplest method is based on comparison of the fresh air quantities which are necessary for dilution of emitted pollutants fluxes to the level of their limit values in the atmospheric air [5]. In Canada, USA, Finland and Hong Kong, in case of multicomponential pollution fields a subindex is calculated for each individual pollutant by a segmented linear function and the maximum of all subindices is selected as the complex index for the given site [1, 6-9]. In some investigations the subindices were also calculated while taking into account the limit values, but additionally different biologically dangerous effects of pollutants were accepted and the complex index by summation of subindices or by root-mean-square method was established, correspondingly [10-12]. The main advantage of the last methods is the principle that harmful effect of different pollutant groups may differ in respect to health in case of equivalent overcoming of limit values. At the same time the following serious faults must be taken into account: the sum total of subindices described in the method [10] would characterize the pollution situation only in case when all pollutants in the air belong to the same synergetic group of harmful substances. It is also absolutely non-acceptable that in case of root-mean-square method [12] the value of complex index (common index for given system) can be smaller than the highest subindex for individual pollutants.

The Finnish Meteorological Institute [2] recommends for calculation of air quality index another method which is based on a power equation in which the power changes, depending on the levels of the subindices and their mutual interrelations. As a result, the value of complex index is always equal or exceeding the values of subindices, but this method does not take into account different dangerous effects of pollutants.

In many cases special index categories (such as very good, good, satisfying, fair, unhealthy, passable, poor etc.) are used for qualitative estimation of air pollution conditions, based on the health effects; effects on nature and materials are also considered [1, 6, 13].

Air Quality Complex Index (AQI) for Estimation and Management of Air Pollution Situations

Calculation of AQI

This elaborated method for calculation of AQI enables to take into account the factual (monitored) or computed concentrations of the pollutants in the overground air layer in respect of health and nature, as well as different dangerous effects of pollutants etc. This index system is based on following main presumptions:

- Estimation of air quality, characterization of pollution situation and effects for local inhabitants and nature is possible
- Value of the AQI for multicomponential pollution fields should always exceed or equal the maximum value of subindices (AQI_{sub}) for individual pollutants
- The monitored or computed (by special programs) concentrations (C) of pollutants in the ambient air should be taken into account, including the short-term maximum and average concentrations for longer periods
- The various biologically dangerous and synergetic effects of pollutants etc. should be accepted
- The index will follow the limit values (recommendations of the WHO, EU, UNECE, Estonian state normatives etc.) of pollutants, which are based on the effects on nature and men health (Table 1).

Calculation of AQI is based on the comparison of the concentrations of individual pollutants C in the overground air layer with their limit concentrations (Lim$C$) in the ambient air, whereas the main aspect has a principle that the pollutant concentrations below Lim$C$ have no harmful effects. In the present time in Estonia (Table 1) following two criteria in respect to residential areas and inhabitants are used: the 0.5-hour or short-term maximum limit concentration (LimC_m) and 24-hour or daily mean limit concentration (LimC_d).

As a rule, the plants are more sensitive to chemicals and the ecosystems are affected essentially if the pollutant concentration C in the ambient air during long period exceeds 50 % of LimC_d value [7]. Table 1 shows that critical loads and guide concentrations (Lim$C_{n,y}$ as a yearly

Table 1. **Air Quality Standards, μg m^{-3} [15-17, 25]**

Pollutant	For man			Ecology (nature)	
	Lim C_m (short-term)	Lim C_d (daily)	Lim C_y (yearly)	Lim$C_{n,d}$ (daily)	Lim$C_{n,y}$ (yearly)
SO_2	L/500 (Estonia, 0.5-hr) G/500 (WHO, 10-min) G/350 (WHO, 1-hr)	L/50 (Estonia) L/365 (USA) G/125 (WHO) G/100-150 (EU)	L/30 (Switzerland) L/80 (USA) G/40-60 (EU)	C/70, crops (UNECE) G/100, ecology (WHO)	C/10, lichens (UNECE) C/20, forest, vegetation (UNECE) C/30, crops (UNECE) G/30, ecology (WHO) G/25, trees (IUFRO) G/50, growing trees (IUFRO)
NO_2	L/400 (Estonia,0.5-hr)*1 G/200 (WHO, 1-hr)	L/150 (Estonia) G/150 (WHO)	G/40 (WHO) L/100 (USA) L/80 (Germany)	C/95, vegetation (WHO, 4-hr)	G/30, vegetation (WHO) C/30, vegetation (UNECE)
NH_3	L/200 (Estonia, 0.5-hr)	L/40 (Estonia)	–	G/270 (UNECE) G/23 (UNECE, 1-month)	C/8 (UNECE)
HF	L/20 (Estonia, 0.5-hr)	L/3 (Estonia)	–	–	P/1-3, lichen*2 P/3-4, conifers*2
Ozone	L/100 (Estonia, 0.5-hr) G/150-200 (WHO, 1-hr) G/120 (Sweden, 1-hr)	L/30 (Estonia) G/65 (WHO) G/120(WHO,8-hr)	–	G/65, vegetation (WHO, EU) C/80, forests (UNECE, 1-hr) C/50, growing period (UNECE, 7-hr)	G/60, growing period (WHO, 100-days)
Total suspended particles	L/150-500 (Estonia) L/200 (Japan, 1-hr)	L/50-150 (Estonia) L/150 (USA) G/70-120 (WHO)	L/50 (USA) L/50 (Sweden, 0.5-yr)	–	P/10, lichen*2 P/20-30, conifers*2 P/50-80, deciduous trees*2
Benzene	L/200 (Estonia)*3	L/200 (Estonia)	L/10 (Germany) G/1 (Netherlands)	–	–

N o t e s : In the parentheses the states and organizations are shown: WHO - World Health Organization, EU - European Union, IUFRO - Union of Forest Research Organization, UNECE - United Nations Economic Comission of Europe. L - limit value, G - guideline or guide value, C - critical load, P - proposal.
*1 The sum of NO + NO_2. *2 Recommended by V. Kryuchkov [17]. *3 The sum of aromatic hydrocarbons: benzene + toluene + xylols + ethylbenzene.

Table 2. **Characterization of Air Quality by Complex Index and Effects to Inhabitants**

AQI	Air quality	Effects
0-50	Good	No effects
51-100	Satisfying	No effects (the effects are improbable)
101-300	Insufficient (unhealthy)	Influence on some sensitive individuals (respiratory illnesses, heart diseases etc.)
301-500	Poor (very unhealthy)	Remarkable effects on general groups of public
More than 500	Very poor (extraordinarily unhealthy)	Strong effects on general groups of public

Table 3. **Characterization of Overground Air Pollution Level and Effects to Nature**

AQI_{sub}		Air pollution level		Effects to nature (ecology)	Conditions
$AQI_{sub,A}$ (by Max$C$) *1	$AQI_{sub,B}$ (by MeanC_y)	Characterization	Zone*2		
0-50	≤ 5	Very low	III-B (0)	No effects or very slight effects are possible	Max$C \le$ Lim$C_{n,y}$ Mean$C_y \le 0.1$Lim$C_{n,y}$
51-65	≤ 5	Low	III-A (1)	Slight effects on materials and natural objects	Lim$C_{n,y} <$ Max$C \le$ LimC_d Mean$C_y \le 0.5$LimC_n
66-100	≤ 50	Moderate	II (2)	Effects on materials and natural objects	Lim$C_d <$ Max$C \le$ LimC_m Mean$C_y \le$ Lim$C_{n,y}$
>100 (101-300)	≤ 50	Relatively high	I-A (3)	Remarkable effects on plants (lichen, trees etc.), effects on materials	Max$C >$ imC_m Mean$C_y \le$ Lim$C_{n,y}$
>100 (301-500)	51-100	High	I-B (4)	Remarkable and strong effects on natural objects, materials	Max$C>$LimC_m Lim$C_{n,y}<$Mean$C_y\le$LimC_d
>100 (>500)	> 100	Very high	I-C (5)	Strong effects on nature	Max$C >$ LimC_m Lim$C_d <$ Mean$C_y \le$ LimC_m

Note: In the parentheses: *1 More frequent values. *2 The zone number corresponding to Fig. 3.

mean) that limit the pollutants load in the air with regards to vegetation (for SO_2, NO_x, NH_3, dust) lie usually in the ranges of $\mathrm{Lim}C_{n,y}$ = (0.1-0.5)$\mathrm{Lim}C_d$, but they may be higher (for example HF, ozone). The short-term high concentrations of pollutants in the air at the level of $\mathrm{Lim}C_m$ and more are often extremely harmful for plants. For example, the most sensitive species, such as alfalfa and barley may show injuries when SO_2 concentrations of 785 μg/m^3 ($\mathrm{Lim}C_m$ = 500 μg/m^3) and more persist for a period of at least 2-3 hours [14]; also, the continuous effect concentrations of 100-500 μg/m^3 may reduce the increment of conifers biomass about 10-50 %.

For this reason the scale of AQI has been constructed so that the index value remains 100 or less (the air quality is good or satisfying), if the concentration C of pollutants in the air lies below of limit values $\mathrm{Lim}C_m$ and $\mathrm{Lim}C_d$, and exceeds 100 (the air quality is insufficient, poor or unhealthy), when concentration C exceeds the above-named $\mathrm{Lim}C$ values. The air quality may be classified as good and pollution level as very low (no effects on inhabitants and nature) when the index does not exceed value of 50, which means that $C \leq 0.5\mathrm{Lim}C_d$ or $C \leq \mathrm{Lim}C_{n,y}$ (Tables 2 and 3).

For every pollutant two subindices (AQI_{sub}) must be calculated:

- by 0.5-hour maximum ($\mathrm{Max}C$) concentration (subindex A)
- by daily ($\mathrm{Mean}C_d$) or annual ($\mathrm{Mean}C_y$) average concentrations of pollutants in the air (subindex B)

The greatest value of subindices (a difference is possible in case of zonation of landscapes - Table 3 and Section “Estimation of Air Quality and Pollution Loads by AQI”) is the Air Quality Index for individual pollutant: AQI_{ind} = MAX{AQI_{sub}}, and AQI = MAX{$\mathrm{AQI}_{i,ind}$} for multicomponential pollution field.

The AQI_{sub} can be calculated in the three ranges by the following formulas:

(i) If the concentration C of pollutants in the ambient air remains equal or below 50 % of 24-hour limit value ($\mathrm{Max}C \leq 0.5\mathrm{Lim}C_d$ or $\mathrm{Mean}C_d \leq$ $\leq 0.5\mathrm{Lim}C_d$):

$$\mathrm{AQI}_{sub,A} = 50(\mathrm{Max}C/0.5\mathrm{Lim}C_d) \quad (1)$$

$$\mathrm{AQI}_{sub,B} = 50(\mathrm{Mean}C_d/0.5\mathrm{Lim}C_d) \quad (2)$$

(ii) If the value of C exceeds 50 % of 24-hour and remains equal or below 24-hour or 0.5-hour limit concentrations ($C > 0.5\mathrm{Lim}C_d$ and $C \leq \mathrm{Lim}C_d$ or $C \leq \mathrm{Lim}C_m$):

$$\mathrm{AQI}_{sub,A} = 50[(\mathrm{Max}C - 0.5\mathrm{Lim}C_d)/(\mathrm{Lim}C_m - 0.5\mathrm{Lim}C_d) + 1] \quad (3)$$

$$\mathrm{AQI}_{sub,B} = 50[(\mathrm{Mean}C_d - 0.5\mathrm{Lim}C_d)/(\mathrm{Lim}C_d - 0.5\mathrm{Lim}C_d) + 1] \quad (4)$$

(iii) If $C > \mathrm{Lim}C_d$ or $C > \mathrm{Lim}C_m$:

$$\mathrm{AQI}_{sub,A} = 100(\mathrm{Max}C/\mathrm{Lim}C_m)^n \quad (5)$$

$$\mathrm{AQI}_{sub,B} = 100(\mathrm{Mean}C_d/\mathrm{Lim}C_d)^n \quad (6)$$

where n is a coefficient which depends on the category of harmful effects of pollutants.

In the I and II range (formulas (1)-(4)) the index is linear and lies in the interval of 0-50 and 50-100 correspondingly. In the III range (formulas (5) and (6)) the index value (100-500 and more) depends upon biological dangerousness of chemicals and will remain either linear or unlinear.

In Estonia, the following categories of harmful effects of pollutants representing their different effects in comparison with SO_2 are established:

I category ($n = 1.7$) - extraordinarily hazardous substances (ozone, chlorine, Hg, etc.)

II category ($n = 1.3$) - very hazardous substances (styrene, H_2S, formaldehyde, nitrogen oxides, phenols etc.)

III category ($n = 1$) - hazardous substances (SO_2, aromatic hydrocarbons, oil shale fly ash, smut etc.)

IV category ($n = 0.9$) - slightly harmful substances (NH_3, CO, aliphatic hydrocarbons, etc.)

The values of the n coefficient are given according to the data of hydrometeorological centre [3, 12].

In case of using this index system for estimation of the air quality in respect of nature, when the $C = \mathrm{Mean}C_y$ (computed or monitored data) and recommended annual limit concentration $\mathrm{Lim}C_{n,y}$ for plants (trees, lichen etc.) are known, then for the formulas (1)-(4) the value of $0.5\mathrm{Lim}C_d = \mathrm{Lim}C_{n,y}$ and subindices by following formulas can be calculated:

- If $\mathrm{Max}C \le \mathrm{Lim}C_{n,y}$ or $\mathrm{Mean}C_y \le \mathrm{Lim}C_{n,y}$ then

$$\mathrm{AQI}_{sub,A} = 50(\mathrm{Max}C/\mathrm{Lim}C_{n,y}) \quad (1a)$$

$$\mathrm{AQI}_{sub,B} = 50(\mathrm{Mean}C_y/\mathrm{Lim}C_{n,y}) \quad (2a)$$

- If $\mathrm{Lim}C_{n,y} < \mathrm{Max}C \le \mathrm{Lim}C_m$ and $\mathrm{Lim}C_{n,y} < \mathrm{Mean}C_y \le \mathrm{Lim}C_d$ then

$$\mathrm{AQI}_{sub,A} = 50[(\mathrm{Max}C - \mathrm{Lim}C_{n,y})/(\mathrm{Lim}C_m - \mathrm{Lim}C_{n,y}) + 1] \quad (3a)$$

$$\mathrm{AQI}_{sub,B} = 50[(\mathrm{Mean}C_y - \mathrm{Lim}C_{n,y})/(\mathrm{Lim}C_d - \mathrm{Lim}C_{n,y}) + 1] \quad (4a)$$

In case calculation of subindex B by formula (6) (if $\mathrm{Mean}C_y > \mathrm{Lim}C_d$), then $\mathrm{Mean}C_d = \mathrm{Mean}C_y$.

Estimation of Air Quality and Pollution Loads by AQI

If the monitoring data about Max$C$ and MeanC_d are known, the air quality in the residential areas during a day will be characterized according to a special scale (Table 2) as good or satisfying, when the AQI values lie within the ranges of 0-100, and insufficient or poor (unhealthy) when AQI > 100. As a rule, more objective data about air quality can be attained while using for calculation of AQI the concentrations of pollutants which were obtained by automatic air control stations.

Estimation of air quality during longer periods (month, year) occurs by amount of unhealthy days. We recommend to qualify the air quality as "healthy" when the total amount of the days with good and satisfying air quality (AQI < 100) corresponds to the level of 80 precentile during a month and 82-83 precentile during a year. It means that the maximum number of unhealthy days can be 6 days monthly, but not more than a total of 60 days (2 months) yearly. As an additional condition, the maximum quantity of days with AQI > 300 (exceeding Lim$C$ more than 3 times) can be 2 days monthly and 18 yearly, which corresponds to the level of 93-95 precentile of healthy days. If the above-named levels of unhealthy days are exceeded, the air quality during a month or a year can be classified as insufficient for inhabitants. In this respect the management and control of ambient air quality must be taken under attention. Other classifications for estimation the air quality in long-time periods are also conceivable; it will depend on local situation, number of monitored components etc.

Table 4. **Guideline Concentrations of Pollutants (C) at the Different Values of AQI, μg m^{-3}**

Pollutant	n	C	AQI				
			50	65	100	300	500
SO_2	1	Max$C$	25 **(20)**	168 (164)	**500**	1500	2500
		MeanC_d	25 **(20)**	32.5 (29)	**50**	150	250
NO_x	1.3	Max$C$	75 **(30)**	172 (141)	**400**	931	1380
		MeanC_d	75 **(30)**	98 (66)	**150**	349	517
NH_3	0.9	Max$C$	20 **(8)**	74 (65)	**200**	678	1196
		MeanC_d	20 **(8)**	26 (18)	**40**	136	239
Oil shale fly ash	1	Max$C$	50 **(20)**	125 (104)	**300**	900	1500
		MeanC_d	50 **(20)**	65 (44)	**100**	300	500
Phenol	1.3	Max$C$	1.5	16	**50**	116	172
		MeanC_d	1.5	2.0	**3**	7.0	10.3
H_2S	1.3	Max$C$	4	5.2	**8**	18.6	27.6
		MeanC_d	4	5.2	**8**	18.6	27.6
Formaldehyde	1.3	Max$C$	25	48	**100**	233	345
		MeanC_d	25	32	**50**	116	172

Note: The values of MeanC_y concentrations in case of using the formulas (1a)-(4a) are presented in parentheses. The limit values (valid in Estonia) of LimC_m, LimC_d (at AQI = 100) and recommended values of Lim$C_{n,y}$ (at AQI = 50) are given in bold type.

Zonation of landscapes in respect of effects to the nature will proceed by scale of air pollution levels (Table 3). The air pollution zones according to this scale are of prognostic character because for calculation of AQI_{sub} values the computed data of Max$C$ and MeanC_y can be used. If the yearly limit value Lim$C_{n,y}$ is known, then the formulas (1a) and (2a) should be preferred. To define the zone number of pollution level, both subindexes A and B must be taken into account. In case of MeanC_y > Lim$C_{n,y}$ the subindex B is of cardinal importance. For example, if subindex A (by Max$C$) is 150 and subindex B (by MeanC_y) is 80, then the air pollution level can be evaluated as high and zone number is I-B (Table 3). If Mean$C_y \leq$ Lim$C_{n,y}$ then the zone number will be determined by subindex A.

While composing of the scales for estimation of air quality and effects to nature and inhabitant (Tables 2 and 3) the air quality categories recommended in [1, 6] have been also considered.

Table 4 shows the guideline concentrations of pollutants at the values AQI (or AQI_{sub}) of 50, 65, 100, 300 and 500 (the points of inflection of the AQI scale) for other important pollutants found in NE Estonian atmosphere. For example, if we have the following concentrations for SO_2: Max$C$ = 250, MeanC_d = 70 and MeanC_y = 15 μg/m^3, then, according to the Table 4, the corresponding subindeces are lying between of 50-100 (for nature 65-100), 100-300 and 0-50 (for nature), which means that in this situation the AQI exceeds 100 for inhabitants (air quality is insufficient) and subindex A - 65 for nature (the II zone by Max$C$). The level of AQI = 65 corresponds approximately to the concentrations of C = (0.3-0.5)LimC_m and C = (1.5-2.2)Lim$C_{n,y}$.

Results and Discussion

Using the AQI method makes it possible to analyze and generalize the results of ambient air real-time monitoring, as well as to assess and predict the air quality by calculated data in territories, where the monitoring points are absent. In long-time temporal scale the investigations of dynamics of multicomponential pollution loads are conceivable. Next, some typical examples of using the index-system are given.

Estimation of Air Quality in the Residential Areas

Elaborated index method was used for the first time in 1996-97 for analysing the air monitoring data and condition of air pollution in the residential areas of the towns of oil shale mining and processing area - Kohtla-Järve (in Järve and Ahtme district), Jõhvi and Kiviõli (Fig. 4). The air monitoring data (SO_2, NO_2, H_2S, NH_3, phenols, formaldehyde, dust)

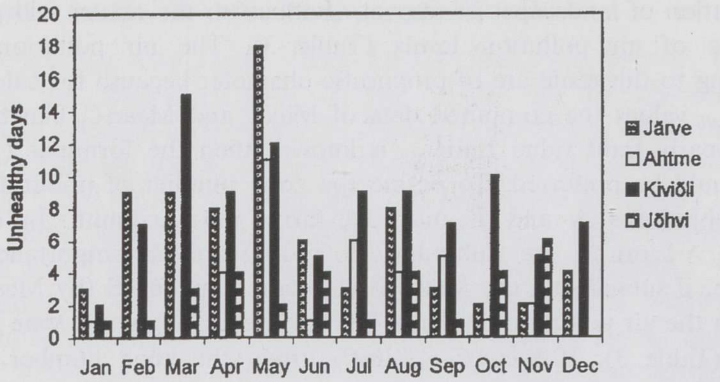

Fig. 1. Total sum of unhealthy days (AQI > 100) in 1996 according to the data of ERLV. Analyzed components: SO_2, NO_2, H_2S, NH_3 (except Jõhvi), phenol (except Jõhvi), formaldehyde (except Ahtme) and dust (only Kiviõli)

Table 5. **Subindices and AQI Values in February 1996 in the Järve District**

Date	AQI_{ind}						AQI	Air quality
	SO_2	NO_2	H_2S	NH_3	Phenol	Formaldehyde		
1	No data							
2	44	13	12	10	33	2	44	Good
3	165	15	50	10	75	24	165	Insufficient
4	48	9	12	28	33	**1204**	**1204**	Very poor
5	78	14	**329**	10	157	8	**329**	Poor
6	56	12	117	59	51	58	117	Insufficient
7	154	15	38	48	58	59	154	Insufficient
8	No data							
9	51	5	12	35	53	12	53	Satisfying
10	50	17	25	12	58	18	58	Satisfying
11	42	13	25	5	53	38	53	Satisfying
12	128	23	134	35	83	59	134	Insufficient
13	51	12	50	20	75	16	75	Satisfying
14	50	49	38	12	67	14	67	Satisfying
15	No data							
16	54	26	38	5	51	12	54	Satisfying
17	53	38	88	20	54	36	88	Satisfying
18	51	28	117	50	182	42	182	Insufficient
19	51	12	25	30	100	14	100	Satisfying
20	62	19	25	28	111	104	111	Insufficient
21	78	21	50	42	53	30	78	Satisfying
22	No data							
23	No data							
24	46	11	12	50	4	8	50	Good
25	42	8	25	42	100	36	100	Satisfying
26	51	15	38	51	67	**550**	**550**	Very poor
27	46	11	50	35	51	12	51	Satisfying
28	50	27	38	25	33	24	50	Good
Unhealthy days	3	0	4	0	3	3	9	

Note: Unhealthy days with AQI = 101-300 are underlined and those with AQI >300 are shown in bold type.

were obtained from Environmental Research Laboratory of Virumaa (ERLV) and by OPSIS-system of automatic air monitoring which is located in Järve district of the town of Kohtla-Järve.

Fig. 1 shows that in 1996 the total quantity of unhealthy days (including very and extraordinarily unhealthy days) in Järve district and the town of Kiviõli, which are located in the neighbourhood of oil shale processing and chemistry plants, was relatively high - in total 75-97 days (at a recommended maximum level of 60 days) during the year, which means that air quality represents a major problem there. This number is 2.4-3.1 times higher than in Jõhvi (31 days) and Ahtme (36 days), which are located about 12 km from industrial region of Järve and where the ambient air quality was strikingly better (healthy). From Table 5, where the results of air quality estimation during 1 month in case of 6 monitored components are shown, it can be seen that in observed period of March 1996 the air quality in Järve region was evidently insufficient (total number of unhealthy days - 9, including 3 days with AQI more than 300). Among the components causing this situation were H_2S and formaldehyde, first of all (AQI more than 300), but also SO_2 and phenol.

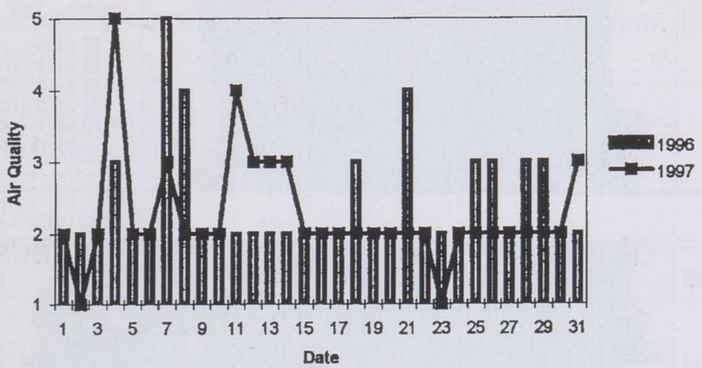

Fig. 2. Air quality in Järve district (the town of Kohtla-Järve) in March 1996 and 1997: *1* - good, *2* - satisfying, *3* - insufficient, *4* - poor, *5* - very poor

Fig. 2 demonstrates the results of comparison of the AQI values in March 1996 and 1997. We can see that in 1997 the air quality conditions have essentially improved, although in both years the monthly sum of unhealty days (9 and 7 days correspondingly, including days with AQI > 300 - correspondingly 3 and 1) exceeded recommended maximum - 6 days.

Zonation of Landscapes by Air Pollution Level

The AQI method may be used for classifying of landscapes into zones proceeding from the air pollution level (air quality) in respect of dangerous effect to nature (Table 3). Zonation of polluted areas is an effective tool for better understanding of correlations between state of nature and air pollution with different ingredients.

For zonation of NE Estonian area the results of calculations of short-term maximum and annual mean concentration fields of oil shale fly ash and sulphur dioxide (emitted from power plants, chemical enterprises etc.) were used. For viewing information about calculated pollution levels, the territory (about 3370 km^2) was divided into areas of 1×1 km

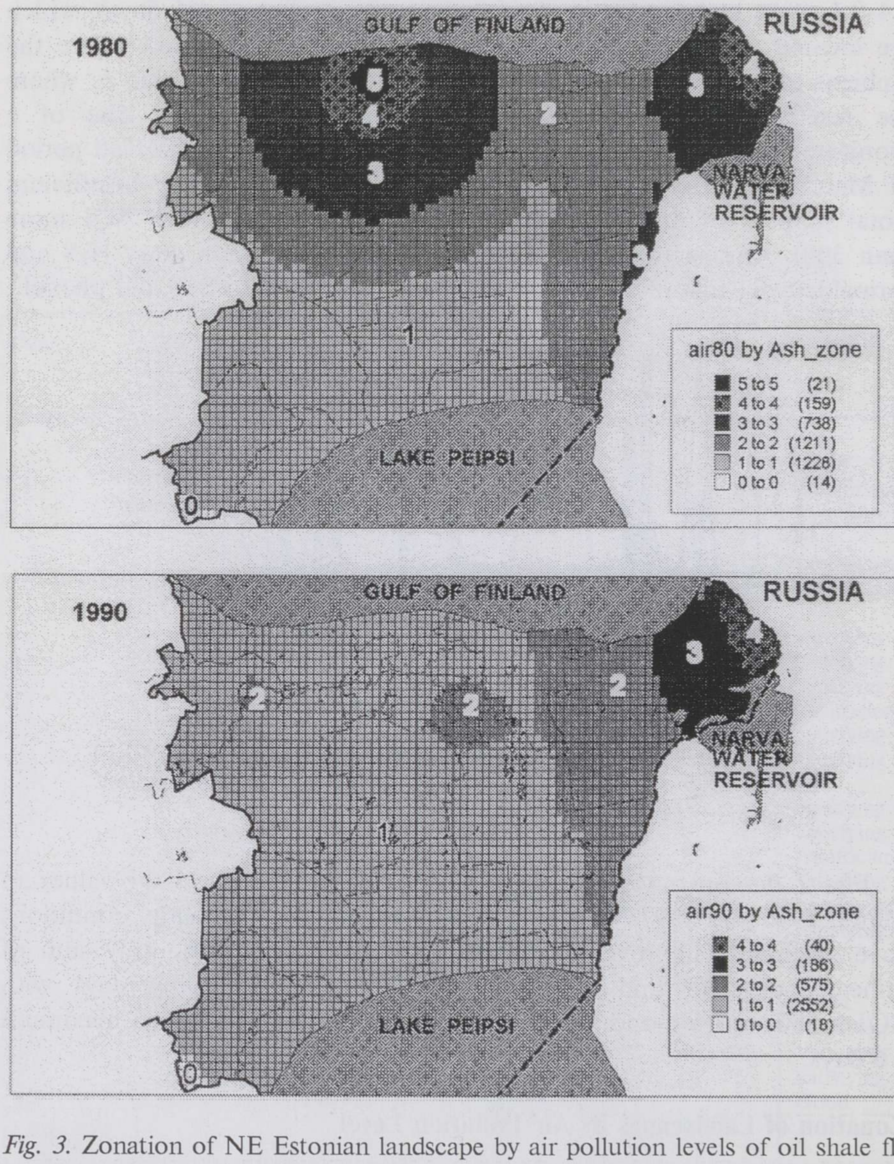

Fig. 3. Zonation of NE Estonian landscape by air pollution levels of oil shale fly ash: *0* - very low, *1* - low, *2* - moderate, *3* - relatively high, *4* - high, *5* - very high. In the squares the area of the zones in km^2 are shown

and for analyzing of calculated data the GIS-methods were used [18]. Each of those landscape squares was characterized by computed air pollution average loads (Max$C$ and MeanC_y). In respect of residents' health, the following limit values of oil shale fly ash, established in Estonia (Table 4), were used: 0.5-hour maximum (LimC_m) - 300 μg m^{-3} and daily mean (LimC_d) -100 μg m^{-3}. Permissible concentration limit of oil shale fly ash load in the ambient air with regard to vegetation can be recommended on the level of Lim$C_{n,y}$ = 20 μg m^{-3}, analogically to dust from power plants operating on coal (Lim$C_{n,y}$ = 10-30 μg m^{-3} for lichen and conifers) [17, 18]. The critical load (Lim$C_{n,y}$) of SO_2 for lichen, forests, crops etc. within ranges of 10-50 μg m^{-3} may be varied (Table 1). Therefore, in zonation of NE Estonian area we were operating with Lim$C_{n,y}$ value of 20 μg m^{-3} as annual mean for SO_2 in atmospheric air in respect to forest trees.

Fig 3 shows the results of division NE Estonian area into air pollution zones by oil shale fly ash in 1980 and 1990. It becomes evident that during these 10 years the pollution situation has essentially changed: the total area 919 km^2 of zones I-C, I-B and I-A in 1980 has decreased to 227 km^2 (I-B and I-A) in 1990; at the same time the area of zone III-A (low pollution level) was increasing more than 2 times (from 1228 km^2 to 2552 km^2).

Table 6. **Estimation of Air Pollution Situation in Different Regions of NE Estonia**

Pollutants	Pollution zones				
	1960	1970	1980	1990	1995
	Kohtla-Järve and Saka				
Fly ash	Very high	Very high	Very high/high	Low	Low
SO_2	Relat. high	High	High	Moderate	Moderate
	Kurtna Landscape Reserve				
Fly ash	Relat. high/high	Relat. high/high	Moderate/low	Low/moderate	Low
SO_2	Moderate	Moderate	Moderate	Moderate	Low/moderate
	The town of Narva				
Fly ash	Low	Relat.high	High	High	Moderate
SO_2	Low	Moderate	Moderate	Moderate	Moderate
	The town of Jõhvi-Ahtme				
Fly ash	Very high/high	Very high/high	Relat.high	Moderate	Low
SO_2	Moderate	Moderate	Moderate	Moderate	Moderate
	Central and Southern parts of the region				
Fly ash	Low/moderate	Low/moderate	Low/moderate	Low	Low/very low
SO_2	Low/very low	Low/very low	Low	Low	Very low/low

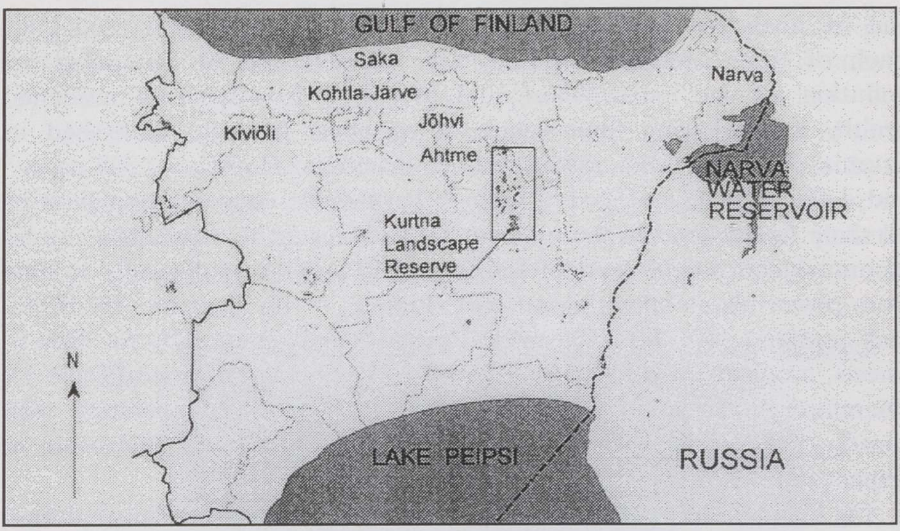

Fig. 4. Location of regions zoned by air pollution situation (Table 6)

In Table 3 (column "Conditions") the intervals of variation for computed values of Max$C$ and MeanC_y, which were used for zonation of NE Estonian landscape by pollution levels in the conditions of air pollution with oil shale fly ash (Fig. 3) and sulphur dioxide are shown. Subindices calculated by MeanC_y values (mainly in the ranges of 1-50 $\mu g\ m^{-3}$ for fly ash [20] and below 25 $\mu g\ m^{-3}$ for SO_2 [24]) are not very high because on the main territory MeanC_y < Lim$C_{n,y}$ and only in the zone I-C by MeanC_y > LimC_d for fly ash (MeanC_y up to 210 $\mu g\ m^{-3}$ and corresponding AQI_{sub} 100-208).

The results of zonation, the changes in pollution situation and its dynamics in the generalized form for different regions of NE Estonia during the period of 1960-1995 are shown in the Table 6 (see also Fig. 4). In many areas (Kohtla-Järve, Saka, Kurtna Landscape Reserve) the role of sulphur dioxide has been increasing in the last years, while compared with alkaline fly ash. Preliminary results of zonation of the landscape noticeably well concur to the results of previous investigations of state of the natural systems and pollution situation dynamics, especially in Saka and Kurtna regions [21, 22] affected by alkaline ash and sulphur compounds.

Conclusions

The calculation of the estimated Air Quality Complex Index is performed using the concentrations of all contaminants which are simultaneously present in the air. It gives information about both the short-term and long-term trends, as well as about possible harmful effects. The practical use of the AQI has proven that it is an effective and easily understandable instrument for assessment of the air quality in the residential and natural areas of the NE Estonian regional system [23].

It becomes evident that NE Estonian industrial-natural territory can be characterized by air pollution zones which are established using the computed AQI values, while taking into account the emission data and distribution of pollutants in the overground air layer.

In future the AQI can be usefully applied to investigate the dynamics and effects of multicomponential pollution fields to nature, for verification of computed and factual results about distribution of pollutants in the air, as well as for analyzing the everyday air monitoring data.

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