Degradation of Cultural Heritage in Surrounding Environment

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1. Introduction

Results in research in atmospheric corrosion and environmental engineering opened in the Czech Republic for 5 decades participated in the development of the theoretical basis in this research area. Technical guidances and standards were elaborated as broad applicable deliverables.

2. Air quality in the Czech Republic

Survey of air pollution data in the period 1982-2000 demonstrates a dramatic decrease of atmospheric pollution between 1995-2000 for concentration of SO_2 and particulates (SPM), not for concentration of NO_x (Figures 1 - 3). High environmental stress is in a part of the North Bohemian region. Yearly annual average concnetration of SO_2 on 94% area of the City of Prague is between 5 – 10 µm.m^{-3}, only in the centre is the average concentration higher, but lower that 15 µm.m^{-3}. The dominating effect of SO_2 is decreasing, with eleved influence of nitrogen compounds, ozone and particulates.

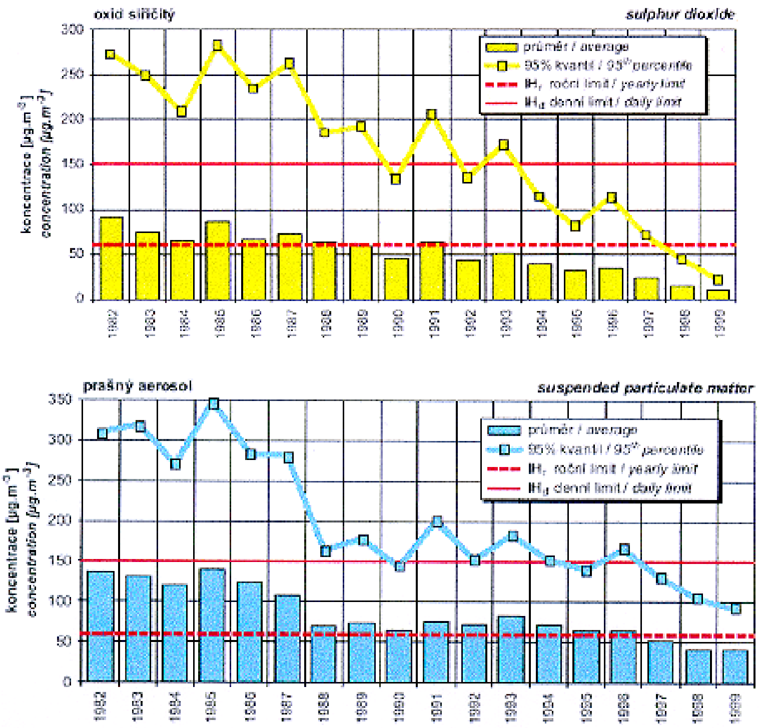

Figure 1 – Decreasing of pollution in Prague

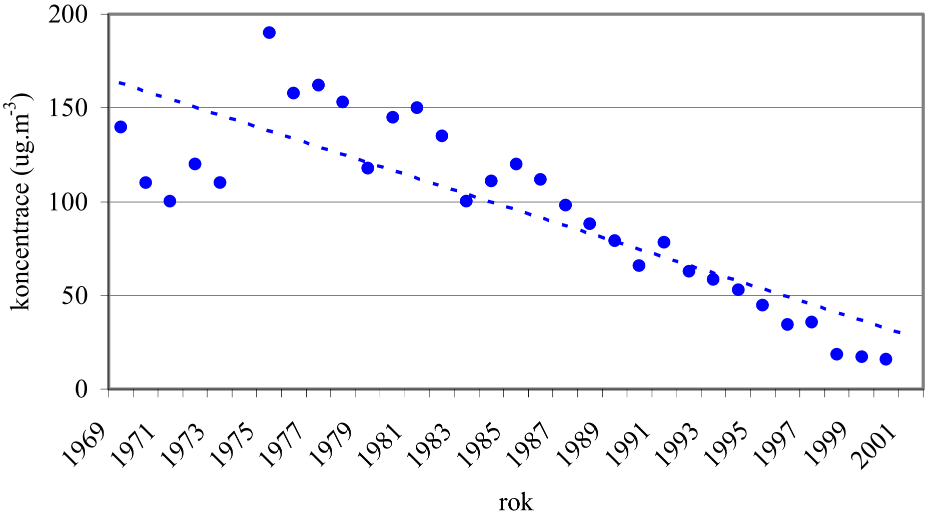

Figure 2 – Decreasing of SO_2 at atmospheric test site Kopisty

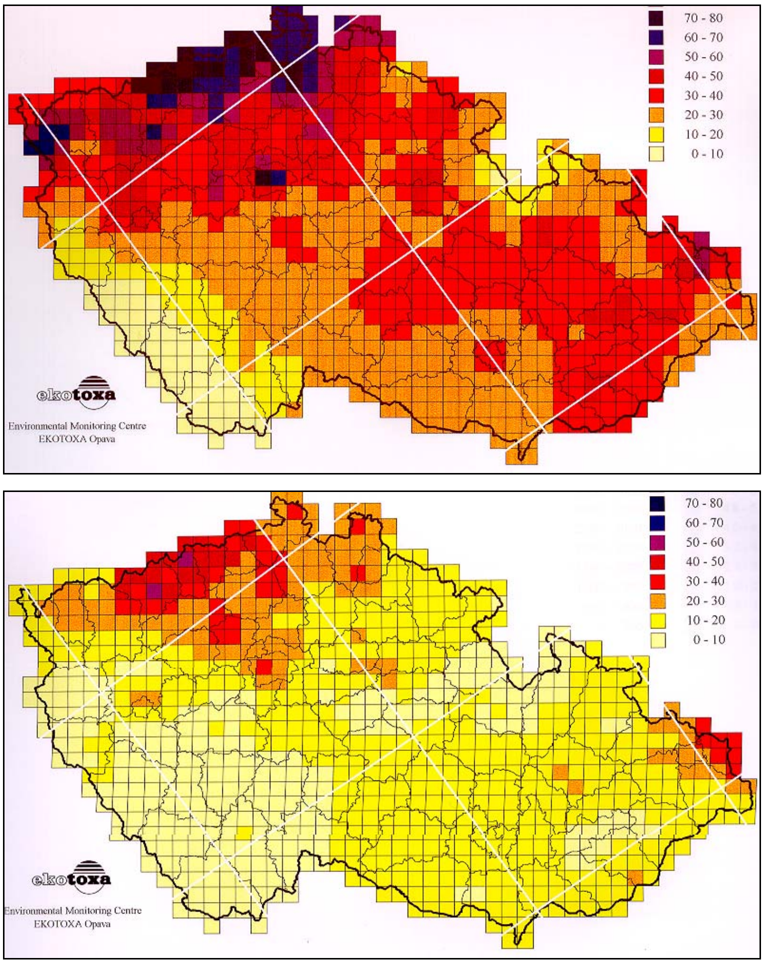

Figure 3 – Decreasing of SO_2 concentration

Annual average concentrations of nitrogen oxides increased in 80ties to 80 – 100 $\mu g.m^{-3}$, then decreased, but later gradual increased to cca 60 $\mu g.m^{-3}$.

Yearly mean concentration of particulate aerosol (SPM) for 83% area of the Czech Republic does not exceed 30 $\mu g.m^{-3}$, decreasing from 80ties (120 – 130 $\mu g.m^{-3}$) is high.

In last years higher attention is given to other pollutants and their mixtures. Decreasing sulphur oxide levels and increasing car traffic causing elevated levels of nitrogen compounds, ozone and particulates has created a new multipollutant situation.

3. Effects of surrounding environment on materilas and monuments. Participation in projects.

The participation in international projects stimulated the Czech research activity in last decade.

EUREKA EU 640 WetDry-Dep

Detailed study of acid deposition and corrosion effects on St.Vitus Cathedral with a complementary targeted field study in the microclimates of this object and atmospheric test site Prague – Bechovice.

The aim of this project was to intensify the knowledge of the corrosion impact of dry and wet depositions on selected construction materials exposed at various locations on buidings and other objects. Development of methods and devices for measurements of dry and wet deposition of pollution and environmental characteristics was a part of this project.

SVUOM within this project realized an extensive experiment on prestigious historical object, the St. Vitus Cathedral in the Prague Castle area, intensified the knowledge of the dry and wet deposition of pollution within a targeted field exposure in microclimates on the locality of the cathedrale and on the atmospheric test site Prague-Bechovice, evaluated corrosivity of selected exposition and exhibition spaces of the Pragur Castle and intensified both theoretical and methodical knowledge of sorption of gaseous pollutants on materials.

EUREKA EU 360 COPAL Technologies for conservation of copper alloys monuments

Systematic assessment of corrosion effects on bronze statues and copper roofs and cladding, evaluation of efficiency of different protection measures, evaluation of properties of the patina layers.

Database for more than 200 evaluated objects was created. Structure is demonstrated as follows:

- identification of object (name, author, year of creation)
- location of object (place, corrosivity of this place, exposure time in this place)
- visual evaluation (colour of patina, forming of crusts)
- description of deffects
- evaluation of corrosion attack (surface corrosion, jointing and fixing materials)
- analyses of patina
- information about previously restoration, conservation, etc.
- recommendation for maintenance

Complex patina layers study gave information about the components of the layers,their structure and transformation during exposure on atmosphere.Testing of protective efficiency of different corrosion protective measures – temporary and longterm- was performed. Results are summarised not only in the research reports,but also two methodic manuals for restorators and other specialists were prepared for publishing.Some of results are presented in figure (Figure 4) and table (Table 1).

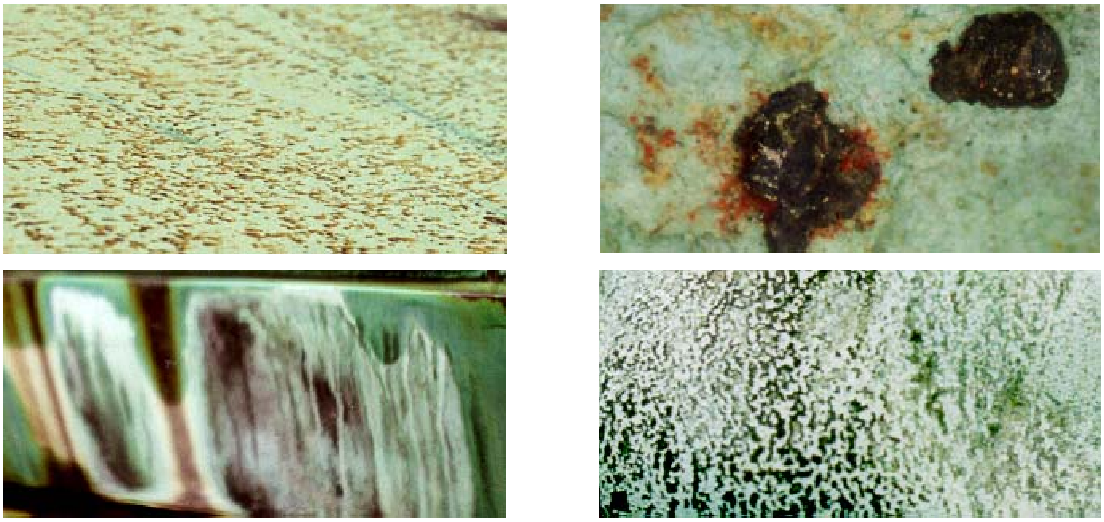

Figure 4 – Corrosion effects on copper roofs

Table 1 – Composition of patina layers

Composition	Objects					
	statues NG, Zbraslav (1994)		statues, copper roofs centre of Prague (1994)		statues centre of Prague (1998)	
	18 samples		57 samples		33 samples	
	abundance	frequency (%)	abundance	frequency (%)	abundance	frequency (%)
antlerite	9	50	18	31	10	30
brochantite	6	33	43	75	17	52
cuprite	3	17	16	28	8	24
atakamite, paratakamite	0	0	3	0	1	3
moolooite	0	0	0	0	1	3
$(NH_4)_2Cu(SO_4)_2.6H_2O$	0	0	4	7	4	12
cholcocite	0	0	0	0	3	9
quartz	12	67	33	58	18	55
gypsum	4	22	2	4	13	40
calcite	0	0	3	5	4	12
ontirely amorphous	2	11	1	2	0	0

UN ECE ICP on Effects on Materials Including Historic Monuments

Participation as subcentre for structural metals and corrosivity trends.

SVUOM participates as subcentre for structural metals and corrosivity trends. The work of the subcentre represents the periodical evaluation of the corrosion effects,statistical analyses for corrosion effects and environmental variables, trend analyses, quantitative evaluation of the effect of pollutants on the atmospheric corrosion of structural metals. A five-factor model was proposed as derived from principal component analysis. This model covers 84% of explained variance. For the purpose of our analyses an additive logarithmic model was chosen as the most advantageous. Other variants of the regression functions may be optimal for other technical and scientific applications.

EU REACH Racionalized Economic Appraisal of Cultural Heritage (ENV4-CT98-0708)

In cooperation with SCI deliverables were elaborated aiming on survey of exposed materials of built cultural heritage,quatification of corrosion effects, maintenance costs and life time assessment. For demonstration of the project approach, two case studies ie for the Municipal House in Prague and baroque houses in Prague and Telc were prepared in a broad Czech partners cooperation. Czech specific needs and monument care directives were afforded for the final tool elaboration.

ISOCORRAG

Establishment and coordination of a wordwide atmospheric corrosion testing programme, evaluation of results, statistic treatment, quantification of the corrosion effects.

This task was not a real scientific project,but the methodology and results contributed to the problem under study. A wordwide atmospheric testing programme was established and in SVÚOM coordinated and evaluated. The net of test sites covered 4 continents (Figure 6). Statistical treatment of short-term and long-term results was performed. Regression functions for quatification of corrosion effects were derived (Table 2). It is necessary to state, that the ISOCORRAG programme does not include data for border facts (tropics, the Antarctic, very dry and warm areas, cold areas and salinity impact in a wider extent) of the atmospheric corrosion effect on metals in a sufficient extent and frequency. The derived D/R functions (Figure 5) are not general applicable.

Table 2 – Regression function used for calculation of the one.year corrosion loss

LnCorr = a + b1.SO2 + b2.SAL + b3.TOW

	Partial regression coeff.				Beta-weights			
LnCorr	a	SO2	LnSAL	LnTOW	SO2	LnSAL	LnTOW	R-SQ
Fe	3,65	0,11	0,14	0,88	**0,37**	**0,31**	**0,51**	0,63
Zn	0,39	0,10	0,13	0,55	**0,37**	**0,32**	**0,36**	0,49
Cu	0,35	0,05	0,15	0,70	**0,21**	**0,37**	**0,47**	0,58
Al	-1,97	0,14	0,23	0,22	**0,39**	**0,41**	0,11	0,39

For technical reasons the values of SO_2 concentration are divided by ten and the time of wetness is expressed in terms of relative wetness per year.
Significance of Beta-weights /standard regression coefficients):
underlined….5% level of significance; **bold** ….1% level of significance

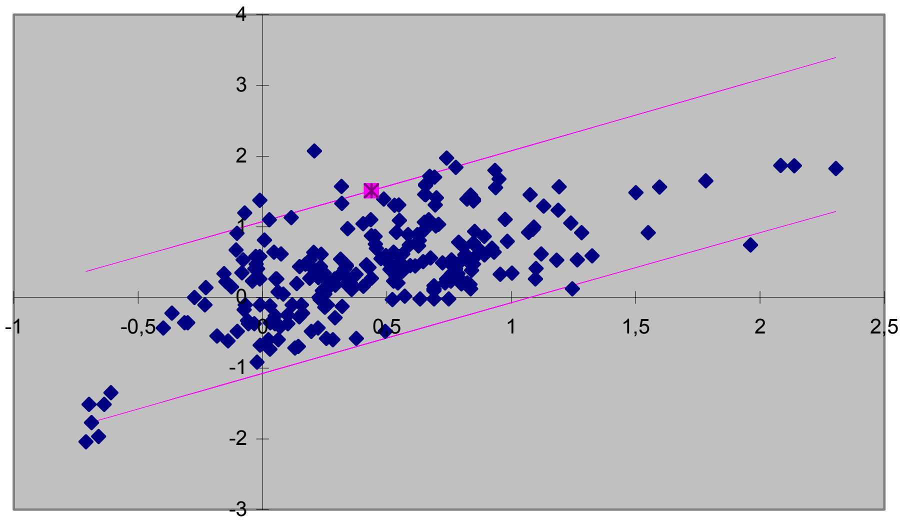

Figure 5: Analysis of residual and standard error of prediction – Zn model:

*ln(COOR) = A + B1*SO2 + B3*ln(Cl) + B3*ln(TOW)*

95% confidency interval for predicted value

The approach was proposed for the statistically professional manner of application of D/R functions in different tools and directives and standards.It is necessary to consider two selection errors:

- selection error of the regression model coefficients.i.e. selection error of the whole regression function
- residual spread of individual observations arround the regression function.

Characteristics of the regression function are influenced also by reliability of measurements of the input quatities. One sided confidential regions should be sufficient for practical use, because users are interested in the upper reliability of the predicted value.

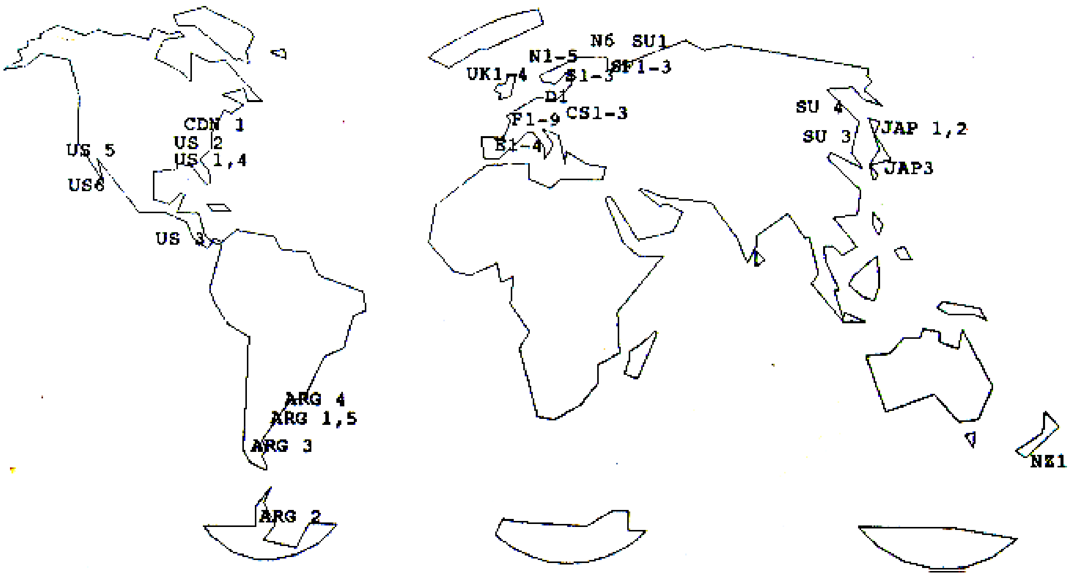

Figure 6 – Locaton of exposure test sites of ISOCORRAG programme

Evaluation of economic losses caused by atmospheric pollution on historic and modern buildings

(Nordic project and projects granted by the Czech Ministry of Environment)

Within the Nordic project (1991) study for 3 towns including Prague City complex was elaborated.

Elaboration of models of stock at risk and economic evaluation of costs of the deterioration damage focused on methods of evaluating damage caused by pollution to construction objects of a residential character (1999). After studying statistical data, observing in the field and using typization of construction objects of a residential character carried out before, a simplified solution model, which is suitable for demonstrating relations within the solved issue, was proposed and verified. These solutions are more effective for the needs of the decision making process at regional and national bodies. The model was proposed with respect to the needs of the Ministry of Environment of the Czech Republic, which provided a grant for this project.

Solution steps:

- getting familiar with a region and selecting districts with characteristic objects
- typization of family houses and residential houses, determination of material composition of outdoor surfaces
- formation of model city districts with a defined number of typized objects
- determination of materials exposed to the environment in model districts

- narrowed selection of materials and systems differentiated by serviceability and costs for maintenance and repairs (Table 3 and Figure 7)
- economical analysis for categories of pollution by SO_2 (P_0 – P_3 according to ISO 9223)
- relations within the evaluated system

Table 3 – Annualized costs for renewal of materials according to the level of atmospheric pullution

	Annualized costs (CZK/(m^2.year))			
	Classified interval of pollution by SO_2 (μm/m^3)			
Main selected materials	P_0	P_1	P_2	P_3
Plasters				
Thick concrete plaster	206	206	207	208
Materials with coating systems				
Steel with coating	108	136	153	225
Zinc-coated steel with coating	98	108	124	153
Plasters with coating	34	35	35	39
Wood with coating	269	301	357	403

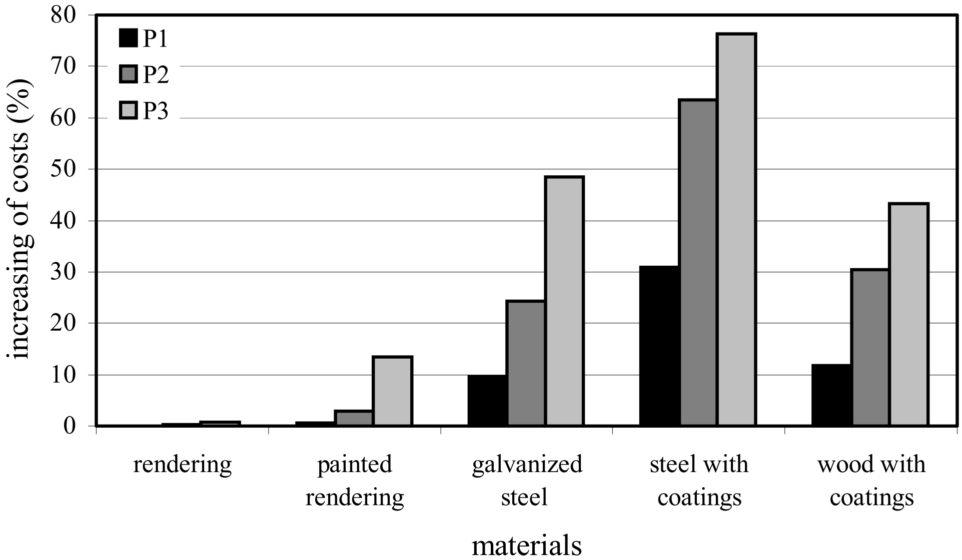

Figure 7 – Increasing of annual costs (%) of renewal of different materials with increasing pollution intervals

Other research programs and activities

Problems of deterioration of metals (iron, bronze, silver), restoration and conservation are matter of study in a special laboratory of the Institute for Archeology of the Czech Academy of Sciences and in some regional institutes for monument care and laboratories of regional museums. Methods for electrochemical deionisation (decreasing of chloride content) of layers on metallic archeological objects are tested. Improvement for measuring technique were proposed.

Deterioration of natural stones and other anorganic materials of historic buildings, statues and other monuments are subject of systematic study in the National Institute for Monument Care in cooperation with different specialists for modern evaluation techniques. The sensitivity of natural stones to degradation due to the effects of environmental factors in relation to their chemical composition and physical characteristics is evaluated. Durability of clay tiles and other roofing materials of monuments are tested.

Other work of this institute is concentrated on the evaluation of long term environmental effects on stone statues on the Charles bridge in centre of Prague. After visual evaluation, ultrasonic measuring was applied for internal materials defects determination. Basing on 3D digitalisation, computarized models of originals and copies of the statues were constituted.

Testing of historic and modern consolidation products for natural stones is important for elaboration of maintenance technologies.

Extensive survey of Saint´s colums and pillars includes large study of natural stones identification and corrosion effects evaluation.

Evaluation of environmental stress for monuments is not only task for scientific institutions. For a good understanding between different authorities elaboration of guidelines and standards is important. Basis for application of them form monitoring systems. A complex monitoring system applicable for monuments was elaborated and tested on exemple of St. Vitus Cathedral, a prestigious national monument situated in the area of Prague Castle in centre of City of Prague (Figure 8). This monument is exposed to two categories of risk factors ie air pollution and other environmental factors and human factors,tourism, vandalism etc. The monitoring system respects ideas of relevant resolutions of the cultural heritage committee of EC.

Figure 8 - Test site on St. Vitus Cathedral

Mapping

Czech specialists belong to the first in mapping of environmental stress and corrosion effects on materials and technical, above all electrotechnical equipment. Examples of maps from late 80ties are presented in Figure 9. A specific model for mapping consisting in chronological transformation of environmental data and degradarion rates was used for mapping of environmental stress on electrotechnical materials and components. New maps according to the material part of the UN ECE Manual for Mapping can be elaborated when national finacial support will be obtained.

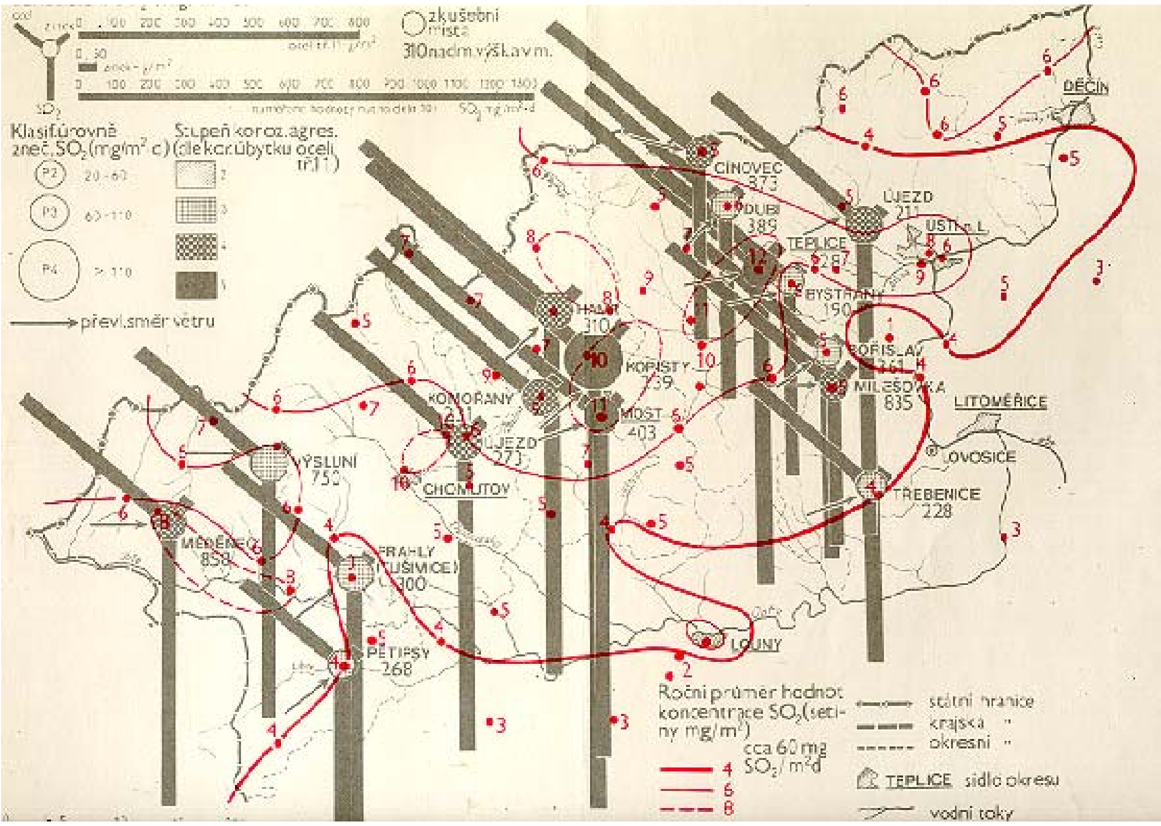

Figure 9 – Map of corrosivity for North Bohemia in period 1975-1980

Environmental stress for important Czech historic monuments

In the Czech Republic more then 38 000 immovables are registred as safeguarded, 131 as national cultural monuments. Ten Czech monuments are registred in the UNESCO monument list. Town monument reservations (40) and town monument zones represent the most important historic parts of the old towns. Four of monuments registred in the UNESCO list (Telc, Ceský Krumlov, Holasovice and Kromeriz) are located in areas with low environmental impact with SO_2 (yearly average concentration lower than 10 $\mu g.m^{-3}$). Other five (Kutna Hora,Litomysl, Lednice-Valtice, Zelena Hora, Saint column in Olomouc) are located in areas where the SO_2 concentration does not exceeds 20 $\mu g.m^{-3}$ in winter. Environmental impact is highest for the Prague town monument reservation.

4. Future research activities

Participation in recently opened research programmes MULTI-ASSESS and Bronzart.

Continuation of the work on national programmmes granted by the Czech Ministry for Culture.

Participation in the UN ECE ICP on Effects on Materials Including Historic Monuments.

Implementation of results on different national and international levels including ISO and CEN standardization.

5. Literature:

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