ps.5 Planning of environmental monitoring network in Estonia using sensitivity analysis

Antti Roose, Project Manager, University of Tartu, Estonia

Introduction

Estonia has inherited a tradition and expertise of monitoring programmes providing a good starting point for environmental synthesis including the spatial analysis which is one of the key tools as it assists in problems of interpretation and reasoning. Considering European integration the research is needed to evaluate present environmental monitoring network of Estonia and to engineer the new monitoring scheme according to the new regulations and public needs. First, the requirements of EC directives set new standards for environmental monitoring. Second, the economic efficiency applies for public services. Third, standard procedures, routines and stability should be kept at the appropriate level to serve time series approach. However, the monitoring network can be optimised in both spatial and temporal scales. Appropriate data density and quality, efficient sampling strategies, rotational principle of monitoring activities are challenging for many projects in the programme. Environmental monitoring does not have to be observation *per se,* but certainly it carries purpose of dissemination of information and raising environmental awareness. Integration of different monitoring projects in different scales and sampling frequencies could create knowledge surplus. Essentially monitoring for management is a about making a decision on available evidence and with a cost structure for errors rather than in demonstration of an impact in a very conclusive manner. Still, misconceptions surround the use of spatial analysis in the monitoring programme, and there is a need to understand local variations in more complex relationships. Below the approach is advocated how sensitive monitoring might be to sampling strategy, which refers to the temporal frequency and spatial extent over which the monitoring is conducted rather than analytical method by which data are collected in the inventory.

The impact of EU accession

Estonia began accession negotiations with the European Union in 1998, the environmental negotiation chapter has been provisionally closed in June 2001 (Ministry of Foreign Affairs, 2001). Based on the conclusions of the screening and negotiations, Estonia is prepared to adopt and to implement the *acquis* with respect to the environment in full on the date of accession, with the exception of the following items: renovation of sewerage systems and urban waste waters treatment facilities; construction of petrol vapour regeneration systems and implementation of new methods of disposal of oil shale ash.

Of paramount importance for, the implementation of environmental directives is development of adequate monitoring system in Estonia. In particular, the adoption of the Water Framework Directive of the European Union includes examinations of the complex cause-and-effect relationships of human pressures to the water environment. Therefore, comprehensive changes are required in the water management and monitoring, new quality standards are set up. The indexation of rivers and lakes based on new standards also uses spatial modelling techniques. Among other tasks the implementation of nitrogen compounds vulnerable zones action programme, monitoring of discharge of dangerous substances into surface water and enforcing of adequate groundwater protection measures are most capacious areas of the European harmonization in Estonia. While the actual models and up-to-date reporting depend upon data availability, monitoring as a strategic instrument is to be designed and adjusted to satisfy public need for effective, appropriate environmental action.

Framework of sensitivity analysis and power analysis

Here, the objective of modelling in a data-rich environment brings together four criteria. Data has to be examined in order to select:

- optimal sites and stations to monitor
- optimal indicators to monitor
- optimal frequency and seasonal distribution for sampling
- testable hypothesis and statistical methods

Sensitivity can be understood in relation to the impacts. Sensitivity analysis is a structured framework for evaluating environmental monitoring network against multiple criteria. This study defines the spatial sensitivity of monitoring network by categories and sites, exploring how effective and informative is monitoring network. Set of indicator variables is chosen for water monitoring.

The identification of system change due to an impact consists of two phases: detecting a significant change and identifying the change if any with the putative cause. The development of new network requires spatial analysis of selected monitoring data, which demonstrates perturbation in various magnitudes of impacts. Assessment requires the calculation of the magnitudes of changes. The method of testing for differences for this study was t-test and analysis of variance (ANOVA), taken $p < 0.05$. Time series were decomposed into a year-to-year variation.

Power analysis shows us whether the inventory observation is likely to be capable of detecting an environmentally important difference in the mean values of two samples. The number of possible permutations involving sample size is enormous. The one of the simplest techniques is performing a *t*-test to examine whether the means of two samples are the same or different.

The Environmental Monitoring Programme

The Estonian Environmental Monitoring Programme includes 60 sub-programmes with more than 1600 monitoring stations all over Estonia. Since 1994 the environmental monitoring is carried out as a comprehensive national programme to identify long-term and large scale changes in the Estonian environment. Linking survey information with environmental research at a network of monitoring projects is the unique approach among other European nations. Prioritising sub-programmes to represent all types of natural environment is a complex managerial planning problem in which integrated assessment needed. In the programme development, data quality and indicators appraoch are two horizontal tasks for all projects covered by the programme umbrella. For data completeness, precision and accuracy, these tasks include the strong spatial stance, and many statistical and technological hurdles. As a whole, the national monitoring network and spatial distribution of stations are shown in Table 1 and in Table 2.

The programme tracks environmental quality by 10 sub-programmes in 1633 stations over the country. Quality controlled time-series exist from 1984 the earliest. As the basis for the analysis of geographical distribution the administrative units, notably counties are taken. Density is the highest in the islands where dominate the biodiversity programmes and in the metropolitan area since the number of stations is determined by pollution controls. In human impact stance, there are more stations per 1000 inhabitants again in the sparsely populated western and island counties.

Table 1. Monitoring network.

Monitoring network	Stations 2001	Temporal frequency	QC time series from
Air	27	on-line	1991
Groundwater	445	monthly	1992
Rivers and lakes	87	monthly	1992
Marine	87	monthly	1993
Biodiversity	858	yearly	1994
Forest	91	monthly	1988
Integrated	2	monthly	1994
Radiation	26	on-line	1990
Seismic	2	on-line	1987
Soils	8	yearly	1984
KOKKU	1633		

QC – Quality Control

Table 2. Distribution of monitoring stations.

County	Stations	Stations density per 100 km^2	Stations per 1000 inhab.
Harju, incl. Tallinn	253	5.8	0.5
Ida-Viru	213	6.3	1.1
Saare	184	6.3	4.6
Lääne-Viru	130	3.8	1.7
Pärnu	124	2.6	1.2
Tartu	109	2.9	0.7
Lääne	91	3.8	2.9
Hiiu	75	7.3	6.4
Põlva	73	3.4	2.0
Jõgeva	59	2.3	1.4
Valga	53	2.6	1.4
Viljandi	53	1.5	0.9
Järva	48	1.8	1.1
Rapla	41	1.4	1.0
Võru	35	1.5	0.8
On the map	1541		

Tests for the selection optimal stations

Obviously, there are trade-offs as well synergy effects within and among the different monitoring networks. Here, in this application, we focus on water quality assessment, river and marine monitoring are selected for sensitivity analysis. The surface-water-quality assessment sub-programme is designed to describe the status and trends in the surface water resources and to provide a understanding of the natural and human factors that affect the quality of resources. Sampling is conducted in 59 important rivers, and the marine monitoring has focused on three bays, Tallinn, Pärnu and Narva, affected by the highest nutrient loads. Utilising integrative and resolution power of indicators in the spatial analysis is the key, which opens the summation of processes and of impacts. The most powerful layers, or indicative variables are identified and pre-selected by spatial variability. Three indicators, biological oxygen demand (BOD_7), total nitrogen (TN) and total phosphorus (TP) are included at the river monitoring section, and four indicators, dissolved nitrogen (DIN); total nitrogen (TN); dissolved phosphorus (DIP); total phosphorus (TP) in the marine monitoring section. Data on nutrient loads is available at monthly resolution. National synthesis study for EU accession has been involved compilation and critical analysis of existing information on water quality, trends and probabilities, shown in Table 3, Table 4 and Figure 1.

Table 3. Number of rivers according to the quality standards.

Indicator	I class ☺	II class ☺	III class ☺	IV class 😐	V class ☹
	Excellent	Good	Satisfactory	Bad	Very bad
BOD_7	46	12	1	0	0
TN	22	17	10	3	5
TP	17	21	12	5	4

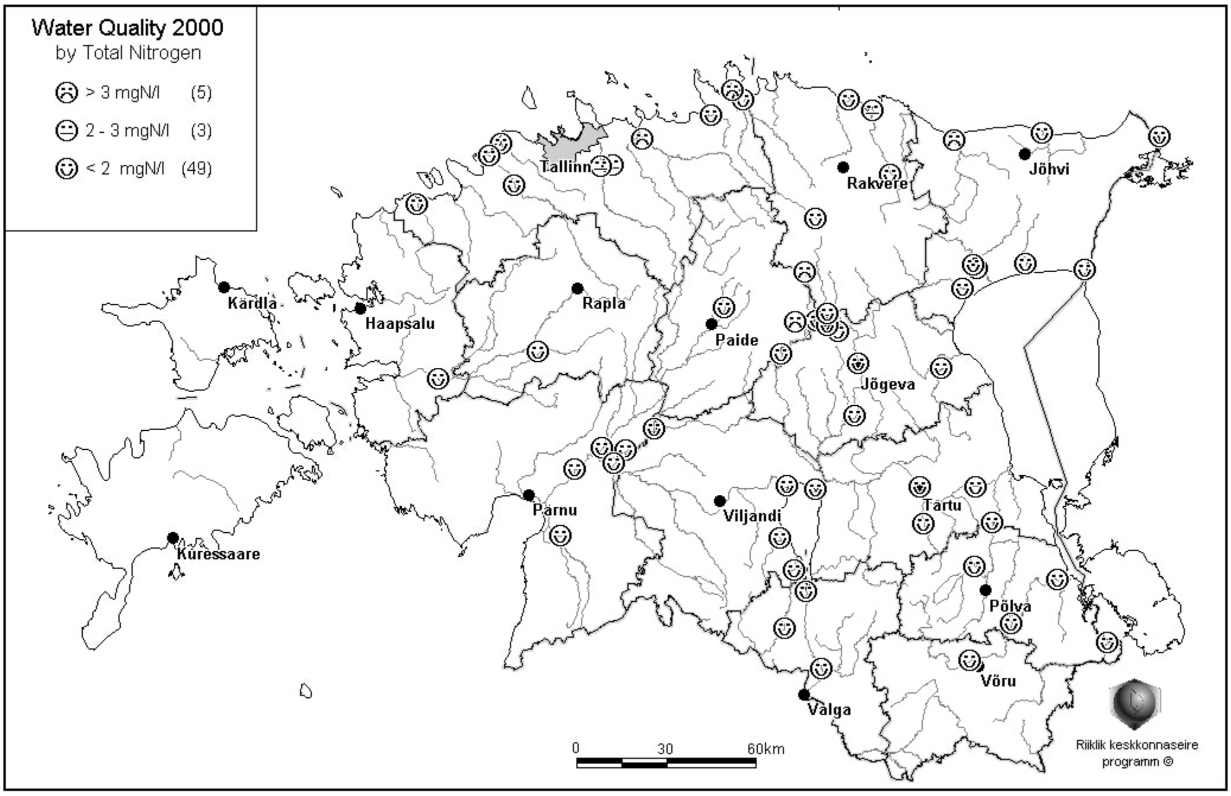


Figure 1. Water quality levels by the standard of total nitrogen in 2000.

Table 4. Comparison of quality indicators of reference (7) and impact stations (52) in 2000.

Station	Indicator	Units	Observations	Mean	Distribution						
					Min	10%	25%	50%	75%	90%	Max
Reference	BOD_7	mgO_2/l	42	1,9	1,0	1,1	1,4	1,7	2,3	2,6	3,9
Impact	BOD_7	mgO_2/l	512	1,9	0,5	1,1	1,4	1,8	2,3	2,8	6,4
Reference	TN	mgN/l	42	1,25	0,33	0,47	0,77	1,125	1,6	2,0	3,37
Impact	TN	mgN/l	512	1,92	0,04	0,63	1,0	1,6	2,4	3,7	8,44
Reference	TP	mgP/l	42	0,041	0,009	0,02	0,023	0,038	0,055	0,07	0,084
Impact	TP	mgP/l	512	0,034	0,002	0,005	0,01	0,02	0,041	0,072	0,41

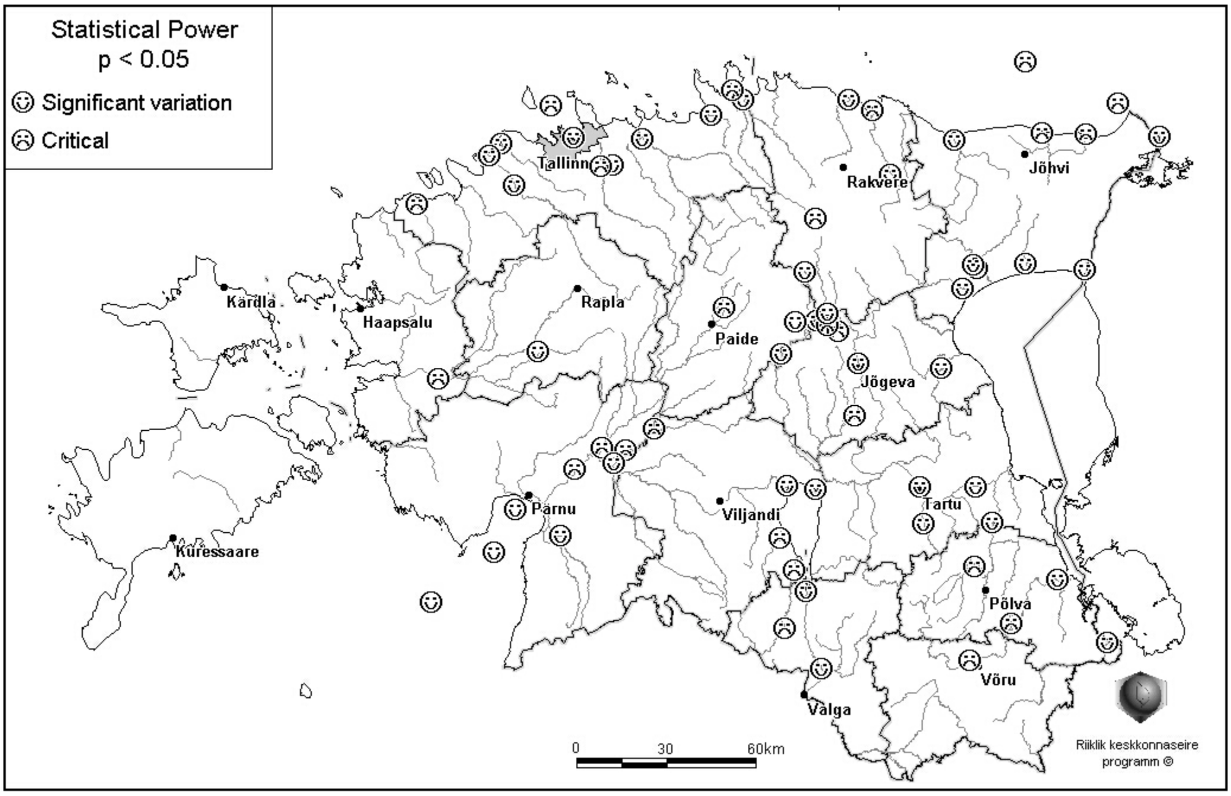
Having the basic data about water quality and trends the aim is to determine the best monitoring network for a new standards. Two components of time series were found as the parameter estimates in a two-way ANOVA. The results of applied procedures to the model of river monitoring is summarised as follows. Decomposed yearly variation confined temporal relation between human impacted and reference stations. As the standard deviation increases, the effect size of sampling becomes smaller. It is anticipated that nutrient concentrations reflect a significant variation between stations for TN and TP, shown in Table 5. Annual variations what should be interpreted carefully decrease for all indicators.

Table 5. P-values for three-way ANOVA with nutrient variation divided into station and yearly variation. Significant variations at a 5% level are highlighted.

Indicator	Station variation	Yearly variation
BOD_7	0.096	0.232
TN	0.036	0.088
TP	0.038	0.081

Significant differences are detected in 39 rivers of 59 for BOD_7, 19 rivers for TN and 38 rivers for TP. The fewest number of significant variations were detected for TN concentration, indicating the data is too weak for statistical analysis. Results are strongly influenced by changed analytical methods as well by dramatic decline of non-point pollution loads. Standard deviation of means of indicators reflects clearly the size of river basin that is why lower order streams are preferred. No doubt, the magnitude of influence of uncertainty in each variable varies with the location along the river. In conclusion, 38 river stations, shown in Figure 2, as the sensitivity of BOD_7 and TP, are the true representatives of monitoring areas, and others should be considered carefully and needed looking further. The small number of reference stations (7) allows excluding natural pressures in the planned network.

Figure 2. Power of river and coastal sea monitoring network, p value 0.05.



The sensibility analysis of coastal monitoring stations shows that three stations in the Pärnu Bay and just one station in the Tallinn Bay do represent conditions and impacts. The use of other stations should be considered carefully, in particular because of low intensity of sampling in Narva Bay (Integrated assessment, 2001). Consequently, marine monitoring lacks more often statistical power.

Table 6 P-values for three-way ANOVA with nutrient variation divided into station and yearly variation for Narva Bay. Significant variations at a 5% level are highlighted.

Indicator	Station variation	Yearly variation
DIN	0.507	0.679
TN	0.012	0.011
DIP	0.053	0.001
TP	0.025	0.121

Conclusions

The rationale for such research is for purposes of setting monitoring network. The results presented above suggest that when selecting monitoring stations, it is far better to consider the coverage of stations across an entire territory than to select sites based solely on individual merit. The proposed model of sensitivity analysis is an effective way of doing this, detecting significant change. The rivers showing the lowest coefficient of variation would be the most appropriate sites to sample. Naturally, it is easier to detect a larger difference than a smaller difference. On the other hand, the ecological importance of a change does not necessarily correlate in a linear way with the effect size. As the Water Framework Directive focuses on effect of human pressures the monitoring stations should be located near to important pollution areas, such as larger cities and outlets of larger catchments. Where the size of the dataset makes modelling infeasible, heuristic approaches are efficient, easily applied and result in solutions comparable to those obtained using simulations. Even without consideration of the results of a power analysis, sample sizes have often been too small, in particular in biodiversity and ecological monitoring in this case. It is the temptation to declare a critical number of sites and samples as being absolutely necessary, but since this would depend on too many other environmental variables, there would be too many critical numbers.

Decision making process requires another interpretation of sensitivity, in which indicators should be attributed to the impact layers according to their relative importance and response time. The most important distinction of this approach from making a conclusion about putative cause is that one is not generalizing to other situations.

Finally, we would like to emphasize that pollution characteristics might be extremely complicated, both in pollution source, spatial distribution and the level of pollution. It is possible that several monitoring patterns depending on spatial scale needs to be utilized in a practical pollution investigation. For example, if part of the network is found more seriously polluted than other parts, a more focused sampling scheme may need to be applied in the catchments. For the further discussion, there is a danger in categorizing a set of indicators strictly by environmental dimension, prevailing spatial reasoning.

References

Integrated Assessment and Reporting of the Marine Environmental Monitoring Data, 2001. Report. DHI – Water & Environment, Estonian Marine Institute. 85 pp.

Ministry of Foreign Affairs, Estonia, Press release of June 7, 2001. Overview of Estonia's Accession Negotiations with the European Union.

Sheppard, Charles R. C, 1999. How Large should my Sample be? Some Quick Guides to Sample Size and the Power of Tests. In: Marine Pollution Bulletin Vol. 38, 6. pp 439-447