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Map of Soil Vulnerability and Degradation in Estonia

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ABSTRACT

Proceeding from the percentage of natural stable situation, 13 generalized taxa were distinguished on the map of soil vulnerability and degradation. Most Histosol and Gleysol expanses as well as large forested areas on different soil complexes are natural stable. Neglected drainage systems have often led to continuation of gleying and restoration of waterlogging of formerly drained areas. This kind of physical degradation is actual, even on neighboring forested and arable lands. Owing to privatization of land and changes in the types of machinery used today, decrease in soil compaction and consequent surface reductomorphic processes are evident. As the majority of Estonian territory is plain and soil texture is loamy, water and wind erosion do not present a natural hazard. Changes in land use have resulted in the decline of erosion even on the endmorainic hills of South-Eastern Estonia. Acidification has occurred in some sandy Podzols; alkalinization and contamination with heavy metals is relatively high in the region of oil-shale and power industry in North-Eastern Estonia. Chemicals applied in agriculture do not act as pollutants for soils but represent a risk for water. Increase in urban land conversion is characteristic of Northern Estonia, but is revealed also in other localities. Some local industrial enterprises and former Soviet military objects play an important role in soil contamination and pollution. Changes in economic situation in Estonia have positively influenced soil status and contemporary soil processes.

INTRODUCTION

In most countries systematic soil surveys were started in the 1950s against the background of an urgent need for increased agricultural production. The methodologies and scales of the surveys varied widely from large to small. In Estonia, systematic large-scale soil mapping was initiated in 1949 with involvement of students of agronomy. From 1954 special survey was carried out under supervision of the Ministry of Agriculture. The soil cover of Estonia was mapped, using the scale 1:10,000, up to 1992. On the basis of this large-scale survey, generalized middle-scale maps (1:50,000; 1:100, 000) for all counties and for some natural regions were compiled during 1954–1990. At the same time, small-scale maps (1:200,000; 1:500,000 and 1:1,500,000) were produced for the whole Estonia (Rooma & Reintam, 1976; Kokk & Rooma, 1989; Rooma & Voiman, 1996; Rooma, 1996). In one case (Rooma & Reintam, 1976), FAO–1974 nomenclature was used besides traditional local soil taxonomy.

In line with the activity of European Soil Bureau in 1995, a digitized (digitations by A. Kull) "Soil Map of Estonia, 1:1,000,000", compiled on topographic basis with FAO–1990 nomenclature in Legend, was produced by I. Rooma and L. Reintam (1998). This map was edited and published in "Soil Geographical Data Base of Europe at Scale 1:1,000,000" by the Institut National de la Recherche Agronomique (INRA, France) and presented at the 16th World Congress of Soil Science, Montpellier, France, in 1998. Within the Soil and Terrain Vulnerability in Eastern and Central Europe (SOVEUR) Project, advised by the International Soil Reference and Information Centre – ISRIC (Batjes, 1997; Batjes & van Engelen, 1997), a soil map of 1:2,500,000 was produced by I. Rooma and L. Reintam (Fig. 1). Since mechanical and chemical degradation of soils has been and still is of global importance, its mapping and related issues have been the focus of long-term worldwide research (Oldeman et al., 1990). The impact of agricultural management on the development of both sustainability and vulnerability of ecosystems, as well as on economy and ecology needs to be ascertained (Blum, 1995). Against the background of the present situation, where increase in human-induced soil vulnerability and degradation has become evident, the SOVEUR Project was launched in Central and Eastern Europe (Batjes, 1997; van Lynden, 1997a, b). The soil map compiled by us (Fig. 1) served as the basis of "Soil Degradation Map of Estonia" produced in accordance with ISRIC methodology within SOVEUR. The aim of this paper is to present the map together with complementary materials.

MATERIAL AND METHODS

Large-scale soil maps were used for compiling both maps with the scales 1:500, 000 and 1:1, 000,000 that served as a basis for the map of 1 : 2, 500,000. Thirteen soil map units (SMU) with various combinations of associated soils were distinguished. Since Gleysols and Histosols cover 34 and 23% of the territory, respectively (Reintam, 1995), they are represented in all SMUs with the exception of sandy massifs of Haplic Podzols. In large mire areas, Gleysols are lacking. Except on Histosol polygons, all SMUs consist of 3–4 soil taxonomic units (STU) while their relative minimum area was estimated at 15% (Batjes & van Engelen, 1997).

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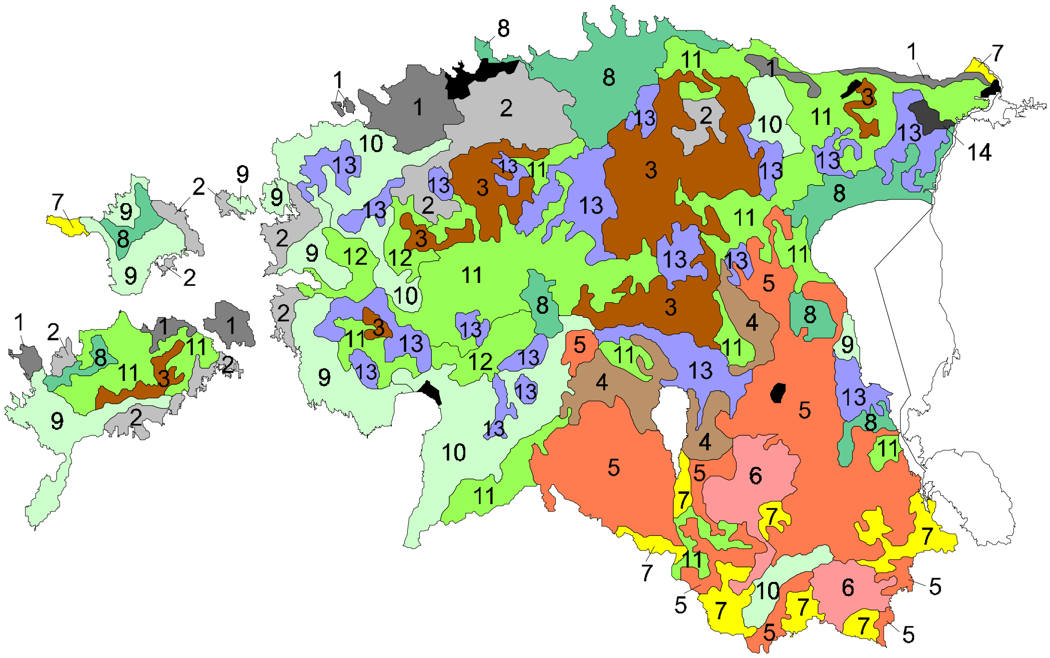
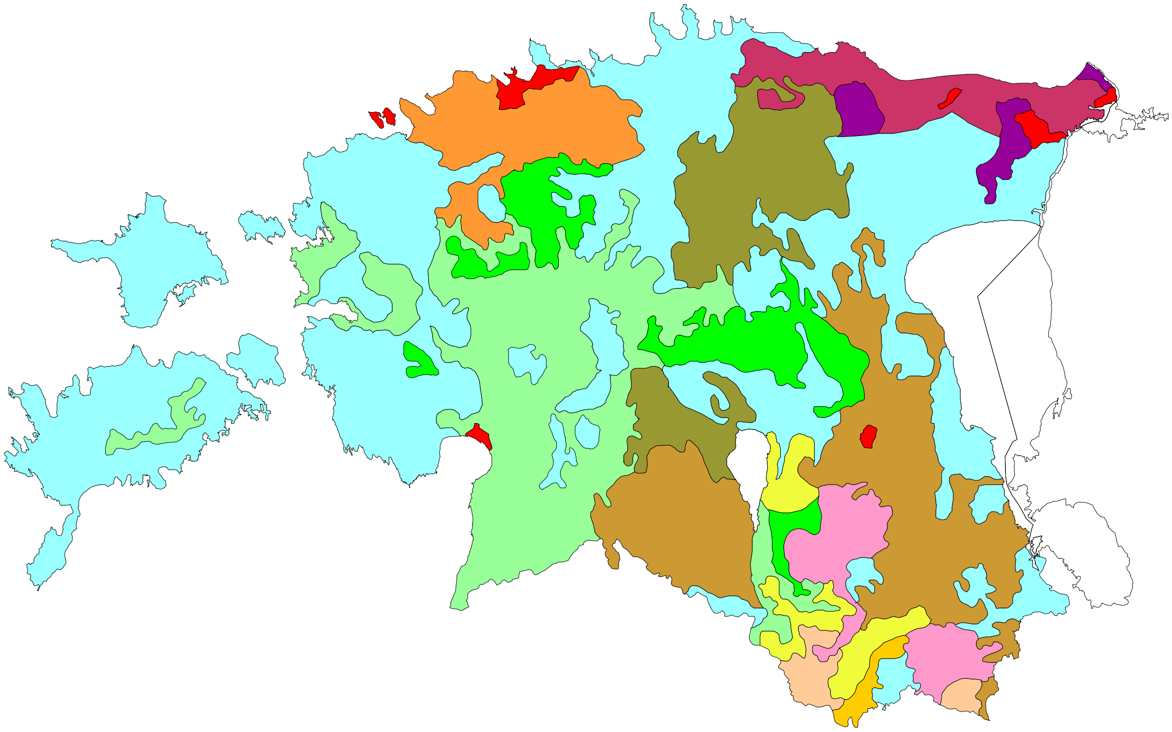


Soil units	Map No	Symbol	Associated Soils	Textural Class
	Map units			
Calcaric Regosols	1	RGc	GLe, LPk	2, 3
	2	RGc	GLe, HS	2, 3
Calcaric Cambisols	3	CMc	LVk, GLe, HS	3
Calc(ar)ic Luvisols	4	LVk	CMc, GLe, HS	2, 3
Stagnic Luvisols	5	LVj	PLe, GLe, HS	2
	6	LVj	PZh, LVk, HS	2, 1
Haplic Podzols	7	PZh	PZc, HS, PZg	1, 2
Carbic Podzols	8	PZc	PZh, HS, GLe	1
Eutric Gleysols	9	GLe	RGc, HS	1, 2
	10	GLe	PZc, PZh, HS	1, 2
	11	GLe	CMg, CMc, HS	3
	12	GLe	CMg	4, 5
Histosols	13	HS		
Soils disturbed by man	14			

Textural classes EC system:
1 - coarse, 2 - medium, 3 - medium fine, 4 - fine, 5 - very fine

Figure 1. Soil Map of Estonia (1:2,500,000). Symbols of associated soils unopened in the Legend: LPk – Rendzic Leptosols, PLe – Eutric Planosols, PZg – Gleyic Podzols, CMg – Gleyic Cambisols.



	Sn	Cph	Ca	Cs	Cn	Pc	Pu	Pw	Wt
	100%								
	70...100%					0...1	0...-1	-1	
	50...70%				1	1	0		
	50...80%				0...1	0...1			10%
	25...50%					30-50 %			
	25...30%				1	1	-2		
	<30%					50-60 %			<10%
	30...50%				1	1			10%
	50...70%		0		1				10-30%
	<25%				0...1		0...-1		65%
	0%	-1		-1			-1		
	<10%			-2					
	0%	Towns, mines							

Figure 2. Soil Degradation Map of Estonia 1 : 2,500,000. Sn – stable natural; Cph – soil pollution by heavy metals; Ca – soil acidification; Cs – soil alkalinization; Cn – fertility decline and reduced organic matter content; Pc – soil compaction; Pu – urban and industrial land conversion; Pw – waterlogging; Wt – water erosion. Rates: 1...3 – decrease in degradation; 0 – unchanged situation; -1...-3 - increase in degradation

The map of soil vulnerability and degradation was compiled using the same scale with initial polygons of SMUs as the basis. Soil pollution with heavy metals (Cph), water erosion (Wt), alkalinization (Cs), acidification (Ca), fertility decline and reduced organic matter content (Cn), compaction (Pc), urban and industrial land conversion (Pu), waterlogging (Pw) as well as their occurrence percentage, impacts, degrees, causes and rates were assessed and described by the methodology elaborated in ISRIC (van Lynden, 1997a,b). Land without human-induced degradation was estimated as stable under natural conditions (Sn). Mire, forest and conservation areas as well as some agricultural areas with low intensity and/or sustainable management were considered stable. Proceeding from the territorial percentage of natural stability on a territory (0% in urban, mined, polluted and/or contaminated areas to 100% on wetlands, in nature reserves and more or less virgin forest areas, etc.), generalized soil degradation units (SDU) were distinguished on the map of soil vulnerability and degradation (Fig. 2). In most cases they correspond completely with SMUs, but in some cases the latter are divided into several SDUs, especially in North- Eastern Estonia.

RESULTS AND DISCUSSION

Most Histosol and Gleysol expanses as well as large forested areas on different soil associations are entirely or to the extent of more than 70% natural stable. Areas where the share of natural stable soil situation is 50–80% can be divided into two categories: a) western lowland areas with current increase in both waterlogging of drained arable land and industrial or urban conversion, and b) southeastern endmorainic hills with water erosion, compaction, acidification and/or reduced organic matter content in the rest of the territory. Within other SDUs the percentage of natural stable area, in most cases characteristic of Histosols and Gleysols, is less than 50%. By 1994, 66% of arable land had been drained. Drainage covers an area of 738,000 ha, including 643,000 ha of tile drainage (Soovik et al., 1996). Enlarged drainage was necessitated by two main reasons. First, it was intensively developing grassland husbandry in the interest of which various Gleysols, Histosols, and a large number of Gleyic formations were drained and cultivated. Second, the necessity for enlargement of drainage arose in connection with construction activity as a result of which large productive areas were subjected to urban and industrial conversion. Many Gleyic and Carbic Podzols, sandy Dystric Gleysols, Rendzic Gleysols, Dystric Histosols, etc., unsuitable for cultivation, were drained and tilled. The thin epipedon was buried into depths, while podzolic and/or gleyic subsoil were lifted to the surface; compaction of drained soils took place. Instead of the expected positive effects there arose and persisted complicated problems related both to land use and soil efficiency. Poorly functioning drainage systems have led to continuation of gleying and progress of initial waterlogging in large drained areas. Such kind of physical degradation tends to have a negative impact even on neighboring forested and arable lands.

Long-time use of heavy machinery resulted in compaction of topsoil but also of the subsoil of certain soil types (Nugis & Lehtveer, 1992, 1994). This disturbed uptake of nutrients by vegetation, caused destruction of microbal processes, and moisture and oxygen relationships. Intensification of reductomorphic processes resulted in formation of ferrous iron, its complexities with phosphates and migration of the latter in compacted soils (Reintam, 1996). The degree of soil compaction depends on the carrying capacity of the soil (Lehtveer, 1989). Of the total of more than 800,000 hectares of arable land with a carrying capacity less than 140 kPa occur in various regions of Stagnic and Gleyic Luvisols, Planosols, and drained Gleysols with medium fine, fine, very fine or bisequal texture which are more sensitive to compaction. Rendzic Leptosols and Calcaric Regosols of the North-Estonian Plateau and sandy Podzols of South Estonia are comparatively compaction resistant. As a result of land privatization and the advent of new type tractors and other agricultural machinery, decrease in soil compaction and accompanied seasonal surface overmoistening has taken place. Only Stagnic Luvisols and Planosols of Southern Estonia and clayey Gleysols of the western lowland are still compacted.

Erosion endangered areas with an inclination of the terrain larger than 3° make up 105,800 ha which is about 10% of arable land and 2.7% of the total territory (Kokk, 1977, 1995). Eroded and deluvial soils form 5.5% of arable land. Eroded soils on the terrain with an inclination larger than 10°, accompanied by corresponding deluvial formations, occupy an area of more than 4,000 hectares. In the hilly topography of Võru, Valga and Põlva counties (South-Eastern Estonia) erosion endangered areas account for 36, 29 and 28% of arable land, respectively. At the same time, in Haanja and Otepää-Karula Uplands (polygons 6 in Fig. 1) about two thirds of SDUs are erosion endangered (Fig. 2). The share of erosion endangered area in the peripheral part of these elevations is 10–30% per SDU. On the South-Eastern Tilly Plateau erosion (<10% per SDU) occurs only on valley verges. In the islands of the West-Estonian Archipelago, and in the sandy coastal areas of some mainland counties 77,400 hectares of land may be endangered by wind erosion (Kokk, 1978). In fact, this problem is not acute because of protective role of vegetation. As the overwhelming majority of the Estonian territory is plain and soil texture is loamy, water and wind erosion do not present a natural hazard. Land use changes towards decreasing tillage and annual crop cultivation have brought erosion decline even in the hilly topography of South-Eastern Estonia.

Over the last decades, rapidly growing towns, rural settlements, and industrial enterprises have spread at the expense of fields and forests causing increase in urban and industrial land conversion. As a result, ecosystems have been destroyed on more than 200,000 ha of productive arable soils (Kokk, 1992a). However, the area covered by stone and asphalt can even be twice as large as that. Urban land conversion is characteristic not only of Northern, especially North-Eastern, industrial Estonia, but also of fast developing rural areas in the whole country. Several local points of industry as well as former Soviet military objects (airports, submarine nuclear bases, storage of nuclear residues, etc.) play an important role in soil contamination and pollution in urban-conversed (degraded) SDUs. Local soil pollution with fuels and other oil products as well as with nuclear residues is also characteristic of former military and military-industrial polygons. Soil degradation, induced by both chamber-and-pillar, and open-pit-quarry mining of oil shale and phosphorite, has deformed the entire soil cover and deteriorated soil physical, chemical and moisture relationships (Reintam & Leedu, 1994).

The chemicals used in agriculture do not usually act as pollutants for soils because some of them (nitrates) cannot be fixed and accumulated in soil, while others (phosphates, heavy metals) are able to form relatively stable complexes within solid soil structure. Their behavior as chemical time bombs is plausible. Although inadequate agrotechnology and non-utilization of nutrients from manure and fertilizers cannot induce chemical degradation and/or pollution of soils, they give rise to contamination of soil water and natural waterbodies with nitrogen. Therefore, any soil serves as a transfer medium for removal of chemicals, which are used in agriculture, or domestic management but remains unfixed in soil. Soil compaction promotes reduction processes, while formed ferrous phosphates contribute to water contamination as do nitrates in case of excessive nitrogen fertilization, extensive use of slurry and/or intensive clear cutting of deciduous forests (Mander & Kull, 1998). This has occurred in places in Estonia with the main source of water contamination with phosphorus being sewage. The present reduced use of fertilizers is evident (Table 1). During the last 2.5 decades the efficiency of fertilizers has been about 8 food units per kg NPK (Kevvai, 1994), which is nearly by one-third less than that revealed by field experiments. Pesticides have never been a problem in Estonia (Tables 2 and 3) because their residual accumulation in soils and contamination effects has had only a very local character (Lõiveke, 1994). Like fertilizers, pesticides do not damage soils but affect organisms and water.

In 10–12% of cases the concentration of lead, uranium, cadmium and some other heavy metals in the industrial regions of North-Eastern Estonia is above the maximum permissible limit (Petersell & Ressar, 1993; Petersell et al., 1994, 1997). In 2–3% cases of total these concentrations are twice as high. A similar content of heavy metals in soils and plants in North-Eastern Estonia demonstrates their increased biological absorption. At the same time, geochemical mapping shows that on most of the territory metal relationships are far below the level of maximum permissible concentration (Petersell et al., 1997).

Besides acid deposition (Frey, 1988, 1989; Oja et al., 1998) and slight acidification of sandy Podzols in Southern Estonia, alkaline deposition via the atmosphere is characteristic of the region of oil-shale and cement industry (Kokk, 1988, 1992b; Rajaleid and Tuuga, 1989; Mandre, 1995). At the same time, neutralization of acid contaminants has occurred largely because Rendzic Leptosols, Calcaric Regosols, Calcaric Cambisol–Luvisol complexes and different Gleysols on calcareous deposits form about 50% of soil cover. About 75% of soil parent materials and 50% of bedrock are calcareous. Alkaline dusty deposition in industrial areas leads to changes in interactions within the system of coniferous forest and soil (Mandre, 1995; Oja et al., 1998), but also to decrease in the buffer capacity of soils on calcareous rocks.

Chemical denudation of soils suggested as a probable outcome of natural pedogenesis in some studies (Kask, 1996) is an obvious exaggeration that has arisen from the podzolic concept and from an overestimation of the importance of podzolization in soils. Actually, only 9.2% of soils are podzolic by nature and can be degraded by subsequent breakdown of their mineral particles and leaching of formed organo-mineral products. Some podzolic properties can also be found in 5% of soil cover. Accumulative pedogenetic phenomena are characteristic of about 44% of soils, while profile balance diagnostics involves more than 10% of soils. Therefore, the probability of progress of soil chemical denudation cannot be reliable.

Table 1. Use of mineral fertilizers in Estonia, kg·ha^{-1} (Kärblane, 1996).

Years	N	P_2O_5	K_2O	NPK
1950	5.7	21.4	24.0	51.1
1960	12.0	41.9	38.4	92.3
1970	72.1	56.6	80.0	208.7
1980	89	54	83	226
1990	76	56	88	220
1991	63	43	70	176
1992	36	23	44	103
1993	28	11	22	61
1994	29	10	14	53
1995	22	4.5	5.5	32

Table 2. Use of pesticides, in tons for the whole country.

Years	Herbicides	Insecticides	Fungicides	Total
1961	200.0	465.1	161.9	827.0
1970	314.6	100.2	107.4	522.2
1980	1,083.9	63.2	407.6	1,554.7
1989	1,470.2	44.5	301.4	1,816.1
1990	1,168.4	29.7	209.1	967.1
1991	735.8	25.2	206.1	967.1

Table 3. Use of the active substance of pesticides, kg ha^{-1} of arable land.

Years	Active substances
1989	1.002
1991	0.580
1992	0.442
1993	0.140
1994	0.210

CONCLUSIONS

Changes in political and economic situation in Estonia, as well as the departure of Soviet troops have had a favorable impact on soil status and contemporary soil processes. More than half of the country's is natural stable. Due to decline of tillage intensity soil erosion has slowed down even in the hilly endmorainic topography. Changes in mechanization of agriculture have resulted in evident decrease in soil compaction. The fallowing of some arable land has led to stabilization and/or improvement of humus status, although the quality of humus is still reduced in Stagnic Luvisols, some Calcaric Regosols and sandy Gleysols. Urban and industrial land conversion is the main cause of soil degradation not only in the surroundings of towns and mines, but also around large rural settlements. Pollution with heavy metals and soil alkalinization are also related to urbanization and the influence of power, cement and oil-shale industry.

However, information about contemporary changes in the structure of private land use and crop rotation as well as the impact of clear cutting on formation of chemical, physical and humus relationships in soils and their associations are scanty. Data on the potential pollution load, which causes contamination of the more dynamic constituents of plant-soil systems are still inadequate. Soil monitoring including changes in regimes and processes should cover at least the following objects: (a) Rendzic Leptosols and Calcaric Regosols in Northern Estonia, (b) Calcaric Cambisol-Luvisol association in Central Estonia, (c) Stagnic Luvisols in Southern Estonia, (d) Gleysols in Western Estonia, (e) Luvisol-Planosol complex in Southern Estonia. The results of the studies carried out within the framework of the International Biological Programme could be used as a benchmark for contemporary monitoring.

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