State and Possibilities of Soil Salinization in Europe

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Introduction

The protection of the environment is a cardinal problem in our epoch and will also be one of the main tasks of mankind in the forthcoming centuries.

There are numerous adverse environmental phenomena which urgently demand scientists and policy-makers to characterize and analyse the environmental hazard and to elaborate the necessary predictions and plans of action for the combat against adverse processes threatening natural resources and the human race.

In Europe - a continent with high-level technology and science, as well as a dense population - a lot of experience has accumulated in respect of environmental issues. This makes possible the preparation of predictions for the future not only on this continent, but in other areas as well.

Among environmental hazards, salinity is remarkable and occurs in all continents. In comparison with Asia, Africa or Australia, the salinization of soils and waters is less extended in Europe. Nevertheless, it represents a growing hazard, making it necessary to continue the study of this problem in numerous European countries /SZABOLCS, 1987/.

The total territory of salt affected soils exceeds 10% of the total surface of the continents /this percentage is somewhat lower in Europe/. Soil salinity is closely related to the salinity of waters which also impairs the possibility of utilizing water for irrigation and drinking purposes. The salinity of soils and waters exceeding the given threshold values can be considered as toxic for plants, animals and humans /KOVDA, 1947; ALEKSEEVSKY, 1981/. The territory covered by salt affected soils is growing rapidly due to natural, but mainly to man-made factors, like irrigation, deforestation, overgrazing, desertification, etc. /SZABOLCS, 1979/.

Based on recent estimates of research organizations as well as affiliated UN organizations the extent of potential salt affected soils exceeds at least 2 to 3 times the acreage of existing saline soils. The rate of man-made salinization is accelerating due to intensive agriculture, domestic water use and other reasons /DREGNE, 1976/. Among the human-induced effects resulting salinization, apart from irrigation, the climatic changes of late years caused by the increasing CO_2 concentration of the air and atmosphere play an increasing role.

The major cause of soil salinization is the accumulation of electrolytes in the soil horizons. This accumulation can be the result of different processes under different environmental conditions, which can be divided into two main groups:

1. Accumulation of salts by weathering of rocks, transport of them by water, wind, etc. to the spot.
2. Circumstances hindering the removal of salts /bottomland position, improper drainage, etc./.

Whenever any of such processes occurs, sooner or later soil salinity will develop. Depending on the local environmental conditions different types and sub-types of salt affected soils may form with different pedological, physical, chemical and biological properties /KOVDA, 1980/.

The different types of salinity have different effects on the productivity of land. Salt affected soils occur with a very wide range of salt concentration, pH, morphology, etc. /SZABOLCS, 1989a,b/. However, there are only a few chemical elements and compounds which play a decisive role in the salinization and alkalization of grounds, soils and waters. They are as follows /SZABOLCS, 1979/:

Cations: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+};

Anions: Cl^{-}, SO_4^{2-}, HCO_3^{-}, SiO_3^{2-}.

The ions and compounds, the migration and accumulation of which lead to the formation of saline and/or alkali soils, behave diversely in the weathering processes taking place in the earth's crust.

It is evident that in arid and semiarid areas the weathering processes result, as a final product, in water soluble compounds which, due to the lack of precipitation, are not removed from the place of their formation. These final products are mainly responsible for the salt accumulation in rocks, soils and waters.

Table 1

Sequences of ion extraction during weathering

Sequence of extraction	Ions	Energy coefficient
I	Cl^{-}, Br^{-}	0.23
	$(NO_3)^{-}$	0.18
	$(SO_4)^{2-}$	0.66
	$(CO_3)^{2-}$	0.77
II	Na^{+}	0.45
	K^{+}	0.36
	Ca^{2+}	1.75
	Mg^{2+}	2.10
III	$(SiO_3)^{2-}$	2.75
IV	Fe^{3+}	5.15
	Al^{3+}	4.25

In Table 1, according to FERSMAN /1934/, the places of the dominant elements in the sequence of extraction are demonstrated. The sequences with growing numbers indicate the decreasing mobility of elements during the weathering processes.

According to FERSMAN, the energy coefficient can be calculated on the basis of known lattice energies in inorganic salts. These values are called "experimental energy coefficients" and are considered the most reliable ones. The energy coefficients of FERSMAN are closely related to the sequence of the extraction of ions from minerals, to the rate of migration of ions, and to their ability to accumulate in sediments and soils.

The weathering of rocks has been the primary source of soluble salts getting into natural waters, sediments and soils /POLYNOV, 1956/.

From Table 1 it follows that the elements and compounds with a dominant role in salinization and alkalization are mainly in sequences I and II; in other words, they are capable of intensive migration. In spite of this, very diverse values can be measured as to the mobility of the mentioned compounds, and their occurrences in rocks and waters are similarly diverse.

While we have quite reliable records on the extension of the saline soils which have been formed by natural processes in the different regions and countries, the soils which became salinized due to human action have not been registered with accuracy.

Major aspects of recent and potential soil salinity in Europe

In Europe, like on all of the continents, salt affected soils occur in different places. The total extension of salt affected soils in Europe surpasses 50 million hectares which is quite remarkable considering the total territory of this continent. Salt affected soils occur to a considerable extent in Austria, Bulgaria, Czechoslovakia, France, Greece, Hungary, Italy, Portugal, Rumania, Spain, the USSR and Yugoslavia. Hungary, Spain and the USSR are the three European countries where more than three quarters of all salt affected soils of this continent occur. Apart from the twelve countries listed above, in at least ten other European states different types of salt affected soils can be found to a limited extent. Among these countries those should be mentioned which have a seashore strip with a steady accumulation of sodium chloride from the sea water. Other sources of soil salinization also occur. The greatest part of European salt affected soils can be found in the semiarid steppe and forest steppe regions of the USSR, on the second and third lowlands of the Danube in the territories of Czechoslovakia, Rumania, Hungary, Yugoslavia, and in Spain. Nevertheless, as far as annual temperatures, precipitation and local altitudes are concerned, the conditions of occurrence of salt affected soils may be quite different. In Table 2 the regional occurrence of salt affected soils in the twelve European countries most affected are given with the indication of some climatic characteristics and of altitudes /SZABOLCS, 1974/.

In Table 3 data on soil salinization in Europe are shown. Tables 2 and 3 clearly demonstrate that in Europe salt affected soils occur both in semiarid and in semihumid climatic conditions and they can be found on altitudes as low as less than 100 m above the sea level and as high as over 500 m above the sea level as well.

As it has been mentioned, no reliable records are available on the potential extension of salt affected soils. In Europe, like on other continents, local estimates and studies are only available in a few countries in this respect /SZABOLCS, 1974/.

Table 2

Regional occurrence, climatic characteristics and altitude of European salt affected soils

Country, region	Mean annual temperature °C	Mean annual precipitation mm	Altitude m
AUSTRIA			
Pulkantal /Illmitz/	9.2	566	187
Seewinkel /Apetlon/	9.8	623	140
BULGARIA			
Danube Valley	11.6	585	50–100
Maritza, Tundja, Strema Valley	12.3	500	100–200
CZECHOSLOVAKIA			
South Moravia	9.0	500–550	200
Danubian Lowland	9.0–10.0	500–600	100–150
East Slovakian Lowland	9.0	600–650	100
FRANCE			
Atlantic sea coast	10.5–11.5	700–800	0–100
Mediterranean sea coast	14.0–15.0	550–650	0–100
GREECE			
Ionian sea coast	17.5–18.5	650–750	0–100
Thessaloniki Plain	14.0–15.0	500–600	0– 50
HUNGARY			
Hungarian Plain	10.0–10.5	524–585	80–120
ITALY			
Northern Italy	13.7	744	0–100
Southern and island region	17.6	478	0–100
PORTUGAL			
Atlantic sea coast	14.0–18.0	660–1400	0–100
RUMANIA			
Black Sea shore - Danube Delta	11.0–11.3	359–439	0– 50
NE Rumanian Lower Danube Plain	9.6–11.1	400–515	0–100
Western Rumanian Lower Danube Plain	10.6–11.5	480–570	100–200
Tisza Plain	10.7–10.8	558–620	80–100
Moldavian Table-Land	9.0–10.5	399–588	200
SPAIN			
Southern region	17.6–18.3	535–651	30–100
South-Western region	17.0–17.6	295–419	0– 60
Basin depression of the Ebro	14.6–15.1	324–378	118–380
Central plateaus	11.6–14.2	389–403	700
USSR			
Ukraine	7.0	500–550	100
Oka-Don Plain	7.0– 8.0	500–550	100–200
Preazovian Plain	9.0–10.0	300–550	100
Prevolgian Plateau	6.5– 7.5	500–600	200–300
Precaspian Lowland	6.0	150–250	0–100
Transcaucasian Plains	14.0	200–250	100–200

Table 2 /continued/

Country, region	Mean annual temperature °C	Mean annual precipitation mm	Altitude m
Armenia	11.3-14.0	200-220	500-700
Transvolga Region	4.0- 5.0	300-400	100-200
YUGOSLAVIA			
Vojvodina	10.0-10.5	550-600	100
Macedonia	11.2	652	100-200
Adriatic sea coast	14.5-15.5	500-900	0- 50

Table 3

Distribution and extent of soil salinization in most affected European countries

Countries	Mapping units (area in 1000 ha/area in percentage of the total salt affected area)				Total area in 1000 ha
	Saline soil	Alkali soil without structural B horizon	Alkali soil with structural B horizon		
			non-calcareous	calcareous	
Austria	$\frac{0.5}{25.0}$	$\frac{-}{-}$	$\frac{-}{-}$	$\frac{-}{-}$	0.15
Bulgaria	$\frac{5.0}{20.0}$	$\frac{-}{-}$	$\frac{20.0}{80.0}$	$\frac{-}{-}$	25.0
Czechoslovakia	$\frac{6.2}{5.8}$	$\frac{7.5}{7.1}$	$\frac{2.7}{2.5}$	$\frac{4.3}{4.1}$	20.7
France	$\frac{175.0}{70.0}$	$\frac{-}{-}$	$\frac{75.0}{30.0}$	$\frac{-}{-}$	250.0
Greece	-	-	-	-	3.5
Hungary	$\frac{1.6}{0.1}$	$\frac{58.6}{4.7}$	$\frac{294.0}{23.1}$	$\frac{31.9}{2.5}$	386.1
Italy	$\frac{50.0}{20.0}$	$\frac{-}{-}$	$\frac{-}{-}$	$\frac{-}{-}$	50.1
Portugal	-	-	-	-	25.0
Rumania	$\frac{40.0}{16.0}$	$\frac{100.0}{40.0}$	$\frac{110.0}{44.0}$		250.0
Spain	-	-	-	-	840.0
USSR	$\frac{7546.0}{16.0}$	$\frac{1616.0}{3.4}$	$\frac{20382.0}{43.1}$	-	29544.0
Yugoslavia	$\frac{20.0}{7.8}$	$\frac{50.0}{19.6}$	$\frac{110.0}{43.1}$	$\frac{75.0}{29.5}$	255.0

In Table 4 an estimate is given for a few European countries of potential salt affected soils assumed to be threatened by developing irrigation. These estimations were made by local contributors and were based on physicogeographical factors of the given territories, taking into account the possible extension of irrigated agriculture for the future.

Table 4

Acreage of existing and estimated territories of potential salt affected soils /as a result of irrigation/ in a few European countries

Country	Salt affected soils /ha/	
	Existing /non irrigated/	Potential if irrigation increases considerably /~ 100%/
Austria	500	2,500
Czechoslovakia	25,000	80,000
Hungary	740,000	885,000
Italy	500	400,000
The USSR	28,000,000	18,000,000

Even though we accept the fact that irrigation is the main agent of soil salinization in Europe, other possible man-made changes leading directly or indirectly to the same state must not be excluded.

From the major processes involved in man-made salinity the following will be discussed in this paper:

1. Existing and potential soil salinity caused by irrigation;
2. Existing and potential soil salinity caused by climatic changes in the mediterranean region;
3. Existing and potential soil salinity caused by possible sea level elevation in North-Western Europe.

Accordingly, three scenarios corresponding to the above three processes were set and studied in this paper.

In order to characterize potential soil salinity for the next 50 to 70 years it is necessary to register and to study the present situation of soil salinization in Europe and to examine the possibility, probability and rate of adverse processes some aspects for their prediction and prevention as well as the possible means of intervention available for scientists, decision-makers and politicians to arrest, limit or control future soil salinization in the short, middle and long run.

Figure 1 shows the present extension of salt affected soils in Europe.

Scenarios for the characterization of potential soil salinization in Europe

For the studies of potential soil salinity in Europe we have taken into consideration that due to the different factors, both natural and man-made, several major processes can produce salinization in different parts of Europe in the next half century.

We selected the following three scenarios which represent the most important processes of potential salinization in different parts of our continent:

Fig. 1
Present situation of soil salinity in Europe

1. Potential increase in soil salinity caused by the extension of irrigation (Scenario 1)
2. Potential increase in soil salinity caused by climatic changes (Scenario 2)
3. Potential increase in soil salinity caused by sea-level rise (Scenario 3)

Evidently, those regions of Europe have been selected for the above listed three scenarios, respectively, where the potential salinization processes in the given area may most probably result from the important causes described in the corresponding scenarios.

For Scenario 1 regions with continental and semiarid climate of the continent were chosen where the main hazards of secondary salinization are present and irrigation is extending. For Scenario 2 the mediterranean region of Europe was selected where possible changes in the climate, like increasing temperature and decreasing precipitation /due to the changes in the CO_2 balance of the atmosphere/ may result in secondary salinization. For Scenario 3 certain coastal areas of North-Western Europe were chosen where possible sea-level elevation /in consequence of the same phenomenon mentioned in connection with Scenario 2/ may cause remarkable soil salinity.

The location of the territories for the three scenarios are shown in Fig. 2.

The three scenarios cover a major part of Europe as well as most of the areas with potential salinity, caused by different direct or indirect man-made salt accumulation processes.

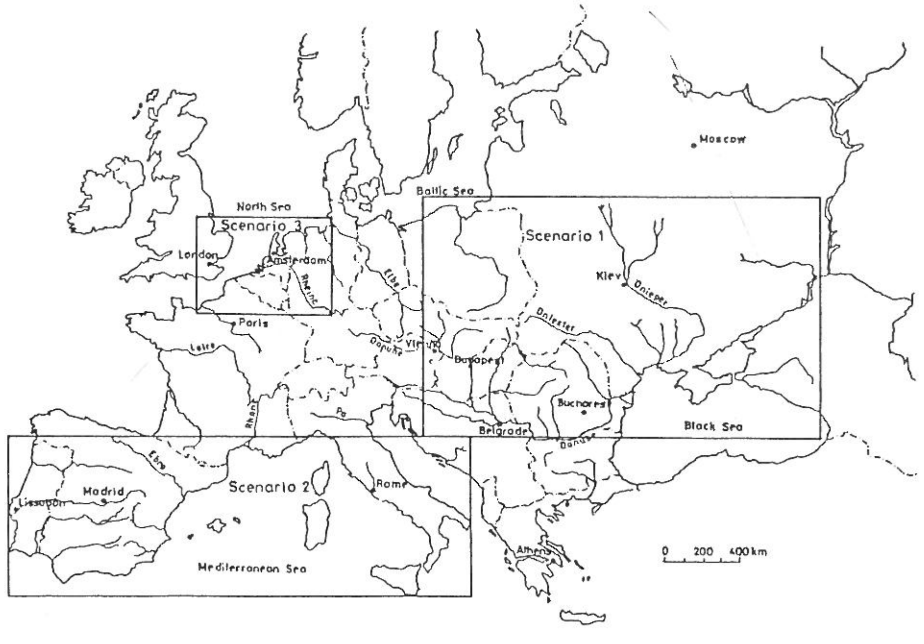

Fig. 2

Location and territory of Scenarios 1, 2 and 3 in Europe

Scenario 1: Existing and potential soil salinity caused by irrigation

For Scenario 1 we selected a part of Europe /See Fig. 2/ where, in consequence of both climatic and economic conditions, irrigation has been practised for a long time. More than half of all irrigated areas in Europe are situated in the territory of Scenario 1. As can be seen from Figure 1, salt affected soils are rather extended in countries indicated in Scenario 1. A great part of existing salt affected soils is situated in the vicinity of irrigation systems or even within their territories.

In nearly all countries included into Scenario 1 the further extension of irrigation has been envisaged. In countries where the precipitation is low, a greater increase has been planned /e.g. the USSR, Bulgaria, Rumania/ than in countries which do not suffer from aridity /Austria, Poland/.

At the present time, in the countries of Scenario 1 the ratio of irrigated soils is lower than 20%, in most cases below 10%, of the total agricultural land. The envisaged increase of irrigated areas is different in the various countries, but in no case will it be more than 100% for the next fifty sixty years. One of the main limiting factors of the extension of irrigation in the future is the shortage of good quality irrigation water in most countries concerned.

In Scenario 1, taking into consideration the above described circumstances, we assumed that up to the middle of the 21st century the irrigated territories will double as a maximum and calculations were made according to such aspect.

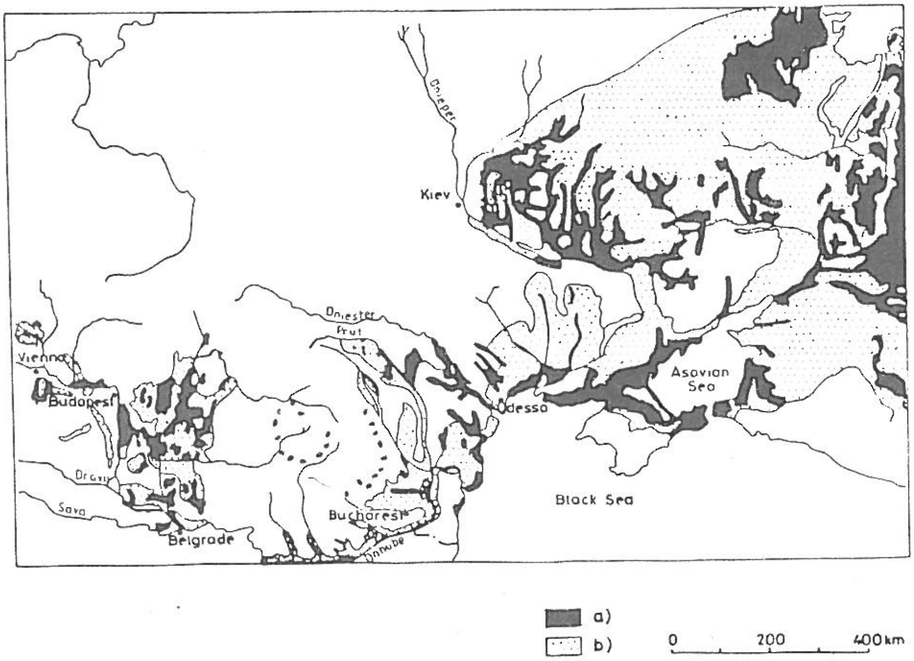

Fig. 3

Territory of salt affected soils and potential soil salinity as a consequence of extended irrigation /Scenario 1/. a/ existing salinity; b/ potential salinity

There are two main processes of salinization caused by irrigation:

1. Salt accumulation in soil layers from the salt content of irrigation water;
2. Salt accumulation in soil layers from the salt content of rising salty groundwater.

As related to soil salinization from irrigation water in the countries demonstrated in Scenario 1 there are acceptable regulations for quality control of irrigation water. Consequently, only a small part of present secondary salinization processes develop as a result of poor quality irrigation water. In the case of soil salinization from groundwater, the table of the salty groundwater /which sharply rises in most irrigated areas/, unfortunately, results a great part of soil salinity at the time being and this process can be predicted as the most hazardous one also for the future.

Considering climatic, physico-geographic, hydrological, agricultural and pedological aspects, we have elaborated a map demonstrating the hazard of soil salinity for the territory of Scenario 1 with the following assumptions:

1. Until 2050 the present irrigated areas will increase, but be doubled as a maximum.
2. There won't be substantial changes in climate and no elementary disaster will occur.
3. The present quality requirements for applied irrigation water will remain.
4. The present riverbeds and major hydrological constructions will remain.

Figure 3 demonstrates the extension of existing and potential soil salinity in the area of Scenario 1, according to the above described conditions.

The territory indicated on Fig. 3 represents different areas intensively affected by both present and potential salinization, including large areas of the European part of the USSR, Rumania /total/, Hungary /total/, Austria, Yugoslavia, Czechoslovakia and Poland. Although Scenario 1 includes only about 20% of the total land area of Europe, about 50% of all salt affected soils of the continent may be found here.

As it can be seen from Fig. 3, the territory of potential soil salinity in the given scenario exceeds that of existing salinization and is nearly two-times more.

The figures are as follows:

- Total territory of Scenario 1 /excluding the surfaces of the Black Sea and the Azovian Sea/	2,079,840 km^2
- Territory of existing salinization /10.5% of the total territory/	218,383 km^2
- Territory of potential salinization /20.1% of the total territory/	418,047 km^2.

It is also clear from the Figure that potential salinity may develop surrounding the present salt affected soils and may threaten fertile areas which are covered by non-salt affected soils at the time being. It can also be seen that in practically all areas where salt affected soils occur at this moment the hazard of further salinization exists. The riverbeds of the Danube, Prut, Dnieper, Don and Volga, as well as most lowlands of the region are especially endangered. In such territories where salt affected soils may be found at present in smaller or larger spots of various size, as a consequence of secondary salinization caused by further irrigation, large continuous territories will be covered by saline soils. Evidently, potential salinity also exists on such large areas where salt affected soils cannot be found at the present time.

The potential salinity of soils not only diminishes the ecological potential of the given area but often entirely prevents agricultural production. Besides, drinking water for animals and humans may also be salinized and the toxicity of herbs and other native plants may develop.

A more detailed map /original scale 1:500 000/, prepared for Hungary, is demonstrated in Fig. 4.

On Fig. 4, besides the existing salt affected soils, those areas are indicated as potential salt affected soils, where under the influence of increasing irrigation, secondary salinization and alkalization may occur.

Scenario 2: Potential soil salinity caused by climatic changes

For Scenario 2 we selected the major mediterranean areas of Europe /see Fig. 2/, where at present salt affected soils are extended mainly in the Iberian Peninsula and only to a smaller extent in Southern France, Italy, Sicilia, Sardinia and Corsica, as well as the Dalmatian coast of the Balkan Peninsula. The total area of this scenario is 1,979,959 km^2, with 885,826 km^2 land surface. In comparison with the salinity conditions of Scenario 1, the extension of salt affected soils in Scenario 2 is much lower, it is nearly half of the percentage.

We assumed that due to the possible climatic changes, as a consequence of CO_2 accumulation and other causes, the average annual temperature of the territory will increase by about 1 °C in the next 50-70 years. Consequently, the aridity index will also increase, which creates progressive salinity on those marginal territories where at the time being salinity does not exist or can be found only in latent form in grounds or in waters. The following assumptions were taken into consideration:

1. The currently irrigated areas will not be changed substantially.
2. No natural disaster or tectonical changes will happen.
3. The present riverbeds and major hydrological constructions will remain.

In Fig. 5 the territory of salt affected soils and potential salinity as a consequence of climatic changes are demonstrated for Scenario 2.

As it can be seen from Fig. 5, the territory of potential salinity /like it was shown on Figs. 3 and 4/ substantially surpasses that of existing salinity in all affected areas. While at the time being the total area of salt affected soils in Scenario 2 is 56,168 km^2 /6.34% of the total land surface/, which is twice as much as existing salinity. The dry areas of the Iberian Peninsula /like Castilia, the Ebro Valley, South-Western France/ and also several areas in the Italian and Balkan Peninsulas are particularly exposed to potential salinity due to the increasing aridity.

For the areas demonstrated in Scenario 2, we made a calculation of "aridity factor" values based on the precipitation factor according to LANG. The LANG-factor gives fairly good information of aridity-humidity conditions by the application of a simple quotient of average annual precipitation and average annual temperature /Table 5/.

Our calculations for selected places of Scenario 2 clearly show that in case of one Celcius centigrade increase in the annual mean temperature the R/F index changes substantially by about 10%, which means a considerable increase of aridity and, consequently, the hazard of soil salinity.

It is interesting to note that in all of the eight locations approx. the same degree of decrease in the R/F value /which means increasing aridity/ can be observed.

Such phenomenon is a consequence of the similarity of ecological and particularly soil conditions in the whole mediterranean region selected for the study in Scenario 2.

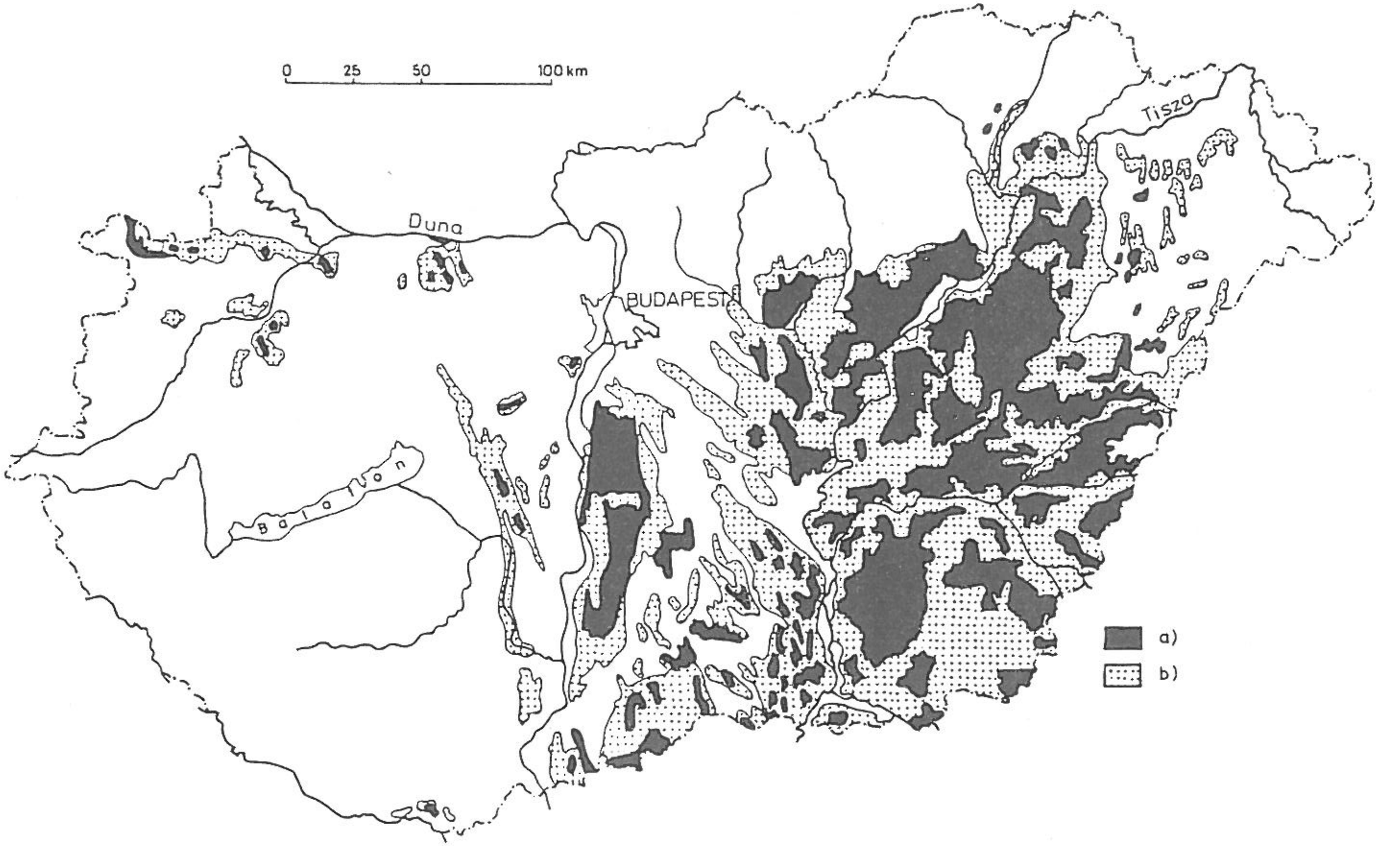

Fig. 4

Present and potential soil salinity in Hungary. a/ Present salt affected soils; b/ potential salt affected soils.

If the calculations were made by other aridity factor methods the consequences would be similar because the increasing soil aridity and, consequently, increasing salinity hazard are the evident results of the higher mean annual temperature.

Table 5

"Precipitation factor" according to LANG in Scenario 2 /Mediterranean region of Europe/

Location	Present R/F	R/F if annual mean temperature will increase by 1 °C
1. Middle part of the Iberian Peninsula /Madrid/	31.27	29.18
2. Southern part of the Iberian Peninsula /Iaen/	35.22	33.27
3. Southern France /Nimes/	50.76	47.46
4. Corsica /Ajaccio/	46.10	43.14
5. Sardinia /Sassari/	37.27	35.17
6. Italy /Terni/	61.27	57.42
7. Southern Italy /Catanzaro/	60.22	56.63
8. Yugoslavia /Dubrovnik/	79.00	74.38

$$R/F = \frac{R}{F} \quad \frac{\text{/average annual precipitation, mm/}}{\text{/annual mean temperature, }^{\circ}\text{C/}}$$

It must be noted that if the increase in the average annual temperature will surpass 1 °C, the increase in salinity will not be linear, but rather exponential compared to the data of Fig. 5. The salinity in the mentioned territories threatens very fertile agricultural lands and must be predicted in order to elaborate the necessary preventive measures in good time before the climatic changes occur. It is to be remarked that the potential salinity in Scenario 2 equally endangers river valleys and estuaries /Ebro, Neretva, Rhone, Guadalquivir, Tajo, etc./ as well as plains and plateaus /Catilla, Aragonia, Umbria/.

Scenario 3: Potential soil salinity caused by sea-level elevation

For Scenario 3 we selected a part of North-Western Europe /See Fig. 2/ where the following two conditions are favourable for the study:

a/ Measureable extension of salt affected soils at the present time;

b/ Good probability of sea-level elevation due to global climatic changes in the next 50 years.

The total territory of Scenario 3 is 344,942 km^2, with 226,393 km^2 land surface, including the South-Eastern part of England, the Western part of the Netherlands, Belgium and the North-Eastern part of France bordered by the North Sea, the Atlantic Ocean and the English Channel. In this scenario mainly coastal saline soils with high sodium chloride content occur in several seashores and attached territories.

The territory of existing and potential salinity in Scenario 3 is demonstrated in Fig. 6.

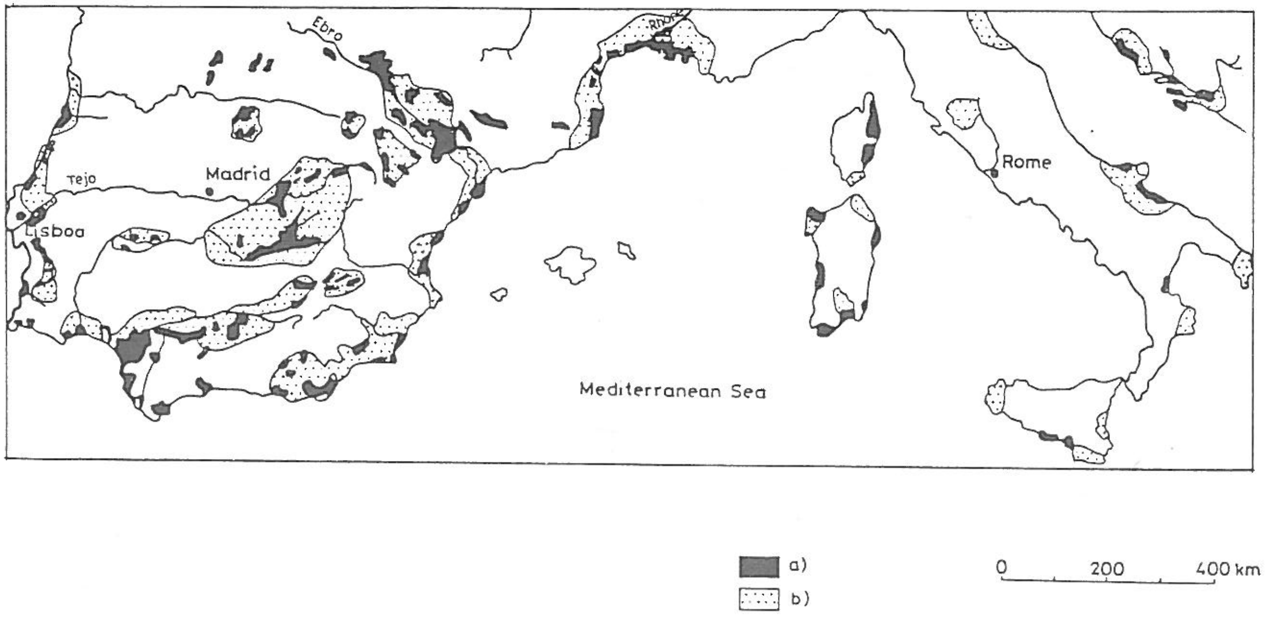

Fig. 5
Territory of salt affected soils and potential salinity as a consequence of climatic changes /Scenario 2/
a/ Existing; b/ potential salinity

It was assumed that - due to global climatic changes - the expected sea-level elevation will be 1 cm per year in average and consequently, the effect of seawater on land will provoke further salinization. However, the following were also taken into consideration:

1. Irrigation will not be extended on the territory.
2. No natural disaster or tectonical changes will happen.
3. The present riverbeds and major hydrological constructions will remain.

Changes in aridity, humidity conditions apart from sea-level elevation were not considered.

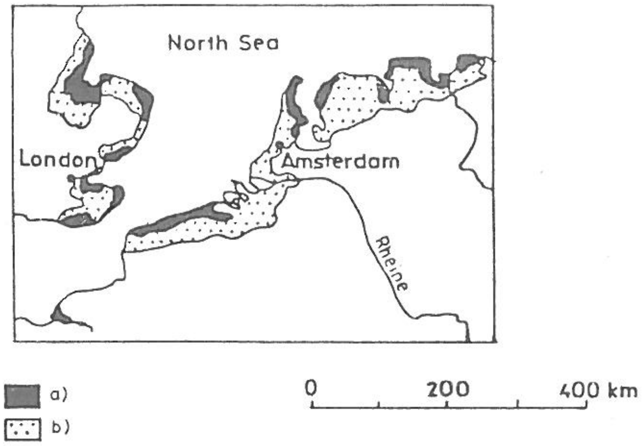

Fig. 6

Territory of salt affected soils and potential salinity as a consequence of sea-level elevation /Scenario 3/. /The map was prepared with the contribution of E. MOLNÁR/. a/ Existing, b/ potential salinity

As it can be seen from Fig. 6, the territory of potential salinity caused by sea-level elevation substantially surpasses that of existing salinity. This is also valid for the two other scenarios, proving that all over Europe potential salinity constitutes a much greater hazard than existing salinity.

In Scenario 3 salinity caused by seawater is essential /10,520 km^2/ and constitutes 4.65% of the total land surface. At the same time, the area of potential salinity is 24,977 km^2, which is 11,03% of the total land surface.

In Scenario 3 the same rule can be observed as in the other two scenarios, namely, that potential salinity may be expected in territories surrounding the existing salt affected soils.

It should also be noted that if sea-level elevation surpasses the values taken for granted in this study, the extension of potential salinity will not be linear, but will increase in an even higher degree.

The three scenarios, which have been elaborated and demonstrated above, represent the main processes leading to the hazard of secondary salinization in Europe. However, they do not exhaust all the possibilities of this phenomenon, which may develop due to other factors like: changes in the cropping pattern, intensive use of chemicals, changing farming management, etc.

In order to predict the adverse salinization processes more detailed and more exact, appropriate methods of special survey should be elaborated. We are in the possession of a number of such methods, as well as methods for the prevention of salinization mainly in irrigated agriculture. In the following part of this study such experiences and recommendations will be described and discussed.

Prognostics and prophylaxis of secondary salinization

It is very difficult and expensive to reclaim the secondary saline soils, therefore the prevention of such processes is highly desirable.

In the three scenarios described above the main possible potential soil salinization processes for Europe were described.

In the following mainly the prognostics and prophylaxis of secondary soil salinization caused by irrigation will be described which process is related to Scenario 1. We are in possession of knowledge and experience mostly related to this kind of salinization, while less experience is available related to the subjects of Scenario 2 and 3.

In case of future development of irrigation not only the pedological but also the general environmental influence of irrigation will assume new dimensions both, in favourable and adverse effects.

If the territory of irrigated land doubles or trebles, the irrigated plants will be able to produce higher amounts of biomass and harvest, through photosynthesis and to consume as much as 30-40 billion tons of CO_2 annually, instead of the recent 15-20 billion tons /KOVDA, 1980/.

The different processes of potential soil salinization in Europe are interrelated, namely the salinization caused by irrigation and that caused by CO_2 accumulation in the atmosphere and consequent climatic changes. However, in this paper the separate actions are interpreted and the study of joint actions remains for future investigations.

The technical literature presents many examples that clearly show that the success of irrigation is also interrelated with numerous vital problems. As it is clear from the mentioned example, the aim of irrigation development is to improve the food situation as well as the environment. It is also evident that the hazard of secondary salinization and alkalization will be one of the major obstacles in the way of this development if we do not intensify the study of this risk and apply the methods for its prediction and prevention.

It is a must to intensify both the theoretical and technical activities relating to the hazard of secondary salinization and alkalization. Up to now the influence of the geochemical and hydrogeochemical processes have been underestimated in many places which, sooner or later, result in salt accumulation by irrigation in the given territory. While an abundance of studies and quality requirements for irrigation water is available /SZABOLCS and DARAB, 1982/, the effect of groundwater on soil salinity is often left out of consideration.

After the 2nd World War irrigation in Hungary sharply increased to more than tenfold of the prewar extension. Consequently, secondary salinization has developed in many irrigated areas.

Before planning new and extending existing irrigation systems a comprehensive preliminary study is necessary not only of soils and surface waters, but also of underground waters and layers /DARAB and FERENCZ, 1969/.

In Fig. 7 the quality requirements for irrigation water in Hungary are demonstrated. The original of this map was prepared in scale 1:500,000, which is relevant for general planning of the distribution and application of irrigation water.

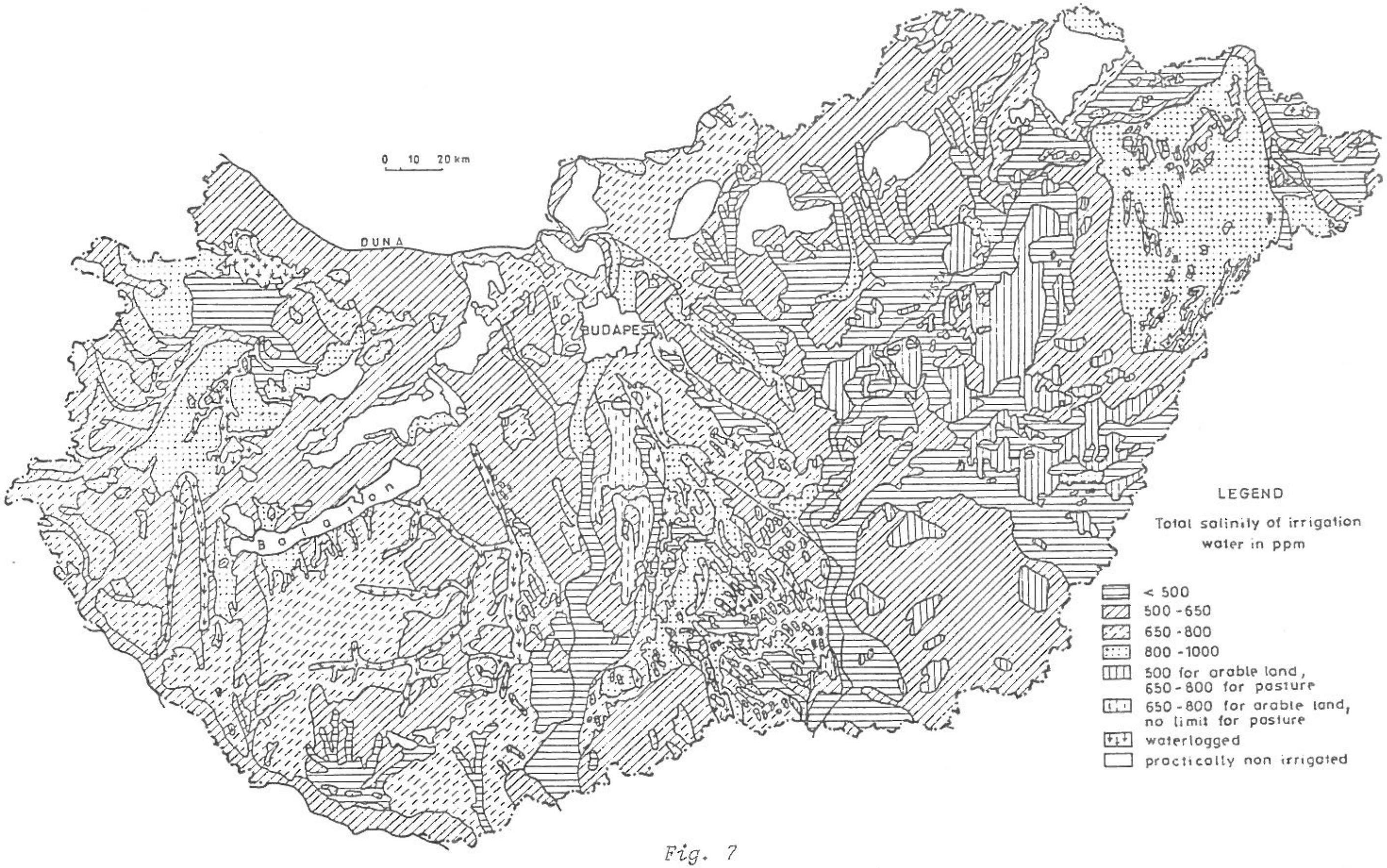

Fig. 7
Quality requirements for irrigation water in Hungary

In relation to the influence of groundwater on salt accumulation first of all the so-called critical depth of the groundwater table should be determined. This level means the depth below which, owing to natural or irrigated conditions leaching prevails, while above this level salt accumulation takes place in the soil profile. In other words the salt regime of the given territory is in equilibrium at the critical depth.

Based on the determination of the critical depth it is possible to elaborate a specific turning point scenario which enables us to trace and to record the early warning signals on the accumulation of salts coming from below.

The following data are needed for the establishment of the salt balance, regardless of the extent of the area concerned:

1. The total amount of soluble salts at the beginning and at the end of the observation.
2. The increase of soluble salt contents during the observation.
3. The decrease of soluble salt contents during the observation.

Three types of salt balances may be distinguished:

1. Stable salt balance.
2. Balance of salt accumulation.
3. Balance of leaching.

The salt balance of a soil depends on the joint effect of numerous factors. Among these factors the following must be specifically mentioned:

- The depth and chemical composition of the groundwater;
- The influence of relief;
- Irrigation technics;
- Calculation of the salt balance.

With the knowledge of the factors influencing the increase and decrease of the salt contents of soils, the salt balance may be established on the basis of the following equation:

$$b = a + d + \frac{cv}{M\,t_{fs}} \cdot 10^{-5}$$

Where:

b = soluble salt content of the soils at the end of the observation, in mg/100 g soil;
a = soluble salt content of the soil at the beginning of the observation, in mg/100 g of soil;
c = the salt concentration of the irrigation water, in g/l;
v = the quantity of the irrigation water applied during the observation period, in m^3/ha;
M = the thickness of the soil layer for which the salt balance was established, in m;
t_{fs} = the bulk density of the soil;
d = the salt regime coefficient of the soil, in g/100 g of soil.

The change that has occurred in the salt contents of a soil during the observation period is expressed in the salt regime coefficient.

Salinity hazard

For the control of the possible hazard of salinization and/or alkalization in irrigated areas, or areas to be irrigated, the following factors should be studied and determined:

1. Climatic factors, such as: temperature, rainfall, humidity, vapour pressure, evaporation and their fluctuations and dynamics.

2. Geological, geomorphological, geochemical, hydrological, hydrogeological and hydrochemical factors, such as: natural drainage, the depth and fluctuation of the water table, the direction and velocity of horizontal groundwater flow, the salt contents and composition of the groundwater, etc.

3. Soil factors, such as: soil profile, texture, structure, saturated and unsaturated water conductivity, soluble salt contents, salt composition and salt profiles, exchangeable cations, pH, etc.

4. Agrotechnical factors, such as: land use, crops, cultivation methods, etc.

5. Irrigation practices, such as: the amount of irrigation water, the method, frequency and intensity of irrigation, salt contents and composition of irrigation water, natural and artificial drainage, etc.

Preliminary survey and control of irrigated soils

The above mentioned factors determine the aims and methods of the preliminary survey of soils made in order to define the degree or the existence of potential salinity and/or alkalinity.

The soil properties, groundwater depth and chemical composition as well as the salt balance and hazard can be demonstrated on maps with recommendations for the technics of irrigation and water use.

Evidently, the environmental conditions on the one hand, and the methods of the utilization of the territory in question, on the other hand, should be taken into consideration when an area is evaluated in this respect. Due to this fact, different limit values and different methods - based on uniform principles - should be selected in the course of this procedure.

In Table 6 a scheme of methods recommended for the control of salinity and alkalinity in irrigated areas is given.

This table shows that the prediction of secondary salinization and alkalization of the soils to be irrigated should be based on a preliminary survey of the landscape and soils before the construction of the irrigation system. In this way, it is possible to take the necessary steps for the prevention of adverse processes.

During irrigation, a well-organized monitoring of the soils and water properties is to be conducted in order to record changes, if any, and to underlie taking precautions, if necessary. Monitoring methods as well as timing and location of sampling depend upon local conditions.

In the course of making the survey and monitoring, in order to develop a reliable method for the prediction of salinization and alkalization, the following problems must be solved:

1. The main sources of water soluble salts /irrigation water, groundwater, surface waters, salty deep layers, etc./ must be identified.

2. The main features of the salt regime must be characterized /salt balance/; and the whole range of natural factors influencing the salt regime must be analyzed.

Consequently, an exact salinity and/or alkalinity prognosis must be based on the evaluation of many natural and human factors and a thorough knowledge of the existing soil processes.

The mapping of the results of preliminary and subsequent surveys constitutes not only a good display of soil and environmental conditions of the irrigated areas, or areas to be irrigated, but also gives guidelines for proper irrigation and land protection. Such systems elaborated by various authors, for different places and conditions are also available in technical literature /SZABOLCS, DARAB and VÁRALLYAY, 1969a,b/.

In the following, Hungarian experience on the above described study will be reviewed.

Table 6

Scheme of methods recommended for the control of salinity and alkalinity in irrigated areas

A. Before the construction of the irrigation system	Preliminary survey	
	Landscape	Planned irrigation
	climate	available irrigation water quality and quantity
	hydrology	groundwater depth and quality
	hydrogeology	technology of irrigation
	geomorphology	cropping pattern tolerance
B. During irrigation	Monitoring	
	salinity and alkalinity of soil and depth of the groundwater table	
	chemical composition of groundwater	
	chemical composition of irrigation water, filtration	
	physical soil properties	
	toxic elements, if any, in soil and water	

After the 2nd World War, and especially after the establishment of the Tisza-I /Tiszalök/ Irrigation Project /1953/, irrigation was started on large territories of the Transtisza /Eastern/ part of the Hungarian Plain. Although at the time the harmful soil processes that could occur due to irrigation were known /at least generally/ from Hungarian and foreign data and experiences, proper attention was not paid to them during the territorial installation and technical planning of the project and in irrigation practices. Consequently, on the territory of the Tisza-I Irrigation Project about 120.000 hectares were affected by undesirable soil processes, such as peat formation /about 6 000 hectares/, salinization and alkalization /about 100 000 hectares/ and a combination of these processes /about 20 000 hectares/.

Based on extended geological, hydrological, climatic, pedologic and agrotechnical studies, an integrated map was prepared in the scale of 1:500 000, indicating the practical possibilities of irrigation in Hungary.

Fig. 8 demonstrates those possibilities in respect of salinization in Hungary which determine whether the further extension of irrigation can be recommended or not in a given region.

This map can be used for planning irrigation systems in different areas of the country and it is useful mainly for decision-makers and experts in irrigation, agriculture, etc.

In order to recommend methods for irrigation in respect of preventing secondary salinization a more detailed survey is necessary. In a great part of irrigated areas in Hungary such survey was carried out and maps have been prepared. This approach can also be extended to other areas and adapted by both decision-makers and farmers as well as civil engineers and economists in order to arrest and/or mitigate the secondary salinization in the praxis of irrigated agriculture.

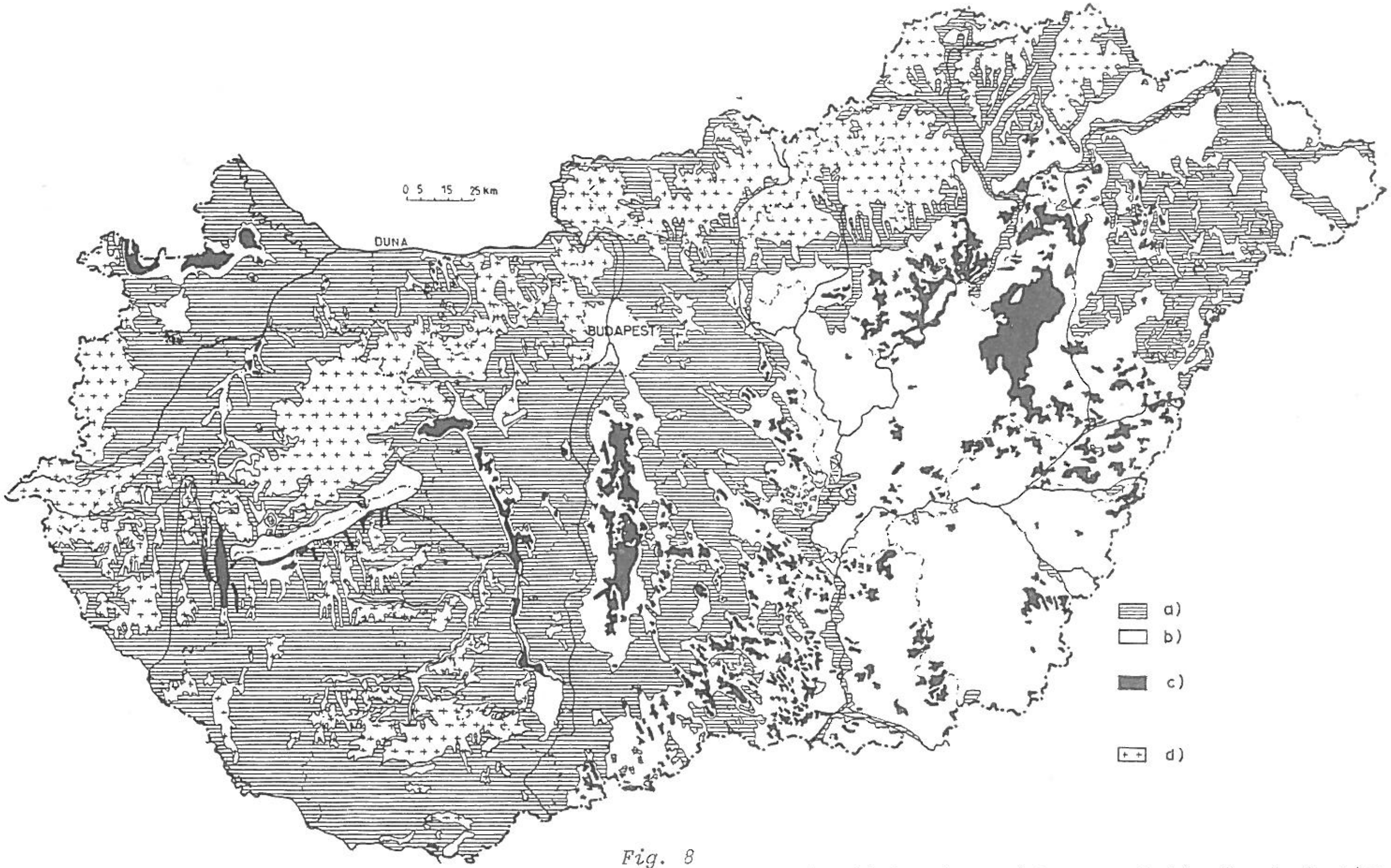

Fig. 8

Possibilities of irrigation in Hungary in respect of prevention of salinization. a/ Areas suitable for irrigation; b/ Areas conditionally suitable for irrigation; c/ Hazard of secondary salinization and/or waterlogging /not recommended for irrigation; d/ Hilly and mountain areas

Presently, both national and international organizations elaborate a great number of prognoses and predictions for the future, particularly, for the decades following the millenium. Numerous social, economical and environmental processes are inserted in such prognostics with a different level of accuracy and reliability. The salinity of soils and waters belong to those processes which can be comparatively reliably predicted and measured. Salinization processes on the other hand are closely related to other effects and human actions, i.e. irrigation and drainage, agricultural patterns, riverbed regulation, etc. Based on the above mentioned and other considerations the activity on the prediction of salinization should be extended mainly to the following items:

a/ Elaboration of methods for the prediction of salinization in the most affected areas of the world.
b/ Elaboration of methods of detailed survey and prognoses.
c/ Elaboration of methods of monitoring and tracing the early warning signals on salinization and alkalization.
d/ Encouragement and extension of international collaboration on soil salinization and alkalization, including education, publication and exchange of experience.

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