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DYNAMICS OF SOIL AND GROUNDWATER POLLUTION BY IRRIGATION OF SEWAGE

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SUMMARY

Soils consisting of brown earths and lessivês on a basis of pleistocene sands and boulder clays, respectively, have been used as irrigation fields to take up of mechanically treated sewage from a large city for more than 8 decades. Under a current research project, the soil, the percolation zone and the groundwater which have been exposed over such an extended period are studied for characteristic chemical and microbiological changes. First results of the studies to establish the heavy metals burden of the soils as a consequence of many years of irrigation and the reduction of this burden after discontinuation of irrigation are presented. Exposure to sewage over many years will result in contamination by heavy metals which, however, remains essentially limited to the upper soils. A regeneration period of 18 years has resulted in a reduction of the heavy metals content to ranges normally exhibited by analogous sites that had not been exposed to sewage.

In the sewage-exposed soils, the microbiological activity that could be evaluated as one of the characteristics of the capacity to eliminate organic pollutants was found to be clearly elevated. After discontinuation of sewage irrigation, this activity became less. Even under a heavy sewage load, there was an adequate "microbiological filtration effect". It has been possible to demonstrate a comprehensive influence of sewage irrigation on the chemism of groundwater. Even in groundwater that had been subject to a considerable pollution load, the limiting values of the Drinking Water Regulations of the Federal Republic of Germany were surpassed only in respect of its nitrate content.

SUBJECT OF STUDY

The investigations described included brown earths and lessivês, the underlying percolation zones in pleistocene glacial sands and groundwater at the irrigation fields of Berlin-Karolinenhöhe. Detailed pedological and geological studies permitted the establishment of analogous sites for areas which had been (1) irrigated since 1900 and still are, (2) irrigated between 1900 and 1962, and (3) not irrigated.

The fields investigated have been irrigated exclusively with mechanically treated sewage from an area of mixed urban and industrial character.

The maximum irrigation amounted to 20.6 x 10^6 m^3 in 1961, corresponding to an average discharge of sewage for irrigation of more than 7000 mm/a. Since 1961, the amounts of sewage irrigated have dropped considerably to a present level of approx. 1000 mm/a (2-4 x 10^6 m^3).

The present heavy metals contamination of the irrigated sewage and the groundwater are shown by the values depicted in Fig. 1. Earlier data on the concentration of heavy metals in sewage are not available. It can be assumed, however, that in principle the heavy metals content of the sewage irrigated in former times were not below the present values.

A precipitation of between 750 and 400 mm/a results in newly formed groundwater of more than 100 mm/a.

Mineralogically, the pleistocene glacial sands may be characterized as quartz sands containing around 10 % feldspar and between 3 and 5 % mica (silt $<$ 10 %). Significantly high contents of organic matter were found only down to less than 1 m below surface level while the irrigated area exhibited contents between 10 and 12 % in the upper soil. Even in the B_v horizon+) down to 80 cm depth, organic contents of up to 5 % could be found. In non-irrigated upper soil, the content of organic matter was considerably less; it could hardly be demonstrated in lower soils. Although the area that had not been subject to irrigation for 18 years exhibited a clear decrease of the content of organic matter in the upper soil, elevated contents in the lower soil which may be as high as approx. 4 % were a striking finding.

In the vertical soil profile, a reduction of the exchange capacity and a simultaneous decrease of organic matter were found. An examination of the prevailing pH values exhibited a prevalence of acid conditions in the upper layers of untreated soils and of the soils that had been subject to treatment for 18 years. At the irrigated site, only moderate to weakly acid reactions were found to be present. This difference to the other two types of soil indicated a marked regeneration at the site that had not been irrigated for 18 years.

RESULTS

The distribution of elements found at the brown earth site in the zone between the surface of the earth and the surface of the groundwater can be seen from Fig.2. The distribution curves demonstrate a clear accumulation of heavy metals in the humous upper soil even for the non-irrigated site which indicates the role of the upper soil in respect of the filtration and buffer capacities.

+ according to German classification

For this reason, the first detailed studies had to be devoted in particular to the depth range between 0 and 3 m. The results of examinations for cadmium, chromium, lead and zinc are presented as examples (Fig. 3). It is shown by the study that in the continuously irrigated soil down to depths of 0.5 m values were found which, except for zinc in some cases, surpassed the tolerance limits common in the Federal Republic of Germany (Cd 3 mg/kg; Cr 100 mg/kg; Pb 100 mg/kg; Zn 300 mg/kg).

Following non-irrigation for a period of 18 years these metal contents obviously returned to ranges characteristic of non-irrigated soil and except for the lead findings in 1980 they were clearly below the tolerance limit. The lead contents for 1980 document values above the tolerance limit both for the soil that had not been irrigated for 18 years and for the generally non-irrigated soil. This is attributed to the general environmental exposure in the Berlin area.

Comparison of the heavy metals contents found with the clay rock standard according to Turekian and Wedepohl illustrates the degree of contamination and the retention capacity at the contaminated sites on the one hand and the development of regeneration at the sites that had not been exposed since about 18 years on the other (Fig. 4).

To obtain an idea of the mobilizability, a determination of metal contents due to anthropogenic influences and similar parameters, the soils were made subject to a series of extraction methods of rising intensity (Fig. 5). In a simplified form, the respective extract may be assigned to defined types of element fixation.

In respect of the element fixation types for cadmium (Fig. 5), the high proportion of the organically fixed phase is striking: in irrigated soil it is recognizable down to a level of 2 m depth.

Also for zinc, it could be demonstrated in a continuously irrigated soil that there has been carbonate precipitation which in a very weak form was still present in parts of the soil that had not been irrigated during the last 18 years. At the irrigated site, also lead was present with an organically fixed phase that had risen to a 30 %. This phenomenon also characterizes an elevated mobility of the lead. Especially in the case of zinc, a preponderance of carbonate phases, oxidizable phases, organic substances and organically fixed phases was seen in the upper soil of the irrigated site.

When summarizing the microbiological studies performed, the following tendencies are seen (Fig. 6) -

- Irrigation of sewage means a supply both of nutrients and of microorganisms resulting, especially in the upper soil, in a considerable increase of the zymogenous microflora and in analogy, an increased elimination capacity of the soil;
- The microflora decomposing the organic matter supplied already within the uppermost layers of the soil is thus taking care of the biological purifi-

cation of the irrigated sewage;

- Even under a considerable sewage load, an adequate "microbiological filter effect" is maintained;
- Variation in the sewage load imposed on the soils studied does not result, apart from clear differences in biological activity, in differences concerning the presence of autochthonous soil microflora;
- Following microbial decomposition of easy-to-utilize organic substances, autolytic processes result in a rapid decrease of microbial counts;
- From the different types of microorganisms introduced into the soil with sewage, except for spore-forming organisms, only a few remain active over an extended period. In an analogous way, this is also true for coliform bacteria:Down to a depth of 0.3 m, they exhibited a reduction by 99 %. At depths below 0.30 m, neither coliforms nor Salmonella and Shigella species were found;
- Aerobic decomposition processes result in a partial elimination of ammonia and nitrogen as well as in an increase of nitrate (nitrification). Also, a rise of the bacterial count at a depth of 10 - 12 m below surface level in the fully irrigated area indicates the presence of a nitrogen source.

Investigation of the filtration capacity of exposed and non-exposed brown earths in small-size laboratory lysimeters has shown, in a simplified view, three different types of behaviour in respect of the percolation of synthetic and normal sewage -

- Processes of desorption or leaching gradually removing from the soil the existing concentrations of e.g. boron;
- Processes of elimination of e.g. cadmium which resulted, both for exposed and non-exposed sites of brown earth, in an almost quantitative fixation of the cadmium concentration introduced;
- Processes of mobilization of e.g. zinc which at the non-irrigated brown earth site liberated amounts of zinc exceeding the concentration present in the synthetic sewage used so that previously adsorbed zinc must have been mobilized.

A characteristic influence on groundwater quality was seen for the entire aquiferous area below the irrigated area (Fig. 1). It is suggested by "indicator ions" such as Cl^- and Na^+ and also by conductivity values that the groundwater sampled in its foremost part had been regenerated from the irrigation field filtrate. This was found to be true both for an extremely local suspended horizon (7) mostly fed by irrigation and the regional picture in the area of irrigation fields (3,4,5,6,8).

REFERENCES

1 K.K. Turekian, K.H. Wedepohl, Bull.Geol. Soc.Ass. Am. 1972, 175-192

Fig. 1: **Influence of Sewage Irrigation on Groundwater Quality**

		LF µS	NH_4 mg/l	NO_3 mg/l	PO_4 mg/l	Cl mg/l	Na mg/l	K mg/l	Cd mg/m^3	Pb mg/m^3	Zn mg/m^3	Cr mg/m^3
1.	Sewage, mechanically treated	1500 - 1700	40 - 90	0	10 - 70	120 - 260	177 - 183	24 - 25	0,7 - 6,2	10 - 198	50 - 1870	2 - 68
2.	Sewage, higly chemically treated	1300	0,2	180	n.n.	220	152	22	1,5	27	174	5
3.	Groundwater, exposed to other irrigation fields effluents (14, 15, 16, 17)	880 - 1400	n.n.-0,8	60 - 160	n.n.-20	120 - 300	100 - 170	14 - 23	0,7 - 1,4	13 - 17	70 - 250	2
4.	ditto, (1664, 1665)	1300 - 1500	0,2 - 1,5	140 - 200	n.n.	150 - 190	130 - 200	16 - 20	0,8 - 1,0	13 - 17	220 - 370	2
5.	Groundwater additionally exposed to highly chemically tr. sewage infiltration (1, 3, 8, 13)	(670) 1050 - 1240	0,2	110 - 250	0	8 - 200	(15) 60 - 103	14 - 20	0,7 - 1,7	16 - 21	140 - 320	2 - 3
6.	Groundwater exp. to sewage irrigation (57)	1500	0,2	280	23	168	142	23,5	1,5	19	400	3
7.	Perched groundwater influenced by irrigation only	1110 - 1210	0,2 - 3,0	190 - 280	5 - 27	155 - 168	127 - 136	18 - 21	0,9 - 4,3	11 - 56	70 - 2320	2 - 17
8.	Groundwater before discharchging into receiving water	580 - 1210	0,2 - 1,0	n.n. - (130)	n.n.	40 - 130	(150) 27 - 98	7 - 10	1,1 - 3,3	27 - 38	480 - 200	4 - 11
9.	Groundwater not influenced by irrigation or artificial infiltration	90 - 788	<0,01	<0,01 - 95	n.n.	8 - 61	2,5 - 32,4	1,6 - 5,6	0,9 - 1,4	16 - 18	60 - 336	2 - 3
10.	Groundwater from water-works wells	643 - 809	0,8 - 2,2	<0,01 - 0,03	<0,01-0,02	62 - 100	37 - 70	2,5 - 6,3	0,5 - 0,6	26 - 38	60 - 73	3 - 5

n.n. – nothing established

( ) – eventually non representative values

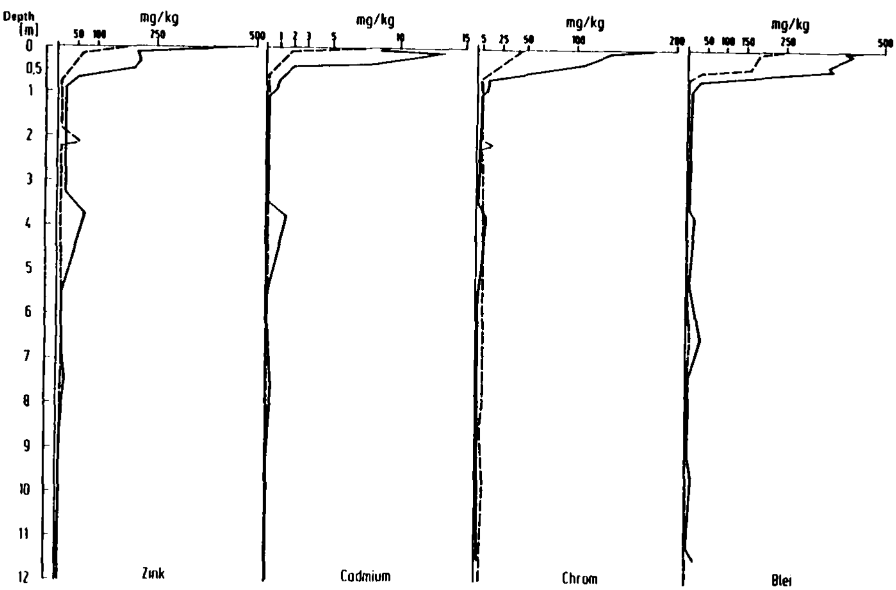


Fig. 2: Elementdistribution as a function of the depth (Brownearth, site A never irr., C cont. irrigated)

A - - - -

C ——

Fig. 3: Elementdistribution as a function of the depth, Brownearth sites
BROWNEARTH SITES

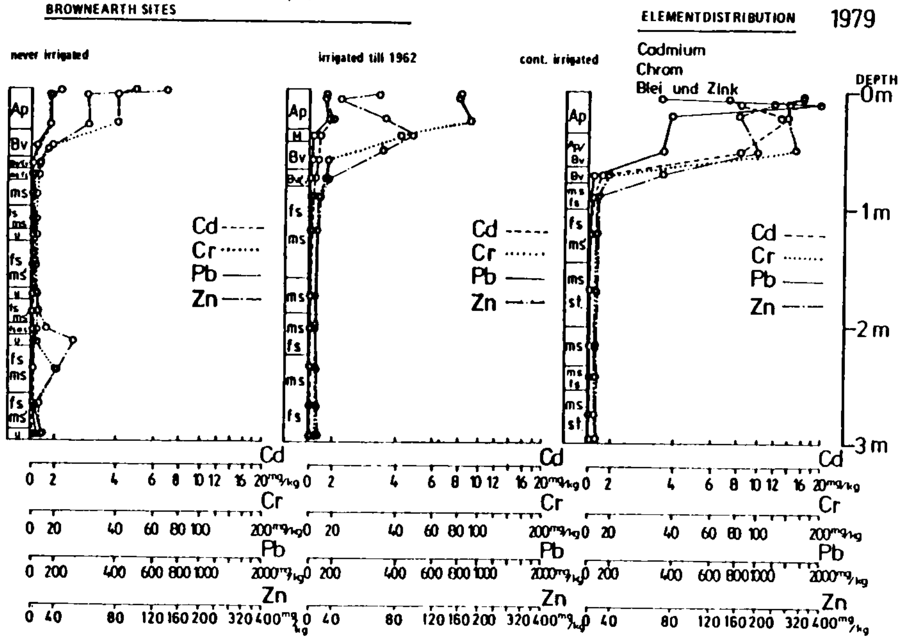


Fig. 4: Accumulation of Heavy Metals in Upper Soils
(as compared with the Clay Rock Standard, TUREKIAN & WEDEPOHL, 1971)

BROWNEARTHS

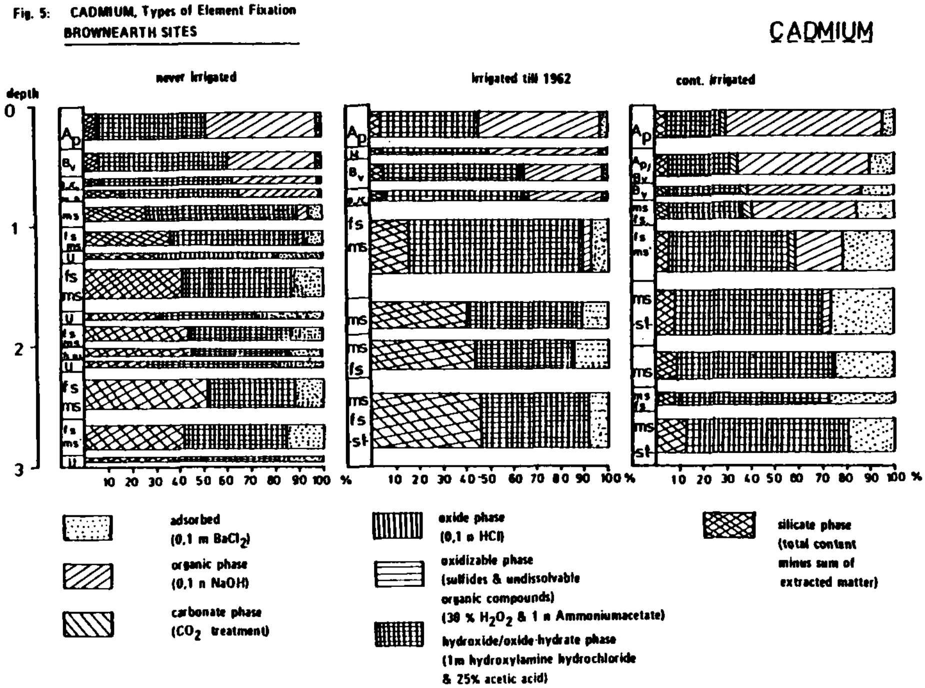
Element	Clay rock standard mg/kg	Continuously irrigated mg/kg	Accumulation factor	not irrigated since 1962 mg/kg	Accumulation factor	not irrigated mg/kg	Accumulation factor
Zink	95	610	6,4	193	2,0	161	1,7
Cadmium	0,3	18,1	60,0	3,1	10,0	2,1	7,0
Chrom	90	185	2,0	142	1,6	96	1,1
Blei	20	2840	142,0	330	16,5	310	15,5

LESSIVÉS

Element	Clay rock standard mg/kg	Continuously irrigated mg/kg	Accumulation factor	not irrigated since 1962 mg/kg	Accumulation factor	not irrigated mg/kg	Accumulation factor
Zink	95	512	5,4	138	1,5	101	1,1
Cadmium	0,3	11,9	40,0	1,9	6,3	2,3	7,7
Chrom	90	138	1,5	115	1,3	120	1,3
Blei	20	590	29,5	286	14,3	266	13,3

Note : Results are mean values from 10 comparable samples per site

Fig. 5: CADMIUM, Types of Element Fixation
BROWNEARTH SITES



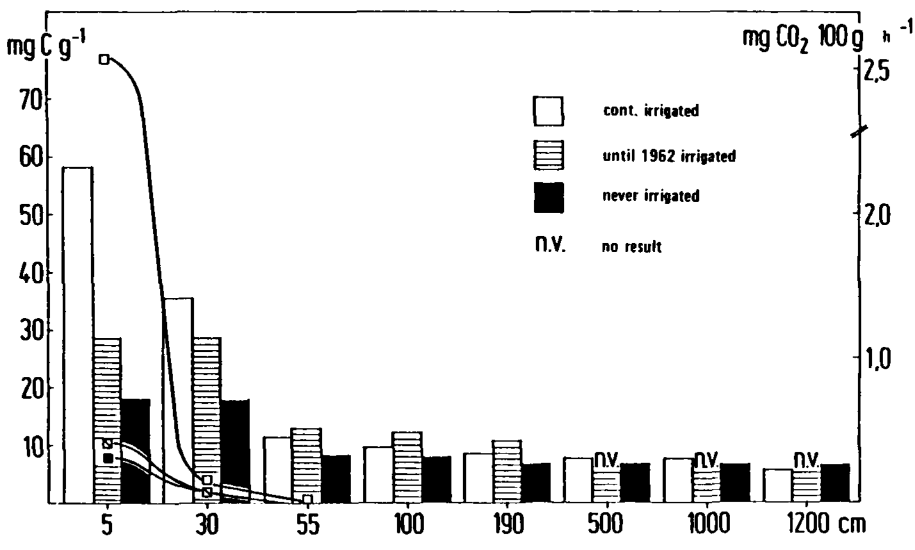


Fig. 6: Respiration Activity and Content of Organic Carbon as a Function of the Depth