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CONTENTS OF SOME TRACE ELEMENTS IN SOIL IRRIGATED WITH MUNICIPAL WASTEWATER

The effect of chemical composition of wastewater on physicochemical properties and soil conditions is one of the most important problems in the present investigations concerning environmental aspects of the agricultural utilization of wastewater.

Composition of soils and their physicochemical properties affect significantly the quality of ground water being under the influence of fields irrigated with wastewater.

The paper presents the results of two year experiments conducted on irrigated fields in the Wrocław region. In the investigations account was taken of the presence of some heavy metals in municipal wastewater used for irrigations in different levels of soil profiles, as well as in ground and drainage waters.

1. INTRODUCTION

The influence of wastewater on physicochemical properties of soil and soil conditions is one of the most important problems in the investigations concerning the environmental aspects of agricultural utilization of wastewater. Composition of soils and their properties significantly affect, among others, the quality of ground water being under the influence of field irrigated with wastewater. Ground waters in these regions, being intensely supplied with water due to irrigations, are very often the source of water for many users.

Agricultural utilization of wastewater has been recognized by many specialists in sanitary engineers and higienists in Poland as one of the most reliable methods of aquatic environment protection against organic pollution, wastewater micro-organisms and eutrophication. Still, however, saltiness or chemical contamination of ground water is possible due to ill-planned irrigation or to incorrect maintenance of the irrigated soils.

In the investigations conducted on the irrigated fields in Wrocław area, attention was paid to the problem of ground water and soil pollution with trace elements which are now classified among the potentially most controversial pollutants of the environment.

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2. IRRIGATED FIELDS WITHIN THE CITY OF WROCŁAW

Wrocław, in its central part, has the sewerage system of the combined type, and in the remaining districts — of separate type. Municipal wastewater is mainly treated in the complex of irrigated fields which takes about 93% (Q_{mean} about 170,300 m^3/d) of the total influent from the city. Irrigated fields were designed and build in the nineties of the last century. With the development of the city the area of the fields was getting larger amounting to about 1 500 ha at present.

The increase in the area of irrigated fields was accompanied with their modernization concerning the pre-treatment of wastewater and construction of a new system draining off the wastewater. In 1973 a new rain gun (sprinkling machine) Szewce was constructed, its task is to ease the irrigated fields (fig. 1).

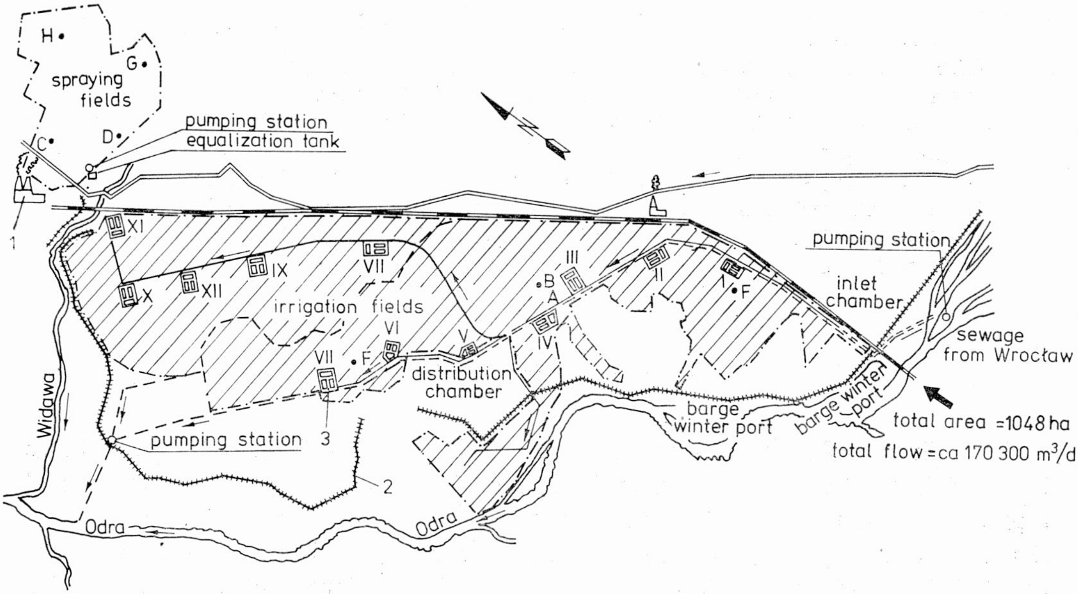


Fig. 1. Wrocław sewage farm

=== delivery pipe, —— sewage ditch, — — — drainage ditch, —.— border of sewage farm, 1 — drying of green fodder, 2 — river embankment, 3 — settling tanks I-XII, A—H— points of drainage and ground waters sampling

Rys. 1. Wrocławskie tereny nawadniane

=== rura doprowadzająca, —— rów ściekowy, — — — rów drenażowy, —.— granice terenów nawadnianych, 1 — suszenie zielonej paszy, 2 — wał rzeczny, 3 — osadniki I-XII, A—H— punkty poboru próbek wody drenażowej i gruntowej

The area adapted to irrigations consists of light soils and moderately stiff soils. Their subsoil is composed of fine-grained sands, sands with gravel and gravel. Impermeable layer is 10-20 m thick.

Filtration coefficient of the water-bearing layer amounts to 4×10^{-4} m/s. Some of 1 081 ha are irrigated as grassland (meadows and pastures).

Wastewater for irrigations are mechanically treated in 12 earth settling ponds each having two compartments (the volume of each — $11\text{-}18\times10^3$ m^3) localized on fields subject to irrigations along the supplying collecting pipe. The average time of filling one compartment with sludge amounts to about 4-5 years, and the drying time (falling to summer months) lasts for 4-5 months. During this period the accumulated fresh sludge becomes almost entirely mineralized. Dehydrated and dried sludge is removed, for sale, and the emptied digesters are prepared to the next cycle.

3. PHYSICOCHEMICAL CHARACTERISTICS OF MUNICIPAL WASTEWATER

Raw municipal wastewater pumped into irrigated fields is characterized by higher than normal concentrations, the composition is characteristic for the large urban industrial agglomerations. The statistical analysis has shown high BOD and dry residue variations.

In the investigations performed special attention was given to the presence of trace elements. Their concentrations are not high (table 1) except for zinc which exceeds the admissible standards for wastewater utilized in agriculture.

Table 1

Pollution index of sewage used for irrigations

Wskaźniki zanieczyszczeń ścieków miejskich wykorzystywanych do nawodnień

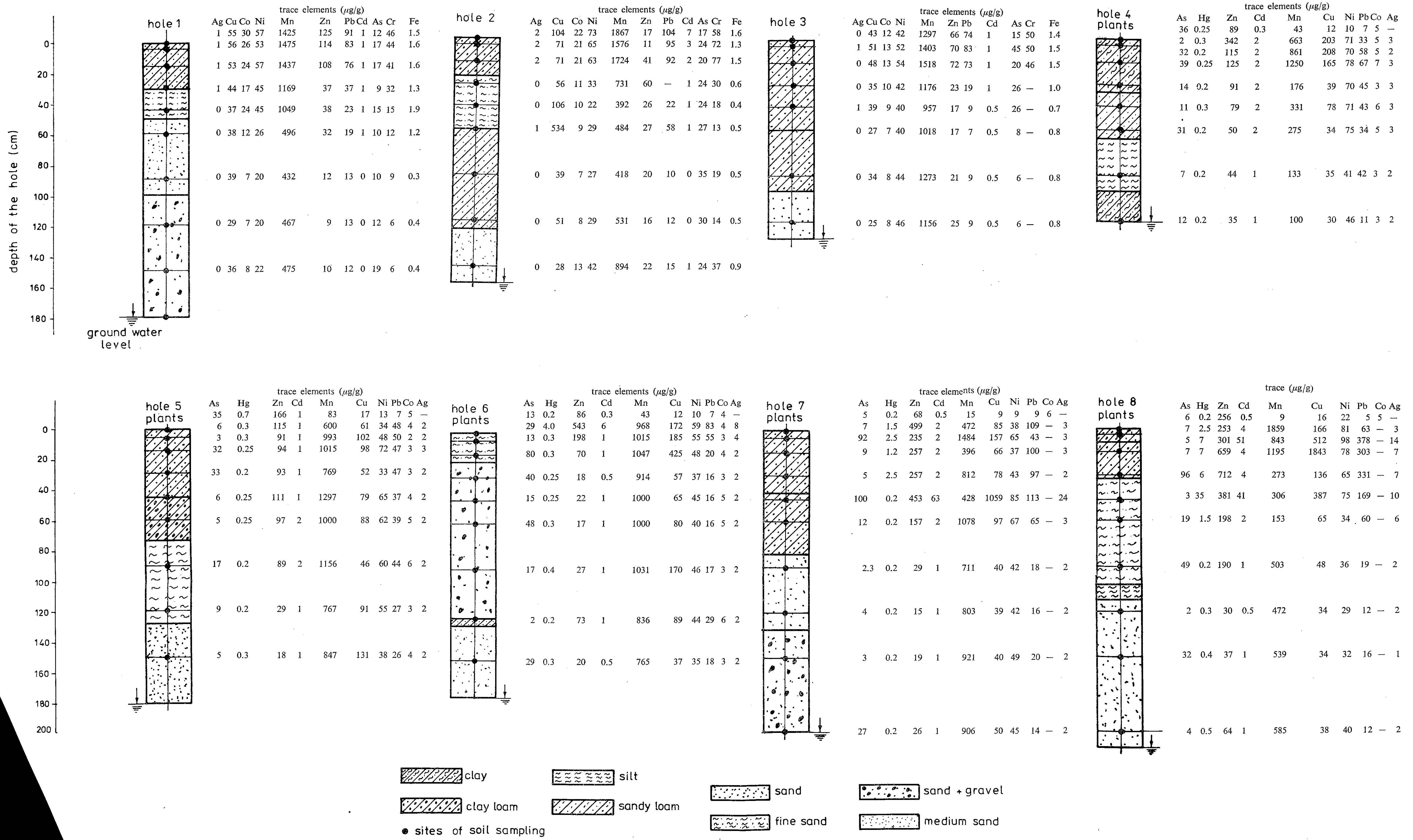
Index	Unit	Raw sewage	Treated sewage
pH	—	6.5—7.7	7.3—7.5
acidity	mval/dm^3	0.0—1.0	0.4—0.6
alkalinity	mval/dm^3	3.4—10	3.3—3.4
BOD_5	mg O_2/dm^3	160—320	110—116
PV	mg O_2/dm^3	180—240	57—74
COD	mg O_2/dm^3	967—1237	191—294
chlorides	mg Cl/dm^3	142—200	156—168
conductivity	µS/cm	1560—2000	1650—1890
total solid residue	mg/dm^3	1061—1721	914—1001
total soluble compounds	mg/dm^3	689—870	726—785
total suspended matter	mg/dm^3	372—851	186—228
sulphates	mg SO_4/dm^3	147—192	172—215
N total	mg N tot/dm^3	45.3—50.9	41.9—45.3
N organic	mg N org/dm^3	15.8—19.1	13.9—14.0
P total	mg P/dm^3	8.1—19.3	12—15.1
Na	mg Na/dm^3	83—195	—
K	mg K/dm^3	25—43.5	—
Ca	mg Ca/dm^3	135—185	—
As	mg As/dm^3	0.001—0.076	—
Hg	mg Hg/dm^3	0.4—2.0	—
B	mg B/dm^3	0.13—0.24	—
Ag	mg Ag/dm^3	0.001—0.005	—
Cu	mg Cu/dm^3	0.11—0.57	—
Ni	mg Ni/dm^3	0.06—0.15	—
Zn	mg Zn/dm^3	1.07—2.80	—
Pb	mg Pb/dm^3	0.02—0.1	—
Kd	mg Cd/dm^3	0.012—0.100	—
Mn	mg Mn/dm^3	0.10—0.35	—

Table 2

Range of mean concentrations of physicochemical values of ground and drainage waters within the sewage farm of Wrocław
Zakres średnich stężeń fizykochemicznych wskaźników wód gruntowych i drenażowych na terenie wrocławskich pól irygowanych

Index	Piezometers on sewage farm	Piezometers on non-irrigated fields	Deep-wells on sewage farm	Wells outside the irrigated field	Drainage waters
solid residue, mg/dm^3	838—1228 (959)*	391—6383 (1590)	601—887 (719)	601—1484 (1097)	669—785 (713)
dry eight, mg/dm^3	527—818 (657)	361—5534 (1271)	370—649 (491)	384—915 (764)	320—489 (414)
alkalinity, mv/dm^3	4.1—7.9 (5.7)	1.3—13.1 (4.6)	3.1—6.1 (4.5)	2.0—5.3 (3.6)	5.1—7.2 (6.7)
PV, mg/dm^3 O_2	3.7—39.4 (14.4)	2.5—29.1 (10.06)	3.0—5.5 (4.1)	3.2—25.5 (8.8)	4.1—14.7 (8.1)
N total, mg/dm^3	4.8—24.3 (14.9)	1.6—19.8 (8.03)	2.6—18.1 (6.8)	2.3—8.5 (5.1)	4.5—16.1 (8.4)
nitrates, mg/dm^3	0.61—18.8 (5.6)	0.09—18.1 (3.24)	0.14—3.66 (1.2)	0.14—72.0 (33.95)	0.23—0.44 (0.37)
chlorides, mg/dm^3	121—156 (138)	26—154 (92)	83—144 (120)	51—171 (112)	79—118 (92)
sulphites, mg/dm^3	108—270 (194)	105—269 (194)	144—237 (175)	130—339 (206)	111—165 (144)
K, mg K_2 O/dm^3	13—28 (19)	3—191 (37)	4—22 (10)	8—210 (90)	3—5 (3)
P, mg P_2O_5/dm^3	0.02—0.28 (0.17)	0.03—0.43 (0.12)	0.04—0.11 (0.08)	0.04—0.90 (0.27)	0.05—0.11 (0.08)
Fe, mg/dm^3	0.25—13.3 (3.02)	0.10—15.2 (4.94)	0.43—13.6 (4.02)	0.004—7.8 (1.29)	0.09—2.02 (0.84)
Mn, mg/dm^3	0.12—1.31 (0.50)	0.08—2.56 (0.75)	0.09—0.96 (0.39)	0—0.50 (0.22)	0.1—0.47 (0.27)
pH	7.0—7.2	—	—	—	6.9—7.1
conductivity, $\mu s/cm$	900—1215	—	—	—	765—915

* In brackets there are mean values of mean concentrations



Hole 1 — trace elements (μg/g)

Ag	Cu	Co	Ni	Mn	Zn	Pb	Cd	As	Cr	Fe
1	55	30	57	1425	125	91	1	12	46	1.5
1	56	26	53	1475	114	83	1	17	44	1.6
1	53	24	57	1437	108	76	1	17	41	1.6
1	44	17	45	1169	37	37	1	9	32	1.3
0	37	24	45	1049	38	23	1	15	15	1.9
0	38	12	26	496	32	19	1	10	12	1.2
0	39	7	20	432	12	13	0	10	9	0.3
0	29	7	20	467	9	13	0	12	6	0.4
0	36	8	22	475	10	12	0	19	6	0.4

Hole 2 — trace elements (μg/g)

Ag	Cu	Co	Ni	Mn	Zn	Pb	Cd	As	Cr	Fe
2	104	22	73	1867	17	104	7	17	58	1.6
2	71	21	65	1576	11	95	3	24	72	1.3
2	71	21	63	1724	41	92	2	20	77	1.5
0	56	11	33	731	60	—	1	24	30	0.6
0	106	10	22	392	26	22	1	24	18	0.4
1	534	9	29	484	27	58	1	27	13	0.5
0	39	7	27	418	20	10	0	35	19	0.5
0	51	8	29	531	16	12	0	30	14	0.5
0	28	13	42	894	22	15	1	24	37	0.9

Hole 3 — trace elements (μg/g)

Ag	Cu	Co	Ni	Mn	Zn	Pb	Cd	As	Cr	Fe
0	43	12	42	1297	66	74	1	15	50	1.4
1	51	13	52	1403	70	83	1	45	50	1.5
0	48	13	54	1518	72	73	1	20	46	1.5
0	35	10	42	1176	23	19	1	26	—	1.0
1	39	9	40	957	17	9	0.5	26	—	0.7
0	27	7	40	1018	17	7	0.5	8	—	0.8
0	34	8	44	1273	21	9	0.5	6	—	0.8
0	25	8	46	1156	25	9	0.5	6	—	0.8

Hole 4, plants — trace elements (μg/g)

As	Hg	Zn	Cd	Mn	Cu	Ni	Pb	Co	Ag
36	0.25	89	0.3	43	12	10	7	5	—
2	0.3	342	2	663	203	71	33	5	3
32	0.2	115	2	861	208	70	58	5	2
39	0.25	125	2	1250	165	78	67	7	3
14	0.2	91	2	176	39	70	45	3	3
11	0.3	79	2	331	78	71	43	6	3
31	0.2	50	2	275	34	75	34	5	3
7	0.2	44	1	133	35	41	42	3	2
12	0.2	35	1	100	30	46	11	3	2

Hole 5, plants — trace elements (μg/g)

As	Hg	Zn	Cd	Mn	Cu	Ni	Pb	Co	Ag
35	0.7	166	1	83	17	13	7	5	—
6	0.3	115	1	600	61	34	48	4	2
3	0.3	91	1	993	102	48	50	2	2
32	0.25	94	1	1015	98	72	47	3	3
33	0.2	93	1	769	52	33	47	3	2
6	0.25	111	1	1297	79	65	37	4	2
5	0.25	97	2	1000	88	62	39	5	2
17	0.2	89	2	1156	46	60	44	6	2
9	0.2	29	1	767	91	55	27	3	2
5	0.3	18	1	847	131	38	26	4	2

Hole 6, plants — trace elements (μg/g)

As	Hg	Zn	Cd	Mn	Cu	Ni	Pb	Co	Ag
13	0.2	86	0.3	43	12	10	7	4	—
29	4.0	543	6	968	172	59	83	4	8
13	0.3	198	1	1015	185	55	55	3	4
80	0.3	70	1	1047	425	48	20	4	2
40	0.25	18	0.5	914	57	37	16	3	2
15	0.25	22	1	1000	65	45	16	5	2
48	0.3	17	1	1000	80	40	16	5	2
17	0.4	27	1	1031	170	46	17	3	2
2	0.2	73	1	836	89	44	29	6	2
29	0.3	20	0.5	765	37	35	18	3	2

Hole 7, plants — trace elements (μg/g)

As	Hg	Zn	Cd	Mn	Cu	Ni	Pb	Co	Ag
5	0.2	68	0.5	15	9	9	9	6	—
7	1.5	499	2	472	85	38	109	—	3
92	2.5	235	2	1484	157	65	43	—	3
9	1.2	257	2	396	66	37	100	—	3
5	2.5	257	2	812	78	43	97	—	2
100	0.2	453	63	428	1059	85	113	—	24
12	0.2	157	2	1078	97	67	65	—	3
2.3	0.2	29	1	711	40	42	18	—	2
4	0.2	15	1	803	39	42	16	—	2
3	0.2	19	1	921	40	49	20	—	2
27	0.2	26	1	906	50	45	14	—	2

Hole 8, plants — trace (μg/g)

As	Hg	Zn	Cd	Mn	Cu	Ni	Pb	Co	Ag
6	0.2	256	0.5	9	16	22	5	5	—
7	2.5	253	4	1859	166	81	63	—	3
5	7	301	51	843	512	98	378	—	14
7	7	659	4	1195	1843	78	303	—	7
96	6	712	4	273	136	65	331	—	7
3	35	381	41	306	387	75	169	—	10
19	1.5	198	2	153	65	34	60	—	6
49	0.2	190	1	503	48	36	19	—	2
2	0.3	30	0.5	472	34	29	12	—	2
32	0.4	37	1	539	34	32	16	—	1
4	0.5	64	1	585	38	40	12	—	2

Fig. 2. Occurrence of trace elements in the sewage irrigated soil
Fe in % of dry matter, holes 3 and 7 — control holes outside the sewage farm

Rys. 2. Występowanie wybranych elementów śladowych w poszczególnych poziomach profilu glebowego
Fe w % suchej masy, otwory 3 i 7 — otwory kontrolne poza terenami nawodnienia ściekami

4. QUALITY OF GROUND WATER

Investigations with a system of piezometers and drilled wells have confirmed the hypothesis about a small influence of irrigation with municipal wastewater on the quality of ground water. The range of concentrations of main physicochemical components of the examined ground and drainage waters are shown in tables 2 and 3. Considering the nature

Table 3

Concentrations of trace elements in ground and drainage waters within the sewage farm

Stężenie elementów śladowych w wodach gruntowych i drenażowych na terenie pól irygowanych

Index	Drainage water	Groundwater	Drain ditches
As, mg/dm³	0.04	0.009–0.05	0.019–0.03
Hg, mg/dm³	<0.2–0.2	0.7–0.8	<0.2–0.9
B, mg/dm³	0.240	0.11–185	0.137–0.182
Ag, mg/dm³	0.002–0.003	0.002–0.006	0.003–0.004
Cu, mg/dm³	0.040–0.060	0.03–0.211	0.020–0.11
Ni, mg/dm³	0.075–0.120	0.060–0.095	0.061–0.120
Zn, mg/dm³	0.68–1.46	1.18–1.27	0.20–2.83
Pb, mg/dm³	0.034–0.052	0.024–0.043	0.023–0.043
Cd, mg/dm³	0.002–0.011	0.003–0.005	0.003–0.012
Mn, mg/dm³	0.090–0.64	0.086–0.430	0.170–0.750

of the object examined the results obtained are fully representative for these types of treatment under similar climatic and soil conditions. Two-year control of the composition of ground water within the area of irrigated fields allowed to state that ground water within the objects irrigated with municipal wastewater may perform an important role in water supply for economic purposes, the quality of which is better than that of surface water [1].

5. CONCENTRATION OF TRACE ELEMENTS IN SOIL

Considering the long period of exploitation of irrigated fields it was expected that the analyses would provide information about trace elements in the irrigated fields. It was expected that the accumulation of the individual trace element would depend on the kind of soil and thickness of its layer. To perform the required analyses 8 wells were bored to the level of the water surface. The exploratory bore holes were located with respect to the kind of soil and time of field exploitation.

Control bore hole (no. 4) was situated outside the influence of irrigations. The arrangement of layers of the soil profiels was determined in sites of exploratory bore holes, and the kind of soil — by its mechanical composition.

6. DISCUSSION AND CONCLUSIONS

Chemical analysis of soil was restricted to several selected elements (fig. 2). In upper, surface soil layer the concentration of trace elements was higher than in deeper layers. This gives evidence to a higher sorption capacity of the upper layer. The range fo concentrations of the determined microelements is, however, similar to that presented by PAGE for soils not irrigated with wastewater. The concentrations of trace elements stated in the present investigations are within the range of values given by Polish literature for soils in natural conditions [1-3]. Higher concentrations have been only stated for copper, zinc and manganese.

Higher concentrations of copper and zinc were stated only in surface layer, while in deeper layers of the soil the concentrations of these elements are similar to those occurring in nonirrigated field. Manganese appears in the highest concentrations but this element is widespread in nature. According to KABATA-PENDIAS its concentration in soils varies within 10-100 μg/g [4], and according to PAGE it reaches even 4 000 μg/g [5]. ROHDE states that soils manured with sludge contain 100-170 μg Mn/g, but this value should be considered as a low one.

In the examined soil profiles no significant influence of the kind and the thickness of the separate soil layers on the concentrations of separate elements has been found. Low concentrations of trace elements in soils, stated in our experiments, may be due to high hydraulic loadings with wastewater as well as due to low concentrations of the elements examined in raw wastewater and their assimilation by plants.

Summing up, it may be stated that long term irrigation of fields within the city of Wrocław did not influence the accumulation of trace elements in soil, which, in turn, could deteriorate the purity of ground water and the usability of the plants growing within this area.

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ZAWARTOŚĆ NIEKTÓRYCH ELEMENTÓW ŚLADOWYCH W GLEBIE NAWADNIANEJ ŚCIEKAMI MIEJSKIMI

Oddziaływanie chemiczne ścieków na fizykochemiczne właściwości i zmianę warunków glebowych jest jednym z istotnych elementów prowadzonych aktualnie badań dotyczących aspektów środowiskowych rolniczego wykorzystania ścieków. Skład gleb i ich właściwości fizykochemiczne mają istotny wpływ na

jakość wód gruntowych znajdujących się w rejonach oddziaływania pól nawadnianych ściekami. Wody gruntowe, zasilane intensywnie w wyniku nawodnień, stanowią często ważne źródło wody dla wielu użytkowników.

W artykule przedstawiono wyniki dwuletnich doświadczeń przeprowadzonych na wrocławskich polach irygowanych, uwzględniając występowanie niektórych metali ciężkich w ściekach miejskich używanych do nawodnień, w różnych poziomach profilu glebowego, w wodzie gruntowej i w wodach drenażowych.

DIE KONZENTRATION VON EINIGEN SPURENELEMENTEN IM MIT ABWASSER GESPEISTEN BODEN

Die Wirkung des Abwassers auf physikalische und chemische Beschaffenheit von Böden, stellt heutzutage ein sehr wichtiges Element der Untersuchungen bei der landwirtschaftlichen Abwasserverwertung dar. Die Zusammensetzung und die physikalisch-chemische Beschaffenheit des Bodens übt einen relevanten Einfluß auf die Güte des Grundwassers dort aus, wo sich die Wirkung der Abwasserbewässerung merklich macht. Die Grundwässer werden durch Bewässerung mengenmäßig angereichert und recht häufig für verschiedene Zwecke genutzt.

Der Beitrag beinhaltet die Ergebnisse von zweijährigen Untersuchungen auf dem Gelände der Rieselsfelder von Wrocław. Spezieller Augenmerk wurde dem Vorkommen von Schwermetallen gewidmet: sei es im kommunalen Abwasser, in verschiedenen Bodentiefen, im Grundwasser und im Abfluß aus der Drainage.

СОДЕРЖАНИЕ НЕКОТОРЫХ СЛЕДОВЫХ ЭЛЕМЕНТОВ В ПОЧВЕ, ОРОШАЕМОЙ ГОРОДСКИМИ СТОЧНЫМИ ВОДАМИ

Химическое воздействие сточных вод на физикохимические свойства и изменение почвенных условий является одним из существенных элементов проводимых в настоящее время исследований, касающихся аспектов окружающей среды сельскохозяйственного использования сточных вод. Состав почв и их физико-химических свойств оказывает существенное влияние на качество грунтовых вод, находящихся в районах воздействия полей, орошаемых сточными водами. Грунтовые воды, интенсивно питаемые в результате орошений, часто представляют собой важный водный источник для многих потребителей.

В статье представлены результаты двулетних опытов, проводимых на вроцлавских орошаемых полях, учитывая наличие некоторых тяжёлых металлов в городских сточных водах, употребляемых для орошения, на различных уровнях почвенного профиля в грунтовой воде в дренажных водах.