

Toxicity Assessment of Contaminated Soils of Solid Domestic Waste Landfill

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Abstract

The paper delivers the analysis of an 18-year dynamic pattern of land pollutants concentration in the soils of a solid domestic waste landfill. It also presents the composition of the contaminated soils from different areas of the waste landfill during its operating period. The authors calculate the concentrations of the following pollutants: chrome, nickel, tin, vanadium, lead, cuprum, zinc, cobalt, beryllium, barium, yttrium, cadmium, arsenic, germanium, nitrate ions and petrochemicals and determine a consistent pattern of their spatial distribution within the waste landfill area as well as the dynamic pattern of their concentration. Test-objects are used in experiments to make an integral assessment of the polluted soil's impact on living organisms. It was discovered that the soil samples of an animal burial site are characterized by acute toxicity while the area of open waste dumping is the most dangerous in terms of a number of pollutants. This contradiction can be attributed to the synergetic effect of the polluted soil, which accounts for the regularities described by other researchers.

Introduction

Human-induced land degradation embraces about 20% and threatens more than 60% of the globe ecosystems [1]. Alongside with the climate change it causes irreversible changes of agro-landscapes and becomes one of the prior issues of land management, economical and environmental activities of the society [2]. The land operational loads result in soil degradation (physical condition, agricultural characteristics) and loss in natural and economic value of lands.

Solid domestic waste landfills (SDW), authorized and non-authorized garbage dumps, animal burial sites, etc. are a source of special concern. Their intensive and extensive grow is caused by urban and rural settlements development [3]. These sites are typically very dangerous for human health. The main risk factor is the pollution of soil and regeneration waters [4] with harmful domestic wastes: paints, pesticides, oil, pharmaceuticals, household chemicals, electronic and electrical equipment, photo chemicals, personal hygiene means, luminous tube lamps, heavy metals, timber treated with harmful substances, etc. [5]. Besides, the SDW landfills are the source of air pollution accompanied by decomposition products, unpleasant smells, methane outbursts and fires, dust, garbage moved by wind, opportunistic pathogenic and pathogenic microflora, helminth eggs, flies, ravens, larvae and rodents.

The interaction of SDW with water (snow, rain) produces toxic filtrate water that flows through soil pores and can reach aquifers. Long-term chemical research of soils and filtrate waters conducted in the USA (500 waste landfills, 230 chemical compounds) discovered the dependence of filtrate water's chemical composition on the age of a waste landfill, its geographical location, climate and



geological characteristics [6]. Such variety of factors can form different chemical transformation models and hinders consolidation of information.

Soil quality is typically evaluated on the basis of chemical analysis that doesn't take into account synergetic and antagonistic effects of the whole polluting complex and doesn't characterize its toxicity level for organisms [7]. Besides, the number of pollutants is much greater than the number of analysis methods used nowadays [8]. It makes it necessary to use biotesting as an additional assessment tool for determining toxic level of soil [9].

The aim of the research is to compare chemical analysis data with biotesting data of SDW landfill conducted in 1995 and 2013.

To achieve the aim the following tasks are to be solved:

1. to identify the soil pollution level on the SDW landfill based on 14 elements chemical analysis
2. to conduct biotesting of the same samples, compare the results and to draw conclusions.

Research object, tools and methods

The SDW landfill near village Novomikhailovka was used from 1964 till January 2011. Its total area is 54.3 ha; the animal burial site area is 729 m². A daily waste volume reached 5400 m³. The first set of tests was conducted to study the dynamic pattern of soil pollution level year-wise (1995, 2011, and 2013). In 1995 The SDW landfill was actively used. In 2011 it was officially closed but it was still being dumped illegally, which implies additional pollution of the area. The second set of tests was conducted to analyze soil chemical pollution level and soil phytotoxicity studying the samples taken in 1995 from different areas of the landfill (recultivated area, animal burial site, open waste dumping area and reference (background) area – northwards from the landfill).

The soil sampling and acid digest preparation were conducted according to the standard techniques. The extractable copper, cadmium, zinc, chrome and plumbum was determined by means of an atomic absorption spectrophotometer AAS -1 (Germany) (measurement uncertainty (μ) 5-7%). pH was determined by means of pH-meter Mark -903 ($\mu < 0.02$) [28]. Nitrate ions were determined by means of a photoelectric colorimeter ($\mu < 20\%$). An atomic absorption spectrophotometer AA-7000 "Shimadzu" (Japan) ($\mu < 20\%$) was used for arsenic determination. The IR spectroscopy method was applied to determine the rate of petrochemical pollution of the soils. The air samples were tested by means of a gas analyzer ($\mu < 20\%$). The confidence coefficient of the measurements is $P=0.95$.

The experimental part of the research was conducted in 1995 and 2014 in the accredited laboratories of Tomsk Polytechnic University and Tomsk State University, Center of Laboratory Analysis and Technical Measurement of the Siberian Federal Region, Center for Hygiene and Epidemiology in the Tomsk Region and the department of Tomsk specialized inspection of State Ecological Control and Analysis of "Regional Committee for Environmental Protection and Nature". The soil samples were cleaned of mechanic impurities, put into plastic boxes (1 liter) and moistened up to 60% of maximum water capacity.

To determine the soil toxicity level seeds of *Cucumis sativus* L. (hybrid "Estafeta") were used as a traditional test-object [10]. Their laboratory percentage germination is 80 %. The test was repeated four times with 50 seeds for each set. The seeds were sown 3 cm distance from each other at 1 cm depth. They were watered as long as the substrate dried out. The morpho-physiological method was used to measure seed vigor, germination capacity and their degree of development. The ruler was used to measure 10-day plant biometrics (accuracy up to 1 mm) and the analytical balance "VLR-200" was used for weight measuring. Statistical data processing was carried out by means of software STATISTICA.

Results and discussions

The research results prove that petrochemicals and zinc were the most significant pollutants in 1995-2013 (76-134 and 37-62 mg/kg respectively). The second group of pollutants included nitrate ions and heavy metals (mobile forms): copper, plumbum, nickel and chrome with the concentrations over the range of 2-30 mg/kg. The third group consisted of cadmium and arsenic (mobile forms) with their

concentrations ranging from 0.005 to 6.225 mg/kg. The maximum general pollution level was registered in 1995, that is the active operational period of the SDW landfill (figure 1). By 2011 the contamination level reduced (5 times) and in 2012 slightly increased (zinc, copper and nickel). This fact can be attributed to the official closure of the SDW landfill and further renewal of illegal waste dumping. The pH value of the salt-water soil digestion was steady and didn't change from year to year (about 6.8).

The comparative analysis of the ultimate composition of the operating landfill's soils shows highly inhomogeneous spatial distribution of the elements over the SDW landfill areas (table 1). The closest to the reference (background) values are those measured in the recultivated area. The most contaminated are the soils under the open waste dumping area. According to the chemical analysis there is an intensive accumulation of the majority of the 24 studied elements. The soils of animal burial site take the in-between position. They are of semi-fluid consistence and characterized by strong smell.

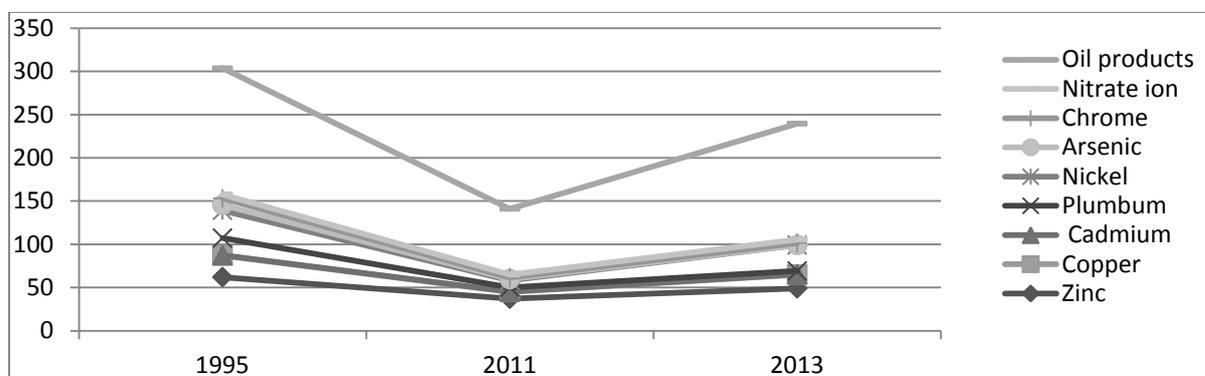


Figure 1. Dynamics of soil pollutant (mobile forms) concentrations (mg/kg) on the SDW landfill.

It is necessary to note that even after the operational period of the SDW landfill was finished the air sampling taken in 2013 revealed the following pollutants (mg/m³):

- a) at the boarder of the sanitary protection zone: carbonic oxide CO (0.01-0.32); benzol (up to 0.047); toluene (up to 0.08);
- b) at the working area of the SDW landfill: carbonic oxide CO (0.37), benzol up to 0.0363); (toluene (up to 0.005);
- c) at the closed area of the SDW landfill: carbonic oxide CO (0.28);
- d) garden plots of the citizens (residential area): carbonic oxide CO (2.24); benzol (up to 0.0924);
- e) in the Bekkari hollow: carbonic oxide CO (0.35); benzol (0.1199); toluene (0.059); nitrogen dioxide (0.0071).

Table 1. Element concentrations (mobile forms) in the soils of the SDW landfill near the settlement Novomikhaylovka during its operating period (1995)

Area		Concentration of Elements (mobile forms), mg/kg													
		Cr	Ni	Sn	V	Pb	Cu	Zn	Co	Be	Ba	Y	Cd	As	Ge
1	Reference (background)	62	22	1,6	46	15	20	32	6,5	0,5	220	12	2,5	5,0	0,2
2	Recultivated	100	40	3,2	96	30	33	31	9,5	0,7	330	20	3,7	7,3	0,2
3	Animal burial site	100	41	3,0	97	25	16	53	20,3	1,0	405	20	4,7	6,5	0,3
4	The area under open waste dumping	146	41	4,8	85	35	25	80	18,1	0,9	442	21	1,7	9,3	0,3

The soil biotesting confirms actual toxicity occurrence. The seeds germinated more slowly and the sprouts were weaker. They were characterized by low morpho-physical characteristics (plant's weight, leaf area) (figure 2). The seeds in the soil from the animal burial site didn't germinate at all, which allows us to make a conclusion about its hyper-phytotoxicity.

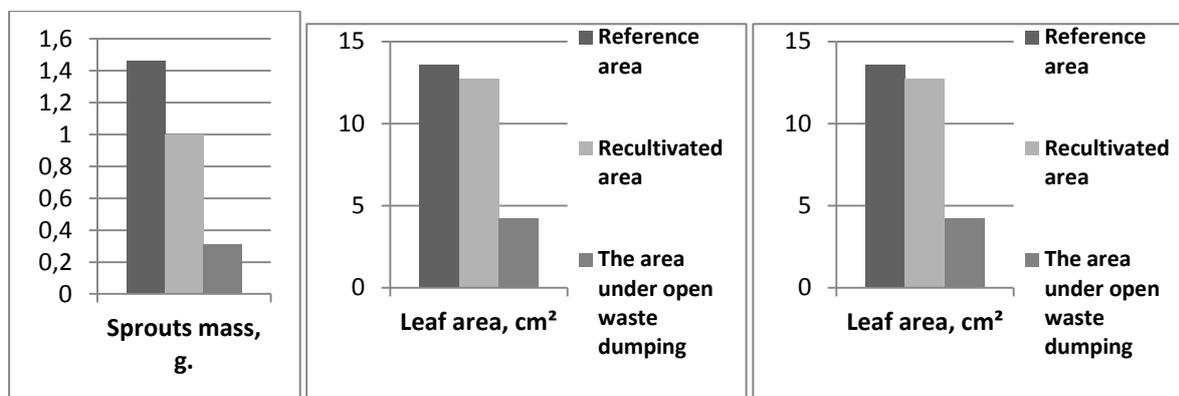


Figure 2. Phytotoxicity of the soil samples of the SDW landfill taken from different areas in 1995. SV – seed vigor (the number of sprouts appearing above the soil surface on the 5th day, %; Germination capacity – the final number of sprouts, %).

It is necessary to note that according to the chemical analysis it is the area under the open waste dumping that is the most contaminated one. But the animal burial site appears to be the most phytotoxic one. These differences can be adjusted by taking into account the following:

1. Chemical substances interact with each other in the soil thus strengthening and weakening biological influence. That is why it is difficult to give an integral evaluation of such a complicated multi-elemental composition in terms of the degree and direction of its synergetic effect.
2. Biological objects have selective sensibility when exposed to particular factors. Even slight exposure can cause significant changes in their metabolism.

Conclusion

The biotesting proves that the soil pollution on the SDW landfill is comparable with the direct soil exposure with diesel and biodiesel [8], as well as with petrochemicals [12]. It allows applying the recommendations developed by the authors mentioned above to the polluted soils of SDW landfills: 1. For effective depollution of the contaminated soils of SDW landfills it is necessary to ensure effective assessment and control of the landfills (areas and distribution of waste disposal) and SDW (content and amount); 2. It is necessary to classify SDW according to the degree of integral toxicity impact on living organisms; decay rate in the natural environment; and particular induced changes in the biosphere; 3. Special attention should be paid to minimization of SDW amount by introducing separate waste collection and waste recycling, thus reducing the landfills' areas with the final disposal of them in the long view.

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