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Unequipped Municipal Solid Waste Landfills as an Environment Threat

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ABSTRACT

Unequipped municipal solid waste (MSW) landfills are a huge problem and threat to the environment and public health for dozens of countries with "developing" economics. There are results of experimental research regarding ecological threats from municipal solid waste (MSW) in Ukraine on the examples of four real large landfills (in fact, unequipped MSW dumps) of typical Ukrainian industrial city 1 million population. Special attention is given to such problems as biodegradation and self-ignition of MSW in unequipped dumps, as well as emission and spreading of greenhouse and toxic gases, filtration of toxic leachate, and also spreading toxic (heavy) metals which differently pollute air, the soil and underground water.

The purpose of this research is a comprehensive qualitative and quantitative study of all properties of REAL unequipped MSW landfills that can threaten the environment and health of the population. To do this, within two years, 4 real un-equipped landfills in a Ukrainian city with 1 million populations were studied. These landfills operated for 15-50 years and accumulated 50-150 thousand tons of MSW.

Keywords: Municipal Waste, Landfill, Environmental Threats, Pollution.

Introduction

The municipal solid waste (MSW) management is a particularly critical problem for countries similar to Ukraine with "developing" economics [1]. From about 200 countries of the world, more than 50% of them do not have a modern waste management system (i.e. they were not preliminary sorting of MSW and collection of toxic "biogas" and leachate; in addition, they had constant hotbeds of smoldering and burning) and pose a huge multilateral threat to the environment and health of nearby residential areas. So, approximately 5 billion m^3 (over one billion tons) of MSW have been accumulated in Ukraine; it is disposed of at 800 large municipal landfills, and their total surface is more than 50 thousand hectares (including 500 m of sanitary zone for each). All them are 60-90% full, many of them are overfilled and should have been closed a long time ago. Also, there appeared thousands of unauthorized ("wild") MSW dumps [2].

A lot of Ukrainian MSW dumps are permanently smoldering or even burning, especially during summer time. In addition to traditional toxic "fire gases", it has been shown that the maximum concentration of dioxins in air (2 m above of one ton of burning waste) can exceeded the European Union standard of 0.1 nanogram/m^3 [3, 4,5].

Besides, when waste are disposed of in a landfill, the available oxygen may be quickly used up, so that the subsequent microbial activities goes from aerobic to anaerobic. These dangerous biological processes of MSW degradation have been described [6, 7]. Therefore, MSW can cause significant damage to the environment if they are not stored in a properly engineered system. Some of the problems that might occur are the following: emission of biogas and other toxic gases, spread of pathogenic bacteria, and also pollution of soil and ground water by highly toxic leachate [8].

It would be desirable also to note: deep studying of REAL unequipped and semi-illegal large MSW dumps (containing tens of thousand tons of MSW) is accompanied by huge technical complexity and labor input and even some health hazards for researchers. Perhaps, it is why in scientific literature the quantitative studying of real large unequipped MSW dumps is deficiency. Thus, the purpose of this research was to provide a qualitative and quantitative estimation of the degree of environment pollution by poorly equipped real MSW landfills.

Materials and Techniques

Note: Determination of the measurement error presented certain difficulties for us, since we were dealing with an indefinite mixture of components that changes in space (around the landfill) and time (due to biodegradation processes in the body of the landfill). Therefore, in addition to taking into account the "relative error" and the "error dispersion" of the results in the series of measurements, we also added "measurement error due to changes in measurement conditions" [9]. I want to emphasize that the real measurement error of such "undefined" mixtures as MSW is many times higher than the accuracy of the device used for measurements.

Measurement of biogas emission for real landfills in typical Ukrainian industrial city 1million population was fulfilled with the help of an individual multi-channel gas analyzer "MX-21-Plus" (France) and portable mobile ionic spectrometer "Multi-IMS" (Droger, Germany). The most "young" landfill No. 4 was chosen by us for gases analysis (see Table 1). The measurements of biogas were done in 8 boreholes of 2 m deep; each hole was at the square of 5x5 m. An average value was used on the basis of 3 measurements performed with an interval of 10 minutes. Analysis of the atmosphere above the real landfill was fulfilled on 1 m over the surface. The inaccuracy of all measurements did not exceed 8%.

In order to calculate the maximum theoretical biogas production at MSW landfills of Donetsk city we used the following formula for first order reactions [10]:

$$V = \Sigma V_0 Q e^{-k\tau} \quad \textbf{(Eq. 1)}$$

where:

V_0 – the theoretical MSW methane production potential, m^3/t (for "average" Ukrainian MSW is equal 80);

Q – the average quantity of MSW received at a landfill, t/year (see Table 1);
k – the average constant of methane production, l/year (food – 0.35, paper – 0.12, textiles – 0.05, plastic – 0.01);
τ - the time of landfill operation, year (see Table 1).

The quantity of leachate (**V_f**) which might be produced at the working area of the landfill (dump) depends mainly on the amount of annual precipitation **(P)** of the region, evaporation **(V),** and water absorption by landfill wastes (**W**) *(Qasim, 1995)*. However, we added to this formula another summand **R**:

$$V_f = [(P\text{-}I\text{-}W\text{-}F) \bullet S \bullet 10^{-3}] + R \qquad \text{(Eq. 2)}$$

where:

P – precipitation for this area, mm/y-m^2 (1 mm = 10 tons of precipitation per hectare; for East Ukraine P=500);

V - evaporation rate, mm/y•m^2 (for East Ukraine V=200);

W - water absorbed by solid waste, mm/year•m^2 (for East Ukraine W=100);

F - water drained, mm/year•m^2 (for East Ukraine F=10);

S - landfill working area, m^2;

R - water produced during MSW degradation, m^3/year, which is 0.3 m^3 (tons) of H_2O for every 1000 m^3 of natural biogas emitted.

Underground water samples for analysis were taken at the landfill border at the depth of 10-15 m. Altogether there were 8 wells: 2 at each of 4 sides. Three samples were taken from each well. The result of the analysis is an average value received for 3 samples. After that, an average value was obtained for all wells. Soil samples were taken at the distance of 500 m (sanitary zone) from the landfill border at the depth of 0.2-0.3 m also from four sides. From each side 3 samples were taken. After that all samples were averaged through quartering and the analysis was fulfilled. Atomic absorptive spectrophotometer “MGA-915” (Russia) was used to measure toxic (heavy) metals in soil, water and ash (samples of MSW were incinerated for that). The inaccuracy of the analysis did not exceed 8%.

Chromatograph “Chromatech” (Russia), which has been modified by us for heating of columns up to 325°C, was used to study combustion of MSW. MSW sample (225 g; composition is according to Table 1; the speed of air supply into column was constant, being 1 liter/min). The tests were conducted with MSW being heated (in the thermostat) by +70°C, 120°C, 170°C, 220°C, 270°C, and 325 °C (when the temperature was higher than 300°C some of MSW components started to burn - for instance, the temperature of self-ignition of pressed paper is about 250°C).

We analyzed of soil and also toxic gases in air samples (1 m over ground) on border of a sanitary zone (SZ) of the burning MSW dump No. 3 (500 m from edge of a dump), with help portative analyzers “MX-21-Plus” and “Multi-IMS” (samples of air and soil were selected and delivered to laboratory for analysis of the heavy metals with help atomic absorptive spectrophotometer).

We have measured concentrations of toxic gases produced after MSW incineration and total concentrations of “heavy” (toxic) metals in the ash. We measured the part of heavy metals, which transforms in more “volatile” forms and is emitted into the atmosphere together with combustion gases as well as the part of heavy metals that enter the ash. Besides, we studied a separate part of heavy metals in the ash, which is “labile” and can migrate from ash into soil. The inaccuracy of all measurements did not exceed 6%.

Results and Discussion

Gas research of 4 real MSW landfills

In fact, there are not the classic landfills, there are the large unequipped dumps because the MSW are delivered there by dump trucks and then compacted by the tractors (up to density 0.6 t/m^3). These dumps aren’t equipped with any technical means for collecting biogas and leachate. Besides, the wrong storing leads to self-heating and smoldering inside the MSW, and then to spontaneous ignition of separate sites of a dump.

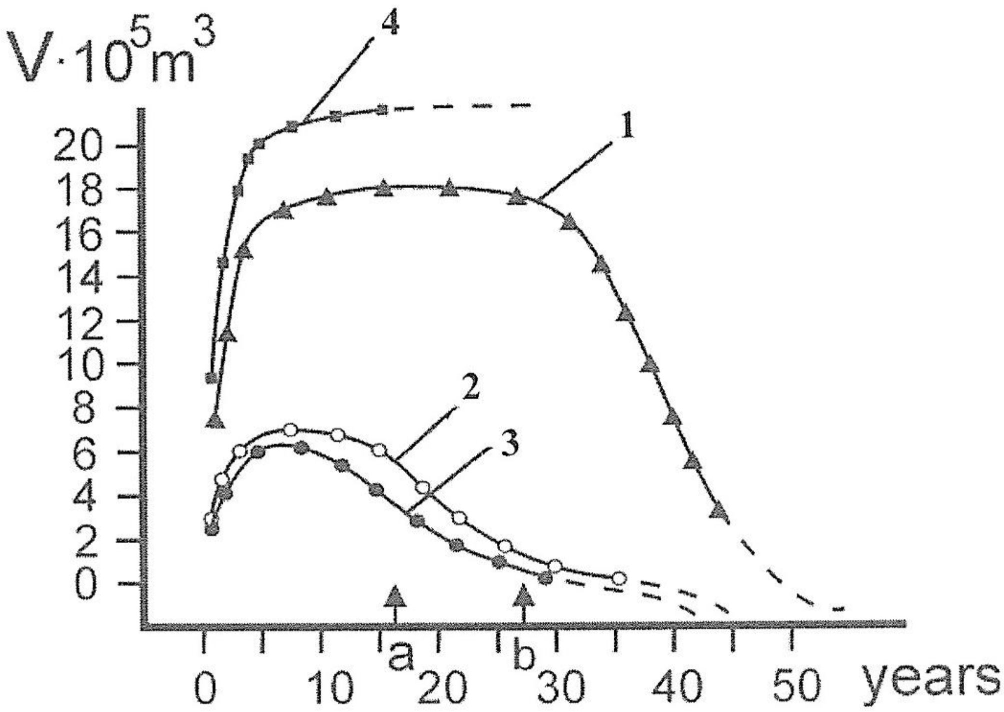
Landfills	Years of operation	Average quantity of MSW received each year (tons)*	Working area, hectares	Depth, m (average)	Average composition (mass. %)
No. 1	47	115,000	11	25	food-26; plastic-20; paper-11; glass-6; wood-8; metal-8; textiles-4; stones-6; sweepings**-11.
No. 2	37	51,000	4	12	
No. 3	29	48,000	5	10	
No. 4	15	155,000	24	18	

*) The bulk density of incoming MSW is 0.25 t/m^3, after landfill compaction it is 0.6 t/m^3.

**) Approximately 1/3 of sweepings is an organic matter.

Table 1: Real Landfills Characteristics

The volumes (theoretical maximum possible) of biogas emitted from real landfills No.1-4 were calculated according to formula (Equation 1). The results are illustrated at Figure 1.



("a" is sign when delivery of MSW to No.4 landfill was limited;
"b" is the same for No.2 and No.3 landfills)

Figure 1: The volumes (theoretical maximum possible) of biogas emitted from real landfills No.1-4

As we can see from Figure 2, the biogas emitted from the No.1-4 landfills during biodegradation term reach their maximum at 1/4 – 1/3 of the full working period that is connected with activity of bacteria and also alterations of pH and temperature in a dump body (similar curves like overturned parabola were described by [11, 12]. Graph 1 also shows that, for example, landfills No.2 and No. 3, in fact, were already almost full 10 years ago but MSW delivery wasn't stopped there (only were limited) as this zone of this city has no other place to store MSW.

At the depth of 25 m, from the bottom layers of most "old" No.1 landfill there have been taken samples of "residual" MSW. The age of these MSW layers corresponds to 45 years. The samples were tested for the level of moisture and the share of organic components. The average result received on the basis of three samples is the following: level of moisture - 5.1%, the share of organic components - 13.5% (the initial share 45 years ago was about 75% - see Table 1). Thus, during 45 years MSW has been considerably mineralized as a result of a deep biodegradation of organic components of MSW.

Measurements of biogas (there are, basically, greenhouse gases) emissions at 4 real landfills (from 2 m deep boreholes) show the following composition of biogas (see Table 2).

No.	Biogas (vol. %)	
	CO_2	CH_4 (methane)
1	69	31
2	67	33
3	60	40
4	55	45

Table 2: Biogas (greenhouse gases) emission from real landfills

In fact, the data of Table 2 have shown: at such landfills as No. 1-2 the process of biodegradation has almost finished, while at No. 3 and especially No. 4 «more young» landfills (see Table 1) it is still active.

Gases sampled above (1m) the real landfills surfaces were tested for dust, hydrogen sulfide (H_2S), nitrogen dioxide (NO_2), ammonia (NH_3), sulfur dioxide (SO_2) and carbon monoxide (CO) - see Table 3. These results show that the local atmospheric concentrations above the landfills were often more the norm (especially for dust and NO_2). At landfills with smoldering waste - No. 1 and No. 2 - the share of carbon monoxide sharply increases.

Parameter	No. 1	No. 2	No. 3	No. 4	MPC*
Dust	0.8	0.5	0.6	0.3	0.15
H_2S	0.01	0.053	0.05	0.003	0.005
NH_3	0.013	0.01	0.04	0.023	0.04
NO_2	0.09	0.05	0.06	0.052	0.04
SO_2	0.14	0.05	0.012	0.018	0.05
CO	3.1 (smoldering)	5.6 (smoldering)	1.6	0.7	3.0

*)MPC - maximum permitted concentration in air of settlements (average daily).

Table 3: Atmosphere composition at the level of 1 m above the landfill ground (mg/m^3)

However, additional researchers found that biogas also contains micro-amounts of highly toxic chlorine hydrocarbons, for example, chlorides methane (less 5 ppm).

Leachate Pollution

None of the four landfills has a leachate collection system. We have analyzed leachate composition at No. 3 landfill; the data are listed in Table 3. We have studied the composition of underground water the samples of which were taken from the wells surrounding No. 3 landfill. The sampling was done from the depth of about 5-10 m.

Parameter	Concentration (mg/l)	MPC*
BOD**	2130	350
Oil products	110	0.5
Ammonia nitrogen	512	10.0
SSAM***	0.3	0.01
Fe	190	0.3
Ni	0.3	0.1
Zn	11.4	1.0
Pb	4.1	0.03
Cd	0.06	0.001
Cr	0.4	0.05
Hg	0.2	0.0005

*) MPC- maximum permitted concentration;

**) BOD - biochemical oxygen demand - is the amount of dissolved oxygen needed by aerobic biological organisms in a water;

***) SSAM - synthetic superficially-active materials.

Table 4: Leachate composition at No. 3 landfill

Data of Table 4 demonstrate that concentration of toxic substances in leachate is in hundreds, and sometimes thousand times more sanitary norms (MPC), i.e. leachate is highly toxic and a very dangerous liquid.

The calculation of leachate volume produced at No. 3 landfill has been done by formula (Eq. 2). If to apply the equation to No. 3 landfill, which occupies 3.1 hectares (Table 1), using R = 200 m^3/y and the values shown in Table 7, the expected annual leachate production will be 298 m^3/y:

V_f = [500 – 200 – 100 – 10] = 190 x 5 x 104 x 10^{-3} = 5890 + 300 = **298 m^3/year.**

Uncontrolled production of such big volumes of toxic leachate should inevitably worsen ecological conditions of nearby underground water and soil.

For check of possible soil pollution on border of a sanitary zone (SZ-border) No. 3 landfill (a concentric circle of 500 m from edge of landfill) were analyzed samples of soil (see Table 5).

Parameter	**MPC** (mg/kg)	**Real concentration**	**Outreaching**
Cd	0.2	0.78	4 times
Ni	4.0	3.3	7
Pb	6.0	1.9	3
Hg	0.05	0.3	6
Nitrates	10	82	8
Oil products	0.3	3.6	12

Table 5: The results of soil research on the SZ-border for No. 3 landfill

The data of Table 4 confirm the worst fears regarding high danger of leachate from unequipped MSW dumps.

The danger of MSW smoldering processes

For studying of danger of self-heating and self-ignition of MSW stored on unequipped dumps, samples of MSW (in briquettes with density 0.6 t/m^3) were exposed to thermal destruction in the laboratory adjustable furnace at temperatures of 100-375 °C. Results of measurements– in Table 6-7.

We have measured concentrations of toxic gases produced after MSW incineration (including such super-toxic ones as hydrogen cyanide - HCN, hydrogen chloride - HCl, formaldehyde - CH_2O) and total concentrations of “heavy” (toxic) metals in the ash (with help of a mass-spectrometer). After that, we measured the part of heavy metals, which transforms in more “volatile” forms and is emitted into the atmosphere together with combustion gases as well as the part of heavy metals which enter the ash. Besides, we studied a part of heavy metals in the ash, which is “labile” (soluble) and can migrate into soils (if it will be washed out from ash by rain). The results of the measurements are provided in Table 6-7.

Concentration of toxic gases							
CO	**SO_2**	**H_2S**	**C_6H_5OH** (phenol)	**NO_2**	**HCL**	**HCN**	**CH_2O**
678	8.8	13.7	5.7	41	0,2	0,12	19.8

Table 6: Concentration of emitted toxic gases after MSW incineration (mg/m^3)

Parameter	**Concentration of toxic metals in MSW ash (mg/kg)***						
	Pb	**Ni**	**Cr**	**Cu**	**Zn**	**Hg**	**Co**
Sample of initial MSW	511	140	190	1270	2410	3.2	46
Sample of MSW ash	288	120	180	1100	2080	0	36
Quantity of toxic metals that was washed out from the ash – imitation of rain	48.3	8.5	9.9	15.7	23.8	0	1.34

*) **Pb** – Lead; **Ni** – Nickel; **Cr** – Chromium; **Cu** – Copper; **Zn** – Zinc; **Hg** – Mercury; **Co** – Cobalt;

Table 7: Concentration of toxic metals in initial MSW and its ash

By comparing the data of Table 7 we can see that ash accumulates all of toxic metals, excluding mercury and lead: mercury completely evaporates into air and lead – half-on-half.

Therefore, the proposal to use ash after utilization MSW through incineration - for building materials [13] causes concern.

So, we have established that during the incineration of MSW the vast emission of toxic gases in the atmosphere will take place. Some parts of each of the heavy metals are taken to the atmosphere together with combustion gases, the other parts enter the ash. At the same time, some parts of heavy metals that have passed into ash are in a soluble form, i.e. they might (in case of precipitation of ash on wet soil) enter in the soil. It is interesting to note that each heavy metal has its "own character".

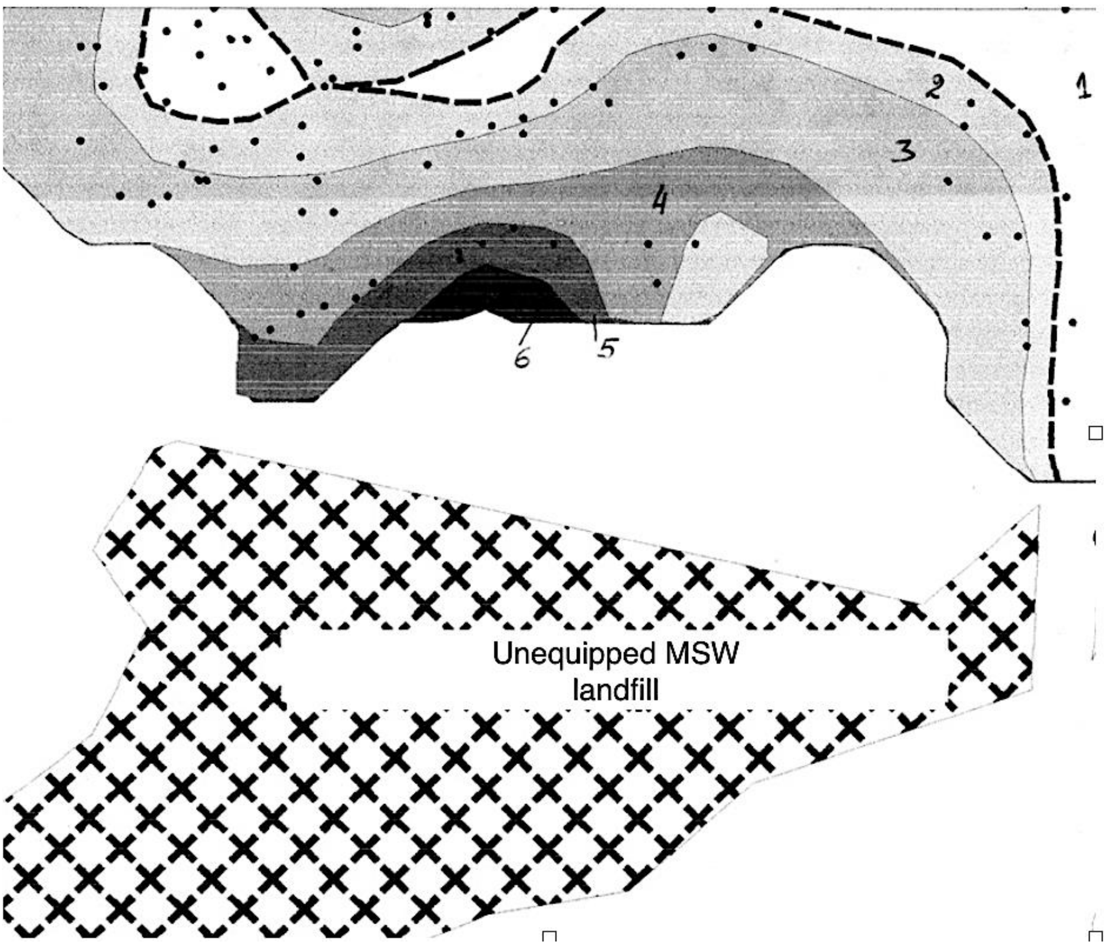
For check of air pollution on the border of a sanitary zone (SZ-border) for smoldering No. 1 landfill (a concentric circle of 500 m from edge of landfill) samples of air were analyzed (see Table 8).

Parameter	MPC	Number	Exceeding
NO/NO_2	0.035	0.55	16 *(times)*
H_2S	0.05	0.39	8
HCl	0.2	0.8	4
Ash	0.1	0.71	7

Table 8: The results of research of the SZ-border for No. 1 landfill (mg/m^3)

Evidently, combustion gases from the smoldering dumps have high toxicity (see Table 8) and high danger for environment and human health.

Thus, the data of Table 1- 8 and Figure 1, 2 show that Ukrainian MSW landfills which are not equipped by collection systems for biogas and leachate, present a big threat for the environment and human health – see Figure 2.



zone 1 - more than 66 years, 2 – 63 years, 3 – 59 years, 4 – 55 years, 5 – 51 years, 6 – less than 50 years;
(1969 data of Donetsk Medical Institute; these temporary unregistered dwellings were demolished in the 1970s)
Figure 2: Map of the average lifetime of people who live nearby unequipped MSW landfill No. 1 (scale: 1 cm – 0.5 km):

The problem of danger of unequipped MSW dumps is typical for the majority of the countries of South America, Asia, Africa and part of Southern Europe. So, in Brazil from 2003 to 2011 1.5 million tons per year of CO_2 (an average) were emitted into the atmosphere [14]. According to the Environmental Sanitation Technology Company (CETESB) study, the 6,000 waste sites in Brazil receive 60,000 tons of waste per day. 76% of this waste goes to dumps with no management, gas collection, or water treatment and 83% of Brazil methane gas emissions come from uncontrolled waste sites. But this problem exists for economically developed countries. So, in Canada, landfill sites produce about 27 million tons of carbon dioxide and methane annually, and only 6.9 million tons (25%) from that are collected [15].

We don't share an opinion [16] regarding "Significant amounts of biogenic carbon may still be stored within the landfill body after 100 year". MSW sample from the real landfill of No.1 at a depth of 25 m and having age about 40 years - contained 13.5% organic components only.

Unfortunately, we didn't study the smoldering Donetsk dumps concerning dioxin due to the lack of access to reliable analyzers of dioxin. Therefore, the scientific paper [17] well fills up a gap in our studying. At research of influence of the illegal burning dumps (including toxic waste) in Italy (province of Campania) on health of local population, it was found high concentrations of dioxins (≥5.0 pg TEQ/g fat) in sheep and cow milk samples, and also dangerous contamination of dioxin and polychlorinated biphenyls in woman milk samples from those living in Campania (at 16.6 pg TEQ/g of fat).

In Table 4, the results of measurement of toxic metals concentrations in leachate are illustrated. But researchers [18] testify that the danger of toxic metals in MSW is underestimated. Baun and his colleagues evidently showed that colloids as well as organic and inorganic complexes take place for all heavy metals in landfill leachate. Besides, standardized procedures for assessing the content of "associated" ions of heavy metals in leachate do not exist. Unequipped dumps are a powerful source of greenhouse gases and, therefore, it is one of "responsible" for negative climate change. In Figure 1 of our paper it is visible, what huge volumes of greenhouse gases (which are estimated by hundreds of thousands or millions of cubic meters) are emitted by each of these four dumps during the activity (20-40 years). According to calculations [19, 20], world emission of biogas (which greenhouse gas is) from 1990 to 2050 will increase by 9 times (from the real 340 Mt in 1990 up to calculated 2900 Mt – if we will not change relation to management of municipal waste).

Conclusions

1. In their present state, these researched MSW dumps don't have any engineering infrastructure (gas collection, filtrate treatment, no smouldering, etc.) ensuring public health and environmental safety.
2. Our studies has provided qualitative and quantitative assessments of such danger factors from unequipped MSW dumps as generation of greenhouse and toxic gases, toxic leachate, and also self-heating and smouldering MSW inside dumps due to bacteria activity.

3. It was established that each heavy metal during the incineration of MSW has its own "character". For example, ash accumulates all of heavy metals, excluding mercury and lead; mercury completely evaporates into air and lead – half-on-half. Also, "soluble toxic metals" can migrate from ash into soil.

4. These problems are typical for many other countries with "developing" economics as their municipal budgets are not sufficient to solve similar problems.

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