Analyses of Environmental Impacts of Non Hazardous Regional Landfills in Macedonia

Katerina Donevska*[*1], Joze Jovanovski[2], Milorad Jovanovski[1], Petko Pelivanoski[1]
[1]Faculty of Civil Engineering,
University Ss Cyril and Methodius, Skopje, Macedonia
e-mail: donevska@gf.ukim.edu.mk

[2]Public Enterprise for State Roads, Skopje, Macedonia

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ABSTRACT

This paper presents an assessment of potential environmental impacts for eight planned non-hazardous regional landfills in Macedonia. Waste quantities for each waste management region and landfill capacities are estimated. Expected leachate quantities are calculated using Water Balance Method. Analyses and comparison of the likely landfill leachate per capita are presented, demonstrating that higher rates of leachate are generated per capita in waste management regions with higher annual sums of rainfall. An assessment of the potential landfill impacts on the water environment taking into consideration local geology and hydrogeology conditions is presented. Some general measures for leachate treatment that are in compliance with the modern EU standards are indicated. The goal of the study is to facilitate a better understanding about the sustainable waste management practices in cases of landfilling of municipal solid waste.

KEYWORDS

Environmental impacts, Landfill, Water balance method, Leachate, Treatment.

INTRODUCTION

Municipal solid waste (MSW) management continues to remain as one of the major problems for today's society. Sustainable management of waste is based on the general goal of minimizing the impact of the waste on the environment in an economically and socially acceptable way. The current best practices for sustainable MSW management are based on the integrated waste management system. Although alternative waste management strategies such as incineration, recycling, and composting, have been developed to reduce the amount of MSW requiring disposal, waste minimization at source remains the cheapest and the most efficient waste management method. This induced the hierarchy of integrated resource management options that has been adopted worldwide: (i) prevention, (ii) reduction, (iii) recycling, (iv) disposal [1]. Minimization of the waste generation at source, reuse, recycling and material/energy recovery processes of MSW are encouraged in order to improve the use of resources. However, even when combination of the waste management methods is employed, residuals remain which must be disposed on a landfill. Although landfilling is placed at the bottom of the hierarchy of options for integrated waste management, it has been the most commonly used method for solid waste disposal [2].

[*] Corresponding author

The decomposition of solid wastes disposed in landfills results as combination of chemical, physical and biological processes, which lead to production of liquid, gaseous and solid by-products [3]. The leachate is the most toxic by-product of the solid waste decomposition, showing significant temporal variability in terms of quantity and leachate composition. Several researchers report contamination of soil [4] and groundwater [5-8] by landfill leachate. Modern solid waste landfills are engineering sites designed and constructed to contain the waste and to minimize the impact on the environment [9], but they can still have impact on human health and the environment.

In the Republic of Macedonia there is some form of organized solid waste management (SWM) service in all municipalities, mostly centred on urban areas. Solid waste disposal in the entire region is based on landfilling. Every settlement disposes waste on its own landfill or dump, while most of the settlements in rural areas dispose the waste in nearby lowlands, farm fields or river banks. Available facilities for disposal of wastes are substandard and do not comply with technical normative and legislative requirements appointed in Council Directive on the Landfill of Waste [10] and recently adopted national legislation. The improper waste management practices generated serious impacts to the soil, ground and surface water. Ground water is mainly contaminated by leachate, which is highly contaminated with toxic organic and inorganic compounds and sometimes with pesticides and heavy metals as well [11]. Active municipal waste landfills are ranked according to the assessment of their environmental risk in three categories: 16 landfills are ranked with high risk, 16 with medium, and 19 with low environmental risk [12]. Most of the existing municipal landfills and dumps sites need to be closed since the site conditions and environmental impacts are significant and remediation measures cannot be implemented efficiently. In order to improve the present situation in waste management sector and to involve principles of sustainable use of natural resources in the future, the National Waste Management Strategy (NWMS) [13] is adopted. The NWMS sets the fundamental directions of the waste management system for the forthcoming period, based on the application of the key principle on waste management, i.e. waste management hierarchy. Although reuse, recycling and material/energy recovery processes of waste streams are encouraged, landfilling remains at the bottom of the hierarchy for disposal of the unusable waste. Therefore, final disposal of MSW is planned on regional landfills.

The total amount of generated waste in the country, including the waste from mining, is estimated at approximately 26 million t/yr [13]. The main waste stream consists of: mineral excavation and ore processing of approximately 17.3 million t/yr, agriculture waste of approximately 4.9 million t/yr, and municipal solid waste of approximately 570,000 t/yr. The prognosis of municipal solid waste rise rate is 1.7%/yr, which leads to a total amount of 700,000 t/yr in the year 2020. Solid waste generation rate per capita varies in the range of 285 to 350 kg/cap/yr. The municipal solid wastes are consisted of household wastes, street sweepings and park green wastes, commercial-institutional waste and wastes generated in industry with a household-like character. However, a small part of the household waste stream has hazardous properties (batteries containing heavy metals and acids, etc.) [13].

In the present study, the focus is on environmental impacts assessment on the water environment caused by planned non-hazardous regional landfills in the Republic of Macedonia. Considering geographical distribution of waste generation and basic principle to cover a territory with more than 200,000 inhabitants, 8 waste management regions are considered. Suitable potential landfill locations are selected and waste quantities and landfill capacities are estimated. Knowledge of the likely leachate generation of a landfill is a prerequisite to the planning of a leachate management strategy and treatment. Water balance method is used to assess likely leachate generation volumes for each landfill. The intention of this paper is to demonstrate the estimated leachate quantities and their spatial variability due to the different climate conditions in each SWM region. Considering leachate quantity and local conditions at landfill site technical measures for leachate treatment are indicated.

METHODOLOGY

Water Balance Method is used to estimate leachate generation volumes on annual level. Parameters used include waste volumes, input rates and absorptive capacity, effective and total rainfall, infiltration and other site parameters [14].

$$Lo = [ER(A) + LW + IRCA + ER(l)] - [aW] \quad (1)$$

where:

- L_0 – leachate produced (m^3/yr);
- ER – effective rainfall (use actual rainfall (R) for active cells) (m/yr);
- A – area of cell (m^2);
- LW – liquid waste (also includes excess water from sludges) (m^3/yr);
- $IRCA$ – infiltration through restored and capped areas (m per year);
- l – surface area of lagoons (m^2);
- a – absorptive capacity of waste (m^3/t);
- W – weight of waste deposited (t/yr);

Effective Rainfall (*ER*) is defined as Total Rainfall (*R*) minus Actual Evapotranspiration (*AE*) i.e. $ER=R-AE$. For individual landfills the common practice is to estimate rainfall by using data from the nearest meteorological station or rainfall gauging stations [14].

Evaporative losses are a combination of evaporation of water from the surface and transpiration of water by plants where vegetation is present. Transpiration due to vegetation can effectively be ignored for the purposes of water balance calculations on uncompleted landfills.

Water Balance Method is used for different SWM regions, represented with different climate types.

BACKGROUND AND STUDY AREA

Among basic strategic principles for development of the Macedonian waste management system set in the NWMS of the Republic of Macedonia [13] is the regional municipal waste management system. According to the national documents [11], treatment and final disposal of municipal solid waste is planned on regional landfills. In this respect, it is adopted that the country may optimally organise 5 - 8 waste management regions, generally comprising of one or more statistical regions [13]. In this paper, the analyses of the expected leachate generation rates and assessment of the impacts on the environment are prepared for 8 waste management regions (Figure 1) which are identical with established statistical regions in the Republic of Macedonia [15].

For each SWM region a suitable landfill location is proposed, compliant with variety of criteria for non-hazardous landfill site selection related to economic, ecological and environmental health sectors. The climate conditions (including rainfall and temperature) and the geological conditions of the proposed locations for regional landfills are presented in Table 1.

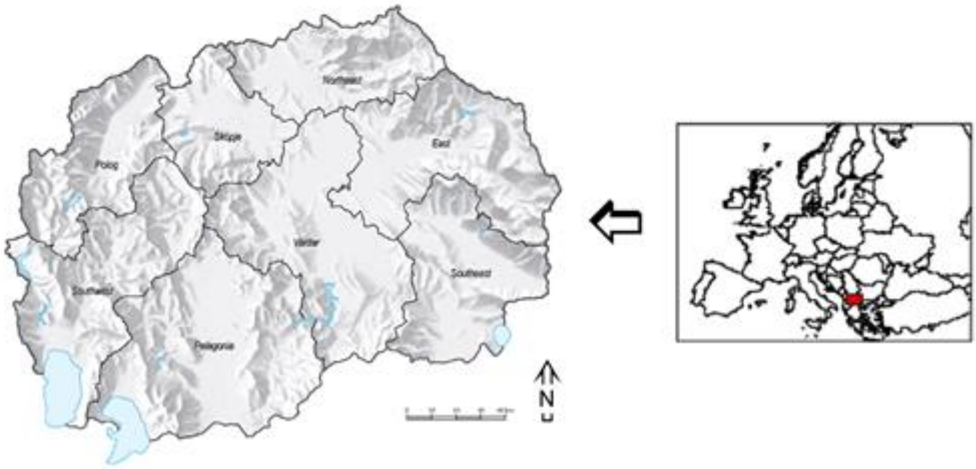

Figure 1. Location of the study area

In spite of the relatively small area of Macedonia, different climate types are characterized over its territory, from continental, changed continental, sub-Mediterranean (changed maritime) to mountainous climate with various sub-types.

Table 1. Climate and geology conditions for planned regional landfills

No.	Region	Proposed location for landfill	Average annual rainfall (mm/yr)	Average annual temperature (°C)	Geology of the site – permeability (m/s)
1	East Region	Karbinci	464.0	12.8	Sandstone, claystone and marl layers, $k<10^{-8}$ m/s;
2	Northeast Region	Staro Nagoricane	502.8	11.8	Massive reef limestone, clayey-gravelly-limestone material, $k<10^{-8}$ m/s to 10^{-6} m/s;
3	Southeast Region	Dobrasinci	565.0	12.7	Uniform clay layers, $10^{-9}<k<10^{-11}$ m/s;
4	Vardar	Rosoman	460.0	13.3	Clay, sand and marl with $k\leq10^{-11}$ m/s;
5	Polog Region	Rusino	798.0	10.3	Clay layers with minimum depth of 2.5m, permeability between $k = 10^{-7}$ to 10^{-8} m/s;
6	Skopje Region	Drisla	498.4	12.1	Clay, sands and mixed layers and rocky materials presented by sands in different granules, k to 10^{-11} m/s;
7	Southwest Region	Location near Struga	793.9	10.7	Composed of non-cohesive to slightly cohesive lithological formations with the grain size distribution from clay materials to gravel, $k = 10^{-7}$ to 10^{-8} m/s;
8	Pelagonia Region	Alinci	537.7	11.3	Precambrian highly metamorphic rocks (marbles, gneiss and cipolines) as well as Quaternary soil debris. The marbles occur as grey-white massive and white to grey-white thin platy to bedded marbles, $k<10^{-7}$ m/s;

The average annual air temperature is between 12 to 14 °C in the region with a sub-Mediterranean climate of 10 to 11 °C in the region with a hot continental climate, 5 °C in the region with a sub-alpine mountainous climate, and 0 °C in the region with an alpine mountainous climate (Figure 2). Considerable differences in rainfall volumes are typical for the county’s climate (Figure 3). The average annual precipitation amounts vary between 600 to 900 mm, except in the central region where the average annual precipitation are nearly or less than 500 mm and in the mountain regions where the annual sums are approximately 1,000 mm [16].

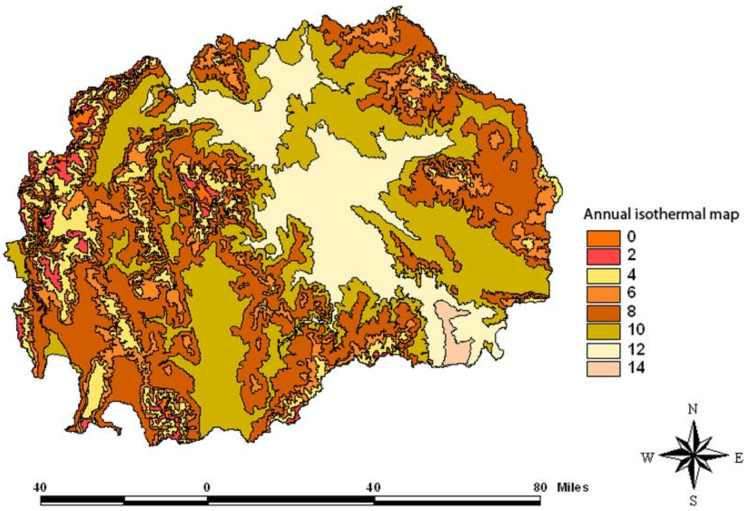

Figure 2. Annual isothermal map of Macedonia

Source: Draft National Action Plan for Land Degradation and Desertification

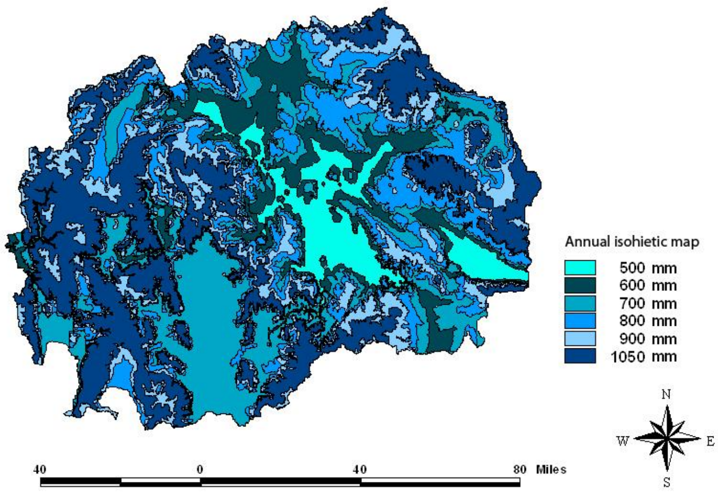

Figure 3. Annual isohietic map of Macedonia

Source: Draft National Action Plan for Land Degradation and Desertification

RESULTS AND DISCUSSION

Analyses of environmental impacts of non-hazardous regional landfills in Macedonia included estimation of solid waste quantities and leachate generation for eight planned regional landfills. Also, taking into consideration local geology conditions on the landfill site, an assessment of environmental impacts on water environment is carried out.

The density of the population and especially the population growth show significant spatial variation through the country. Data about inhabitants and the rate of population increase growth for each of the eight planned waste management regions are based on last Census [17] and feasibility/pre-feasibility reports [18-24]. Solid waste quantities for the landfills are estimated for exploitation period of 25 years. They have been accessed on the basis of average rate of daily waste production per capita of 0.78 kg [11], efficiency of collecting waste of 90% and 1.0% of annual increase of waste production per capita per year. Volume of waste is calculated using average compacted waste density of 700 kg/m^3. Results of the estimated solid quantities and landfill volume are shown on Table 2. The total estimated solid waste quantity for the whole country is approximately 19 million tons of solid waste for the exploitation period of 25 years, while the required capacity for solid waste is estimated on 27 million m^3 (including daily and final cover material).

Table 2. Quantities of generated leachate for exploitation period of 25 years

No.	Region	Population	Waste accepted on the landfill (t/25 years)	Volume of waste (m^3/25 years)	Leachate produced (m^3/25 years)	Maximum leachate flow (l/s)
1	East Region	181,858	1,493,598.7	2,133,712.4	487,738.1	0.98
2	Northeast Region	172,787	1,603,555.9	2,290,794.1	572,687.6	1.18
3	Southeast Region	171,416	1,759,347.7	2,513,353.9	732,574.4	1.46
4	Vardar Region	154,535	1,295,234.1	1,850,334.4	417,518.5	0.84
5	Polog Region	304,125	3,063,416.9	4,376,309.9	1,886,669.2	3.89
6	Skopje Region	578,144	6,107,201.1	8,724.573.0	2,161,420.9	4.44
7	Southwest Region	221,546	1,895,027.1	2,707.181.5	1,176,069.6	2.32
8	Pelagonia Region	238,136	1,947,009.1	2,781.441.5	764,931.0	1.52
Total quantities for the country		2,022,547	19,164,390.6	27,377.700.7	8,199,609.3	/

The leachate quantity is calculated using Water Balance Method. For water balances carried out on active phases of landfills, it is assumed that the actual rainfall will infiltrate into the waste in total. In areas that have been temporarily capped/restored an infiltration rate of 25-30% of the annual rainfall is used. Infiltration in restored areas varies in the range 2-10% of effective rainfall in a worst case scenario for a geosynthetic clay liner cap. Council Directive on the landfill of waste [10] requires Member States to prohibit the acceptance of liquid waste, meaning any waste in liquid form including waste waters but excluding sludge, to landfill, i.e., liquid waste is set as zero m^3.

The amount of water that can be absorbed without generating leachate depends on the type of waste, its initial moisture content and the density to which it is compacted. An assumption is made that for a waste density of 0.7 t/m^3 the waste is capable of absorbing 0.09 m^3 water per ton of waste before leachate is generated [14].

Total leachate quantities for the whole exploitation period of 25 years are presented in Table 2. They vary in a range from approximately 417,000 m^3/25 years for Vardar region (serves 154,535 inhabitants in 2002) to approximately 2 million m^3/25 years for Skopje region (serves 578,144 inhabitants in 2002).

Rainfall presents one of the major factors contributing to the leachate generation, having in mind that the leachate is generated from liquids existing in the waste as it enters a landfill or from rainfall that infiltrates through the waste within the landfill. Consequently, leachate generation per capita is analysed and compared for eight different landfill locations. The results are shown in Figure 4 illustrating that higher rates of generated leachate per capita are estimated for Rusino landfill in Polog Region and the landfill near the city of Struga for the Southwest Region, i.e. the locations with higher annual sums of rainfall.

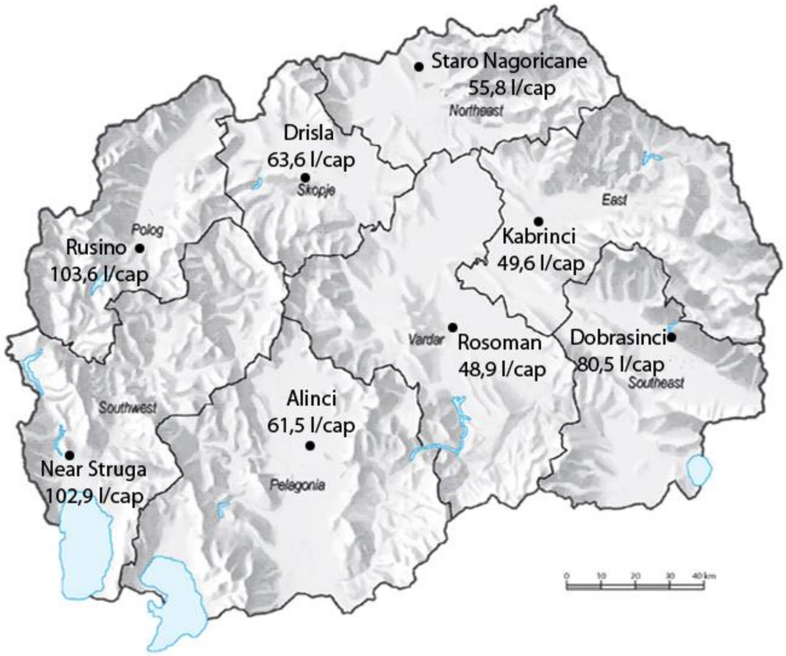

Figure 4. Regional landfill locations and leachate generation in 2012 (l/cap)

Site selection of the proposed regional landfills is based on the criteria appointed in Council Directive on the Landfill of Waste [10] and contemporary methods [25, 26]. Considering local geology conditions for each regional landfill it can be assumed that regional landfills: Dobrosinci (South East Region), Rosoman (Vardar Region) and Drisla (Skopje Region) meet the requirements about the geological barrier appointed in the Council Directive on the Landfill of Waste [10]. Due to the low soil permeability, no significant environmental impacts on the soil and water environment can be expected. For the other landfills geological barrier can be completed artificially and reinforced to meet the conditions appointed for the geological barrier. However, all regional landfills must be designed and contaminated waters and leachate must be treated to the appropriate standard for their discharge in order to meet the requirements in the Council Directive on the Landfill of Waste [10].

Landfill leachate from municipal solid wastes consists of different organic and inorganic compounds that may be either dissolved or suspended. Composition of leachate is expected to vary significantly from landfill to landfill, being mostly affected by the factors such as: solid waste composition, landfill age (age of waste), operation of the landfill, climate, conditions within the landfill such as moisture content, temperature, pH etc. The same factors influence the types, amounts and production rates of contaminants appearing in the leachate at the landfill site, resulting in significant temporal variability of the leachate quantity and its composition. Evaluation of alternatives for leachate treatment must take into consideration temporal variations of the leachate quantity and composition at the particular site [27]. Due to the complex composition of the leachate, a combination of processes for treatment is used, within each process is having a specific role in leachate treatment. Planning the treatment and disposal of leachate involves the following series of essential steps: (1) estimating leachate flow; (2) estimating the leachate contaminant concentrations; (3) identifying the treatment and disposal options within the requirements for leachate quality discharge and costs; (4) selecting flexible treatment and disposal system [3]. Treatment and disposal alternatives include a number of different treatment options like: aerobic or anaerobic processes and physical and chemical methods. Also, some alternatives involve leachate recirculation, i.e. leachate is collected and returned to the top of the landfill. Recirculation reduces the hydraulics peaks and does not eliminate the need for treatments in cases when there is excessive leachate.

CONCLUSIONS

Analyses of environmental impacts of non-hazardous regional landfill are of outmost importance worldwide. In this study, an assessment of the potential environmental impacts on the water environment for eight planned regional municipal landfills in Macedonia is presented, which will aid the overall goal for sustainable waste management. The spatial variation of the leachate generation due to the different climate conditions at the regional landfills sites is shown. Also, an assessment of the potential landfill impacts on the environment taking into consideration local geology conditions is addressed. Some general measures for leachate treatment are indicated, based on achieving the goals to minimize the negative impacts on the environment. Analyses performed in this paper involve estimation of waste quantities for each waste management region and assessment of the landfill capacity. Leachate quantity for the planned regional landfills is calculated using Water Balance Method. Also, analyses and comparison of the likely landfill leachate per capita are presented, demonstrating that higher rates of generated leachate per capita can be expected in waste management regions with higher annual sums of rainfall.

For the case study, the most important part was assessment of the potential environmental impacts based on the local climate and geology conditions. Depending on the data about the geological and hydrogeological conditions below the landfill, a rough assessment of the existence/nonexistence of natural geological barrier providing sufficient attenuation capacity to prevent a potential risk to water environment is included. Also, general measures for leachate treatment are indicated. The paper illustrates sustainable waste management practices in cases of landfilling of municipal solid waste for very varying climate conditions and hydrogeological properties represented by different landfill locations within the whole territory of the country.

The results indicate the influence of climate data on generated leachate: the higher the rainfall, the more landfill leachate. Regardless of the leachate quantity and its composition, all regional landfills should employ facilities for landfill treatment. In summary, the present study shows a rough assessment of environmental impacts from planned regional non-hazardous landfills in various climate conditions.

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