Investigation of the Chemical Content of Two Specific Streams in Municipal Waste: The Case of Hazardous Household Waste and Dental Waste

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Abstract

A variety of chemicals is included in the household hazardous waste and the dental waste fractions that are sadly both parts of municipal solid waste in Greece. These chemical compounds have hazardous properties according to international and European regulations.

In Greece, the categorization of household hazardous waste is not indicated by any legislation, whereas for dental waste the legislation is existent since May 2012, but the development of a management plan undertaken by the Hellenic Dental Association is not yet active. Given that both waste fractions are managed with other municipal solid wastes, they are spotted in solid waste management facilities causing multiple impacts and challenging the labors' health and safety status.

Desk research involving literature and commercial research was conducted in order for the hazardous substances of each of the aforementioned waste stream to be pinpointed; collected data were compiled into databases for those two specific waste streams and were categorized based on their hazardous properties and the waste facility they are most likely to be found in. Parallel field researches were conducted to: (i) determine the uncertainty level of the fractions, composition, and health/environmental impacts, and (ii) specific parameters were introduced to determine their impact due to the status of health and safety conditions within the management facilities in Greece. Despite the fact that HHW is almost 10% of the total MSW, it was found that 4.00% of their compounds involve a toxic risk and 7.16% of them involve combination risks for humans working in treatment facilities; ten chemical compounds, which are included in this fraction, are categorized as R39/23/24/25 (toxic). On the other hand, in DW, 8.82% of the included chemical compounds involve a toxic risk and 11.76% of them involve combination risks for humans.

The qualitative and quantitative analysis of those waste fractions presented in this paper will pave the way toward organization of both waste streams' management plan followed by compiled strategies and recommendations to divert them from the municipal waste stream and lead them to safe and sustainable management paths.

Keywords

Hazardousness · Municipal waste · Waste management facilities · Chemical content · Chemical compounds · Risk level · Uncertainty · Scenarios

Abbreviations

AMS	Alternative management systems
DW	Dental waste
HHW	Household hazardous waste
mE	Microenvironments

MRFs	Mechanical recycling facilities
MSW	Municipal solid waste
SWM	Solid waste management

Introduction

Municipal solid wastes (MSWs) are constituted by a variety of waste fractions and result from various sources which include households, commercial activities, gardens, electric and electrical equipment, private doctors' consulting rooms, etc. Some of these fractions include chemical compounds, which based on the European Waste Catalogue have hazardous characteristics, such as flammable, toxic, harmful, corrosive, irritant, oxidizing, etc. For some of the aforementioned MSWs such as wastes from electric and electrical equipment, batteries, etc., alternative management systems (AMS) are active in Greece, whereas for others such systems do not exist.

Well-established substances, particularly organic chemicals, are less likely to have had to conform to tests for hazardous properties, although many are currently being assessed in light of evidence from long-standing use. It has been estimated that less than 2% of the 30,000–100,000 synthetic (manufactured or extracted) chemicals available today have been tested for toxicity and even fewer for long-term effects (Slack et al. 2009).

Since their toxicity is evident by the moment they are disposed to the municipal bins until their transportation to transfer stations or mechanical recycling facilities (MRFs) or to sanitary landfills, a close identification and research of their chemical content is required for the benefit of both environment and human health. The present paper focuses on two waste streams, which bear the aforementioned characteristics: hazardous household waste (HHW) and dental waste (DW). The specific targets of the conducted research were the following:

- Determination of waste streams according to international and European standards
- Recording of their quality and the determination of chemical compounds from the generation point to the final disposal
- Determination of the hazard risk level as individual waste streams as well as components of the MSW

The potential hazards, which are analyzed, are related to the following:

- Products and chemical composition
- Facilities and the followed management route once they are disposed as waste
- Health and safety status of the facilities' labors, citizens, and urban environment
- Risks related to their presence and their interaction with MSW

Background

Waste Streams Description

Hazardous Household Waste

HHW quantity based on European field researches and Hellenic reports including estimations is low, whereas their chemical content is of great importance for the environmental and health sustainability according to international organizations. According to Wolf et al. (1997), it was found that the consumers actually consume 62% of paint product content, 89% of pesticide product content, 90% of cleaning product content, and only 46% of the automobile product content. The remaining content of the products of each category is disposed along with the packaging in order to be managed.

The basic categories of HHW are (Gurski 1995; Kontogianni et al. 2013; Inglezakis and Moustakas 2015) the following:

- Batteries and accumulators
- Craft and laboratory products (e.g., paints and varnishes, wood preservatives)
- Garden care products (e.g., insecticides, fertilizers, etc.)
- Personal care products
- Cleaning products
- Containing chlorofluorocarbon (CFC)
- Medical products and devices containing mercury
- Automobile products

Perhaps some of the individual end-of-life products (constituting HHW) can be classified into more than one category presented above or combined to form a more analytical list of categories. However, the main purpose of the research was to create a coherent classification to ease the overall description of the HHW fraction. To achieve this, the products involved in the research had to be determined. The great scale of the HHW fraction may lead into wrong perceptions of what is included in this fraction. The products, which fulfill the following parameters, were the ones that were included into the overall research and constitute the HHW fraction:

- They belong to a wide consumer range (e.g., products with high consumption).
- They are products used in households and not for professional or industrial use.
- Their end of life is followed by waste disposal (package and remaining content), not by refill.
- No organized AMS exists for their collection and treatment and they are managed with the MSW.

The categories involved in this desk research resulted to be (a) craft and laboratory products, (b) garden care products, (c) cleaning products, and (d) mercury-containing medical devices.

Dental Waste

DWs include any product used or any item generated by a dental unit due to patient care (treatment and/or restoration) including amalgam, saliva, etc. Dentists restrain from the use of amalgam, and they have partly replaced it with dental resins in new dental restorations, but the removal of old restorations will continue to generate amalgam waste, which contains mercury (Kim et al. 2016).

DWs involve a wide range of waste products in which the biological hazard is dominant. Yet their chemical content is also of significant concern even though it has not been thoroughly investigated. The waste categories include waste packages and product remaining from treatment or diagnosis activities such as (Ferraris et al. 1999) X-ray, infection control, tooth fillings, pharmaceutical products, prosthetic dentistry products, and cleaning products. Some of the chemical contents have been targeted for causing allergic reactions to patients and being ecotoxic.

The aforementioned groups of products were involved in the overall research aiming to pinpoint the chemical identity of the fraction. The individual products had to fulfill the following parameters:

- They constitute exclusively dental materials/products approved by the National Medical Association.
- Their end of life is followed by waste disposal (package and remaining content), not by refill.
- They are disposed as solid waste in the waste bin of the dental unit (not in dental technician's office or in the households) and not in sewage.

Current Management Trends

Hazardous Household Waste Stream

Worldwide HHW management initiatives have been undertaken by municipal, governmental, or environmental organizations. In most countries, though HHW is not considered a hazardous fraction worthy of separate treatment, they are landfilled along with all MSW generated or they are recycled in MRFs since their packaging is usually recyclable. This remark raises worries regarding the chemical compounds' impact to workers of MRF where the content of the recycling bins is heading (Kontogianni and Moussiopoulos 2017).

During an info day on recycling issues, in the frame of the international project Zero Waste (MED 2012) (where the outcomes of a field research on recycling were presented), scientists came to the conclusion that a significant percentile of the citizens (who are actively participating in recycling procedures) did not know or did not follow the proper recycling rules, e.g., cleaning of the product packages prior to their disposal in recycling bins. This remark also raised worries regarding the chemical compound's impact to workers of MRF where the content of the recycling bins is heading.

Based on the available data for annual HHW generation per capita, the average value and standard deviation is 3.23 ± 1.71 kg/inh (26 values in total, range 0.4–7.9 kg/inh). There is considerable scattering of values, as expected, due to the different collection methods and management schemes used in different countries. In terms of annual HHW collection per capita in Europe, the average is 2.18 ± 1.20 kg/inh (11 values, range 0.97–5.2 kg/inh). The quantities of HHW separately collected in EU range between 1.3 and 5.2 kg/inh/year depending on the country and the collection method used (Inglezakis and Moustakas 2015).

In China, on the other hand (Gu et al. 2014), research results indicate that the rate of HHW generation was 6.16 (0.16–31.74, 95% CI) g/person/day, which accounted for 2.23% of the household solid waste stream. The major waste categories contributing to total HHW were home cleaning products (21.33%), medicines (17.67%), and personal care products (15.19%). Packaging and containers (one way) and products (single use) accounted for over 80% of total HHW generation, implying a considerable potential to mitigate HHW generation by changing the packaging design and materials used by manufacturing enterprises.

It has been proven in many scientific researches that workers in solid waste management (SWM) facilities suffer from several diseases (of major or minor importance) due to their occupations. Manual sorting may be associated with exposures to large quantities of airborne bacteria, endotoxin (Poulsen and Dandanell 1995), and in general toxic compounds. The range of those diseases is very wide, and one of the major sources of uncertainty is that it usually takes several decades for a person to develop any symptoms of the (potentially severe) illness (Kontogianni and Karagiannidis 2009). The aforementioned is enhanced by the results of a recent study conducted in MRFs in the UK, where the scientists pinpointed health symptoms in employees which varied in terms of severity and frequency according to the length of time working and their assignment.

Dental Waste Stream

EU has not yet enacted specific legislation on DW management, which is therefore covered by a more generic legislation related to medical waste. Dental associations and/or health ministries of certain EU member states (e.g., the Netherlands, Sweden, Denmark, France, New Zealand, and Switzerland) have taken measures toward their sustainable management (WSDA 2004) as the ones indicated below:

- Best management practices (BMP) late on commented implementation.
- DW management guidelines have been handed to dentists by the dental associations.
- Dental amalgam use banning (as soon as each of their National Boards of Health is convinced that available non-mercury alternatives have full substitution capabilities).
- Strict law forcing each dental unit to have a disposal contract with a local disposal company, and the cost is included in the total cost of each dental therapy.

DW for the last two decades has been a “silent” fraction; its existence among MSW preoccupied the dentists, their associations, and the Hellenic Ministry of Health since they were not considered as part of the overall waste resulting from healthcare activities. Until recently, no measures were undertaken to avoid their disposal in municipal bins or the health impacts derived from this practice. Only recently, a new law (Common ministerial decision 1537/2012) introduced DW as one of the healthcare waste fractions, which need to be separately managed and treated. Unfortunately, for the time being (16 months after the law enactment), DW is still disposed along with MSW violating the existing aforementioned law. The reason is mainly due to the delay of the informational campaign conduction by those responsible for the overall planning as well as the lack of equipment procurement by the responsible dentists (e.g., amalgam separators) (Dental Association of Thessaloniki).

A pyrolytic incineration facility for medical wastes that could manage certain DW already exists, but numerous encountered problems (regarding the healthcare waste collection, transportation and management often-excessive entailed costs as well as competition from various mobile autoclave units) are aggravating its operation (Sanida et al. 2004). DW management cost seems to be a particularly important issue that complicates motivation toward management issues. Thereby, usual everyday practice still includes dumping the majority of dental solid wastes into household disposal sites and sanitary landfills without any recycling and separation process (Kontogianni et al. 2008).

Material and Methods

Determination of the Xenobiotic Compounds

The organization of the overall research was a prerequisite for determining the exact waste flows of the selected waste fractions as in the case of Greece. The microenvironments (mE) and checkpoints where the chemical compounds of both investigated fractions were studied are depicted in Fig. 1.

Both fractions’ waste identity is altered in transition from mE I to II due to factors such as compression in waste collection vehicles, high temperatures, etc. which lead to anaerobic conditions where the reactivity among chemicals is high and the outcome cannot be predicted. Due to this fact, research was performed toward the determination of existing chemicals separately in the two individual mE.

Chemical compounds of the first mE were determined through the conduction of interviews with producers and sellers of the corresponding products of both investigated waste fractions. Additionally, contacts were made with international associations who have performed investigations on those products’ chemical compounds (e.g., AISE) and international reports. On the other hand, chemical compounds of the second mE were retrieved from international bibliography and scientific papers for both fractions: HHW (Gurski 1995; Gendebien et al. 2002; Slack et al. 2005;

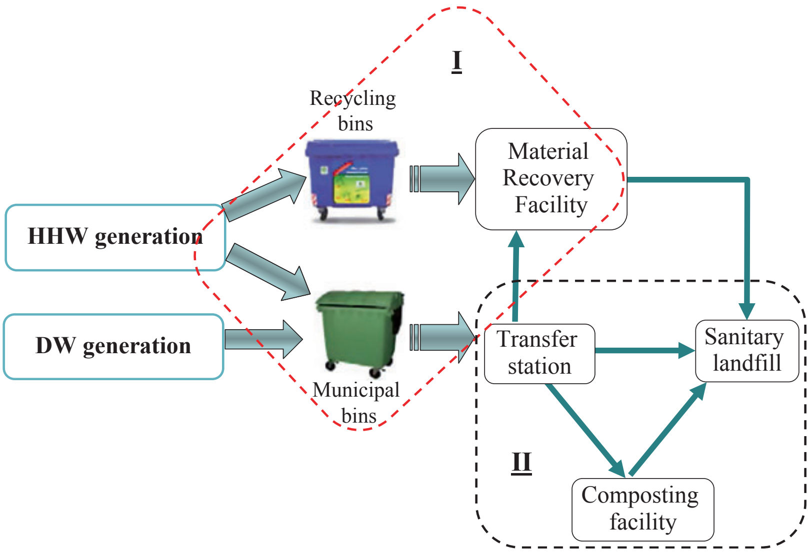

Fig. 1 Determination of the research microenvironments: (I) bins and material recovery facilities and (II) transfer stations, sanitary landfills, and composting facilities

Schrab et al. 1993; Karpinski and Glaub 1994) and DW (Miller et al. 1986; Lohbauer 2010; Van Landuyt et al. 2007; Hagiwara et al. 2006).

Overall, for both waste fractions, 125 chemical compounds were listed in the first mE and 86 for the second mE. The categorization and processing of information for each one of the listed chemicals assisted in the development of extended databases.

Development of Databases and Linkage to the Population Target Group

The chemical listing was followed by the determination of their properties based on information retrieved from EU legislation (OJ 2000, 2008a), international databases (i.e., IRIS), and scientific papers and reports (Gendebien et al. 2002; EEA 2010; Turner 1980; Kontogianni 2013; Slack et al. 2005). The categorization was performed based on the hazard symbol, risk phrases (Rx), and risk combination (Rx/Ry/Rz/, etc.) of each individual chemical compound. The data processing presented researchers with preliminary data regarding the hazardousness of the investigated fractions.

Information regarding each individual chemical compound risk phrase and the risk combination phrase retrieved from CLP legislation (OJ 2008b) proved valuable to create a linkage between the existence of those waste fractions among MSW and the potential impact on SWM facilities' personnel who were the primal population target of this research. Toward this, a list of parameters which are endangering health and safety conditions in any given facility was developed in order for their potential influence from chemical compound properties to be investigated.

Uncertainty Level Assessment for Both Fractions

Unlike consumer products, the waste does not have a fixed composition even though it comes from it. Their quantity can be estimated by carrying out a field investigation and by trying to limit the involved errors, but as far as qualitative recommendation is concerned, the uncertainty factor comes in anyway and is categorized as follows:

- Qualitative composition of the waste that can be changed during the use of it before it is transformed into waste (e.g., due to mixing with another product of same category or due to reactions among its active ingredients)
- Mixing with other categories of waste due to joint rejection, mismanagement, or non-application of segregation

In the routes that a waste follows starting from production to final disposal, uncertainty may be significantly reduced or limited, but its description is qualitative.

The calibration of the effects of HHW and DW and the uncertainty estimation presuppose the definition of the steps of their management. The individual steps need to be determined and described in terms of properties and dangers in order for the waste fraction hazards to be assessed.

There are three steps in addressing uncertainties using the statistical approach (Soltani et al. 2017):

- Finding the origin of uncertainties and estimating them
- Evaluating the impacts of uncertainties on outputs
- Explaining and presenting the results

The description focuses on the two steps and their influence on the overall composition under the prism of the influence factors. According to the current situation, the management chain is completed by the final disposal of the wastes in the sanitary landfill or their treatment in a MRF in order to be forwarded as secondary raw materials to another production process. The steps are hereby presented:

- B_1: Temporal storage in the generation site (house/dentistry)
- B_2: Mixing with other materials in the temporal storage bin
- $B_{3.1}$: Disposal in municipal bins (mixed waste)
- $B_{3.2}$: Disposal in municipal bins (recyclables)
- B_4: Collection and compaction within transportation vehicles
- B_5: Transportation to transfer stations
- B_6: Handling in MRF
- B_7: Final disposal in sanitary landfill
- E: Temporal storage in MRF

According to 2008/98/EC (which amended the EU directive 75/442), waste is "every object, product or compound whose owner disposed or intends or is obliged to dispose." The definition includes uncertainty due to the inadequacies in the disposal route or even the interpretation of these (Hoffmann and Hammonds 1994). In the case of HHW and DW fractions (given that they are not investigated on a great scale so there are not many available and cross-referenced data), the estimation of the disposal impact of the streams is an apprehension of estimation that involves "uncertainty."

The objective properties of the MSW stream are assessed based on the technological and scientific data and questions that have arisen about it (e.g., the level of risk or harmful effects on the environment). For this reason, three levels of analysis were developed, backed-up with the corresponding criteria, which are presented below:

- Uncertainty level (concerning composition, concerning impurities)
- Potential environmental impacts (greenhouse effect, acidification, eutrophication, ecotoxic properties, toxicity to humans)
- Potential safety risks (fire, biological hazards, reactivity risks)

Health and Safety in Solid Waste Management Facilities

Solid waste management (SWM) facilities in terms of OHS requirements present no major differences to those existing for all other industrial facilities but often attract much more political and social attention for obvious reasons pertaining to SWM. The latter comprises of a wide range of activities encompassing reduction, recycling, segregation (separation), modification, treatment, incineration, and disposal at varying levels of sophistication (Hamer 2003). Besides the accidents related with mechanical and electrical equipment handling, by personnel with no adequate expertise, undercover hazards related to multitude health problems among workers at WM plants exist. They are partly owed to the composition of the treated waste (e.g., handling of organic waste, in landfills, potential existence of medical or other types of hazardous waste, etc.), the chemical nature of the waste (e.g., toxic, corrosive, etc.), and the parameters which increase the chemical reactivity. The health problems in SWM facilities involve pulmonary disorders and gastrointestinal problems due to high concentrations of total airborne dust, bacteria, fecal coliform bacteria, and fungal spores. Also the labors suffer from symptoms of organic dust toxic syndrome (cough, chest tightness, dyspnea, influenza-like symptoms such as chills, fever, muscle ache, joint pain, fatigue, and headache); gastrointestinal problems such as nausea and diarrhea; irritation of the skin, eye, and mucous membranes of the nose and upper airways; etc. (Gladding et al. 2003).

To ensure the validity of the research, the outcomes of the health and safety research were taken into consideration; based on the outcomes, certain parameters were taken into consideration and applied where necessary (Kontogianni and Moussiopoulos 2017). Those are listed below:

Table 1 Average calculated hazard level per facility type out of the SWM facilities investigated (Based on Kontogianni and Moussiopoulos 2017)

Facility type	Calculated average hazard level	Hazard level clarification
Sanitary landfills	5	Low
Material recovery	5.375	Low

- Presence of dust
- Filter maintenance program
- Use of security equipment
- Knowledge of first aid
- The presence of responsible safety officer
- The presence of garbage on the perimeter
- The presence of unwanted animals and birds
- Possibility of fire nearby

The abovementioned parameters calibrated the health and safety status in Hellenic facilities; MRFs, transfer stations, and sanitary landfills (taken into consideration in the present study) are among them. The overall results for all the investigated SWM facilities in Greece are presented in Table 1.

Hazard Assessment

The development of scenarios was based on the what-if methodology and specifically the potential events that may occur during the processes involved in the management of MSWs and on the hazard identified because of the presence of HHW and DW fractions in them.

Through the question-answer process, scenarios are produced, and the answers lead to the identification of conditions to be dealt with, results and practices that can mitigate or eliminate the hazard, and potential risks. The disadvantage of the method is that it relies heavily on the experience of those who apply it, so there is a possibility that a parameter of the study object is ignored; it was supported by other tools as well (hazard and operability study (HAZOR), fault tree analysis (FTA)). Following the process, both scenarios and conclusions emerge.

Due to the structure of the database with the HHW and DW compounds, it was considered as an optimal and most effective solution to examine separately the following: the disposal bins (composite or recyclable), MRF, transfer stations, and sanitary landfills.

The scenarios are designed to investigate the hazard on a case-by-case basis and have emerged by examining the data of each of the two mE (as presented in Chapter ► Determination of the Xenobiotic Compounds). There are combinations that have to do with any given property of HHW or DW chemical compounds as well as the conditions prevailing in each mE and the potential impacts on SWM facility labors, citizens, and urban area.

The scenarios that were investigated took into account the following by the application of appropriate indexes:

- Properties of the included chemical compound in the investigated fractions
- Uncertainty level of each investigated fraction
- Ranking of the health and safety status in corresponding facilities and urban area

Results

Uncertainty Analysis Results

The uncertainty analysis was carried out separately for the two pathways that can be followed by the HHW stream (management with mixed municipal waste, management as recyclables). The management path of DW is considered only one: management with mixed waste and final disposal in sanitary landfill.

The uncertainty calibration was performed on a scale of 0–5 (low and high levels of uncertainty, respectively) based on a series of chemical compound-related criteria and the databases as described in Chapter 3.1, in addition with the criteria presented in Chapter ▶ Uncertainty Level Assessment for Both Fractions.

Figure 2 illustrates the overall uncertainty for HHW and DW streams for all the individual stages of their management. Both the risk and the uncertainty of the current content appear to be increasing as their management proceeds and they intensify, as they do not follow a separate appropriate management course with the appropriate security measures for the population, the facility labors, and the environment.

With an extensive field research, one can determine the amount of HHW or DW, and at the same time, in collaboration with the production companies, their chemical

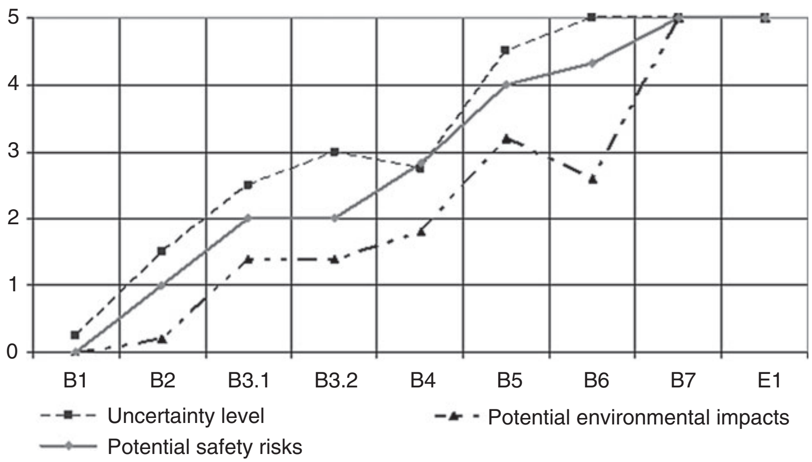

Fig. 2 Uncertainty level assessment results for the potential management routes that HHW and DW fractions may follow as components of the MSW stream

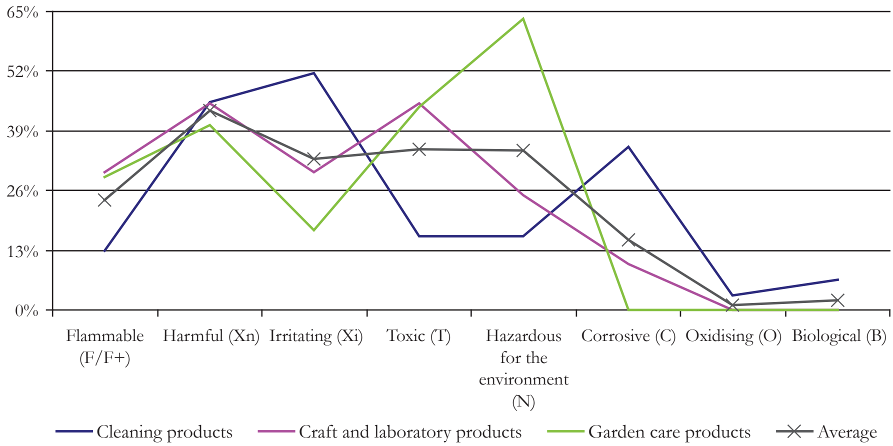

Fig. 3 Percentage of the properties of the chemical compounds included in hazardous household waste fraction because of their presence in microenvironment I (municipal and recycling bins and material recycling facilities)

content can be identified; the chemical reactions that are taking place are difficult to be determined because they depend on factors such as frequency of disposal, collection frequency, meteorological conditions, etc. The formation of the chemical compound in each mE took into consideration the results and applied certain uncertainty factors affecting the probability of chemical compounds' existence and their property hazards. Besides, knowing about the most affecting uncertainties can help the stakeholders adjust their expectations and improve their negotiation outcomes as Soltani et al. (2017) indicate.

Chemical Compound Properties in Determined Microenvironments

The chemical compounds contained in HHW have a wide range of properties. Figure 3 presents the outcomes in mE I where those chemical compounds, which are harmful and hazardous for the environment, constitute the higher percentage. The latter is due to their existence in garden care products; the results introduce concerns regarding the use of such products in households and at the same time their chemical compounds' distribution in surface and underground waters.

The infectious character of DW, which coexists with the chemical content and the hazard arising from it, introduced difficulties to the overall investigation of this waste fraction. Nevertheless, the infectious character was not taken into account since it has been extensively investigated in the case of medical waste. Twenty-four chemical compounds were listed to be existent in DW fraction, and they constitute the most common chemical compounds in dental products. It must be noted that chemical compounds, which are present in illegal medicines or products unauthorized by the Hellenic Medicines Association, were not taken into account in the conducted research.

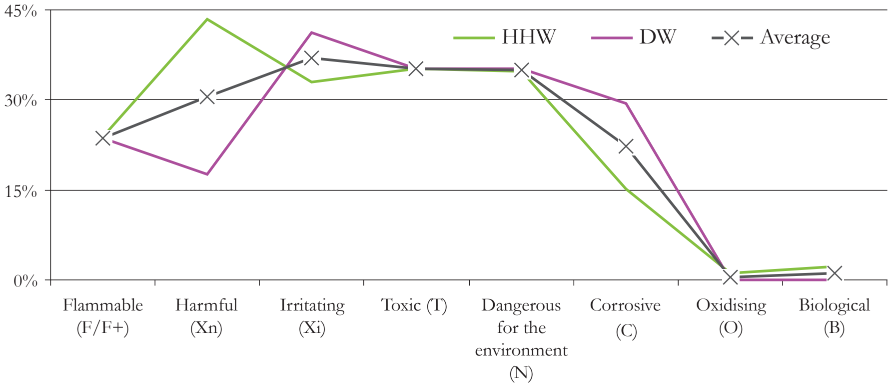

Fig. 4 Percentage of the properties of the chemical compounds included in hazardous household waste and dental waste fractions because of their presence in microenvironment II (transfer stations, sanitary landfills, and composting facilities)

Primal information processing proved that there are compounds with various properties, and Fig. 4 presents their properties percentage in DW fraction and HHW fraction in mE II. In this case, where both fractions are present, one can assume that the chemical compounds' reactivity is higher because of the anaerobic conditions in mE I. That is the reason that the properties of the included chemicals appear in lower percentage than that of the previous case (depicted in Fig. 2).

Health and Safety Condition Influence due to Chemical Compounds Contained in Investigated Waste Fractions

Hazardous Household Waste

The processing of data regarding HHW proved that when precaution measures are not applied, on average 4.00% of those compounds involve a toxic risk and 7.16% of them involve combination risks for humans working in the facility. When health and safety parameters in SWM facilities (indicated in the given mE) are not applied, risks for the personnel are increasing as depicted in Table 2. HHW fraction percentile in MSW is estimated to be less than 10%. So the hazard of the HHW fraction is minimized due to blending with other wastes as well as due to the pickup efficiency of MSW.

Nevertheless, six chemical compounds bearing increased hazardous properties were found to be existent in municipal bins as well as in MRF facilities; one of them belongs to "garden care products" (dimethoate, 60-51-5) and five of them belong to "craft and laboratory products" (ethylbenzene, 25036-25-3; aromatic hydrocarbons C9–C12, 67989-52-0; epoxy resin (molecular weight <700), 25068-38-6; aromatic hydrocarbons C9–C11, 2530-83-8; naphtha, 8030-30-6). All aforementioned chemical compounds are categorized (based on CLP legislation; OJ 2008) to be R45, that

Table 2 Percentages of the chemical compounds of HHW contributing to health and safety risks as a result of measures not applied

Health and safety measures not applied in the facility. Equipment for:	R-phrases (%)	Combinations (%)
Skin protection	14.39	–
Inhalation protection	9.68	–
Eyes and skin protection	10.37	1.25
Eyes and inhalation protection	1.28	5.00
Skin and inhalation protection	3.16	9.17
Eyes, skin, and inhalation protection	0.96	21.25

Table 3 Percentages of the chemical compounds of DW contributing to health and safety risks as a result of measures not applied

Health and safety measures not applied in the facility. Equipment for:	R-phrases (%)	Combinations (%)
Skin protection	19.61	–
Inhalation protection	5.88	–
Eyes and skin protection	9.80	11.76
Eyes and inhalation protection	2.94	5.88
Skin and inhalation protection	12.75	5.88
Eyes, skin, and inhalation protection	8.50	35.29

is, compounds “potentially responsible for carcinogenesis.” Additionally, ten more chemical compounds are categorized as R39/23/24/25, that is, “Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed.” Most important was the presence of benzene among the chemical compounds (which is classified as a certain carcinogenic). Its presence in sanitary landfills (mE II) together with the aforementioned findings raises concerns primarily for the health and safety of SWM workers.

Dental Waste in the Municipal Fraction

As far as DWs are concerned when precaution measures are not applied, on average 8.82% of those compounds involve a toxic risk and 11.76% of them involve combination risks for humans. In SWM facilities of mE II, lack of health and safety measures was noted; the linkage among properties and risk is depicted in Table 3.

The direct use of dental products on patients is potentially the main reason for which no certain carcinogenic compounds were located. Worries were raised only for one compound found in products used for prosthetic dentistry (methyl methacrylate). It was found to be categorized as R39/23/24/25 (Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed) and R23/24/25 (Toxic by inhalation, in contact with skin and if swallowed) at the same time.

Table 4 Presentation of the reporting parameters for each scenario

Potential risk		Level of reported hazard[a]				
Percentage	Characterization	High (4)	Significant (3)	Average (2)	Low (1)	Nonexistent (0)
>50%	Very probable	S	S	S	M	A
>1/10	Probable	S	S	S	L	A
$>1/10^2$	Often probable	S	S	M	L	A
$>1/10^3$	Often but probable	S	M	M	A	A
$>1/10^4$	Slightly probable	M	M	L	A	A
$>1/10^5$	Not very probable	M	L	L	A	A
$>1/10^6$	Completely not probable	A	A	A	A	A

[a]Hazard characterization:
None/negligible (A) = 0, low (L) = 1, medium (M) = 2, significant (S) = 3

Hazard Assessment of Waste Fractions

The conduction of the hazard assessment for the determination of the potential hazard imposed the composition of Table 4, through which the level of hazard was defined.

Hazardous Household Waste

For each one of the four hazard levels, 392 scenarios were investigated regarding labors and the environment. The results allocation is presented in Fig. 4; 73.66% of the scenarios proved that the components that are dangerous for the environment (N) have medium probability of occurrence. The hazard distribution is the same for hazard levels 2, 3, and 4 (33–34%). In the case of MRF and for a level 3 hazard, the probability of the involved compounds to be harmless is “often likely” to happen, and the hazard level is significant when labors do not apply or are ignorant of the first aid measures within the facility (0.45% as depicted in Fig. 5).

In the set of scenarios that were run for all the hazard levels examined, several levels of impact probability occurred. This, in combination with the results of Fig. 4, suggests that the possibility of a significant level of risk (4) occurring is negligible. In general, HHW has a negative impact on the MRF’s workforce, and the risk is moderate for each level of risk control. This is reinforced by the fact that eventual risk level 1 cases have a very low chance of occurrence. The most important outcomes of this assessment are summarized as follows:

- 83% of risk level 1 is very unlikely to occur.
- 64.03%v of risk level 2 has medium probability.
- 79.8% of risk level 3 has medium probability.
- 86.73% of risk level 4 has medium probability.

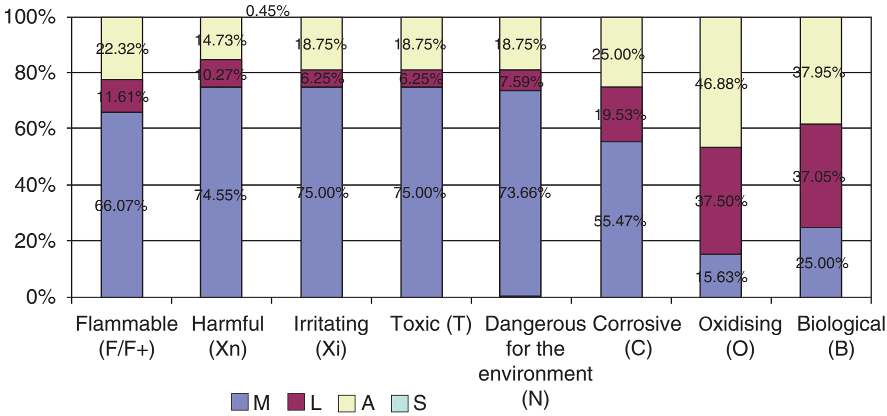

Fig. 5 Probability characterization per hazard level category and property of the chemical compounds in hazardous household waste in MRF

For the case of transfer stations and sanitary landfills, 927 scenarios were investigated; the average risk is characterized as medium. The medium probability of risk is the outcome of 57.61% of the scenarios. On the other hand, significant probability of level 4 hazard occurs when the parameter of "no protection measure taken" is taken into consideration. Overall, the probability of a level 4 hazard is low but certainly higher than the one calculated in the case of MRF; high percentages of risk occurrence were calculated in the case of medium hazard (M) of levels 2, 3, and 4, being ~59%, ~78%, and ~69%, respectively.

For the case of HHW disposal in municipal bins, 305 scenarios were investigated. On average, the risk is low and occurs in 45.74% of the scenarios. Overall, the scenarios proved that in 50.87% of the cases investigated, the probability of any level of risk to the citizens is negligible; in 16.03% of the cases, it is low; and in 33.10% of the cases, it is medium mainly due to the parameter of "animal's access in bins." On the other hand, the risk due to chemical compound, which bears biological hazards (DNA corruption, introduction into the food chain, etc.), is high. Similarly, for the compounds which are characterized as being hazardous for the environment (N), it has 50.91% probability of having medium impacts to city environment and citizens. Mainly based on the later two compounds' properties, high percentage of scenarios where the probability of occurrence is medium for hazard levels 2, 3, and 4 was observed (being ~32%, ~37%, and ~56%, respectively).

Dental Waste Fraction

The development of scenarios for the investigation of DW hazard was affected by the negligible probability of them being treated in MRF; the scenario was considered nonachievable, so their existence was considered a fact for transfer stations and sanitary landfills, and 927 scenarios were developed.

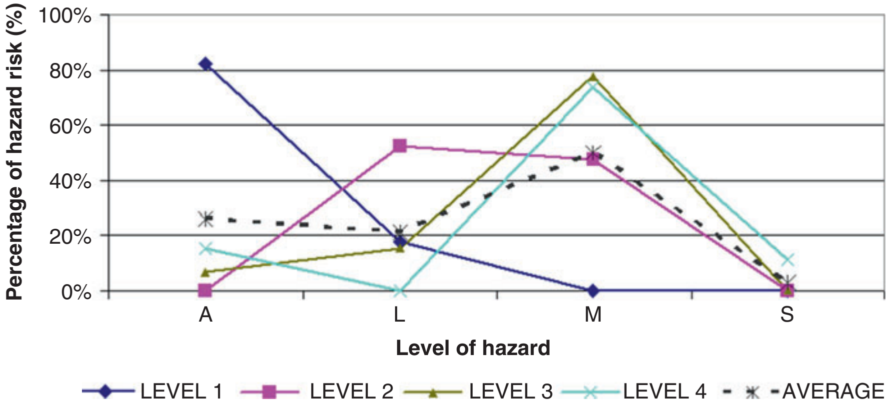

Fig. 6 Percentage of hazard risk for every level of hazard risk (the average hazard risk is indicated as well)

On average, the hazard risk is medium (58.04%). The significant hazard risk (level 4) for those facilities' labors occurs when parameters such as "the use of protective equipment" and the "presence of safety officer" are not applied.

The "presence of litter in the perimeter" increases the introduced toxicity in the flora of the nearby area. Out of the total scenarios which were run for the determination of hazard risk in the case of DW presence in sanitary landfills and transfer stations, 28 of them show a significant probability of high hazard risk. This disturbing fact is attributed mainly to the chemical nature of the waste fraction compounds.

Despite the fact that level 1 hazard risk occurs most often (>80%), they concern negligible hazards, while the significant level hazards 3 and 4 are assessed to have medium probability of occurrence (~75%) as depicted in Fig. 6. The higher probabilities for hazard risk are summarized as follows:

- Low probability of level 1 hazard risk (~82%)
- Medium probability of level 3 hazard risk (~78%)
- Medium probability of level 4 hazard risk (~74%), και
- Medium probability of level 2 hazard risk (~52%)

Five hundred sixty-four scenarios were investigated for the case of DW presence in municipal bins, and the average hazard risk is calculated to be as low as 43.25%. A significant probability of hazard risk was not found (Fig. 7), while the higher probabilities were calculated when the parameters "existence of litter nearby" and "existence of animals in bins" were applied. Those parameters are linked and common within the urban areas. The medium probability of hazard risk is on average 36%, and the low one is 27.71%. It is important to mention that the average is exceeded only for the case of chemical compounds with the characteristic of being

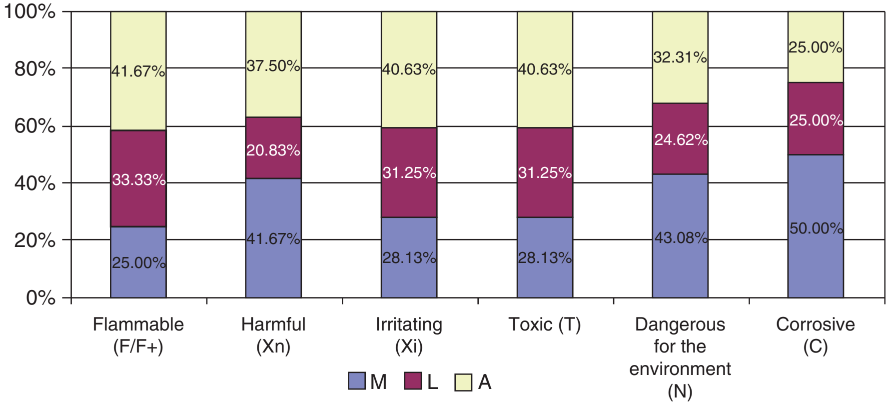

Fig. 7 Hazard risk characterization per hazard category and per property of the included chemical compounds of DW fraction in urban areas

hazardous for the environment (N) and rises up to 43%. Similarly, it happens with those that bear corrosive properties (~50%).

Under the average hazard risk calculation, there are no concerns for the introduced risk by the chemical compounds of the DW fraction. However, the individual study of their properties may be the starting point for a discussion/consultation to change the composition of some products. Besides it came up that, in level 4 hazard risk, the probability is medium in 40 of those compounds and negligible for the rest of them in case the parameter "potential fire in bin" is applied.

Conclusions

Presented in this research paper was the first phase out of an extended (four phases) research during which researchers aimed to identify the hazardousness of the two selected fractions (HHW and DW) which currently in Greece are not managed separately from the MSW (Kontogianni 2013). Any researcher or stakeholder aiming to design or implement a holistic waste management system to avoid treatment of hazardous fractions among the MSW and thus prevent occupational accidents by developing enhanced (integrated) safety procedures can use these approaches and outcomes since they have a global relevance. The major outcome of the overall research would be the development of separate HHW collection and management programs as in other countries worldwide and the incentive for the actual organization of DW program for all private, public, and university dental units since the legislation already exists for more than a year in Greece.

The findings regarding the chemical content of the investigated fractions presented in this paper present strong arguments toward the need of proper management and implementation of waste hierarchy at higher levels.

The uncertainty about the environmental and safety hazards due to the presence of these currents throughout the MSW management course rises as it continues its course from the bin to the final disposal or treatment. The newly introduced HHW stream and the unobstructed rejection of OA in mixed bins do not favor the availability of data on the chemical reactions that take place or the exact composition of the compounds in each product.

The General Chemical State Laboratory, which is a national agency, should adapt strict measures toward the investigation and frequent recording of the investigated commercial products' chemical content to minimize the hazard primarily arising from their disposal in municipal waste bins (mE I). The introduction of an environmental certificate for such product producers is the means to do so, but the overall procedure should be overseen by an independent agency to achieve maximum efficiency. The aforementioned will assist in minimizing the occupational hazard in SWM facilities, which is due to end-of-life product mismanagement.

Due to the presence of HHW, MRF workers face a 68.37% chance of having serious (level 4) health impacts, while 68.8% of workers in transfer stations and sanitary landfills have a significant impact (level 3). For the first case mentioned, 14 substances and for the second one, 10 substances were tested for their toxicological effect. Three and four of these substances were considered the most toxic with certain toxic effects in the body and for which their critical concentration in the air of the workplace was examined.

It is necessary and urgent that the strengthening of health and safety measures and intensive training of occupational health and safety officers and personnel in SWM facilities be a prerequisite to minimize the impacts of the chemicals' properties mostly in mE II. Besides the existence of a structured plan for every facility, the frequent medical examinations (under management supervision and not after personnel's initiative and charge) will seriously act toward the prevention of health risks related to this working activity.

Cross-References

► A Review on Treatment of Pharmaceuticals and Personal Care Products (PPCPS) In Water and Waste Water
► Household Hazardous Waste Quantification, Characterization and Management in Developing Countries Cities: A Case Study
► Sustainable Biomedical Waste Management

References

EEA (2010) European Environmental Agency, Waste and material resources. http://www.eea.europa.eu/themes/waste. Accessed Nov 2010

Ferraris D, Kievit-Kylar D, Moreau T, Moroukian M, Shaner H, Taylor P (1999) Responsible dental office: a guide to proper waste management in dental offices. Northeast Natural

Resource Center of the National Wildlife Federation and The Vermont State Dental Society. http://www.mercvt.org/
Gendebien A, Leavens A, Blackmore K, Godley A, Lewin K, Franke B, Franke A (2002) Study on hazardous household waste with a main emphasis on hazardous household chemicals. European Commission – Directorate general Environment Final report. Belgium (WRc Ref: CO 5089-2)
Gladding TL, Thorn J, Smith R (2003) Air quality and worker health effects in materials recovery facilities (MRFs) in England and Wales, Sardinia 2003: proceedings of the 9th international landfill symposium, 6–10 Oct, Cagliari
Gu B, Zhu W, Wang H, Zhang R, Liu M, Chen Y, Wu Y, Yang X, He SH, Cheng R, Yang J, Bi J (2014) Household hazardous waste quantification, characterization and management in China's cities: a case study of Suzhou. Waste Manag 34(11):2414–2423
Gurski NP (1995) Household hazardous waste: an analysis of two approaches. Bachelor of Science. Faculty of the Graduate College, Oklahoma State University. University of Scranton, Pennsylvania, USA
Hagiwara M, Watanabe E, Barrett JC, Tsutsui T (2006) Assessment of genotoxicity of 14 chemical agents used in dental practice: ability to induce chromosome aberrations in Syrian hamster embryo cells. Mutat Res 603:111–120
Hamer G (2003) Solid waste treatment and disposal: effects on public health and environmental safety. Biotechnol Adv 22(1–2):71–79
Hoffmann FO, Hammonds JS (1994) Propagation of uncertainty in risk assessments: the need to distinguish between uncertainty due to lack of knowledge and uncertainty due to variability. Risk Anal 14(5):707–712
Inglezakis VJ, Moustakas K (2015) Household hazardous waste management: a review. J Environ Manag 150:310–321
Karpinski G, Glaub J (1994) Screening hazardous wastes in solid waste landfills. Waste Age 25(8):91–98
Kim K-H, Kabir E, Jahan SA (2016) A review on the distribution of Hg in the environment and its human health impacts. J Hazard Mater 306:376–385
Kontogianni ST (2013) Hazard analysis of specific waste streams included in municipal solid waste. PhD in Mechanical Engineering. Aristotle University of Thessaloniki
Kontogianni ST, Karagiannidis A (2009) Assessing occupational health and safety factors in Hellenic waste management facilities. In: Cossu R, Diaz LF, Stegmann R (eds) Proceedings of the 12th international waste management and landfill symposium. S. Margherita di Pula (Cagliari), Sardinia, 5–9 Oct, CD-ROM edition
Kontogianni S, Xirogiannopoulou A, Karagiannidis A (2008) Investigating solid waste production and associated management practices in private dental units. Waste Manag J 28(8):1441–1448
Kontogianni ST, Karagiannidis A, Logothetis D, Alexiou G (2013) Investigation of the household hazardous waste stream in a Hellenic municipality. Int J Environ Waste Manag. (Corrected proof). Incomplete
Kontogianni ST, Moussiopoulos N (2017) Investigation of the occupational health and safety conditions in Hellenic solid waste management facilities and assessment of the in-situ hazard level. Saf Sci 96:192–197
Lohbauer U (2010) Dental glass ionomer cements as permanent filling materials? – Properties, limitations and future trends. Materials 3:76–96
MED Programme (2012) Zero waste project (1G-MED08-533). http://www.med-zerowaste.eu/needsupdate
Miller EG, Washington VH, Bowles WH, Zimmermann ER (1986) Mutagenic potential of some chemical components of dental materials. Dent Mater 2:163–165
Official Journal of the European Union (2000) Commission decision of 3 May 2000 replacing decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste (notified under document number C (2000) 1147). No 2000/532. L226: 3–24

Official Journal of the European Union (2008a) Directive 2008/98/EC on waste and repealing certain directives. L 312; p 3–30

Official Journal of the European Union (2008b) Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006. L353: 1–1355

Poulsen C, Dandanell G (1995) Identification and characterization of genes (xapA, xapB, and xapR) involved in xanthosine catabolism in Escherichia coli. J Bacteriol 177:5506–5516

Sanida G, Kallergis K, Karagiannidis A, Rakimbei P, Xirogiannopoulou A (2004) Infectious hospital waste management at the 2nd regional health and welfare authority of Central Macedonia. In: Proceedings on protection and restoration of the environment VII, Myconos, 28 June-1 July, CD-ROM edition

Schrab GE, Brown KW, Donnelly KC (1993) Acute and genetic toxicity of municipal landfill leachate. Water Air Soil Pollut 69:99–112

Slack RJ, Gronow JR, Voulvoulis N (2005) Household hazardous waste in municipal landfills: contaminants in leachate. Sci Total Environ 337(1–3):119–137

Slack RJ, Gronow JR, Voulvoulis N (2009) The management of household hazardous waste in the United Kingdom. J Environ Manag 90:36–42

Soltani A, Sadiq R, Hewage K (2017) The impacts of decision uncertainty on municipal solid waste management. J Environ Manag 197:305–315

Turner GPA (1980) Introduction to paint chemistry and principles of paint technology, 2nd edn. Chapman and Hall LtD, New York

Van Landuyt KL, Snauwaert J, De Munck J, Peumans M, Yoshida Y, Poitevin A, Coutinho E, Suzuki K, Lambrechts P, Van Meerbeek B (2007) Systematic review of the chemical composition of contemporary dental adhesives. Biomaterials 28:3757–3785

Washington State Dental Association (WSDA) (2004) Best management practices for dental office wastes. Department of Ecology, State of Washington, HWTR Publication, Publication No. 06-04-007, Washington, DC

Wolf AA, Kettler LE, Leahy JF, Spitz AH (1997) Surveying household hazardous waste generation and collection. Environ Health 59(7):6–11