Original scientific paper

Impact of illegal dumping sites on the groundwater of Ljubljansko polje

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ABSTRACT:
Due to dense settling and the concentration of numerous economic and other activities, gravel aquifers are threatened. The key conflict on Ljubljansko polje is between the need to protect the groundwater as a source of drinking water for the supply of Ljubljana on one hand and agriculture and various urban-related activities on the other. We used a survey to register and study 1,445 illegal dumping sites in the narrowest and narrow water protection areas, of which Jarški prod on the left bank of the Sava River near Črnuče, the most problematic area, alone has 151 ones. The total surface area of the studied illegal dumping sites amounts to 120,816 m^2, and their total volume is 209,422 m^3. In the area surveyed, we also registered 100 gravel pits, 58 information signs, and 57 road barriers. Two thirds of the waste consists of construction material. A good seventh of the waste is hazardous waste. On Jarški prod, the total surface area of the waste is 26,273 m^2, which means that waste covers 1.2 % of the area. This makes Jarški prod one of the most waste-contaminated areas in Slovenia. An average dumping site on Ljubljansko polje measures 178 m^2, and the total volume of waste amounts to 42,464 m^3. Using a carefully developed methodology, we have planned a priority schedule for the remediation of illegal dumping sites.

KEY WORDS:
Illegal dumping sites, Groundwater, Water protection area, Remediation, Ljubljansko polje, Jarški prod

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INTRODUCTION

Gravel plains and the development of cities have long shared a common history in Central Europe since the majority of cities developed beside the major rivers and their tributaries that created these plains [1]. The forces of nature that had previously shaped these areas acquired a rival, man, who more or less intensively intervened in the natural course of events. He reshaped them according to his needs and according, of course, to the level of technical and technological development.

The results of natural and social processes depend on their duration and intensity. Over a longer period, the impacts of minor changes can become blurred, which means a return to the original state. In the event of more radical and lasting changes, the old landscape systems have acquired new contents [2]. Among man's encroachments, urbanization has a special role, since it causes substantial changes in the environment and its structure.

Modern cities in economically developed countries deviate substantially from the concepts of sustainable development because their activities and populations need extensive land to meet their material and energy demands and for dumping various emissions and wastes.

On one hand, in the irregular relief of Slovenia, gravel plains with aquifers of intergranular porosity are the most important source of drinking water, supplying water to more than 90 % of the population, and on the other, they comprise the economic, traffic and settling core of the country [3]. Modern cities in economically developed countries (and Ljubljana is no exception here) deviate substantially from the concepts of sustainable development because their activities and populations need extensive land to meet their material and energy demands and for dumping various emissions and wastes. Here, they inevitably confront the limitations of ecosystems. The capability of an ecosystem is limited by a three-dimensionally conceived space that includes supplies of natural resources (non-renewable, conditionally renewable, and renewable) and the capacity to absorb waste, pollution, and encroachments on the environment [4]. The degradation of the urban landscape is therefore the consequence of incomplete cycles of matter (e.g. waste) [5,6].

Over the last few decades, Ljubljana has expanded onto former farming land. Crowded roads run in the immediate vicinity of pumping stations, and the area directly along the Sava River has no particular activity aside from the pumping stations, which encourages the illegal waste dumping. The area is easily accessible and crisscrossed by dirt roads, and unpermitted activities are further encouraged by unclear ownership of the land. Numerous abandoned and unrehabilitated gravel pits attract dumping. The main cause of this environment-unfriendly situation is undoubtedly the lack of a mature relationship with the living environment [7].

A cadastre of dumping sites previously existed. In September 1996, the Oikos company surveyed the entire area of the City Municipality of Ljubljana and registered 457 dumping sites with a total volume of 32,782 m^3 [8]. The Bion company also performed a study at the level of the entire municipality, in which the data was processed according to district communities. They studied 278 illegal dumping sites with an estimated total volume of 100,000 m^3 [9]. In all those studies, the limit value for a registered dumping site was one cubic meter of waste. An interesting fact is that according to the cited data the number of dumping sites supposedly decreased by almost 40 % between 1996 and 2004 while the quantity of waste supposedly increased by more than three times, which is probably the result of differing levels of thoroughness in carrying out the surveys.

At the request of the inspection authorities the Snaga company in the last six years (2000-2005) has removed a total of 36,499 m^3 of communal waste from all the illegal dumping sites in the City Municipality of Ljubljana.

Despite the uniform criteria of registering dumping sites with at least one cubic meter of waste, a comparison of various surveys of the area of the entire City Municipality of Ljubljana or its individual parts appears to establish considerable discrepancies. Table 1 presents a comparison of the results of surveys made in 1996 (Oikos d.o.o.) [8], 2000 (Kušar 2000) [10], 2004 (Institute for Bioelectromagnetics and New Biology) [9], and 2006 (Anton Melik Geographical Institute Scientific Research Centre of the Slovenian Academy of Sciences and Arts (AMGI SRC SASA) [11].

Table 1.
Comparison of the results of various surveys of illegal dumping sites in the City Municipality of Ljubljana.

Year of survey	Area included	Surface area (km^2)	Number of surveyed illegal dumping sites	Estimated surface area (m^2)	Estimated volume (m^3)
1996	City Municipality of Ljubljana	275.0	457	70,448	32,761
2000	Open world of Ljubljansko polje	unknown	359	163,400	84,000
2004	City Municipality of Ljubljana	275.0	278	unknown	100,000
2006	Part of water protection area in the City Municipality of Ljubljana	45.8	1,482	122,573	211,279

The substantial differences obtained are probably the result of a number of factors: differences in the exactness of data collected, the subjectivity of surveyors, the variation of quantity and the season the data was collected (visibility is substantially better in winter without a snow blanket).

The fact that illegal dumping sites, especially in the vicinity of cities and water catchment areas, are very disturbing, even dangerous, raises the question of the need for their remediation. Since funding for complete remediation is usually not available, it is necessary to make a priority list of dumping sites to be rehabilitated on the basis of an assessment of their negative impact. This is where the question appears of whether it is possible to use a universal assessment methodology for all cases.

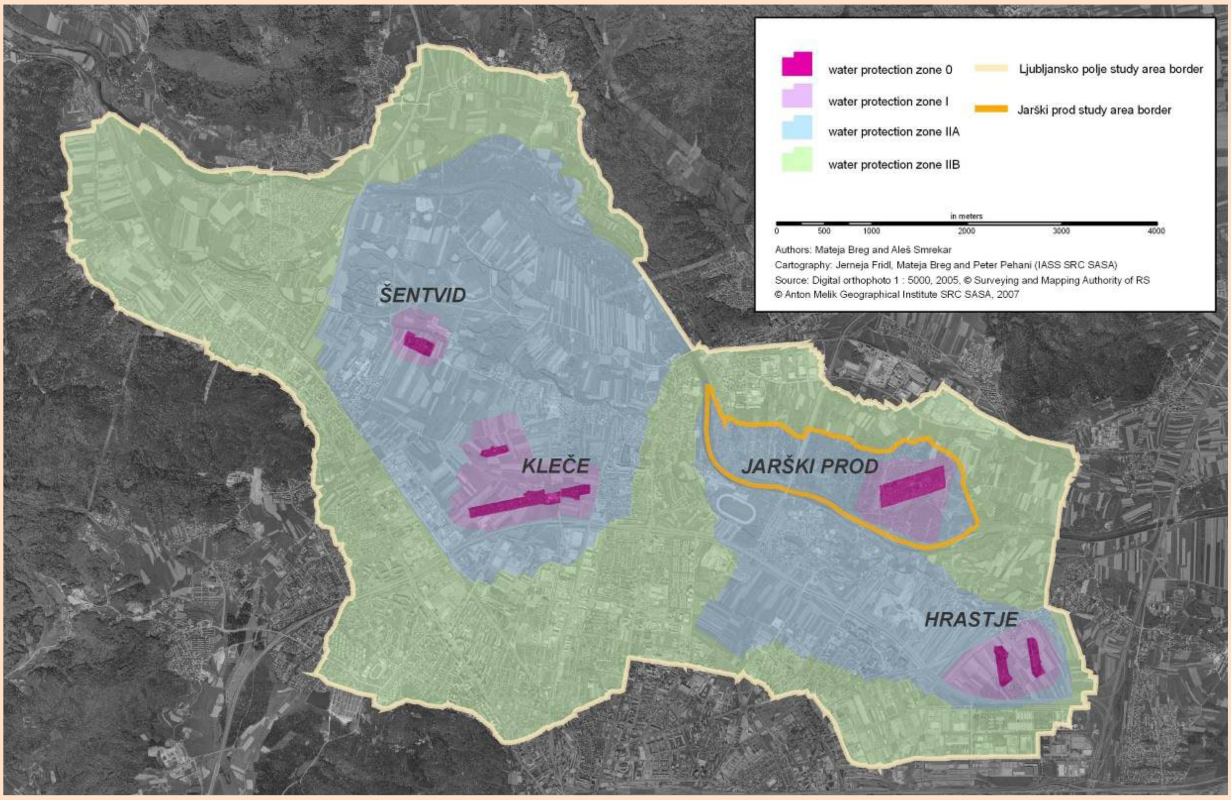
It is believed that this is possible to a certain extent and that the actual implementation depends primarily on the vulnerability and contamination of the specific environment, its land use, and last but not least on the quality of collected data that allows wide selection of applicable criteria. This paper presents one of the possibilities which have been used in the evaluation of illegal dumping sites in a smaller area where a very detailed description of dumping sites were made.

The area that in the past allowed environmentally-friendly activities could very soon become an environmental burden [12]. Although for the time being water analyses still indicate its suitability as a water source, the area of illegal dumping sites presents a hidden threat due to a past illegal dumping, which is still occurring to a smaller extent, since we have no knowledge of what is hidden under the surface. For a comprehensive and long-term successful solution of the problem, the remediation of the illegal dumping sites alone will not suffice; it will be necessary to re-establish the cultural and social values of the area and incorporate them into the permanent value system of the local population.

SURVEY OF THE STUDIED AREA

The City Municipality of Ljubljana supplies its population and companies from a number of water sources. Water started to flow in the first 606 of Ljubljana's houses on May 17, 1890, and the Kleče pumping station remains the heart of Ljubljana's pumping station system. In 1953, the Hrastje pumping station was opened, in 1955, the Šentvid pumping station, and in 1982, the Jarški prod pumping station [13]. The most extensive pumping sites of drinking water for the supply of Ljubljana are therefore situated on Ljubljansko polje, and its pumping stations are incorporated in the central pumping system. According to the Decree on the Water Protection Zone for the Aquifer of Ljubljansko polje [14], an area of 42.98 km^2 lies within the narrowest (0, I) and narrow (IIA, IIB) water protection areas (Figure 1).

Figure 1.
The narrowest and narrow water protection areas of drinking-pumping stations on Ljubljansko polje.



The cleansing capability of gravel and sand cover layers is effective with biological contamination but less so with chemical contamination because the sand for example does not restrain dung-water although it does neutralize acid. In general, the concentration of contaminatants decreases with the distance they travel through the ground. Soluble wastes, including fertilizers and certain industrial waste materials, cannot be removed by filtration, and metallic solutions are not susceptible to biological processes.

The quantity of groundwater contained in the aquiferous gravel-sand and conglomerate layers that fill the Ljubljansko polje basin is estimated at up to 100 million m^3. This is one of the largest reservoirs of undergorund water in Slovenia, a natural resource of regional importance. The depth of the groundwater depends on its water table and the height of the terrain. On a high terrace near Vižmarje the groundwater is found at a depth of more than thirty meters, while between Ježica and Zadobrova, at a depth of only five to ten meters. The annual regime of water table changes in the 1987–2005 period indicates considerable annual oscillation. In the Brod area, the oscillation spans 4 to 6 meters, around the Kleče pumping station 5 to 6 meters, and around the Hrastje pumping station 1.5 to 2 meters [15].

The groundwater flows from the northwest to the southeast or east. In the western part of the aquifer, its velocity is between 5 m/day and 10 m/day, and in the eastern part, mostly between 10 m/day and 20 m/day [16].

The main source for the charging of the Ljubljansko polje aquifer is the Sava river, and the secondary source is the infiltration of precipitation water, which in places is considerably reduced due to urban land use [17]. In its upper part, the Sava charges the aquifer while in its lower part, the groundwater flows back into the river. The second largest surface watercourse on Ljubljansko polje is the Ljubljanica river. However, its flow is slow and its muddy bottom greatly limits the exchange of water between the river and the aquifer [16].

The vulnerability of the underground water depends on the hydrogeological, hydrological, and pedological conditions. Various construction works and excavations such as the excavation of gravel also have an impact on it. There are illegal gravel pits outside the consolidated urban area, especially on the lower terraces along the Sava River. The four large legal gravel pits are located in Stanežiče, in the Dovjež area, southwest of the expressway intersection in Tomačevo, and in Obrije. They are all in the remediation phase. Fortunately, the abandoned gravel pits were not filled up with large quantities of waste because after 1924, when organized waste collection started, the waste was transported mainly to the southern areas of Ljubljana [18].

The four large legal gravel pits are located in Stanežiče, in the Dovjež area, southwest of the expressway intersection in Tomačevo, and in Obrije. They are all in the remediation phase.

From the analysis of changing land use [19] was concluded that urbanization is the most important cause of groundwater pollution. Urbanization has caused the amount of farm land to shrink distinctly, even though agricultural land use has spread ever closer to the Sava River [20]. Allotment gardeners, as a group with a large number of users of agricultural land, are having an increasing impact with their unique cultivation and other activities [21].

METHODS

We collected the majority of the data through field work, in which we recorded the most important anthropogenic elements linked to the degradation of the water protection area and the groundwater. We performed the field survey of the land during the winter when the visibility is substantially better since the vegetation is dormant. We focused on an inventory of surface objects [11, 22].

We itemized each individual heap of waste material with a volume of 1 m^3 or more as a separate dumping site. The inventory included both active and abandoned gravel pits. To draw attention to the inadequacy of legislative measures and the deep entrenchment of illegal dumping, we also registered warning and information signs and the barriers across access roads.

The surveyors entered the data on the properties and features of the dumping sites (e.g., visibility of the dump site, type of access, type of waste, estimation of the quantity of waste etc.) in specially prepared survey sheets on PDA's

We determined the position of individual objects on the terrain using a GPS (Global Positioning System) device and by taking a reading the Gauss-Krüger coordinates of centroids of illegal dumping sites and circumferences of gravel pits. The surveyors entered the data on the properties and features of the dumping sites (e.g., visibility of the dump site, type of access, type of waste, estimation of the quantity of waste etc.) in specially prepared survey sheets on PDA's (personal digital assistants). When the field work was complete, we merged the GPS measurements of locations and the attribute values from the survey sheets in a digital database that served as a basis for the further analyses. We further augmented the database with data acquired from the existing layers of data from various sources (e.g., water-protection areas, numbers of cadastral municipalities and parcels, names and surnames of owners of parcels).

Chemical sampling and analysis of waste

The general methodology used for planning a procedure for assessing the impacts on the environment due to illegal dumping sites is described in the US EPA document RCRA Facility Investigation (RFI) Guidance I-IV, 530/SW-89-031 [23]. The very extensive methodology was elaborated for the study of the most diverse types of contaminated sites and their impact on the environment, particularly on the groundwater. In a specific case, we methodologically used the part related to the impacts of illegal dumping sites. The methodology is somewhat outdated and probably less suitable for the needs of Slovenia. We also considered some modern European approaches to the assessment and remediation of contaminated sites for the protection of the environment from the impacts of hazardous substances elaborated in some international projects. These include:

CARACAS (Concerted Action on Risk Assessment for Contaminated Sites in the European Union, 1996–1998) [24]. The purpose of this project was to survey the current research in the field of degraded areas and to establish scientific priorities for further research on the improvement of the methodology of risk analysis of contaminated sites in Europe.

CLARINET (Contaminated Land Remediation Network for Environmental Technologies, 1999–2002) [25]. The following themes were examined: the regeneration of abandoned degraded areas, the impact of contaminated areas on water resources, technologies and techniques of remediation, aspects of impacts on human health, risk management, and support for decision-making.

RESCUE (Regeneration of European Sites in Cities and Urban Environments, 2002–2005) [26]. The main aim of the project was to develop and test a comprehensive approach to the sustainable regeneration of Europe's abandoned and degraded industrial areas. The suggested methodology is based on the sequence of the following two steps: a) the development of an analytical framework for determining sustainable goals and indicators, and b) the development of tools and recommendations for planning or taking measures in various circumstances.

We assessed the potential hazard of disposed waste on the basis of:

- physical-chemical properties of waste deposed (composition, solubility, stability, granulation);
- placement of deposal: surface – in contact only with meteorological water, surface – in contact with surface waters (lagoons, ponds), depth – in contact with groundwater;
- age of waste.

For sampling, we used the currently standard methods for sampling and preparation of a representative sample of soils on larger areas (ISO/TC 190/SC2, 2002). The methodology involves the division of the surface of the illegal dumping sites with a grid of suitable density (10–100) depending on the size of the area. The manual or machine excavation of material is then undertaken on a suitable number of selected microlocations determined by observations of the terrain and the material and any prior or existing information about possible dumping site sites (especially hazardous waste sites). The excavations cover the entire potential depth to the natural gravel base and even a little deeper. In the process, samples of the material are taken uniformly and notes are made on their observable characteristics (appearance, color, smell, consistency, and individual recognizable elements). The manual sampling was carried out to a depth of half a meter, which sufficed in most cases because the layers of waste were thin. Larger deposits were sampled with the use of a backhoe.

The manual or machine excavation of material is then undertaken on a suitable number of selected microlocations determined by observations of the terrain and the material and any prior or existing information about possible dumping site sites

The samples acquired from all of the sampling points at individual illegal dumping sites were combined, dried in the air at 40 °C, and sieved through a standard 2 mm sieve. We homogenized the fine fragments into a representative sample for analysis, while the rough fragments were weighed and discarded. We defined the prescribed parameters for the characterization of waste using the prescribed analytical methods for wastes and their standard leachates (SIST EN 12457:4).

For the assessment of the obtained results of waste analyses, we used the relevant limit values from the valid Slovene legislation on waste [27], which fully conforms with the environmental legislation of the European Union. We also complied with the limit values from the Rules on Soil Pollution Caused by Waste Deposits [28], which among other things refers to the environmental use of construction waste and excavations.

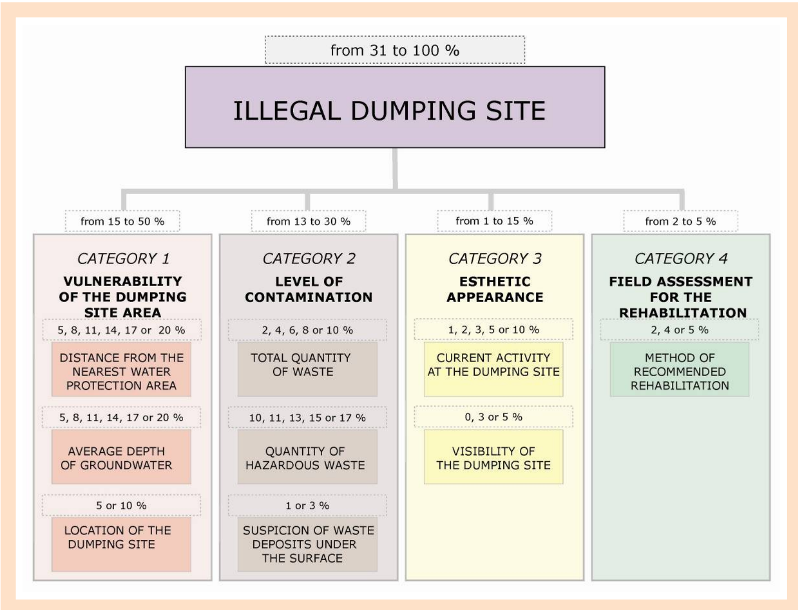
Establishing priority remediations

Establishing priority remediations of illegal dumping sites is done on the basis of carefully selected indicators that we judge to be of key importance from the viewpoint of the environmental issue of illegal dumping sites. The used remediation methodology was developed specially for this research. We combined nine selected indicators into four categories according to their assumed significance from the viewpoint of establishing priority remediation and determined appropriate weights for each.

We assigned different values or percentages to the individual categories and their indicators according to their significance in the total assessment of the necessity of the remediation of dumping sites (Figure 2).

Figure 2.

Classification and evaluation of indicators for establishing priority remediation of illegal dumping sites.



We attributed the greatest weight in the preparation of the priority scale to the vulnerability of the illegal dumping site area; it represents 50 % of the total scale value. Within this category, the primary indicators are the average depth of groundwater and the distance from the boundary of the narrowest water protection area, so converting the percentages directly into weight points we assigned 20 weight points to each of these and the remaining 10 points to the water protection area.

The range of indicators reflecting the properties of the dumping site relative to the level of contamination of the dumping site represents 30 % of the total assessment. The greatest contaminator is hazardous waste or its absolute quantity, to which we have assigned 17 weight points. The total quantity of all waste can contribute 10 points, and a reasonable suspicion that past waste is located beneath the surface of the surroundings of the existing dumping site contributes a further 3 points.We treated the esthetic aspect from the viewpoint that clearly visible and active illegal dumping sites are more problematic because they encourage further illegal dumping. Within this category, to which we have assigned 15 % of the total value in the priority remediation of dumping sites, we have assessed its current activity with 10 points and its visibility with 5 points.

We assigned the smallest percentage in the total assessment to the field estimate of the possibility for rehabilitating the dumping site, assigning it only 5 % of the total assessment due to the subjectivity of the surveyor. A surveyor's subjective opinion about the total danger posed by a particular dumping site, which is based on the characteristics of the dumping site and its distance from a pumping station, is worth considering and assigning weight points to.

The total highest possible number of points obtainable for an individual illegal dumping site is 100; however, the actual values obtained are of course lower (the lowest possible number of points is 29). The round numbers allow a better overview and, relative to the envisaged progression of remediation, the classification of individual dumping sites into priority classes as well as the possible formation of a different number of priority classes.

The points contributed to the total assessment by individual indicators were defined in the following manner:

I. Vulnerability of the dumping site area (50 % of total assessment):

1. Distance from the nearest water protection area (20 %):

Class 1	0 m to 300 m	20 points
Class 2	301 m to 600 m	17 points
Class 3	601 m to 900 m	14 points
Class 4	901 m to 1.200 m	11 points
Class 5	1.201 m to 1.500 m	8 points
Class 6	1.501 m to 1.800 m	5 points

2. Average depth of groundwater (20 %):

Class 1	2.5 m to 4.0 m	20 points
Class 2	4.1 m to 5.0 m	17 points
Class 3	5.1 m to 6.0 m	14 points
Class 4	6.1 m to 7.0 m	11 points
Class 5	7.1 m to 8.0 m	8 points
Class 6	more than 8.0 m	5 points

3. Location in a water protection area (10 %):

Class 1	water protection area I	10 points
Class 2	water protection area IIA	5 points

II. Level of contamination of the dumping site (30% of total assessment):

4. Total amount of waste (10 %):

Class 1	5.001 m^3 to 10.000 m^3	10 points
Class 2	2.001 m^3 to 5.000 m^3	8 points
Class 3	501 m^3 to 2.000 m^3	6 points
Class 4	101 m^3 to 500 m^3	4 points
Class 5	1 m^3 to 100 m^3	2 points

5. Quantity of hazardous waste (17 %):

Class 1	2.001 m^3 to 4.000 m^3	17 points
Class 2	501 m^3 to 2.000 m^3	15 points
Class 3	101 m^3 to 500 m^3	13 points
Class 4	51 m^3 to 100 m^3	11 points
Class 5	1 m^3 to 50 m^3	10 points

6. Reasonable suspicion that past waste is deposited under the surface of the existing dumping site (3 %):

Class 1	reasonable suspicion exists	3 points
Class 2	reasonable suspicion does not exist	1 point

III. Esthetic appearance of the dumping site
(15% of total assessment):

7. Activity of the dumping site (10 %):

Class 1	fully active	10 points
Class 2	partly active	5 points
Class 3	inactive non-overgrown	3 points
Class 4	inactive partly overgrown	2 points
Class 5	inactive overgrown	1 point

8. Visibility of the dumping site (5 %):

Class 1	uncovered	5 points
Class 2	partly covered	3 points
Class 3	covered	0 points

IV. Field assessment of the possibility for the remediation of the dumping site
(5% of On the basis of the characteristics of the dumping site and relative to its distance from the pumping station, the surveyor suggested one of the envisaged recommended methods for the remediation of the dumping site);

9. Method of recommended remediation (5%).

Class 1	complete removal of material	5 points
Class 2	partial removal of material	4 points
Class 3	leveling of material and grassing	2 points

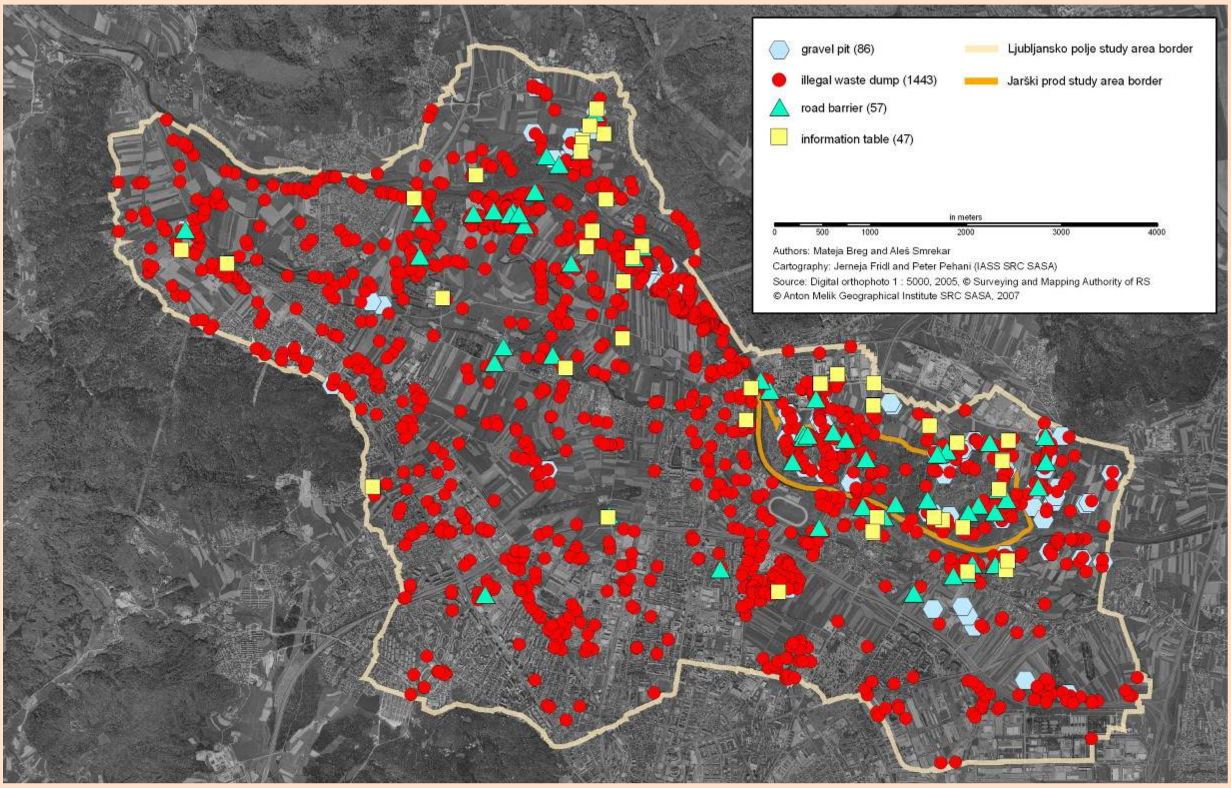
The sum of the points assigned for all nine indicators provided a quantitative assessment of illegal waste dumps with regard to their impact on the water resource and other negative environmental impacts. The dumps were classified into five categories for priority cleanup:

Class 1	from 71 to 90 points
Class 2	from 61 to 70 points
Class 3	from 51 to 60 points
Class 4	from 41 to 50 points
Class 5	from 30 to 40 points

FUNDAMENTAL FEATURES OF THE STUDIED OBJECTS

We found, documented, and studied 1,445 illegal dumping sites on Ljubljansko polje with a total surface area of 120,816 m^2, which means that waste covers 0.28 % of the entire area and makes this one of the most waste-polluted areas in Slovenia. The total volume of the waste is 209,422 m^3. The average dumping site measures 84 m^2 and has 145 m^3 of waste material. We also registered 86 dung pits, 47 information and warning signs, and 57 road barriers on access the roads (Figure 3).

Figure 3.
Surveyed objects.



Size parameters of illegal dumping sites

Among the 1,445 surveyed illegal dumping sites, small dumping sites dominate. A good third of the dumping sites do not exceed 10 m^2, and most (696) are in the 11 m^2 to 100 m^2 size class. Only 199 dumping sites measure more than 100 m^2, and only 24 dumping sites exceed 1,000 m^2, which all together occupy 7.3 % of the total surface area of dumping sites. The surface area of the largest dumping site is estimated to be 6,000 m^2.

757 (52.4%) of the dumping sites do not exceed a volume of 10 m³, but they only contain a small percentage (1.3 %) of the total quantity of the identified waste. On the other hand, there are 36 dumping sites with a volume of 1,000 m³ and more where almost three quarters of the waste is accumulated. The largest dumping site contains about 42,000 m³ or almost one fifth of the identified waste.

A minor portion of the waste is located on privately-owned land, while the majority is on “public asset” category land or land owned by legal entities (Figure 4).

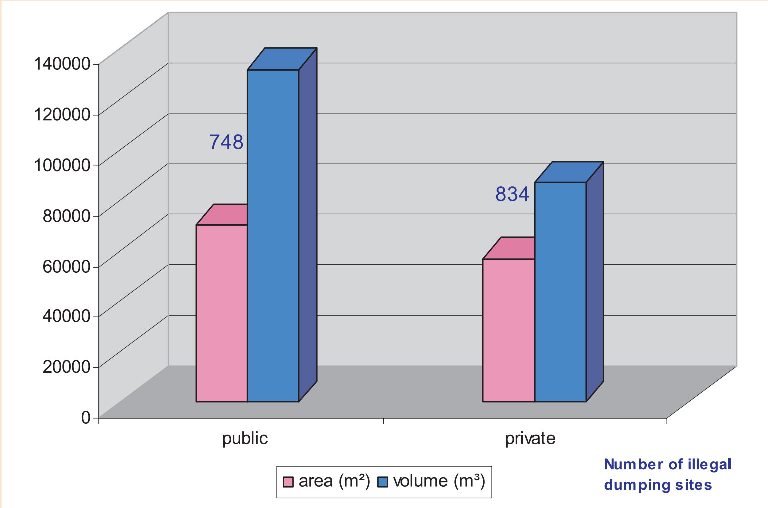


Figure 4.
Illegal dumping sites according to land ownership.

On Jarški prod, we studied 151 illegal dumping sites. Forty dumping sites are fully active, 44 partly active, and 67 inactive. We estimate that some 54 dumping sites have existed for less than one year while 97 are apparently older, which indicates still very active waste disposal activities. Their total surface area is 26,273 m², which means that the area covered with waste amounts to 1.2 % of the total area. The average dumping site measures 178 m².

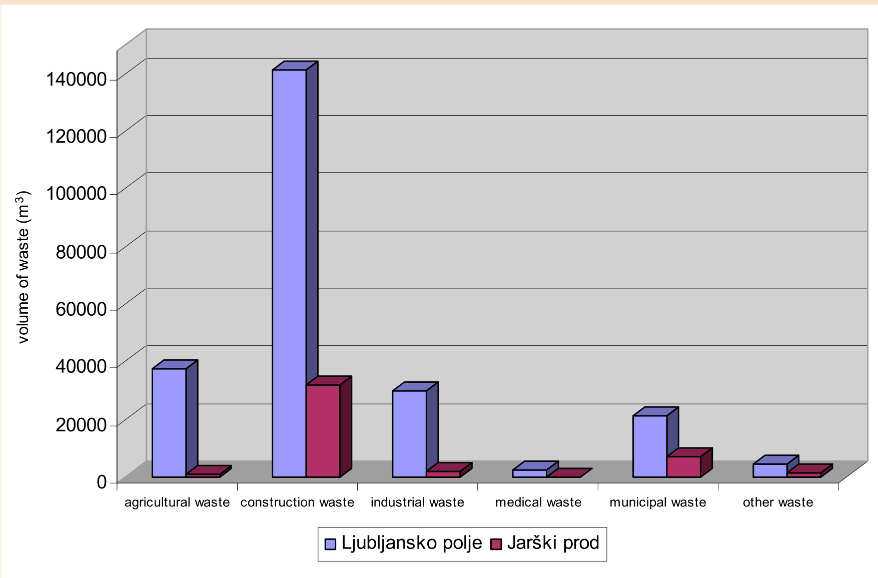


Figure 5.
Volume of deposited waste according to type of waste, comparison of Ljubljansko polje and Jarški prod.

Only thirty are larger than 100 m^2. Four exceed 1,000 m^2, occupying almost six tenths of the total established area of dumping sites. The total volume of the waste is 42,464 m^3.

More than a half of the dumping sites do not exceed 10 m^3, but on the other hand, the six largest dumping sites with volumes of more than 1,000 m^3 have accumulated more than three quarters of all waste.

Composition of waste

Illegally disposed waste is a mix of waste from different sources. Waste from construction and demolition work dominates along with surplus dirt from the excavation of new building sites. There is a great deal of bulky waste: household appliances, furniture, large packaging, electronic devices, vehicles, etc.

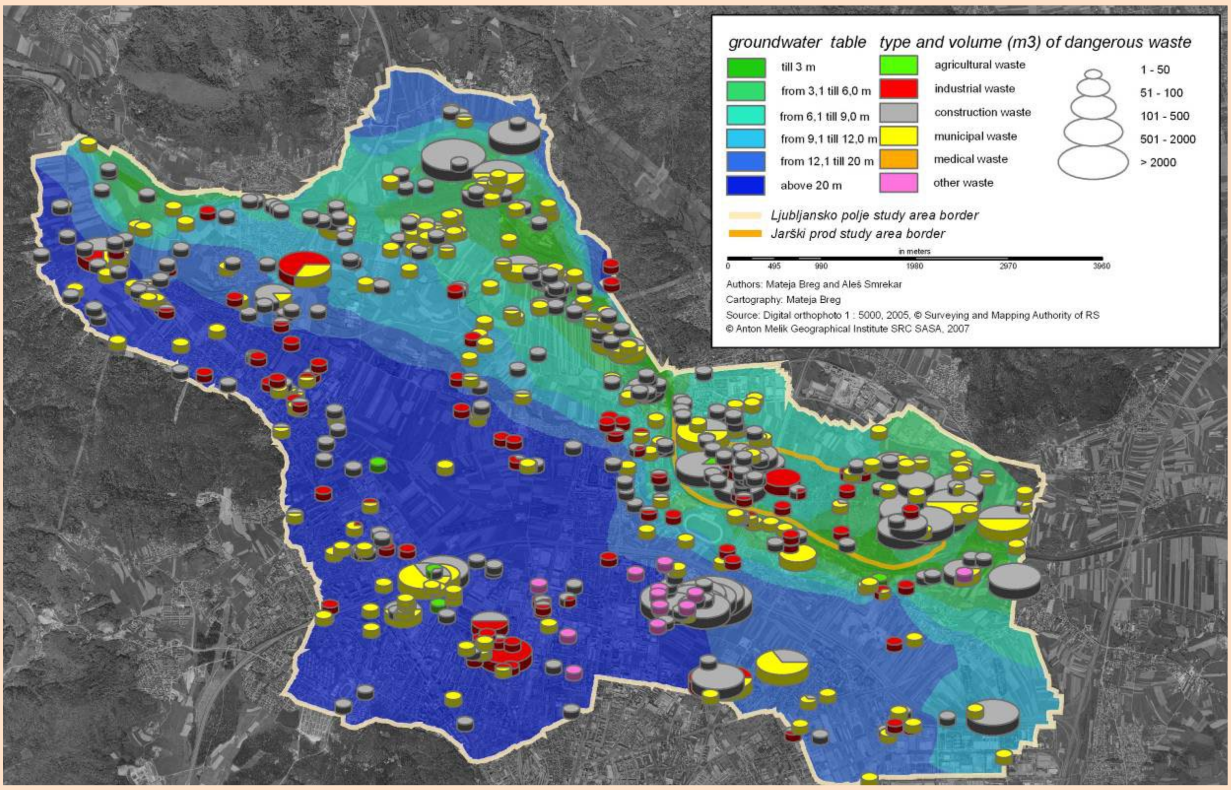
In our research, we classified waste into the following groups:

- primary sector waste;
- industrial waste;
- construction waste;
- medical and veterinary waste;
- communal waste;
- other waste.

The results are showed in Figure 5.

The volume of hazardous waste is 28,749 m^3, 13.7 % of the total volume. Hazardous waste is composed mostly of abandoned cars, barrels with unknown contents (empty barrels are classified as bulky waste), and containers for paints, lacquers, motor oils, and agrochemical preparations (Figure 6).

Figure 6.
Spatial distribution of hazardous waste relative to the depth of groundwater.



The main hazardous construction wastes include asbestos panels, asphalt, impregnated glass wool, tar paper, and unemptied containers. Hazardous industrial waste includes parts of machines and devices, the remains of refrigerators, industrial adhesives, paint and solvent containers, paint in plastic bottles, motor oil, and various types of metal barrels with unknown contents. Communal waste includes the remains of household appliances and other appliances containing parts with environmentally-hazardous substances.

Environmental parameters of dumping sites

On Ljubljansko polje, the distance between dumping sites and the surface of the groundwater varies considerably. At about one sixth (15.8 %) of the dumping sites, it measures only three meters, and at a good sixth (17.3 %) between 3.1 and 6.0 meters. At a good fifth (21.8 %), the distance to the groundwater is between 6.1 and 9.0 meters, in just under one tenth (8.4 %) it is between 9.1 and 12.0 meters, and at a good tenth (10.6 %), between 12.1 and 20.0 meters. Almost one quarter (23.6 %) of all illegal dumping sites are located more than 20 meters above the surface of the groundwater.

Waste is scattered everywhere except in the fenced catchment areas. The largest number of dumping sites (760 or 52.6 % of all sites with a total surface area of 57,340 m^2 or 47.5 %, and a volume of 118,975 m^3 or 56.8 %) are located in the narrow areas with a strict water protection regime (IIA). There are only 71 such dumping sites with a total area of 8,589 m^2 (7.2 %) and a volume of 10,249 m^3 (4.9 %).

Most of the illegal dumping sites are located in overgrown areas. On Ljubljansko polje, we registered 87 gravel pits, and only 15 of them were free of waste (Figure 7).

The locations of illegal dumping sites on Jarški prod are typically hidden from view, and according to quantity more than 95 % of the waste material is deposited in thin forest. We discovered 22 of gravel pits. Their surface area ranges from 25 m^2 to 65,000 m^2, their volume is between 50

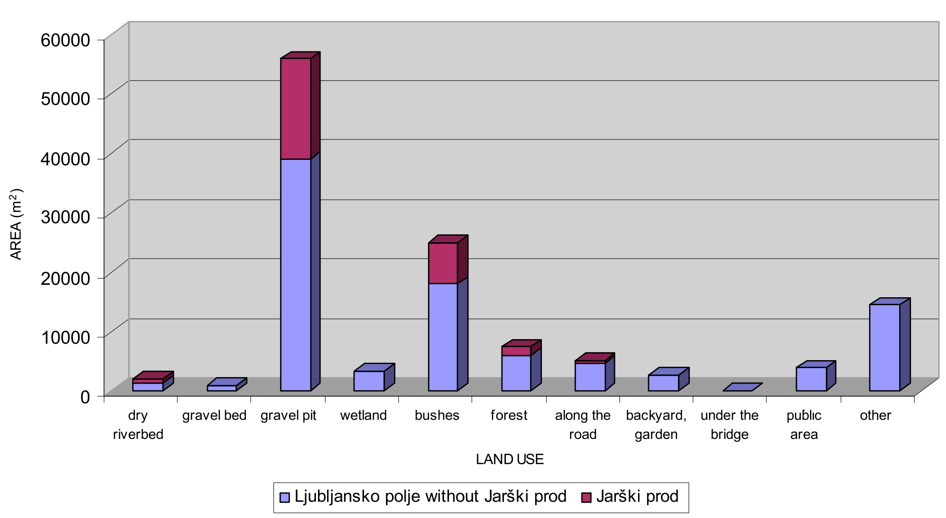


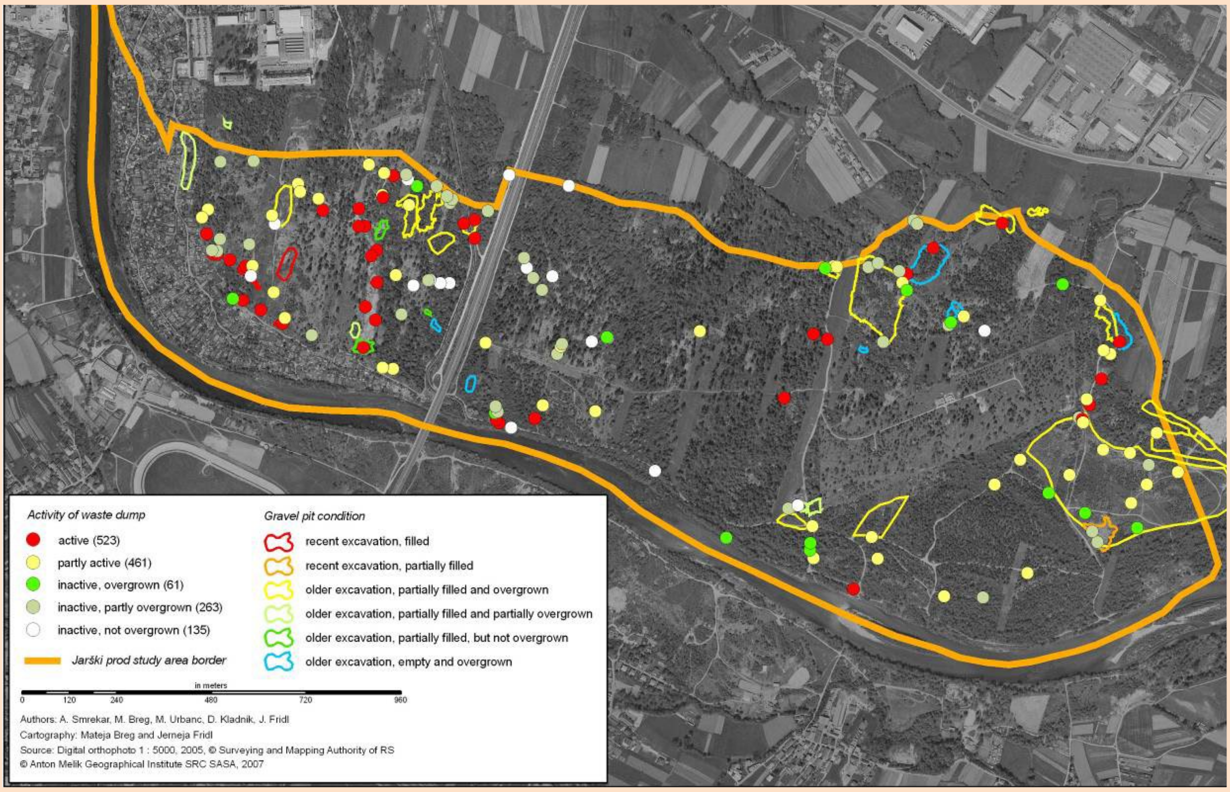
Figure 7.
Area of illegal dumping sites according to land use.

m³ and 130,000 m³, and they are up to six meters deep. The average gravel pit measures 8,550 m² and has a volume of 22,042 m³. Only 38 dumping sites were actually found in gravel pits, but they contained as much as 31,732 m³ or almost three quarters of all the recorded waste.

More than a third (36.2 %) of the dumping sites are still active, just under one third shares go to both partly active and inactive illegal dumping sites. Most (263) of the inactive dumping sites are partly overgrown. Considering the quantity of the waste with more than a half share (51.4 %), inactive dumping sites are in the lead, while fully active dumping sites contribute just under a third (30.9 %) (Figure 8).

Figure 8.

The relationship between the condition of gravel pits and the activity of dumping sites on Jarški prod.



There is reasonable suspicion that additional quantities of past waste are deposited under the surface on 359 dumping sites (24.8 %). Unfortunately, this suspicion applies especially at the major dumping sites where we registered 87,009 m³ or 41.5 % of the total quantity of waste. More than two thirds (67.5 %) of illegal dumping sites are located less than five meters from access roads.

Various types of roads lead to dumping sites. The most common are wagon tracks (491 dumping sites or 24.6 % from the area aspect and 22.6 % from the quantity of waste aspect), followed by dirt roads (364; 59.4 % or 67.6 %) and asphalt roads (340; 10.9 % or 7.7 %). Only a small amount of waste was brought to dumping sites via footpaths (119; 2.7 % or 1.4 %). Similar figures (131; 2.4 % or 1.4 %) apply to dumping sites with no access roads.

Various types of barriers set up on asphalt and dirt roads, as well as on wagon tracks and footpaths, should be the largest hindrance to unobstructed delivery of waste material. Unfortunately, it is possible to get around them in many cases. An interesting fact is that 222 dumping sites with 42.9 % of the total surface area and 55.0 % of the total volume are only accessible by passing road barriers, however, new piles of waste have started to accumulate before the barriers.

RESULTS AND DISCUSSION

Results of analyses of waste deposits relative to limit values

The locations and results of analyses of waste disposed on individual larger illegal dumping sites of Ljubljansko polje and Jarški prod are presented in Figure 9 and Table 2. The samples differ in a number of ways. Samples from the entire Ljubljansko polje are more heterogeneous, moister, and contain more organic substances. Both contain more organic substances than allowed for disposal on inert waste dumping sites or input into the ground. Standard leachates from waste show moderate contamination, but some parameters exceed the limit values for inert waste or waste that can be deposited into the ground as artificially prepared soil. It was concluded that the main potential contribution of the waste to the pollution of the environment is contamination with organic substances of biological and synthetic origin that occur during the spontaneous decomposition of waste in a natural environment.

We analyzed the leachate of an average sample from Jarški prod for potential organic contaminants: polycyclic aromatic hydrocarbons (PAO), absorbent organic chlorine (AOX), lower aromatic hydrocarbons (BTEX), and polychlorinated biphenyls (PCB). The established amounts are well

Figure 9.
Locations of soil sampling on Ljubljansko polje.

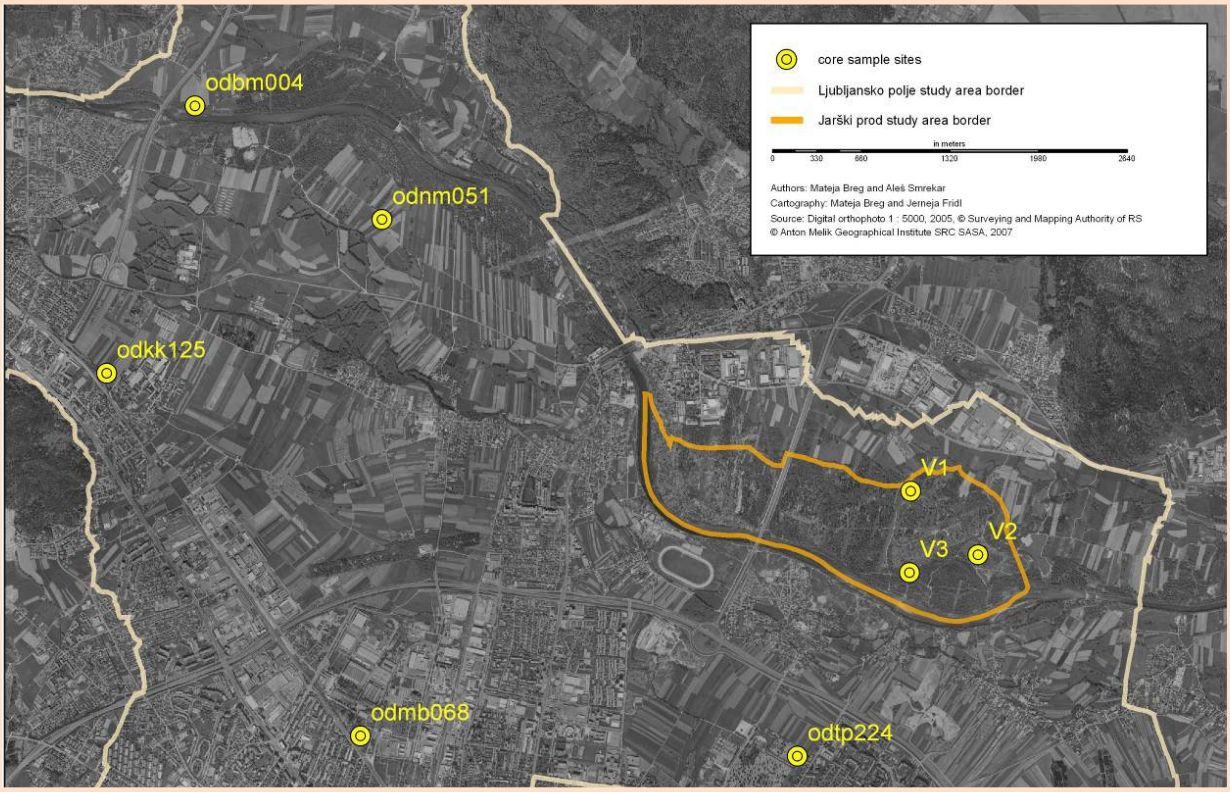


Table 2.
Results of analyses of deposited waste in comparison with limit values.

Waste properties	Method of determination	Unit	Measured values Ljubljansko polje (5 samples)		Measured values Jarški prod (3 samples)		Limit values Regulations for Waste Disposal			
			Waste samples	Standard leachate	Waste samples	Standard leachate	IW	NHWLLOS	NHWHLOS	Soil contamination APS
dried remains (105 °C)	SIST EN 12880	%	76.1-99.0		92.2-93.9		-		-	-
ash (550°C)	SIST EN 12879	% DS	7.8-17.0		1.4-1.8		-	5	-	-
total organic carbon –TOC	SIST ISO 10693	% C DS	3.85-11.12		0.3–5.0		3	3	18	0,3
pH	SIST ISO 10523	/		7.4 - 8.3		7.1-8.1	-	-	-	6.5-8
total soluble substances	SIST EN 12880	g/kg DS		1.0 - 23.5		0.17-0.29	4	60	60	-
DOC	ISO 8245	mg/kg DS		170 - 946		90-102	500	800	7500	50
antimony	ICP MS	mg/kg DS		< 0.06		< 0.7	0,06	0,7	0,7	-
arsenic	ICP MS	mg/kg DS		< 0.1		< 1	0,5	2	2	20
copper	ICP AES	mg/kg DS		< 20		< 1	2	50	5	30
barium	ICP AES	mg/kg DS		< 20		< 1	20	100	100	-
zinc	ICP AES	mg/kg DS		< 40		< 1	4	50	50	100
cadmium	ICP MS	mg/kg DS		< 0.04		< 0.1	0,04	3	1	0,5
total chromium	ICP AES	mg/kg DS		< 5		< 1	0,5	10	10	40
molybdenum	ICP AES	mg/kg DS		< 5		< 1	0,5	10	10	-
nickel	ICP AES	mg/kg DS		< 4		< 1	0.4	10	10	30
lead	ICP AES	mg/kg DS		< 5		< 1	0.5	10	10	40
selenium	ICP AES	mg/kg DS		< 0.1		-	0.1	0.5	0.5	-
mercury	ICP MS	mg/kg DS		< 0.01		< 0.1	0.01	0.2	0.2	0.2

IW = inert waste, NHWLLOS = non-hazardous waste with low level of organic substances, NHWHLOS = non-hazardous waste with high level of organic substances, DS = dry solids, APS = artificially prepared soil intended for landfill.

under the permissible values. This type of chemical pollution from deposited waste is therefore minor, which was to be expected.

The influence of illegal waste dumps on the groundwater quality of Ljubljansko polje

Despite the numerous illegal waste dumps on the catchment areas of drinking water wells, the national groundwater quality monitoring service and the city's drinking water supplier have not confirmed unequivocally the existence of contaminants in the groundwater originating from waste dumps. This is probably due to the following reasons:

- The groundwater flow in the central part of the aquifer is locally relatively high. For example, it was determined that the velocity reached 20 m/day locally [16]. Consequently, a contaminant possibly present in the groundwater is dissolved and removed relatively quickly from the aquifer by natural processes of dispersion, dilution, and biodegradation (in the cases of biodegradable substances).

- The quality of water in the immediate catchment areas of the pumping stations is not monitored and tested frequently. It is therefore possible that the wave of a contaminant moves with the groundwater flow in the period of the year when the groundwater is not sampled.

• A point source contaminant in the Ljubljansko polje aquifer travels within a relatively narrow zone and does not disperse over the wider area. The contaminant can be detected at the sampling sites only if the sampling site is situated in the contaminant's path, which usually does not exceed more than a few dozen meters and depends on the distance of the source point.

• It is possible that a contaminant detected at a particular sampling site originated from an illegal waste dump (e.g., pesticides, volatile organic hydrocarbons) but the researcher assumes it comes from agricultural or household use.

Table 3.
Results of tests of drinking water at the Kleče pumping station in 2005 and 2006.

Parameter	Units	Max. admissible value	Kleče-12 (19.4.05)	Kleče-12 (8.5.06)
Electroconductivity	μS/cm	2500	523	489
Nitrates	mg/l $N\text{-}NO_3$	50	17.0	15.2
Nitrites	mg/l $N\text{-}NO_2$	0.5	<0.001	<0.001
TOC	mg/l C	/	<0.2	1.1
Atrazine	μg/l	0.1	0.0572	0.0343
Desethylatrazine	μg/l	0.1	0.0781	0.0607
Chromium	μg/l Cr^{+6}	50	4	<3
Tri- and Tetra –chloroethylene (sum)	μg/l	10	0.08	0.16

Table 4.
Results of tests of drinking water at the Šentvid pumping station in 2005 and 2006.

Parameter	Units	Max. admissible value	Šentvid-1a (20.4.05)	Šentvid-1a (8.5.06)
Electroconductivity	μS/cm	2500	558	582
Nitrates	mg/l $N\text{-}NO_3$	50	19.0	19.4
Nitrites	mg/l $N\text{-}NO_2$	0.5	<0.001	<0.001
TOC	mg/l C	/	<0.2	0.45
Atrazine	μg/l	0.1	0.0246	0.0225
Desethylatrazine	μg/l	0.1	0.0447	0.0412
Chromium	μg/l Cr^{+6}	50	<3	<3
Tri- and Tetra –chloroethylene (sum)	μg/l	10	<0.06	<0.06

Table 5.
Results of tests of drinking water at the Jarški prod pumping station in 2005 and 2006.

Parameter	Units	Max. admissible value	Jarški prod-3 (20.4.05)	Jarški prod-3 (8.5.06)
Electroconductivity	μS/cm	2500	521	533
Nitrates	mg/l $N\text{-}NO_3$	50	11.0	11.2
Nitrites	mg/l $N\text{-}NO_2$	0.5	<0.001	<0.001
TOC	mg/l C	/	<0.2	0.58
Atrazine	μg/l	0.1	0.0079	0.0069
Desethylatrazine	μg/l	0.1	0.0206	0.0237
Chromium	μg/l Cr^{+6}	50	<3	<3
Tri- and Tetra –chloroethylene (sum)	μg/l	10	0.2	0.2

• The scope of the chemical analyses is limited and can neither quantitatively nor qualitatively include all the substances from the anthropogenic environment.

• Finally, the illegal waste dumps are not such important sources of contaminants as has been assumed.

In dealing with the groundwater quality problems of the Ljubljansko polje aquifer, in addition to the traces of pesticides the traces of volatile organic hydrocarbons (e.g. trichloroethylene (TCE) and tetrachloroethylene) and heavy metals (e.g. chromium) should be discussed. The test results show that the concentrations of contaminants in the drinking water are low and that their presence is not harmful for users. While the previous usage of pesticides in the agriculture is definitely one of their origins in the groundwater, the reasons for the presence of the volatile organic hydrocarbons that have been detected in traces all over the area are not well known and understood. In addition to the dispersed usage of volatile organic solvents in households and industry, the waste dumps could have been one of the sources of volatile organic hydrocarbons in the groundwater of Ljubljansko polje but no research has been done to prove this assumption. Tables 3, 4 and 5 shows main results of the tests of drinking water at selected active wells of the public water supply system in 2005 and 2006.

The results of the drinking water tests confirm that the drinking water in Ljubljana's public water system does not contain contaminants in the concentration range that could make the water undrinkable.

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PRIORITY REMEDIATION OF ILLEGAL DUMPING SITES

In the long run, the cost for the periodic remediation of larger dumping sites is higher than for regular material collection from minor dumping sites, although this only applies when such a system is already established [9]. In time, it will be necessary to rehabilitate all illegal dumping sites; however, due to the large quantity of waste it is unrealistic to expect this to happen in one go. Using the described evaluation methodology for each illegal dumping site, we calculated the total number of points, which reflects the assessment of all of the nine considered indicators given their weighted values (Figure 10).

Due to the substantial weight of the vulnerability of the dumping site area category, which contributes half of all possible points, the 58 illegal dumping sites ranked in priority class 1 with 71 to 93 points (of the theoretically possible 100) are on the majority of the surveyed areas located in the vicinity of pumping stations. This is particularly characteristic for the area of the Jarški prod pumping station.

218 illegal dumping sites (15.1 % of all) obtained between 61 and 70 points and were ranked in priority class 2. On Ljubljansko polje, they are concentrated particularly in four areas, with most located on Jarški prod. There are also major concentrations on the right bank of the Sava River between Jarše and Sneberje, north of Kleče, and southwest of Hrastje.

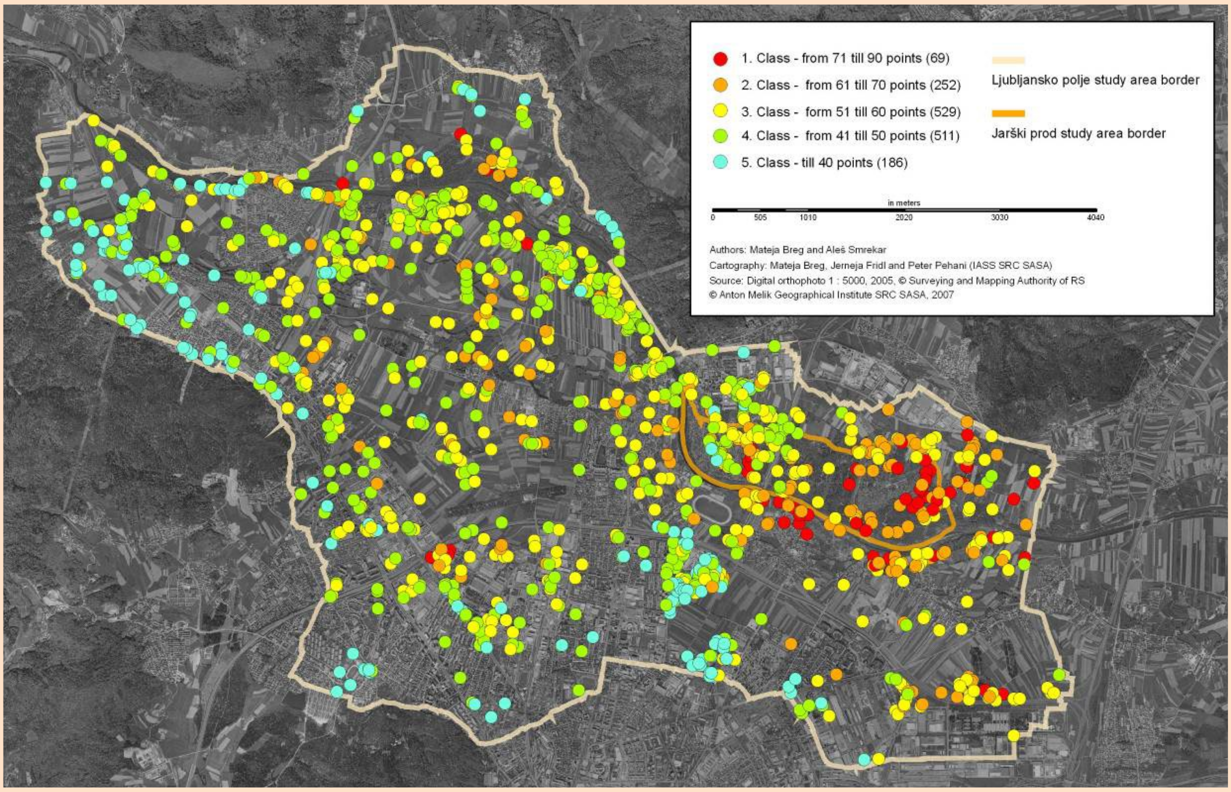

Figure 10.
Priority remediation of illegal dumping sites.

Dumping sites in priority class 3 with 51 to 60 points, in which 491 (34.0 %) of the illegal dumping sites are ranked, are scattered over all of the surveyed areas in no particular pattern. 493 (34.1 %) illegal dumping sites are ranked in priority class 4 with 41 to 50 points. These too are quite evenly distributed, there are fewer in the vicinity of pumping stations of Jarški prod and Hrastje.

Priority class 5 contains 183 illegal dumping sites with less than 40 points (the lowest possible number is 26). They are not placed in the vicinity of the pumping stations, and since their waste is not very hazardous, the need for their remediation is the smallest.

According to the results the selected methodology, it has been concluded that the majority of illegal dumping sites that require immediate remediation (class 1 and 2) which are located in water protection areas I or in their immediate vicinity where the regulations protecting the water resource for the supply of Ljubljana with drinking water are very strict.

Revitalization of the degraded landscape is only possible by employing high quality remediation programs. These require a precise assessment of the existing excessive contamination of the environment and a weighted selection of the most suitable methods and measures to improve the situation. Therefore their implementation demand a special approach according to the Article 56 of the Environmental Protection Act [29].

Next important activity is to prevent further dumping. Road blocks should be set up on access roads leading to the most critical areas. The problem can only be solved permanently through regular monitoring, a system of penalties, and raising the awareness of people who are potential polluters.

Southeast of the Jarški prod pumping station there are a number of illegal dumping sites ranked in class 1 and 2 according to the criteria for the priority remediation of dumping sites that are still active and therefore encouraging further dumping. Dumping attempts could be prevented or at least substantially reduced by simply erecting two gates on the more important access roads north and southwest of this already distinctly degraded area of former large gravel pits. A gate should also be erected on the southern access to this area. The second area that demands immediate protection is the gravel pit site west of Štajerska cesta that has supplied gravel and sand as construction material since 1995.

CONCLUSION

Despite the relatively low concentration of contaminant that could originate from the illegal waste dumps, it can be assumed that every single location where waste is illegally deposited represents a serious threat to the groundwater and the quality of drinking water, since even a small quantity of contaminant can make the water resource undrinkable. The results of research that do not confirm the frequent occurrence of groundwater contamination from waste dumps should not be a reason to neglect the problems related to illegal waste dumps. Beside that also the landscape and ecological characteristics with the emphasis on other negative impacts (specially visual, aesthetic and functional) of illegal dumping sites should be considered.

To successfully implement the established goals of waste management, it is necessary to inform, educate, and raise awareness.

Solving the problem of illegal dumping sites requires two simultaneous approaches. The first is to rehabilitate existing dumping sites and thus remove point sources and larger plane sources of contaminators of the underground water, and the second is to effectively prevent the occurrence of new dumping sites, strictly penalize violators, and organize campaigns to raise environmental awareness.

So far, there has not been enough will – and consequently funds - to resolve this problem. Recently, however, the city authorities have apparently realized the need to take action, shown by the fact that in addition to the waste collection carried out by Snaga the first more comprehensive steps have been taken. A remediation project for the most polluted area of Jarški prod is in the preparation phase, which will be followed by a test implementation of the remediation.

To successfully implement the established goals of waste management, it is necessary to inform, educate, and raise awareness. Endeavours without the support and appropriate level of environmental awareness of the local population will not achieve the goal, a clean and healthy local landscape. It is obvious that a non-problematic environment does not represent a value for many people.

The Spatial Plan of the City Municipality of Ljubljana [30] envisages this area as a forest area with accented ecological and recreational significance. A system of walking and cycling paths could be arranged along the Sava River that with the appropriate remediation would give the area new quality dimensions. There are ideal possibilities here for a water education trail where various items and topics could be presented such as the operation of pumping stations, the dry riverbed of a former watercourse, the regulation of a riverbed, a gravel pit with a profile of the cover layer and gravel on an alluvial plain as an inappropriate source of construction material, and an illegal dumping site as an inappropriate use of a gravel pit just above the groundwater table, etc.

These and other endeavours at the level of the City Municipality of Ljubljana have been undertaken particularly by the Institute for Nature Conservation of the Republic of Slovenia. One of its missions is to publish information and motivation publications such as Environment in the City Municipality of Ljubljana [31] and A Guide to the Protection of Underground Water in the City Municipality of Ljubljana [32].

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