Application of Geographic Information Systems in the Field of Domestic Waste Management

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Abstract. The algorithm of the application of Google Earth software tools for the processing of satellite data about storage facilities of domestic waste is described. The authorized areas of domestic waste and spontaneous dumps have been identified by number, area and characteristics in the city of Kyiv and in the suburban area. It was found that most dumps are located at a dangerously close distance from residential development, which in some cases exceeds the normative indicators. The authors used the methodical approach in defining the area which is unsuitable for housing development and growing of agricultural crops as well as the area of environmentally destructive influence around the dumps.

Keywords: geographic information system, geospatial analysis, tools capabilities, domestic waste, dumps, ecologically destructive influence.

1 Introduction

The main problem of waste management in Ukraine is that the predominant amount of domestic waste is utilized by the landfill method, designed to gradually decompose of waste in the natural environment. At the same time, the mass phenomenon is spontaneous garbage dump, which spreads rapidly throughout the area of country.

It is as necessary to identify the placement of authorized landfills for storage of municipal solid waste (MSW) on the territory as unauthorized dumps, to identify its actual characteristics, to define the actual area of its ecologically destructive influence on the residence of the population and agricultural land. The use of modern geographic information systems (GIS) allows conducting such identification and evaluation.

It is important to build an algorithm for the detection of garbage landfills and dumps with application of GIS tools capabilities and to evaluate the data obtained to substantiate offers of the waste management in the country.

2 Theoretical and Methodological Backgrounds

Nowadays GIS are widely used in different fields. There are many definitions for a geographic information system. The most famous definition of Aronoff, S. (1989): A GIS is a computer-based system that provides the following four sets of capabilities to handle geo-referenced data:

1. input,
2. data management (data storage and retrieval),
3. manipulation and analysis, and
4. output [1].

Y. Shokin and V. Potapov (2015) compared many definitions of GIS in scientific literature and described GIS as an information system that provides for the collection, storage and analysis of spatial information, that is, as a geographic information service [2].

The first developments of the virtual digital platform for Earth monitoring, known as Google Earth today, appeared in 1998. The methods which are used to develop algorithms for this platform have become typical in the development of other geographic information systems.

Today, separate GIS and based on integrated GIS electronic atlases are used for:

• monitoring of the state of land use and the assessment of the condition of agricultural lands;

• cadastral accounting of land, water, resources, as well as resources of forestry and mineral deposits;

• assessing the status of garbage landfills and detecting unauthorized dumps;

• studying and evaluating biodiversity and ecological status of the territories;

• detection of emergency situations (oil spill, fires, flooding, etc.).

Modern researchers have expanded the scope of GIS. In particular, N. Sianko and M. Small (2017), T. VoPham (2018) argue that geospatial data are useful in solving problems associated with demography, population migration and health. T. Paientko (2018) in her work shows the possibilities of using GIS in the development of reforms in the field of public finance [5]. W. Zhou (2018) demonstrates applications of GIS and remote sensing in landslide hazard assessment.

The use of geospatial data has a number of undeniable advantages, the main of which is that these data are available for free general use, as noted by H. Niska and A. Serkkola [7].

The constant growths of living standards in the world and the changes in consumer goods have negative externalities, and H.W. Gottinger (2018) highlights the problem of waste accumulation as one of them. It is important to respond in a timely manner to the negative consequences of waste management, to identify areas of unauthorized dumps. J.F. Salsa and J.L. Gallego (2018) emphasize the need to introduce monitoring systems for the main places of its accumulation in dynamics. As T. Matsuda and Y. Hirai (2018) confirm, monitoring the dynamics of waste quantity and its structure are an effective method in developing scenarios to cover its negative effects. Correct structuring of waste components can greatly facilitate its processing and reduce expenditures of its utilization.

O. Trofymchuk and V. Trysnyuk (2014) combines the methods of remote sensing of the Earth and GIS for inventory of waste disposal area with methods of mathematical modeling and emphasize its importance for the comprehensive study of sources of influence and ultimately for making well-considered decisions in improving the environmental situation in the natural-technological system [11].

Accumulation of significant volumes of data contributes to the development of the intellectual analysis of geospatial data, which is provided on the basis of information about the geospatial locations of objects in local and global systems of coordinates and have a certain number of regularities and dependencies in large databases. Analytical capabilities of modern instrumental geographic information systems are quite diverse. There is the mention by R.N. Clark and G.A. Swayze (2003) that several dozens of different analytical procedures consist of package of blocks with advanced analytical capabilities (packages ARC/ INFO, IDRISI, MGE, PCRaster), arise from a possible simple time analysis and modeling. It should be noted that implemented in different GIS packages analytical procedures have close components. It allows considering the method of GIS analysis, which is the main information potential, without taking into account specifics of GIS packages [13].

First of all, it is necessary in the study to select certain objects in space, in order to limit the scope of research, using the functions of data selection. Such allocations can be made spatially or on the basis of attribute data which are related to spatial objects. The method of data selection is a request of spatial choice. These requests can be combined or executed in a certain sequence to obtain the final result.

Google Earth is a project of Google company that provides satellite imagery (or, in some cases, aerial photos) over the entire terrestrial surface on the Internet. According to N. Gorelick and M. Hancher (2017) photos of some regions have an unprecedentedly high resolution of images. Virtually the entire surface of the land is covered by images which are obtained from Digital Globe and have a resolution of 15 m per pixel. Separate surface areas (capitals and some large cities) have even more detailed permission. Data of terrain elevations have a clearance of about 90 m (about 30 m in the US) horizontally and vertical accuracy – up to one meter.

Google Earth uses Keyhole Markup Language (KML) markup languages to represent geospatial data. A KML file can contain (in the URL form) links to other KML or KMZ files (KML file extensions) which are hosted on the network. It is possible to specify conditions, the regularity of loading and displaying data from these sources [15]. Objects inside the KML file can be organized in hierarchical structures of folders and subfolders in order to easy share or disable images of logically interrelated groups of objects.

Google Earth has a large arsenal of layers, there is the ability to manually select data to display, there are labels (marker and polygon) and various tools for processing satellite data.

The authors have developed a methodological approach to define the area of intense pollution that is unsuitable for normal use (housing development and growing of agricultural crops) due to the significant ecologically destructive influence of dumps. For this purpose, it was used standards of State Construction Norms (SCN) V.2.4-2-2005 "Polygons of municipal solid wastes: main provisions of design" (2015), which states that the distance from residential and public building (sanitary protection zone) should be 500 m, from agricultural land – 200 m. For calculations, the distance indicator from the MSW landfill is 500 m. Although, in our opinion, this distance is not sufficient for the comfortable residence of the population, especially with increasing volumes of the MSW landfill outside.

To simplify the calculations, it was assumed that the area of the polygon in the form of a circle. Authors' formulas were used, which are based on the calculations of the circle area, where the radius is the sum of the radius of the landfill MSW and the radius of the zone of its influence.

The total area of the sanitary protection zone around the MSW landfill (including the MSW landfill) can be calculated by the formula:

$$S\text{spz} = \pi * \left(\sqrt[2]{\frac{A}{\pi}} + 500\right)^2 \quad (1)$$

where,

Sspz – area of the sanitary protection zone (m^2);

A – area of the MSW landfill (m^2);

$\sqrt[2]{\frac{A}{\pi}}$ – the radius of the MSW landfill area in the form of a circle(m);

500 – the radius of the sanitary protection zone (m).

It should be noted that similar dimensions of sanitary protection zone are installed in Turkey and Greece – it is also 500 m, in Serbia is 1 km and in UK is 2 km.

Zone of ecologically destructive influence of dumps on the residence of the population is zone within which the inhabitants of the surrounding settlements experience considerable discomfort due to the unfavorable state of the atmospheric air (evaporation and stink) and water resources (unsuitability for drinking), and so it has influence on their state of health. In our calculations we used standards of SCN V.2.4-2-2005 "Polygons of municipal solid wastes: main provisions of design"(2015), which defined that the distance between the MSW landfill and limits of the resort town, open water reservoirs, reserves, resting places of migratory birds, sea coast should be 3000 m. In addition, according to the results of surveys which were conducted by us inhabitants of villages near MSW landfills, outside the distance of 3000 m complaints about the adverse influence and consequences are reducing (Fig.1).

The total area of ecologically destructive influence zone of MSW landfill (including the MSW landfill) is defined by the formula:

$$S\text{ediz} = \pi * \left(\sqrt[2]{\frac{A}{\pi}} + 3000\right)^2 \quad (2)$$

where,

Sediz – area of ecologically destructive influence zone (m^2);

A – area of the MSW landfill (m^2);

$\sqrt[2]{\frac{A}{\pi}}$ – the radius of the MSF landfill area in the form of a circle(m);

3000 – the radius of ecologically destructive influence (m).

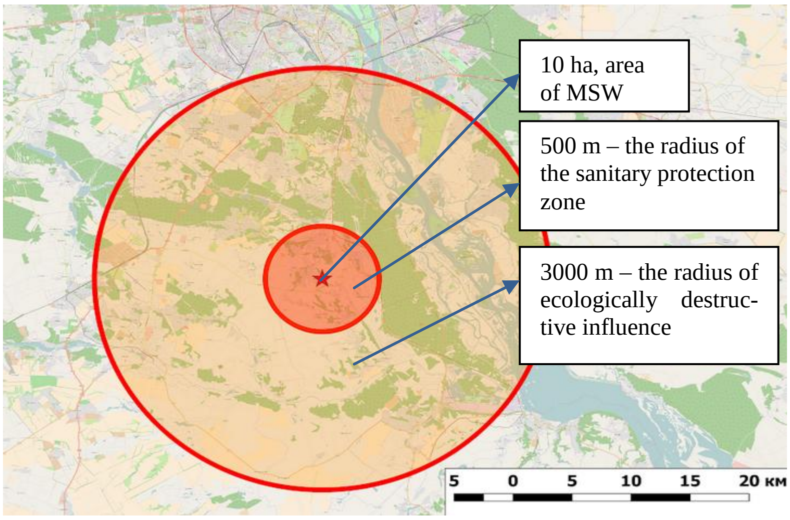


Fig. 1. Scheme of zone of intense pollution and zone of ecologically destructive pollution around MSW landfill.

Authors offer to define efficiency of utilization of domestic waste by its processing with the help of increase in the function of public welfare.

3 Identification of Dumps and Its Real Parameters with Use of GIS

3.1 Case study of garbage polygons, calculation of sanitary protection zones and zones of ecologically destructive influence

The fire at MSW landfill in Lviv city demonstrated that Ukraine is on the edge of an ecological catastrophe due to improper utilization of domestic waste. According to official statistics for 2014-2017, there are 296-366 million tons of waste is produced each year in Ukraine, by the end of 2017 more than 12.4 billion tons of waste has been accumulated in specially designated places for its disposal [17].

According to the calculations of zone of intense pollution (sanitary protection zone) with standard distance of 500 m (according to formula 1), MSW landfill with an area of 1 hectare (ha) leads to unsuitability of 98 ha of land for the residence of the population and cultivation of agricultural crops, while landfill with an area of 10 he transforms to the exclusion zone – 144.5 ha, etc. (Fig. 2).

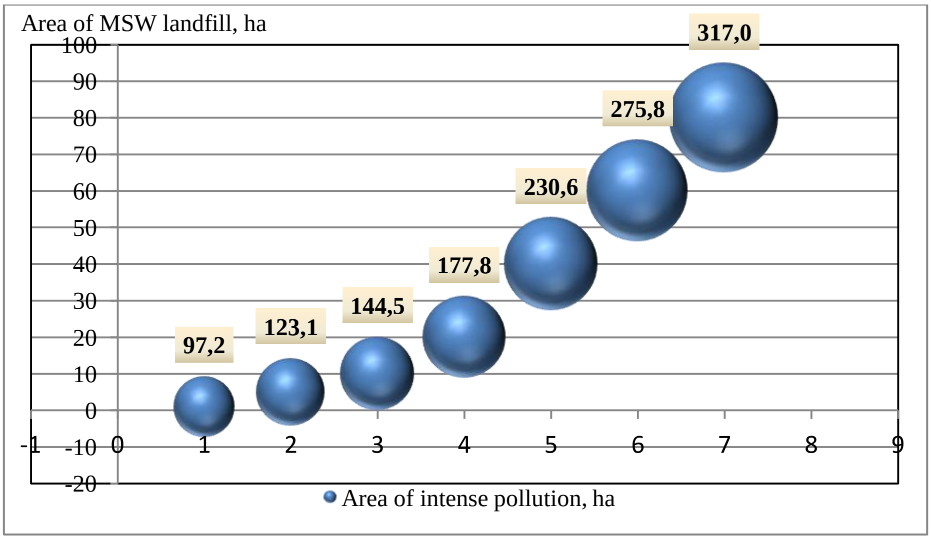


Fig. 2. The dynamics of the expansion of the area of intense pollution, depending on the area of MSW landfill, ha

According to calculations of zone of ecologically destructive influence with a defined distance of 3000 m (according to formula 2), MSW landfill with an area of 1 ha leads to unfavorable conditions for residence of population and decrease in the quality of cultivated agricultural products on 2933.3 ha of land. For the size of a landfill of 10 ha, this area is growing to 3172.2 ha, etc.

Definition of the area of ecologically destructive influence of MSW landfill and the need for its legislative regulation, along with the currently established only sanitary protection zone, is important, including for the compensation (material or otherwise) for residents of the surrounding settlements. This tool will become more and more important taking into account organized protests of residents against dumps near their settlements.

It was used the tools capabilities of geospatial analysis with the help of Google Earth service for the identification of dumps (including unauthorized ones) and its characteristics on the territory of Kyiv city and in the suburban area.

The "Placemark" tool is used to select and save data about the user-selected place on the map. There are several types of marks in Google Earth, which are dot markers in the form of a marker that has only one coordinate point and polygons with a certain number of coordinate points on the plane. The polygon mark serves to highlight an arbitrary shape object. Since the places of domestic waste storage occupy different size of areas, location of garbage landfills and dumps were highlighted with the help of the polygon mark (Fig. 3 and 4). The detected garbage landfills in Kyiv city and the adjacent 20-kilometer area in the amount of 30 units are saved on the local disk as marks.

Further processing of the data involved the insertion of a shape-file into the QGIS software environment (QuantumGIS – a free cross-platform geographic information system) for transforming from a vector layer to a raster (rasterization). The preliminary steps are required to perform the sample, which involves segmentation (clustering) and classification (grouping) of satellite imagery.

According to the Google Earth software, the following characteristics of MSW landfills and dumps on the territory are investigated: perimeter and area of the landfill or dump, changes which occur in the dynamics (for a certain period of time), perimeter and area of ecological destructive influence, distances to residential buildings and agricultural land.

According to data of satellite (a fragment of the satellite map is depicted in Fig. 3), it is defined that the actual area of MSW landfill № 5 in Pidhirtsi village, Obukhiv district, Kyiv region is 80 ha, while officially documented only 63.7 ha [18].

The distance from the landfill to the residential zone is 450 m and to the cultivated agricultural land is 700 m.

Fig. 3. Cartographic image of MSW landfill № 5 in Pidhirtsi village of the Kyiv region

Our calculations according to the formula (1) show that the total area of unsuitable for agricultural use and the residence of population is 317 ha. The area of ecologically destructive influence of landfill on the residence of population and agricultural land is 3857.0 ha.

Similar researches on the construction waste landfill № 6 showed that it is located within the city of Kyiv in the Holosiivskyi district not far from residential micro districts and has an area of about 20 ha according to the satellite (Fig. 4), while according to official documents is 11.6 hectares [18].

It is established that the waste have significant part of domestic garbage that is not specified in the operational documents. Domestic waste and scrap metal continues to deliver to landfill. The active use of the polygon illustrates the dynamics of growth of garbage and changes in its surface. However, there are no waste utilization and aeration systems. The area near the landfill is an industrial zone and is guarded.

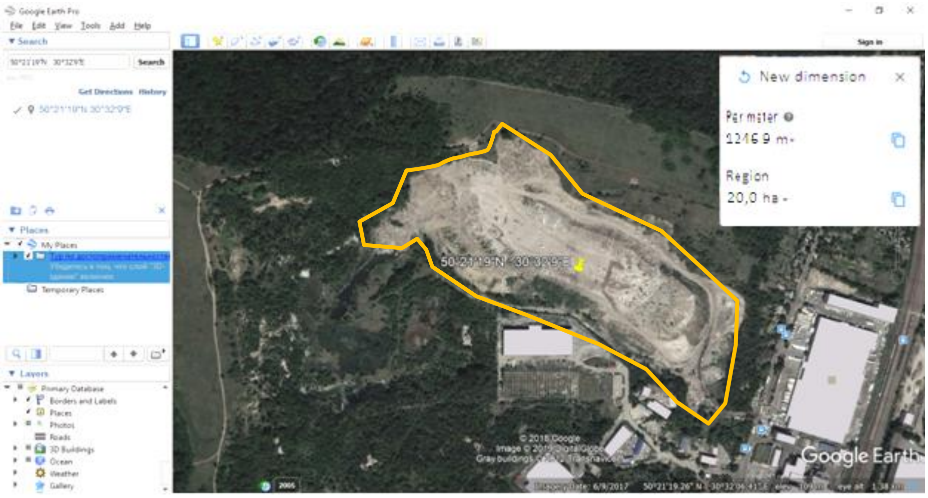


Fig. 4. Cartographic image of landfill of construction waste № 6 in Kyiv city

It should be noted that slightly distant of landfill № 6 to residential districts is only 200 m (while this distance for landfills with domestic waste should be at least 500 m according to state design standards and to the city is 1 km). Taking into account the significant share of domestic waste at the landfill, the total area of unsuitable for agricultural use and residence of the population is, according to our estimates, is 177.8 ha.

Taking into account the negative influence of the polygon on the ecosystem, the conditions in the surrounding areas like the village Korchuvate, the National Museum of Folk Architecture and the open-air "Pirogovo" and other neighbor districts are unfavorable for residence and for rest of population. The ecologically destructive influence of this large storage landfill of construction and other wastes extends to the whole Holosiivskyi district, which is not only densely populated, but also due to the location of the Holosiivskyi Park and the wide forest with lakes, the Natural Park of Feofania, the National Exhibition Center, a number of religious shrines, is an attractive place for the rest Kyiv citizens and guests of the capital. In addition, this area is widely positioned as an ecologically clean area. Therefore, the landfill № 6 does not contribute to the confirmation of the eco-image of this district.

It is annually formed about 1.7 million tons of waste of I-IV classes of danger in Kyiv, from which 258.6 thousand tons are burned, that is, only about 16%, the rest is accumulated in specially designated places for storage, that is, at the landfills [17].

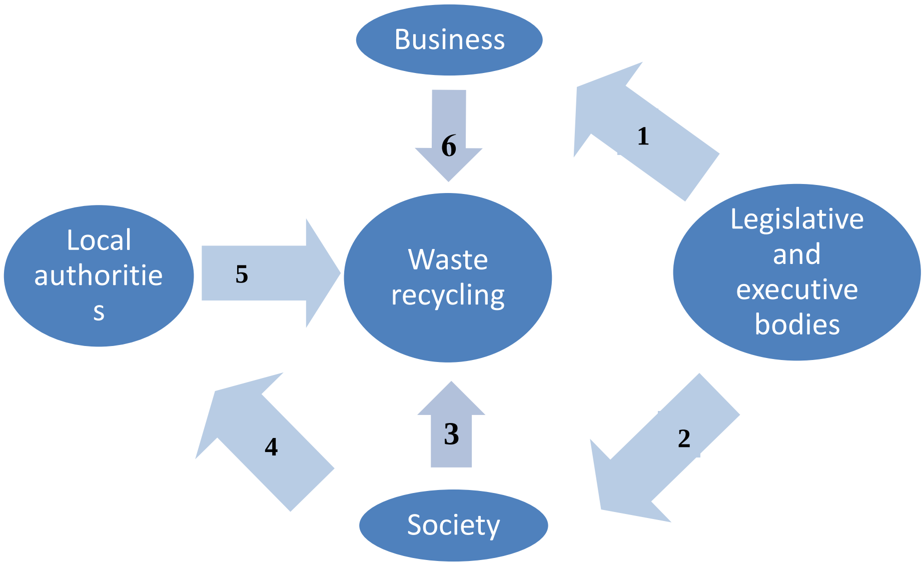
According to satellite data, 30 landfills and dumps in Kyiv city and at a distance of 20 km from the city cover an area of over 160 ha. According to our calculations (formula 1), the area of intense pollution around landfills is 462.6 ha, and the area of ecologically destructive pollution is 4330.8 ha. It is obvious that low-yielding, unsuitable for agrarian use land were allocated under the garbage landfills, but the negative influence of these landfills and spontaneous landfills extends to adjoining cultivated agricultural lands and areas of population residence.

3.2. Participation of stakeholders and its functions in the processing of domestic waste

The prevalence of waste storage/disposal in Ukraine doesn't accord to European practice and doesn't approve by international community according requirements for proper waste management. In particular, European Union strive to process over 20% of plastic by 2030, and to make all packaging plastics easily processed (currently 65% are processed) or reused.

For a long time, the task of waste management in the country is urgent. According to this aim, it is necessary to develop and purposefully implement the relevant organizational and economic mechanism, with the involvement of GIS data and a defined sequence of actions of so subjects as waste producers and other stakeholders.

A wide range of stakeholders should be involved in setting up the garbage processing with their functional responsibilities (Fig. 5).



Designation in the scheme:

1. Introduction of the land market, the abolition of VAT on the import of garbage processing technologies, the abolition of the profit tax for garbage processing enterprises

2. Informing the public about the state of the environment using GIS, introducing penalties for non-sorting of domestic waste

3. Garbage sorting

4. Public control over the activities of local authorities, definition of characteristics of enterprises for the processing of garbage

5. Allocation of areas for storage and garbage processing on the basis of GIS observations

6. Investing in garbage processing

Fig. 5. Participation of stakeholders in the garbage processing

The following sequence of actions for improvement of domestic waste processing is offered:

1) A media advocacy company (television, radio, internet) which explains the benefits of waste sorting and waste management options. At the same time, it is important to demonstrate clearly the data of satellite observations about the danger of dumps near the cities and villages for the life of its inhabitants and for the quality of agricultural land;

2) Implementation of ecological tax for the population;

3) The combination of both of the above measures (i.e., a part of society will sort domestic waste in accordance with the established procedure, and the other – will pay penalties at sufficient quantity for the cost of sorting garbage).

Since Kyiv, due to the large number of citizens, higher levels of their income and consumption, produces a large amount of garbage per person, then it is advisable to start implementation of sorting system and further processing of domestic waste exactly in this city. It is necessary to build a modern complex of waste processing which will be based on recycling. As experience of European countries shows, the average level of profitability of MSW utilization plants is at the level of 3%. Other settlements will support the initiative to organize the sorting and processing of waste if the company is successful.

The components of the growth function of the public welfare from the implementation of the recycling and investment system in the processing of waste can be calculated by the formula:

$$\Delta W = \Delta W_1 + \Delta W_2 + \Delta \mathrm{W}_3 + \Delta W_4, \quad (3)$$

where,

ΔW_1 – improvement of the health of the population due to improvement of environment;

ΔW_2 – increase due to the production of qualified agricultural products from territories without influence of dumps because of taken actions;

ΔW_3 – the cost of raw materials which are produced by waste processing enterprises;

ΔW_4 – increase of employment

Offered components for calculating the growth function of the public welfare are readily quantified and reflect the bulk of the effect of society on the establishment of system for processing of domestic waste.

The efficiency of utilization of waste by processing it from the standpoint of public welfare is equal to:

$$Ew_{/s} = \frac{\Delta W}{\Delta S}, \quad (4)$$

where,

ΔW – growth function of the public welfare;

ΔS – increase of expenses for waste processing.

Increase of expenses in the case of utilization of waste by proper processing is equal to the sum of components:

$$\Delta S = \Delta S_1 + \Delta S_2 + \Delta S_3 + \Delta S_4 \quad (5)$$

where,

ΔS_1 − increase of time expense by population for waste sorting (monetary equivalent);

ΔS_2 − conducting a company to inform the mass media about advantages to introduce garbage utilization by its processing;

ΔS_3 − additional technique expenses;

ΔS_4 − investments in garbage processing (the acquisition of equipment and technology).

According to the current prevailing practice of waste storage, growth function of public welfare is negative: the state of environment, the health status of inhabitants of villages and cities in the places of the location of garbage landfills deteriorates; areas where high-quality agrarian products can be produced are reducing.

For example, according to calculations, investing of garbage processing is $ 1 million that leads to growth function of the public welfare only at the expense of growing volumes of agricultural production by 4.4 million dollars [19]. Such effect can be received from one component of the public welfare function due to investing of waste processing. Calculations of growth function of the public welfare for other mentioned components are the subject of further research of the authors.

4 Conclusions

Modern tools of geographic information systems, and in particular the Google Earth software, provide opportunities for identifying official waste landfills and spontaneous dumps, identifying its characteristics and defining the territory of ecologically destructive influence.

Using the Google Earth tools capabilities, it was formed the information base of the identified 30 official waste landfills and spontaneous dumps on the territory of Kyiv and in the 20-kilometer suburban area. Its actual area (total 160 ha), the distance to residential buildings and the dynamics of changes have been identified. Relying on its own methodological approach, it is defined that the area of intense pollution around dumps that is unsuitable for residence development and growing of crops within the boundaries of Kyiv and the suburbs is in 2.9 times bigger the area of dumps, and the area of its ecologically destructive influence on the environment and residence of the population is in 27 times.

According to cartographic images from the satellite it was exceeded that the actual area of waste landfills and dumps is above the documented area.

Geospatial systems and geospatial analysis should be widely used in many spheres of life. Using it, the authors formed an information base about available official MSW landfills and spontaneous dumps and its actual characteristics. This research material demonstrates and proves the importance of changes in the field of waste management in Ukraine, namely, transition from the storage of domestic waste to its processing.

References

1. Aronoff S.: Geographic information systems: A management perspective. Geocarto International. 4(4), 58-58 (1989). doi: 10.1080/10106048909354237
2. Shokin Y.I., Potapov V.P.: GIS today: state, perspectives, solutions. Computational technologies, 20(5), 175-213 (2015).
3. Sianko, N., Small, M.: The future of GIS in social sciences. Kontakt 19(3), e157-e158 (2017). doi: 10.1016/j.kontakt.2017.08.001
4. VoPham, T.: GIS&T and Epidemiology. Geographic Information Science & Technology Body Of Knowledge, 2018(Q1), (2018). doi: 10.22224/gistbok/2018.1.1
5. Paientko T. Geographic Information Systems: Should They Be Used in Public Finance Reform Development? CEUR Workshop Proceedings, vol. 2104, 233-242 (2018) (Indexed by: Sci Verse Scopus, DBLP, Google Scholar). Available: http://ceur-ws.org/Vol-2104/
6. Zhou, W.: Applications of GIS and remote sensing in landslide hazard assessment. Journal Of Remote Sensing & GIS, 07 (2018). doi: 10.4172/2469-4134-c1-010
7. Niska, H., Serkkola, A.: Data analytics approach to create waste generation profiles for waste management and collection. Waste Management, 77, 477-485 (2018). doi: 10.1016/j.wasman.2018.04.033
8. Gottinger, H. W.: Economic models and applications of solid waste management. Routledge (2018).
9. Saldarriaga, J.F., Gallego, J.L., López, J.E. et al: Waste Biomass Valor (2018). https://doi.org/10.1007/s12649-018-0208-y
10. Matsuda, T., Hirai, Y., Asari, M., Yano, J., Miura, T., Ii, R. Sakai, S.I.: Monitoring environmental burden reduction from household waste prevention. Waste Management. 71, 2-9 (2018). doi: 10.1016/j.wasman.2017.10.014
11. Trysnyuk, V., Novokhatska, N., & Radchuk, I.: Geo-information Technologies for Decision Issues of Municipal Solid Waste. Journal of Environmental Science and Engineering. A 3 (3A) (2014.)
12. Clark, R.N., Swayze, G.A., Livo, K.E., Kokaly, R.F., Sutley, S.J., Dalton, J.B., McDougal, R.R., Gent, C.A.: Imaging spectroscopy: Earth and planetary remote sensing with the USGS Tetracorder and expert systems. Journal of Geophysical Research-Planets, 108 (E12) (2003).
13. Domanska M.V., Bodnar S.P.: Identification of unauthorized dumps due to data of remote sensing. Cartography magazine 7, 114-126 (2013).
14. Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R. : Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18-27 (2017). https://doi.org/10.1016/j.rse.2017.06.031
15. Keyhole Markup Language. Google Developers. (2019). Retrieved from https://developers.google.com/kml/
16. SCN V.2.4-2-2005 "Polygons of municipal solid wastes: main provisions of design" (2015). Retrieved from http://media.voog.com/0000/0036/1658/files/%D0%94%D0%91%D0%9D_%D0%92.2.4_2-2005.pdf
17. State Statistics Service of Ukraine (2019). Retrieved from http://www.ukrstat.gov.ua/

18. Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine (2019). Retrieved from http://www.minregion.gov.ua/
19. Skripnik, A. V., Mihno, I. S.: Domestic waste management from the standpoint of public welfare. Problemy Ekonomiky, 3 81-88 (2016).