Theoretical and practical recommendations on selection of municipal solid waste landfill sites with the subsequent reclamation of disturbed lands in the Konstantinovskiy District, Amur Region

E V Popova and G A Stekolnikova*

Far Eastern State Agrarian University, 86, Politeknicheskaya Street, Blagoveschensk, 675005, Russia

*E-mail: gala76.08@mail.ru

Abstract. The study in hand confirms that the basic strategy of MSW management is landfilling, not recycling. Drawing from the results of the dimensional multiple factor analysis of region-specific characteristics, the authors provide recommendations on selecting MSW landfill sites and their subsequent reclamation for the Konstantinovskiy District, Amur Region.

1. Introduction

In recent years, the volume of municipal solid waste generated both in Russia and worldwide is steadily increasing. This is due to population growth and manufacturing development. The improper collection, untimely disposal, and unsatisfactory neutralization of the resulting municipal and industrial waste create a negative environmental impact, contributing to the pollution of air, land, surface water, and groundwater. Over the last few decades, waste management has become one of the most pressing global environmental issues, however, no country has managed to resolve it completely [1]. Studies of MSW recycling practices in different countries show that a universal method meeting modern requirements in terms of environmental protection, cost efficiency, sustainability, and market demands, has yet to be developed [2, 3, 4].

Having analyzed the MSW disposal and recycling system established in the Russian Federation, we can conclude that the basic MSW management strategy in this country is landfilling, despite the fact that this is the least desirable approach which causes a lot of environmental, sanitary and hygienic problems [5, 6, 7]. However, it will continue to be the most widespread method in the long term. For this reason, waste burial sites are carefully designed as engineering and environmental facilities integrated with larger natural/anthropogenic complexes. Waste storage is allowed only at specialized facilities (landfills that meet legal requirements or open dumps) and only on lands allocated for industrial or special use. In other cases, rezoning and reclamation of lands are required.

The purpose of this study is to develop theoretical and practical recommendations on selecting plots of state or municipal lands for municipal solid waste landfills and their subsequent remediation.

2. Methodology and Research Methods

An MSW landfill placement is a complicated process based on assessment of many different criteria. This process combines a number of environmental, economic, and social factors. Due to a wide variety
of methodologies available in this area of research, it is impossible to choose a single flexible one that can be adapted to basic premises of each specific task [8, 9].

Having studied the approaches to site selection for waste management facilities developed by foreign researchers and the current requirements for such facilities in Russia, we implemented the methodology which includes three consecutive decision-making stages. The diagram of these stages is presented in figure 1.

![Figure 1. Methodology for selecting an MSW landfill site.](image)

The suggested methodology can be used by governments of constituent entities of the Russian as a supporting decision-making tool during the selection of sites for waste management facilities and development of regional waste management programs.

3. Research Findings

The Konstantinovskiy District is located in the south of the Zeya-Bureya Plains of the Amur Region. It borders on the Tambovskiy District in the northwest and north, on the Mikhailovskiy District in the east, and on the state border with China in the south. The area of the Konstantinovskiy District is 1.8 thousand km².

The main production sector of the municipality is agriculture. 87.7% (159,407 hectares) of lands are under agricultural use.

In compliance with the Federal Law No. 89-FZ "On Production and Consumption Waste" dated June 24, 1998, the Government of the Amur Region approved a Regional Program for Waste Management for 2018–2028, which covers MSW management in the specified territory. As a result, all municipalities were divided into five clusters depending on the area of operations of the responsible waste management company.

The Konstantinovskiy District belongs to Cluster 3 and includes 11 municipalities with 15 settlements. The number of citizens in each settlement varies from 326 to 5,296 people in the administrative center of the Konstantinovskiy District — Konstantinovka Settlement.

During the survey of the study area, we identified 14 unauthorized open dumps with production and consumption waste of hazard classes IV–V. The total area of dumps is 327,422 m²; they are mainly located on agricultural land.

When selecting land plots suitable for landfill placement, the location of authorized open MSW dumps and temporary waste accumulation sites is taken into account. The number and the area of landfills are directly dependent on several factors, such as remoteness, geometric characteristics of settlements, and population size. In connection with the studied characteristics of the Konstantinovskiy District, it is necessary to set up 3 facilities for waste accumulation: a temporary MSW storage site (Landfill #1) with a total area of 75,969 m², a waste sorting site with thermal disinfection (Landfill #2) with an area of 8,761 m², and a waste incineration plant (Landfill # 3) with an area of 6,588 m² (figure 1). These land plots comply with the selection criteria at each stage. All prospective sites for MSW landfills undergo the subsequent multiple factor analysis [8].

It should be noted that the proposed land plots for waste accumulation of waste are not located within territories with special conditions for use.
Figure 2. Location of unauthorized open dumps and temporary MSW landfills in the Konstantinovskiy District, Amur Region.

To justify the projected area of the land plot allocated for the MSW storage, we estimated the designed capacity of the landfill on the basis of standards for municipal waste accumulation approved for the Amur Region [6].

The calculation is based on the specific generalized annual MSW accumulation standard per citizen (including MSW from institutions and organizations), the number of citizens served by the landfill, the estimated service life of the landfill, and the degree of MSW compaction at the facility.

Following the recommendation to construct 3 temporary municipal waste landfills in the Konstantinovskiy District, an assessment of the incoming MSW amount depending on the location of settlements has been carried out (table 1).

| Landfill #1 | Landfill #2 | Landfill #3 |
|-------------|-------------|-------------|
| MSW, accum. standard | MSW, incoming volume | MSW, accum. standard | MSW, incoming volume | MSW, accum. standard | MSW, incoming volume |
| 218,110.98 | 204,071.9 | 49,764.87 | 47,365.787 | 49,573.63 | 46,686.63 |

The most significant incoming amount of municipal waste is registered for Landfill #1 — 204,071.9 kg per year, or 93.6% of the accumulation standard. The minimal MSW amount is expected at Landfill #3 — 46,686.63 kg per year, or 94.1% of the accumulation standard.

Cadastral works for the formation of a land plot for a municipal solid waste landfill is a rather lengthy process which requires careful study of additional materials. An increase in the volume of municipal solid waste typically disposed of at unauthorized landfills usually drives local governments to find economic reserves and carry out these works, since landfill formation is necessary measure for further curtailment of environmental pollution.

Such cadastral works are carried out in accordance with the requirements of federal laws and involve preparation of a package of mandatory documents for the state cadastral registration. These works can be of the following types:
— formation of part from the land plot;
— formation of a land plot by splitting, with the preservation of the original land plot in the changed boundaries;
— correction of a registry error in the determination of boundaries and the area of the land plot.

Next, we discuss reclamation measures for lands disturbed after the formation of unauthorized open dumps and allocation of land plots for temporary landfills.
Reclamation of disturbed lands under such sites includes technical and biological stages. In the future, these territories will be used in accordance with their original category and permitted use — for growing agricultural products [10, 11]. It is also necessary to complete cadastral works to restore the original zoning and be able to take measures aimed at reclamation of the fertile layer of disturbed land plots that will be used for cultivating crops. The main activities of the technical stage of the disturbed land reclamation are listed in Table 2.

**Table 2. Activities for technical reclamation of land under unauthorized open dumps (necessary works and execution time).**

| No. | Activities                                           | Scope of works | Execution time, workdays |
|-----|-----------------------------------------------------|----------------|--------------------------|
| 1   | Removal and transportation of production/consumption waste | 298.1 tons     | 5                        |
| 2   | Removal and transportation of contaminated surface soil layer (not less than 0.1 m) | 39,290.6 tons  | 76                       |
| 3   | Transportation and application of a potentially fertile soil layer (the thickness of this soil layer after shrinkage should be at least 0.5 m) | 196,453 tons   | 378                      |
| 4   | Transportation and application of filling fertile soil layer (thickness of this filling fertile soil layer after 117,871.8 tons shrinkage should be at least 0.3–0.4 m) | -              | 227                      |
| 5   | Leveling and compaction of the restoration site      | 327,422 sq. m  | 28                       |
| 6   | Total                                                | -              | 714                      |

Over the next 4 years after the technical stage, the biological stage should be completed. It includes a set of agrotechnical and phytoreclamation measures for the restoration of the territory and involves such works as selecting an assortment of perennial herbs, soil preparation, sowing, and crop tending. Measures for biological restoration of disturbed land plots under unauthorized open dumps and temporary landfills are implemented in the subsequent years (see Table 3).

**Table 3. Activities for biological reclamation of the disturbed land plot.**

| №   | Activities                                      | Execution time, optimal calendar period | Note                                                                 |  |
|-----|-------------------------------------------------|------------------------------------------|----------------------------------------------------------------------|---|
| 1   | Harrowing of the reclamation site               | End of April–beginning of May            | if possible, with the use of equipment                                |   |
| 2   | Sowing of the first-level grasses                | End of April–beginning of May            | To a depth of 2 cm                                                   |   |
| 3   | Roller compaction                               | -                                        | Light rollers                                                        |   |
| 4   | Herbage mowing, 2–3 times during the growth season | After the completion of grass sowing     | At a stem height of 30–40 cm, the chopped herbage should be left on the land plot |   |
| 5   | Roller compaction, undersowing if necessary     | As it grows                              | After the last mowing                                               |   |
| 6   | First-year wintering                            | -                                        | -                                                                    |   |
| 7   | Tending after first-level grasses in their second year of life involves herbage mowing | End of August–beginning of September     | At a stem height of 30–40 cm, the chopped herbage should be left on the land plot |   |
Roller compaction

As it grows

After the last mowing

9 Second-year wintering

Third period (stage), two calendar years

Treatment with a basic mixture of herbicides: Tornado — 3 liters per ha

When weeds appear on the plot

Applied to vegetative plants, the next treatment is after 14 days

10 Disking, harrowing, roller compaction

Beginning of July—end of July

With available tools

12 Sowing of basic grass mixtures

After completion of activities

A grass seeder is used, or the seeds are sown manually with a uniform distribution over the plot

13 Roller compaction

After completion of activities

in Item 11

Light rollers

14 Tending after basic grass mixture crops

As they grow

Mowing, the chopped herbage should be left on the plot

15 Third-year wintering

As they grow

Mowing, the chopped herbage should be left on the plot

16 Tending after basic grass mixture crops

17 Fourth-year wintering

We have calculated the cost of materials used for recultivation and restoration of the biogeocenosis disturbed after the formation of unauthorized dumps and the territory allotted for their temporary storage.

The estimates are based on the standard specifications of agricultural processing technologies and on the average prices of natural products in the Amur Region. The obtained results are summarized in tables 4 and 5. It should be noted that these estimates are not final, since both the market pricing and amount of materials may change in the course of works.

### Table 4. Baseline calculation of the cost of materials used in reclamation of land under unauthorized open dumps.

| №  | Material                  | Cost, rubles per ton | Seed application rate, kg per ha | Necessary to purchase, tons | Total cost, thous. rubles |
|----|--------------------------|----------------------|---------------------------------|-----------------------------|-------------------------|
|    | Filling substances       |                      |                                 |                             |                         |
| 1  | Ground (soil)            | 3,000                | -                               | 11,787.2                    | 35,361.6                |
| 2  | Garden soil (humus)      | 6,000                | -                               | 19,645.3                    | 117,871.8               |
|    | Grass seed               |                      |                                 |                             |                         |
| 1  | Melilot                  | 31,200               | 6-8                             | 0.26                        | 8,122.0                 |
| 2  | Common meadow grass      | 20,800               | 100-150                         | 4.91                        | 10,2128.0               |
| 3  | Timothy grass            | 20,800               | 8-10                            | 0.33                        | 6,864.0                 |
| 4  | Meadow fescue            | 20,800               | 8-15                            | 0.49                        | 10,192.0                |
| 5  | Awnless brome            | 20,800               | 12-17                           | 0.56                        | 11,648.0                |
|    | Total for 5 years of works |                     |                                 |                             | 292,442.4               |

Thus, according to the data presented above, the estimated cost of materials needed for reclamation of land under unaccounted dumps and temporary landfill sites amounts to 292,442.4 thousand rubles and 892,009,3 thousand rubles respectively.

It is possible to estimate the service life of each landfill. Reconciliation of documents and construction usually take up to 3 years. A landfill is operated for 25–30 years, 10 years is needed for
reclamation. Thus, the full lifecycle is about 38–43 years.

Table 5. Baseline calculation of the cost of materials used in reclamation of land under temporary MSW landfills.

| Material                  | Landfill #1 | Landfill #2 | Landfill #3 | Cost, rubles per ton | Seed application rate, kg per ha |
|---------------------------|-------------|-------------|-------------|----------------------|----------------------------------|
| Area, sq. m               | 75,969      | 15,969      | 18,889      |                      |                                  |
| Ground (soil)             | 22,790.7    | 4,790.7     | 5,666.7     | 3,000                |                                  |
| Garden soil (humus)       | 37,984.5    | 7,984.5     | 9,444.5     | 6,000                |                                  |
| Total cost, thous. rubles | 296,279.1   | 62,279.1    | 73,667.1    |                      |                                  |
| Melilot                   | 0.038       | 0.008       | 0.009       | 312,000              | 6-8                              |
| Common meadow grass       | 1.140       | 0.240       | 0.283       | 208,000              | 100-150                          |
| Timothy grass             | 0.076       | 0.016       | 0.019       | 208,000              | 8-10                             |
| Meadow fescue             | 0.114       | 0.024       | 0.028       | 208,000              | 8-15                             |
| Awnless brome             | 0.129       | 0.027       | 0.032       | 208,000              | 12-17                            |
| Total cost, thous. rubles | 315,328     | 66,352      | 78,104      |                      |                                  |
| Total for 5 years of works: |           |             |             | 892,009              |                                  |

4. Conclusion

Summing up all of the above, we can say that, in order to preserve the environment, the construction of landfills for municipal solid waste, MSW recycling and disposal for further reduction in pollution should be one of the priority tasks at all levels (federal, regional and municipal).

Application of dimensional multiple factor analysis in the selection of MSW landfill sites provides for optimal combination of social, economic, and environmental criteria of a specific region.

Reclamation ensures further use of restored lands in accordance with their original category and the intended purpose.

Over time, landfills become part of the geological landscape and begin to operate according to the laws of geological development. This process takes place in a limited timeframe and is influenced by many natural processes.

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