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Geological factors in solid waste landfill site selection

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Abstract

It is possible to define all kinds of substances and materials that become useless as a result of human activities and do not contain enough liquid to be fluid, as "solid waste". This definition includes all sweepings and garbage generated in houses, streets, parks and institutions, solid wastes and wastes resulting from commercial agricultural and industrial activities, and sludge produced in water and wastewater treatment plants. Problems arising from solid wastes, which is one of the important environmental problems of our country, are increasing in parallel with the increasing population, and the necessity of landfills has gained importance in terms of environmental and human health. Solid wastes are generally disposed of through incineration, composting, recycling or landfill. The landfill is an integrated management system that includes the transportation of domestic solid wastes in accordance with the legislation, regular storage, sterilization of medical wastes, leachate treatment and storage gas disposal, and incineration system components. Many criteria are taken into consideration when selecting solid waste landfill sites. During the site selection, the preparation of thematic maps by examining the geological, hydrogeological, and hydrological characteristics of the area in detail is included in the field of geology. Within the scope of the investigation, the importance of geological factors in the selection of solid waste landfill sites was examined and their importance was stated within the scope of sustainable environmental protection.

1. Introduction

Solid wastes are collected in two main groups as medical and chemical wastes which consist of toxic substances and products, and domestic wastes (garbage). The disposal of solid wastes consisting of toxic chemical products requires very special scientific studies and legal regulations. Since storing and isolating them may cause new problems, rendering them harmless by incineration and chemical processes is seen as the most rational approach. Domestic solid wastes consist of domestic wastes from houses in residential areas, plant wastes from parks, gardens, and green areas, treatment sludge obtained from domestic wastewater treatment plants, excavation soil, and construction debris [1].

From ancient times to the present, people have used natural resources to sustain their lives. The disposal of wastes generated in this way did not pose a significant problem for a long time, since the population was low and the land required for the wastes to be absorbed in their natural environment was sufficient [2-6]. Problems related to the disposal of waste have emerged with the gathering of people in large and small communities such as tribes and villages, and the accumulation of waste, which is a part of life [7].

In the 1900s, waste was stored and burned at random places. With urbanization, industrialization, and rapid population growth, the negative effects of waste collection and incineration on the environment and human health have begun to be seen. As a result, methods such as incineration, composting, recycling, or landfilling have been developed for the disposal of solid wastes. Methods, except the last one, are not exact methods for eliminating all the waste. These methods aim to provide economic benefit from wastes. Landfilling is the only way to get rid of the waste completely. All kinds of solid waste can be safely stored in Regular Solid Waste (Garbage) Landfills built in accordance with technical standards. For this reason, there must be at least one Solid Waste Storage Area in all settlements. If the Solid Waste Storage Areas are not selected correctly and built-in accordance with the standards, it may cause irreparable problems in the future (Figure 1). Especially if the wastes come into contact with the groundwater, the effects can continue for 30 to 40 years even if the contact has disappeared. For this reason, the landfill site selection should be made after a serious examination and the Storage Facility should be built in a way that includes the issues specified in the Solid Waste Regulations [8-9].

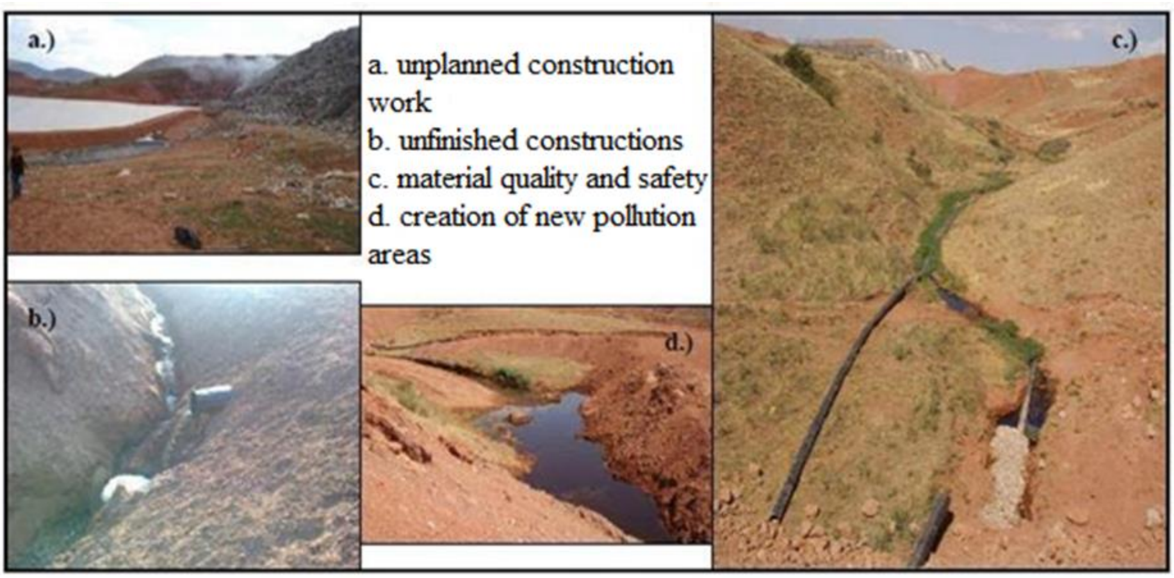

Figure 1. The view of the problems that arise during the construction of a landfill area in pictures a, b, c, d [9]

The first and most important step in the regular storage of Solid Wastes begins with the selection of the appropriate location. The issues that need to be carefully considered in the selection of the appropriate place are as follows:

A. It should not be in the recharge basin of water collection centers for drinking, use, or irrigation purposes.
B. Groundwater should not approach the water table floor level more than 10 meters.
C. The drainage system should be an outward-facing area, where surface water accumulates at least.
D. It should not be an active fault, debris, landslide, avalanche, overflow, and erosion risk areas.
E. The ground should consist of solid, less permeable rocks that geologically and geotechnically suitable.
F. The traffic density should be low, especially away from the main artels.
G. It should be at least visible from the surrounding area, away from the main recreation areas of the city.
H. The storage capacity should be at a level to meet the city's minimum 30-year needs.
I. There should be an area where the clay raw material to be used to seal the top and bottom of the wastes can be easily obtained.
J. It should be open to main air currents in accordance with meteorological conditions.
K. An Environmental Impact Assessment report should be available according to the storage capacity (ONEIA if it is less than 100 tons per day, EIA if it is larger).

Today, most of the garbage collected by the municipalities is haphazardly piled up on the fields created without any precautions and thrown away. While the municipalities, which allocate 40% of their budgets to cleaning expenses, fulfill the duties assigned to them in solid waste management in collecting and transporting, they do not show the necessary importance in evaluation and disposal. Especially the mistakes made in the selection of the "Wild Storage" fields for disposal and the negativities in the operating conditions cause growing problems day by day [10].

The rapidly increasing population and changing living standards make it difficult to control and manage wastes by increasing the volume of waste and diversifying the waste composition. Solid waste management is becoming increasingly important and complex due to the current and potential risks of solid wastes, the reduction of natural resources, economic and other reasons. For this reason, it is necessary to know the elements of integrated solid waste management that include all stages from waste generation to final disposal and their relations with each other (Table 1) [11-12].

Table 1. Suggested methods for determining solid waste storage areas

Karaguzel and Mutluturk [13]	Costa and Ryan [14]	Dörhöfer and Siebert [15]
1. Waste Inventory a. Characteristics of trash to be stored b. Waste amount c. Disposal method **2. Location Selection** a. Geology of the Site b. Hydrogeology of the Site c. Drilling d. Permeability tests e. Meteorological Condition f. Aquifers and Aquitares g. Ground-water **3. Control Systems** **4. Storage Technique**	**1. Geology of the Region** **2. Industry** a. Liquid Waste Production b. Liquid Effect c. Environment d. Geomorphology and Hydrology e. Geology f. Hydrogeology **3. Soil and Water Pollution Studies** **4. Field Studies** a. Field Work Program b. Waste Zones c. Waterways	**1. Site Selection Process** a. Geological Studies b. Hydrogeological Studies c. Mapping positive and negative areas **2. Regional Planning Process** a. Geological Routing Surveys b. Selection of Alternative Region / or Regions c. Effective Environmental Studies, Conferences **3. Permission Process** a. Detailed geological study of the area b. Ground-Water studies c. Climate d. Environment **4. Geological Planning Surveys**

The importance of geological factors cannot be overlooked in the conditions of suitable site selection mentioned above. Geological factors such as surface and underground waters, rock structure, active fault, debris, landslide, avalanche, flood, and erosion risk are particularly important in the selection of solid waste storage areas. Examining these factors and specifying their importance in choosing a suitable site constitute the basis of the research scope.

2. Wastes and Geological Factors

Solid waste occurs as a natural consequence of human life. In parallel with the increasing population and developing technology all over the world, there has been a serious increase in the amount of waste produced by people. Primitive methods applied for the disposal of these wastes threaten human health directly or indirectly. It has become a necessity to use modern technologies in order to minimize the damages caused by solid wastes to humans and nature [13].

Solid waste landfill site selection studies consist of three stages in geological terms. In the first stage, thematic maps are prepared by examining the geological, hydrogeological, and hydrological characteristics of the study area in detail. Since the storage facility is planned to be designed to meet the needs of the region for 50 years, a population projection and waste inventory are prepared to determine the area that will be needed in the construction of the facility. Conservation areas and land use status maps of the basin are also prepared and overlaid with other thematic maps in the computer simulation to obtain a synthesis map showing the regions that are suitable and unsuitable for the construction of facilities belonging to the basin. Alternative areas are determined on the synthesis map prepared in the second stage, taking into account the morphological features suitable for the placement of the facility units. In the third stage, the most suitable area for storage is determined among the alternative areas.

Table 2. Evaluation of alternative areas in solid waste landfill site selection

Criteria	Coefficients	The goodness of the Field Relativity	The score of the Field		
	5= most important 1= least important	3 increasing goodness ↑ 2 1			
Sample:			1st Field	2nd Field	3rd Field
Ground-water depth		3	15		
		2		10	
		1			5

These coefficients range from 1 to 5 and are graded as 1: least important, 2: less important, 3: important, 4: very important, 5: most important. In addition, alternative fields are ranked as 1, 2, 3 relatively to each other according to their goodness for each criterion (3: best, 2: less good, 1: least good). The score of each field from any criterion is determined by the product of the field's number in the ranking and the relevant criterion coefficient. Alternative fields are scored in this way according to each criterion. The alternative area with the highest total score is selected as the most suitable area for storage. In the last stage of the study, engineering geology studies are carried out for the design of the storage facility [16-17].

Table 3. Criteria used in solid waste landfill site selection and their coefficients

Assessment Criteria	Coefficients
Geological Suitability	
- Structural Feature	
- Fault Status	5
- Seismic Impact Zone	4
- Stratigraphic Feature	3
- Contact Relations	3
- Availability of impermeable cover materials	4
Hydrogeological Compatibility	
(Distance to inland surface waters from which drinking and utility water is supplied)	
Distance to lake	5
Distance from streams, springs, etc.	4
Floodplain	4
Geotechnical Compatibility	
Properties of the bedrock	4
Permeability of the soil	5
Ground type	5
Sensitivity of the area	3
Environmental Conditions	
Availability of sufficient space for plant construction and expansion if needed	5
Land use status	3
Protected areas	4
Distance to settlements	4
Suitability of topography	4
Airport security	2
Wind direction	4
Aesthetic	4
Economic Conditions	
Leveling Cost	3
Availability of roads for transportation	3
Distance to waste source	3
Ownership status of the land	2
Infrastructure status	2

2.1. Geological Criteria

Geological conditions are the most important factor in determining the environmental suitability of a storage area. Using geological survey maps and regional geological information is especially important in the initial identification of alternative sites. It is very important to determine the three-dimensional distribution of the natural unit underground, which will form the ground of solid waste landfills. Geological sections should be drawn by determining the distribution of bedrock by drilling.

In geological studies, potential groundwater flow, flow direction, and groundwater level measurements can be made with drillings. Interpretation of aerial photography is also often of great benefit. Flood, avalanche, landslide and erosion zones, floodplains, earthquake-affected zones, marshes, fault zones should be investigated very well with geological studies [18].

2.2. Earthquake Condition

The stability of landfills is an important issue since they are complex structures. Stable landfill design is possible by understanding mechanisms such as settlement, slope stability, and seismic behavior. Storage sites in earthquake zones must be safe against landslides not only under static conditions but also under seismic conditions. Deformations in clay pavements or geosynthetic pavements will cause leaching and thus groundwater contamination. At the same time, fractures or ruptures in the leachate collection pipes and gas collection pipes reduce the usage performance of the landfill. Due to the heterogeneous nature of the waste, settlement, slope stability, and seismic behavior are different and more complex than the ground. Mechanical properties of ECCs, such as strength and compressibility, depend on the composition of the waste, the mechanical properties of the components of the stored material, the water content, and the effect of degradation [19].

The distance of the alternative areas to the active faults, the earthquake history of these areas, and the intensity of the possible earthquakes should be investigated very well. As much as possible, solid waste storage areas should not be built in earthquake-active areas. The solid waste storage area built in such a region may cause serious environmental problems and are very difficult to remove after the earthquake.

2.3. Geotechnical Conditions (Soil Conditions)

In addition to regional and terrestrial geology, determining the kind of material and the method to work within geotechnical conditions is an indispensable work. Research pits and core drilling wells should be performed at the points determined by the observations made from a geological study. Thus, the three-dimensional distribution of the floor that will form the warehouse floor can be determined.

Disturbed and undisturbed samples will be taken from the underground material through pits and drillings, and all necessary experiments will be carried out on these samples in the laboratory. In addition, it is possible to conduct various experiments in drilling and research pits, in the field, and at the wellhead.

These experiments are;

Field Tests: SPT Test, Pressurized water test, Vane Test, Plate loading test, etc.

Laboratory Tests: Unit Volume Weight (dry, wet and normal) Test, Specific Gravity Test, Atterberg Limits (liquid, plastic and shrinkage limit) Test, Sieve Analysis, Uniaxial Compressive Strength, Triaxial Compressive Strength, Shear Box Test, Permeability Test, Consolidation Test, and Compaction Tests. The necessary and appropriate ones among these tests should be performed.

The type, bearing capacity, settlement amount, compressibility, and other physical properties of the soil will be determined by the experiments. Parameters found in these tests will be used when necessary for slope stability analysis. In addition, necessary laboratory tests should be carried out on the soil sample that is intended to be used as a covering material [20].

In general, a waste collection plant suitable for engineering consists of natural and synthetic mattresses, cover layers, and other removal systems that cover natural soil and waste. Fine-grained soils that occur naturally in waste storage can be used as mattresses, and the important thing here is the permeability of the floor mattresses. The permeability of the compressed floor mattresses should be at the rate of 10-5 –10-7 cm/sec, depending on the stored material content. Clay floors are widely used as natural mattresses. Commonly used clay groups are the montmorillonite clay group with very low permeability. Ideally, the natural ground under the storage area is sufficiently impermeable to work as a protective barrier layer. If the ground under the facility does not have sufficient engineering properties, then the natural ground should be replaced with an impermeable clay floor and clay mattresses should be made on the floor of the warehouse. In addition, the facility should be covered with an impermeable cover layer [21].

2.3.1. Clay Mattresses

Clay mattresses are used as foundation and slope mattresses or hydraulic barrier layer (impermeable) in units containing waste, or similarly as cover lining. Compressed clay mattresses are usually made from natural clay materials. The permeability of the compressed clay varies depending on the clay mineral, the void structure, the water content at the time of compression, and the compaction method. In order to obtain a lower impermeability, the water content of the compressed clay should be higher than the optimum water content (ωopt). Soils compressed under optimum water content (ω_{opt}) have a more void structure than soils compressed above optimum water content (ω_{opt}). Therefore, the hydraulic conductivity (k) value also changes as a function of the gap arrangement, and it has been stated that the hydraulic conductivity (k) value gives lower values above the optimum water content (ω_{opt}) [22].

If the clays are compressed at a water ratio higher than the optimum water content (ωopt), the soft and wet grains of the soil are remolded and a smaller void structure is obtained. Thus, lower hydraulic conductivity (k) values are obtained [23].

The following characteristics of the clays to be used as mattresses in solid waste storages will affect the quality of the mattresses to be made; k≤10-7 cm/sec, low shrinkage and cracking properties when dried, having sufficient shear strength, ≥%39-50 percentage of dry weight passing through no.200 sieve, the plasticity index (Ip) (ASTM D4318) should be ≥ 7-10% and the dry weight remaining on the 4th sieve should be ≤20% [24].

2.3.2. Synthetic Mattresses

There are many geosynthetics used for different purposes in waste warehouses. These are synthetics such as geomembrane, geotextile, geonet, or geogrid. Geomembrane is used to provide impermeability in clay mattresses. Geomembranes used in liquid and vapor insulation are flexible, polymer sheets with very low permeability. In landfills, geomembranes are typically used as a ground/foundation or covering layer on their surface, in addition to low permeability mattresses. In order not to pollute the ground and groundwater from the wastewater that will occur in the waste, or to reduce the damage of the wastewater, the ground/foundation mattresses are placed under the waste material. Polyethylene (PE) geomembranes are most commonly used in the foundation and coating systems of waste warehouses. These geomembranes have important properties especially in terms of chemical resistance and durability. High-density polyethylene (HDPE) geomembranes are used in foundation coating systems [25]. However, due to the large accumulations that may occur in the waste, a more flexible geomembrane is needed in the coating systems. For this reason, very low-density polyethylene (VLDPE) is generally used in these applications. It is stated that this material is more flexible and adapts more easily to settlements in the waste without puncturing [24]. Apart from these, there are different geomembranes used in storage units and other impermeability structures.

Apart from geomembranes as mattresses, geotextiles are also used in waste disposal facilities. Geotextiles are widely used as a filter, separation, support, cushion, and drainage material. A relatively new application for geotextiles is as an alternative log coating for waste. Apart from geotextiles, geonet and geopipe can be used in drainage systems. Geogrids are also used in case of carrying capacity problems in storage units. In waste management systems, geogrids can be used to support stratification systems on the weak ground surface or cover mattresses on overhead waste slopes [24-25].

2.3.3. Geosynthetic Clay Mattresses

In recent years, design engineers prefer the use of geosynthetic clay mattresses as an alternative to clay mattresses in covering and covering systems in waste storage due to very low permeability and cost. Geosynthetic clay mattresses are very low permeability insulating materials consisting of powdery bentonite or weak granular layers that can adhere chemically or mechanically to a geotextile or geomembrane. Geosynthetic clay mattresses (Geosynthetic Clay Liner, GCL) are usually made by placing them on top of each other in the field. These are often used as an alternative to compacted clay silts and GCLs have some advantages over compacted clay silts. These are materials that are more flexible, can hold themselves to some extent, and are easier to place. They may be preferred for low construction costs in the fields where low permeability clays are not readily available [26-28].

2.4. Hydrological Condition

The irregular storage of solid wastes causes soil, water, and air pollution. Solid waste and leaking wastewater pollute surface and underground waters, and as a result, they pose threat to human health and the environment. Detailed geological studies in the determination of suitable storage locations and the examination of soil properties, as well as the study of the hydrogeological properties of the region, are important in this respect.

The boundaries and characteristics of the recharge basin in which the storage area is located, the precipitation area, underground seepage, and runoff should be examined, and necessary drainage measures should be taken [29]. The hydrogeological and permeability properties of existing and potential aquifers and lithological units should be described in detail. Structural and surface properties that affect the flow of groundwater and the resistance properties of the material at the bottom of the storage area against deterioration should be determined [30]. Groundwater level should be measured, chemical analysis of water should be done, water reserve and hydraulic slope should be calculated [31]. Due to the spreading and accelerating effect of possible contamination, soils with high permeability values and fissured and soluble carbonate lithological units in which contamination can spread should be avoided [32].

The selected storage location should be outside the protection zone of drinking and thermal water resources, the groundwater level should be at least 3 meters or deeper, and it should not be in the flood and earthquake zone. In order to prevent contamination of ground and surface waters, soil and nutrients, impermeability must be provided for both the ground and the surface [33].

Hydrology is very important in determining the existing natural drainage and flow characteristics. Centennial flood limits should be defined. The waste storage built in the 100-year-old floodplain should be designed by defining the characteristics of the basin very well in order to reduce the temporary water holding capacity of the flood basin and not to interrupt the flow when transporting the solid waste that will harm human health and the environment.

In geological and geotechnical studies, drillings can be used to measure the potential groundwater flow, flow direction, and groundwater level. In addition, all necessary hydrogeological characteristics of the unit forming the floor of the solid waste storage area should be determined in the field, wellhead, or laboratory. Drinking water areas should be determined very well and the interaction with these areas should be examined [31].

2.5. Measures Against Ground and Surface Water Pollution

As long as there are suitable areas in the landfill method, the negative effects on the environment are minimized, while the wastes are decomposed under control and converted into stable substances [34]. While the leachate is filtered through the solid wastes, it is polluted with some chemical, physical and biological events and contains elements and compounds arising from the solid waste content. The source of the leachate is the water content in the stored solid waste and the water entering the tank from outside. The water entering the tank from the outside is formed by the leakage of rainwater over the tank and the entry of surface and underground waters into the tank. Factors affecting the formation of garbage leachate in solid waste storage areas are precipitation, surface flow, groundwater inflow, irrigation, waste degradation, evapotranspiration (temperature, wind, humidity, atmospheric pressure, cover humidity, vegetation, solar radiation), infiltration, moisture of waste holding capacity and permeability [35]. Waste leachate formation in solid waste landfills increases in direct proportion to the amount of precipitation, surface runoff, and groundwater entering the area. In order to minimize leachate formation and to prevent environmental damage of leachate, hydrological and hydrogeological water inflows to the storage area should be prevented. For this, solid waste storage areas should be selected from regions with low rainfall, the top cover should be made and grassed, surface drainage should be made and solid waste should be subjected to adequate compression [36]. Apart from these;

A. In order to prevent the accumulation of rainwater, which is the most effective factor in water pollution, in the storage area, the surface of the tank should be covered with an impermeable clay layer and its surface should be sloped %3.

B. The bottom of the landfill should be made impermeable and the leachate should be drained and collected at a specific point so that the leachate does not mix with the groundwater.

C. The collected leachate should be discharged after being treated in a way that does not pollute the environment [37-38].

3. Conclusions and Recommendations

Mainly geological, hydrogeological, and geotechnical factors play an important role in the selection and evaluation of landfill sites for waste disposal. These factors include not only the physical properties of rocks but also their stratigraphic and structural properties and engineering properties such as permeability, strength, and usability. It is important to consider these factors in selecting sites suitable for any use. The depth of geological information obtained from the surface in site selection can be improved by geophysical studies and drilling. In addition, issues such as the current use of the projected place, distance from settlements, transportation, types and amounts of hazardous wastes are also extremely important. It has been supported by many studies that it would be important and beneficial not to limit the studies to the only surface and subsurface studies, and to pay due attention to shallow and deep researches.

According to the results obtained from environmental protection studies, it has been proven and understood by the studies that the efforts are successful and it is possible to create living environments where the environment is intact or less affected. Therefore, it should be taken into account that environmental protection does not only consist of problems that appear on the ground but that there are/may be ongoing problems underground as well. In addition, reduction at source, recovery, recycling, and composting efforts should be encouraged to reduce the volume of waste. However, source reduction, recycling, and composting can result in a significant portion of the urban waste stream being diverted to landfills. The economic viability of incinerators, on the other hand, depends on the revenue from the sale of energy produced by incineration of waste. International criteria must be used in the classification and disposal of wastes.

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Conflicts of interest

The authors declare no conflicts of interest.

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