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ORIGINAL ARTICLE

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Environmental geological assessment of a solid waste disposal site: a case study in Sivas, Turkey

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Abstract The selection of the disposal site is probably the most important step in the development of solid waste management. In site selection, geology plays a determining role. This study evaluates the characteristics of the environment on the basis of the geological, hydrogeological and geo-engineering properties of the solid waste site of the Sivas city, Turkey. The area is underlain by the Oligocene-Miocene rocks which have limited aquifer properties. Thin Quaternary alluvium and soil cover overlie the Oligo-Miocene rocks, which are represented as well graded sand and inorganic silt of low plasticity. The Quaternary alluvium and soil cover are classified as inorganic clays having a low plasticity and the permeability varies from 1.2×10^{-6} to 3.11×10^{-6} m/s. These values are much higher than 1×10^{-8} m/s, which is accepted for waste disposal standards. Seepage waters have a potential to pollute the ground water and the Kızılırmak River, which is 500 m to the southwest of the waste disposal area and because the disposal site is close to the river, the potential for flash flooding poses a high pollution risk. The waste disposal area must be covered by clay layers or an impervious artificial membrane. In addition, seepage must be controlled and removed from the site.

Keywords Solid wastes · Environmental geology · Site selection · Sivas basin · Turkey

Introduction

The most common methods used for solid waste disposal are: composting, incineration, open dumps, and sanitary landfills. It is essential to dispose the solid waste to a landfill without creating a hazard to public health.

The Sivas city waste disposal site is located to the west of Sivas settlement, at 15 km on the Sivas-Erzincan highway, near Seyfebeli in a valley which widens to the Kızılırmak river (Fig. 1). The selection and planning of a waste disposal area require very careful environmental studies. The solid disposal site of Sivas is evaluated in the frameworks of the above criteria.

The geology of Sivas basin has been studied by many investigators (Kurtman 1973; Yılmaz 1982, 1984, 1994; Yilmaz et al. 1990; Aktimur et al. 1988; İnan et al. 1993; Poisson et al. 1996). Furthermore, karstification and hydrogeological properties of the area have been presented by Değirmenci (1995), Kaçaroğlu et al. (1997), and geo-engineering properties and a land-use map of the area have been prepared by MTA (1996) and Avcı et al. (1997).

Specific studies conducted in the landfill area, however, are not detailed. Therefore, new detailed field and laboratory studies are needed for environmental protection.

Methods of study and data collection

In the geology, hydrogeology, engineering, and land-use maps of the area were compiled from previously

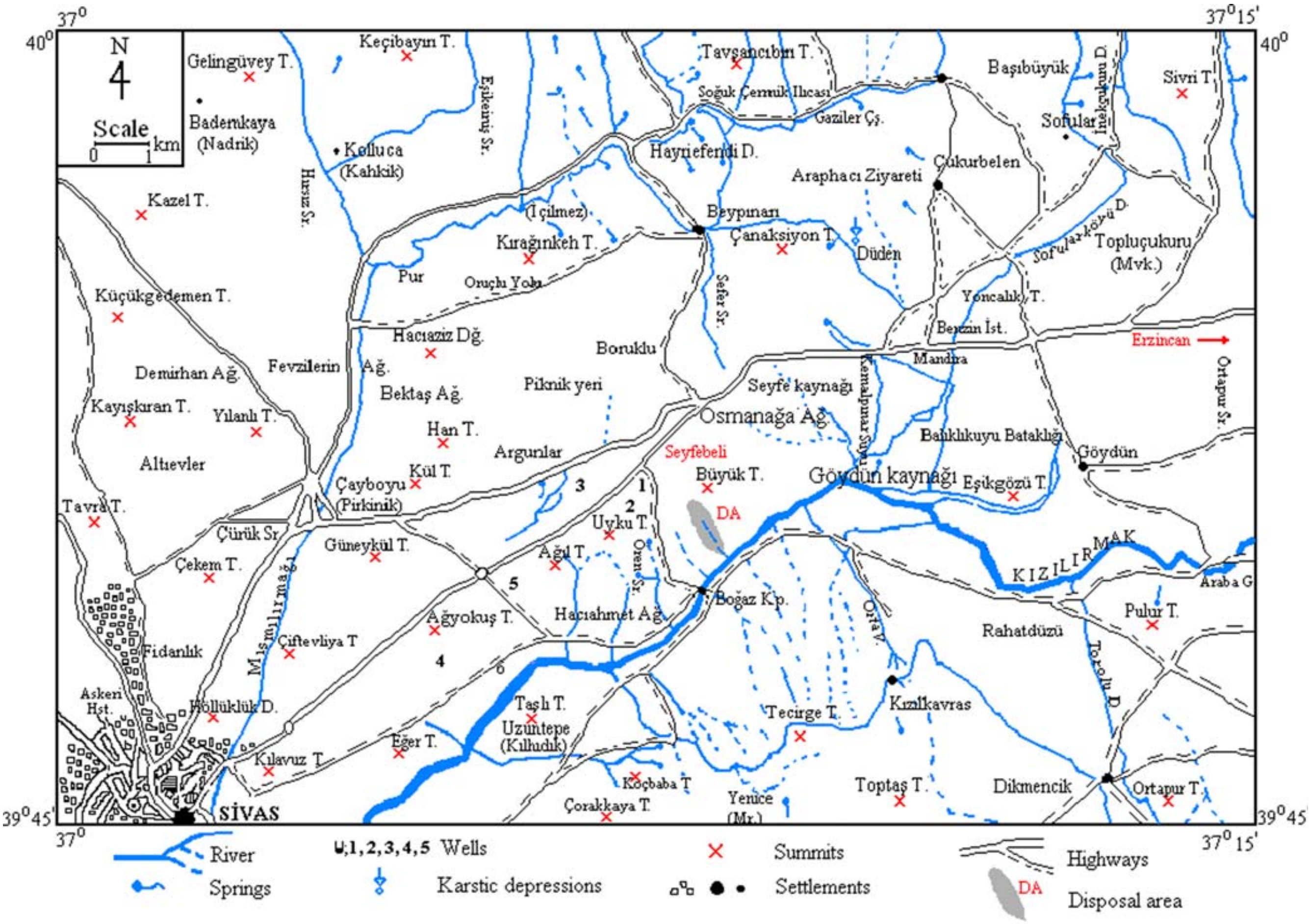


Fig. 1 Location and hydrographic map of the region around the Sivas city solid waste disposal area

published studies and reports, upon which compiled data sets of the solid waste disposal site have been compared in the field. This study includes new geological, hydrogeological, and engineering investigations. On the basis of new site investigations, the previous studies were updated to maximum potential for site selection of landfill in the region.

Water samples from the wells in the study area and from the Kızılırmak river were collected and analyzed to determine the potential impacts of the leachate. In the disposal area, natural hazards such as sever climatic events, earthquake, flood, and landslides might occur in the future. Therefore, the specific data are also needed to predict possible future environmental hazards, and their magnitudes and impacts on the environment.

To determine the grain size distribution in the soils, disturbed samples were taken from the field and analyzed in the laboratory. Samples 1, 6, 7, 8, 9 were taken from Quaternary alluvium. Other samples were taken from Quaternary soils. The soil type of the study area was determined. Undisturbed soil samples were taken from the landfill area, and the liquid and plastic limits of these undisturbed soil samples were determined by cone technique tests in laboratory. Atterberg limits were determined on the basis of the unified soil classification system.

The undisturbed soil samples were analyzed in the laboratory by the falling head permeability technique to determine the coefficient of permeability. On the basis of permeability values, the undisturbed soil indicates "lowly permeability", which however needs to be covered by a natural or synthetic layer.

There was no need to determine the strength of basement units in the study area, as these rock units are thick, resistant and strong enough to carry the loads of the accumulated wastes of the landfill. It is believed that these field and laboratory investigation findings of the proposed Sivas landfill may be utilized as criteria for selecting solid waste disposal sites in other similar regions.

Perspective of environmental geology

Environmental geology provides study methods required information for constructing all types of structures. Environmental phenomena such as surface run off, flooding of rivers, landslides, and earthquakes commonly affect the landfills and other structures such as highways, bridges, and dams. Sanitary landfills are affected by changing environmental conditions. Environmental geology of landfill areas must be examined in detail.

Site-specific geological, hydrogeological, and engineering parameters are necessary to establish a framework for environmentally and geologically sensitive landfills. The environmental assessments of the Sivas landfill area have been studied in detail on both regional and local scale.

Regional studies

The average duration of active use for a landfill is about 25–50 years. However, the effects of the landfill on the environment last for hundreds of years. Therefore, the adjustment of a landfill area must have adequate investigation on a regional scale to map the stratigraphic sequence and main structural elements.

The regional Sivas basin has been studied by Kurtman (1973), Yılmaz (1984, 1994), İnan et al. (1993). All studies show that the Tertiary sedimentary fill of the Sivas basin overlies a mosaic representing ophiolitic melange, metamorphic rocks units, and platform type carbonates of the Taurus Tectonic Belt.

The lowermost unit of the study area is the Oligo-Miocene Selimiye formation. This geologic formation, composed of continental clastic rocks (Fig. 2), unconformably overlies an Eocene sequence including marine clastic rocks (Bozbel formation) and gypsums with clastic rock units (Küçüktuzhisar Gypsums). The Selimiye formation is conformably overlain by the Oligo-Miocene massive gypsum levels of the Hafik formation (Fig. 3).

The lower–middle Miocene sequence, which includes shallow marine carbonates (Karacaören formation) and shallow marine to continental clastic rocks (Apa formation), overlies the older sequences and then underlies the Upper Miocene–Pliocene continental clastics and lacustrine carbonates (İncesu formation). Quaternary alluvium and soil cover unconformably underlie older units.

Surface water resources are shown in Fig. 1. As seen in correlated vertical sequences (Figs. 2, 3) and in the vertical stratigraphic sequence of the region, the most rock units represent the characteristics of an aquifer, or at least a limited aquifer. Değirmenci (1995) and Kaçaroğlu et al. (1997) suggest that these geologic formations with aquifer characteristics are widespread and cover large areas. Landfill site selection requires determining the relationships between rock units and ground water and surface water flows in detail.

Engineering properties of the study area have been evaluated by MTA (1996) and Avcı et al. (1997). An engineering classification of the units is presented in the framework of the unified soil classification system (Fig. 2): Selimiye formation takes place in SW-ML; Hafik formation in ZK-OSK; Karacaören formation in OSK; Apa formation in GW-OSK; İncesu formation in GW-SW, CL-MH-ML, and SK; Quaternary travertine in OSK; Quaternary deposits as a whole GW-SW and CL-ML classes. Some critical explanations of each soil class are presented in Fig. 2.

Local studies

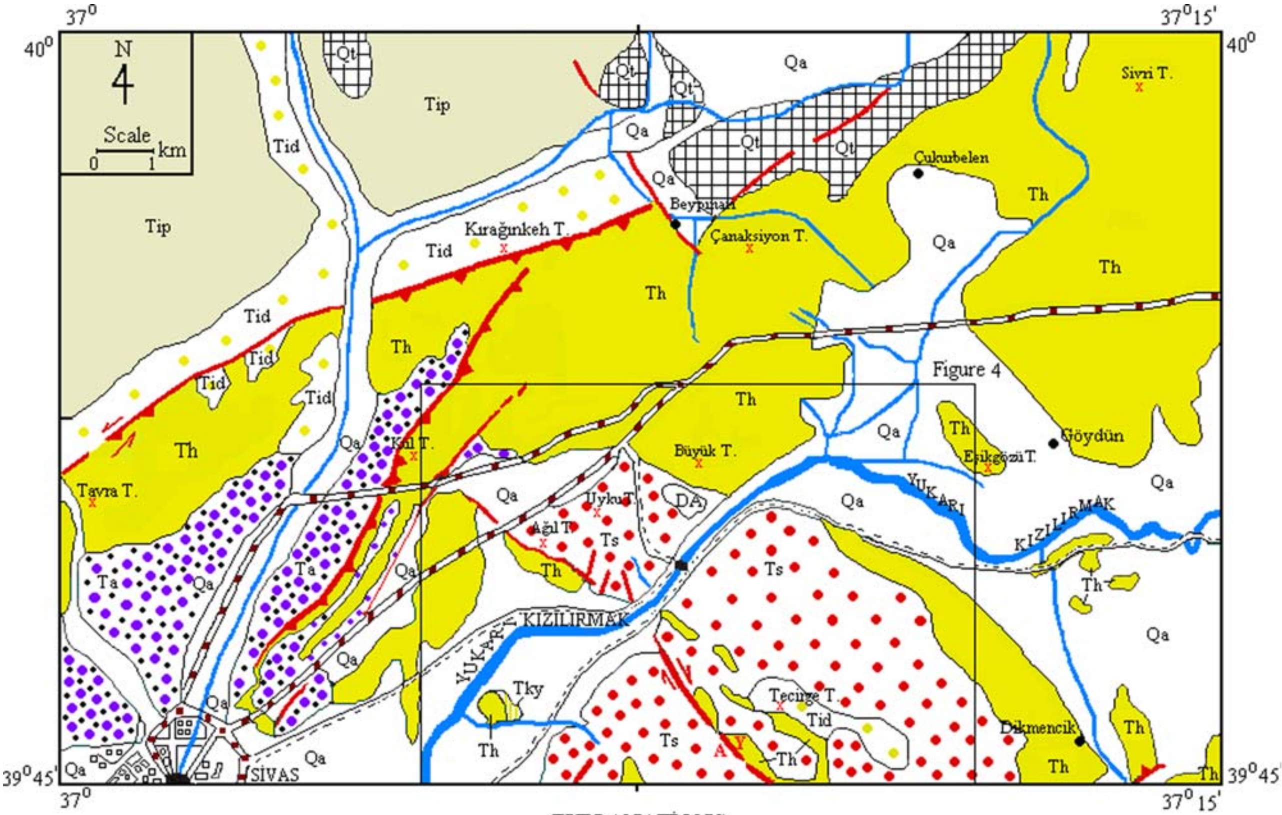
After regional evaluation, a part of the study area for a possible landfill site was examined in detail (Fig. 4). Because regional studies alone do not provide the degree of data required.

Because of continuing impacts of landfills on the environment after active use stops, lithologic and structural characteristics of the geologic formations in vertical sequence were examined in detail. In this potential disposal area, Oligocene Selimiye formation and overlaying Hafik formation represent the basement or bedrock units (Fig. 4). This formation is made up of alternating reddish conglomerate, sandstone, and clay stone subunits which are overlain by thick gypsum blanket of Hafik formation. In the regional stratigraphic framework, both these units overlie Middle–Upper Eocene Bozbel formation and Upper Eocene–Oligocene Küçüktuzhisar Gypsum conformably (Fig. 5), and underlain by the Karacaören formation unconformably (Fig. 2).

Lower Miocene Karacören formation–Yoğurtludağ Member contains shallow marine limestone and overlies the lower levels unconformably. The Karacaören–Yoğurtludağ member is covered by Apa formation, which is represented by shallow marine to continental clastic rock association conformably (Fig. 4). Quaternary alluvium, debris flows, and alluvial cones represent the uppermost level of the area and overlie all other older units unconformably.

The local hydrogeological data obtained from the wells from the west and southwest of the study area and from Kızılırmak River (Figs. 1, 4) suggest that the ground water table (GWT) is deep enough not to be affected by leachate originating from the waste disposal area.

Engineering properties of the study area have been evaluated by MTA (1996), Avcı et al. (1997), and Atmaca (2004). The data from these studies and the current study suggest that Selimiye formation can be categorized as in SW-ML, Hafik formation in ZK-OSK, Apa formation in GW-OSK, Quaternary alluvium in CL-M/GW-SW, Quaternary debris flows in



EXPLANATIONS:

Geological age	Geological units		Geo-engineering classification of the units and their explanations
Quaternary	Qa	Alluvium deposits..............................	CL-ML, Well grained sands-inorganic silts and sands GW-SW, weel-grained pebbles-sands
	Qt	Travertine	OSK, Medium solid rocks
	unconformity		
Pliocene	Tip	İncesu formation, porsuk member Lacustrine carbonates...........	SK, Solid rocks
Upper Miocene	Tid	İncesu formation, Derindere member Fluvial conglamerate and sandstone...	GW-SW, Well-grained pebbles- sands CL-MH-ML, Inorganic clays- silts-silts and sands
	unconformity		
Lower Miocene	Ta	Apa formation Shallow marine and continental clastic rock units Conglomerate, sandstone, claystone	GW-OSK, Well-grained pebbles and pebble/sand mixtures- medium solid rocks
	Tky	Karacaören formation, yoğurtludağ member, Shallow marine limestone	OSK, Medium solid rocks
	unconformity		
Oligocene	Th	Hafik formation Gypsum and in places clastic interbeds	ZK-OSK, Weak rocks-Medium solid rocks
	Ts	Selimiye formation, Reddish continental conglomerate, sandstone, claystone	SW-ML, Well-grained sands-Inorganic silts and sands

SYMBOLS:

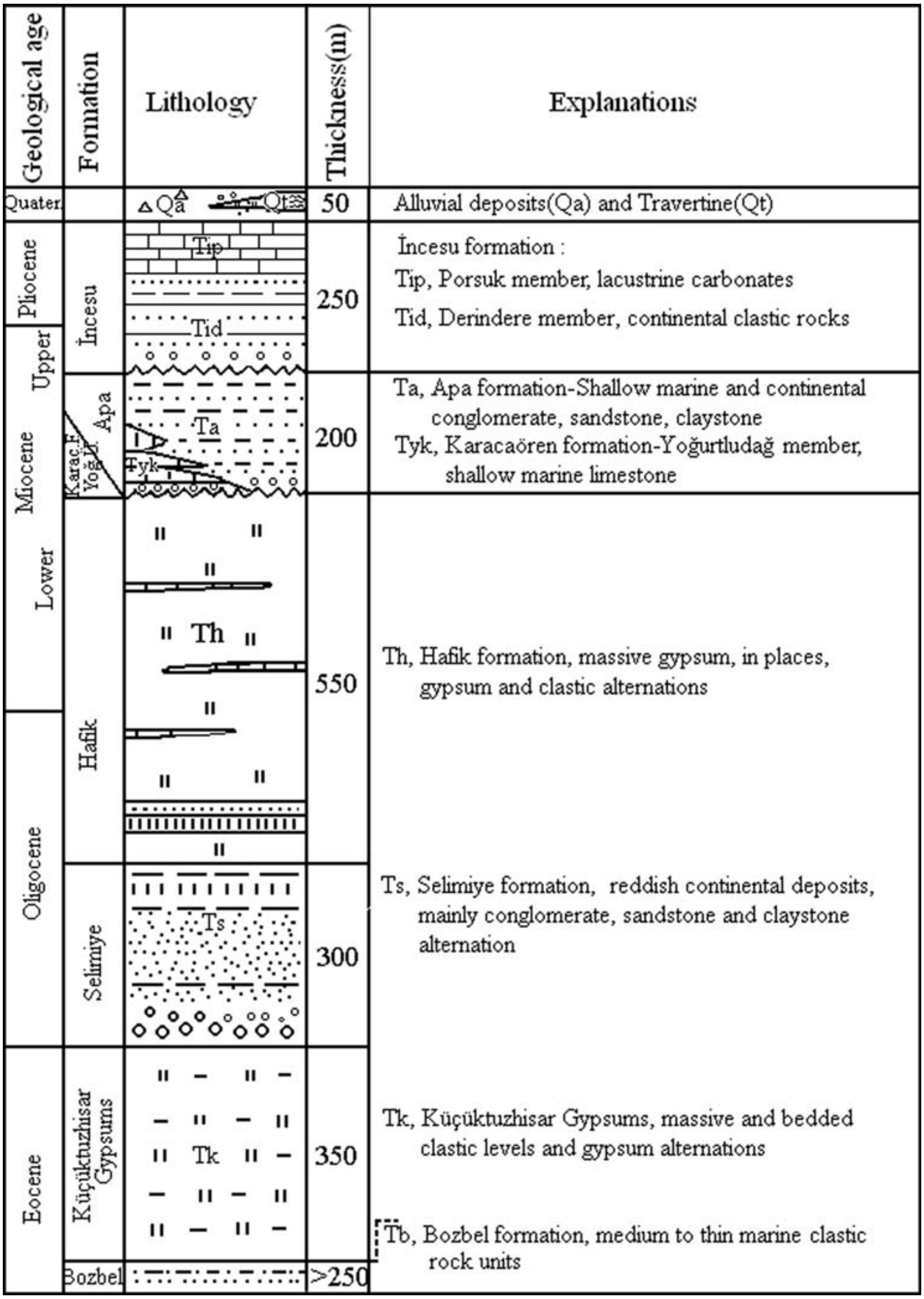
Contacts — Strike slip faults with reverse component — DA Disposal area

◀
Fig. 2 Geological and engineering geological map of the region around the Sivas city solid waste disposal area (After Yılmaz 1994; MTA 1996; Avcı et al. 1997 and new data)

GW, and Quaternary cones in GW classes (Figs. 2, 4 for explanations). All data indicate that bedrock in the proposed landfill area is constituted by heterogeneous rock units.

Local environmental features such as faults, landslides, distance from flood plains and karstic depressions in the study area (Fig. 4) show that the landfill area is not in imminent threat from natural hazards. In conclusion, it is possible to say that waste disposal area is not susceptible to natural and environmental hazards; however, due to the heterogeneity of the basement rock units, leachate waters may affect the GWT through time.

Fig. 3 Generalized columnar section of the region around the Sivas city solid waste disposal area



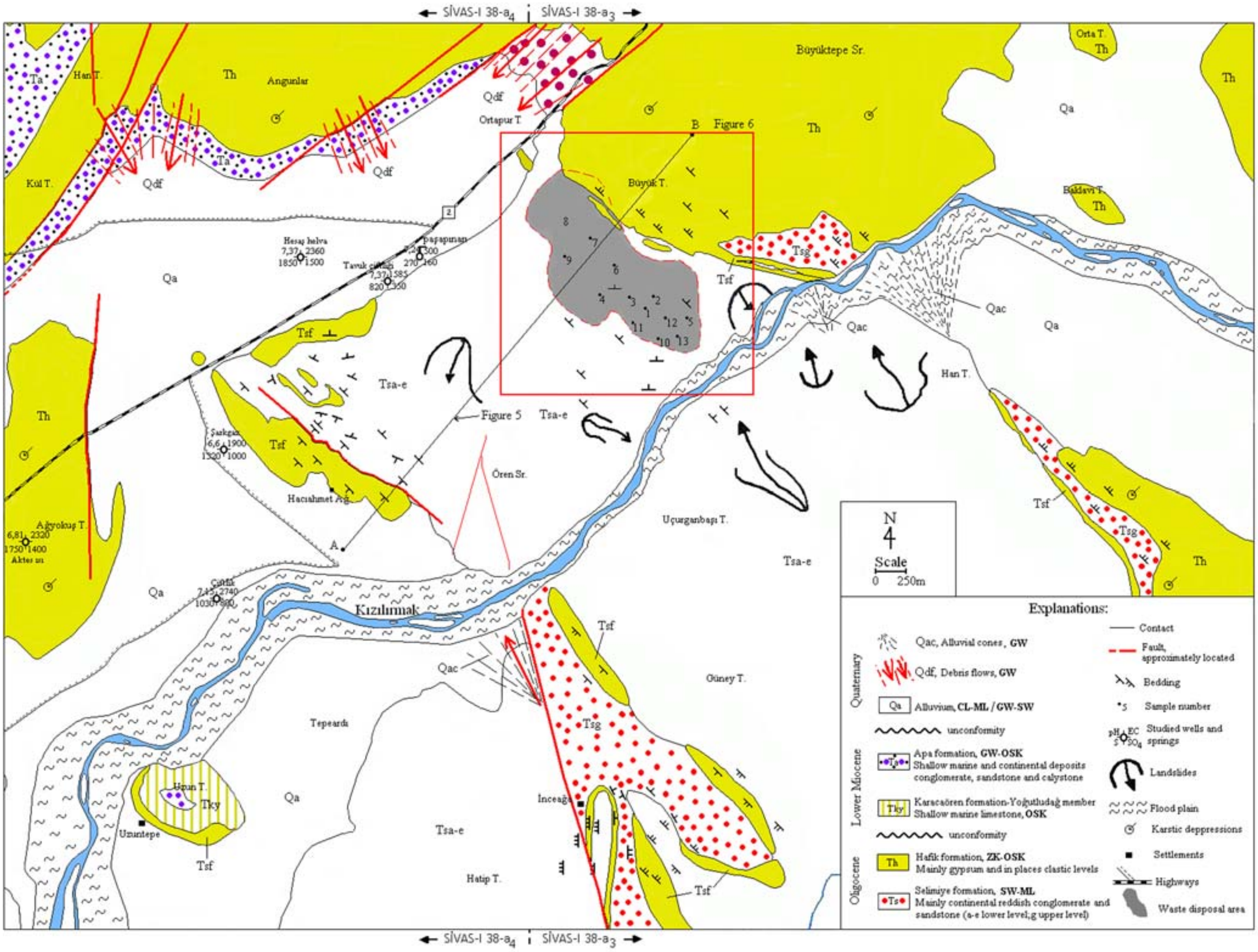


Fig. 4 Engineering geological map of the Sivas city solid waste area (see Fig. 2 for geo-engineering classification)

The landfill specific studies

Local environmental geological conditions help to determine the adverse effects of leachate and surface run off. Geological, hydrogeological, and engineering properties of the landfill area should specifically be studied in detail. An engineering geological map (Fig. 6), stratigraphic vertical section (Fig. 7), and cross sections (Fig. 8) of the landfill area have been prepared for further assessment of environmental geological factors.

The landfill area is situated along a valley which widens to the southeast up to the Kızılırmak River. Geological, hydrogeological, and engineering properties of the area can be seen in Fig. 6. Contours, reflecting topographic setting borders, and environmental fences of the landfill have been indicated as well.

Geological features of the landfill area

Figure 6 shows that the proposed waste disposal area is situated on the Selimiye formation and Quaternary soil cover and alluvium. Selimiye formation has been divided into subunits, ranging from Tsa at the base to Tsg at the top. Characteristics of these stratigraphic levels are presented in Fig. 7. As seen in the vertical sections, the lower levels of Selimiye formation are mainly Tsb and the lower part of Tse, which represents thickly bedded and joined pebbly sandstone. These subunits show typical characteristics of aquifers, and represent the basement of the landfill. The Tsf and Tsg levels of Selimiye formation represent a transition facies between Selimiye and Hafik formations. Hafik formation overlies Selimiye formation conformably. Quaternary soil cover and alluviums, forming along the valley and valley slopes, overlie the older units unconformably. The fine-grained Quaternary units represent the soil formation of the landfill.

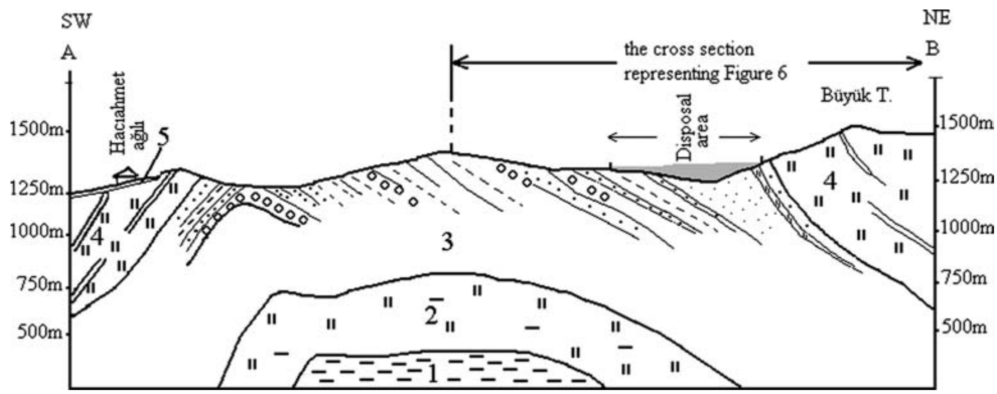


Fig. 5 Cross-section and setting of the Sivas city solid waste disposal area (see Fig. 4 for location). Explanations: *1* Middle–Upper Eocene Bozbel formation; marine, medium to thin grained clastic rocks, *2* Upper Eocene–Lower Oligocene Küçüktuzhisar Gypsums; massive and, in places, bedded clastic intercalations, *3* Oligocene Selimiye formation; continental reddish conglomerate, sandstone and claystone, *4* Oligo-Miocene Hafik formation; mainly gypsum levels and medium to thin clastic levels, *5* Quaternary alluvium

Cross sections of the area have been prepared (Fig. 8). Selimiye formation represents the basement of the landfill. The bedding planes of Selimiye formation dip approximately 45°, whereas in other places, these beds dip about 20–30° (Fig. 8, A–F cross sections). However, along G–H cross-section, this formation seem to have nearly horizontal beds, which may facilitate leachate flow horizontally to Quaternary deposits.

Hydrogeological features of the landfill area

The ground water characteristics and ground water table in the region have been studied by Değirmenci (1995) and Kaçaroğlu et al. (1997). There are no natural springs that directly flow in the landfill area (Figs. 1, 6). The thick-bedded and jointed pebbly sandstone units of the Selimiye formation represent the characteristics of a typical aquifer (Fig. 7). However, these aquifer units are well below the surface. Based on the position of these aquifer units in a vertical sequence (Fig. 8,G–H section), leachate should flow considerably faster in the surface run off compared to downward flow of leachate in porous media to aquifer. As a result, leachate poses more serious threat to the Kızılırmak River than to aquifer units of Selimiye formation. Surface waters of the region are at more risk than the ground water.

Flood potential of the Kızılırmak River was evaluated on the basis of a 100-year flood. The border of the Kızılırmak River's flood plain can be seen in Figs. 4 and 6. The landfill area is not at risk of hazardous flood potential. Since the landfill is situated well below the bottom of the Kızılırmak River valley, any leachate originating from landfill area will not affect the river.

Geo-engineering features of the landfill area

As seen from Figs. 4 and 6, the waste disposal area is situated on the Oligocene Selimiye formation, Hafik formation, and mainly Quaternary soil cover and alluvium. Oligocene Selimiye formation is represented by well-rounded sands-inorganic silts and sand (SW-ML). The Hafik formation, representing bedded gypsum levels, overlies the Selimiye formation conformably and it is defined as weak and medium solid rocks (ZK-OSK) by MTA (1996) and Avcı et al. (1997).

Quaternary soil cover and alluvium represent mainly the basement of the landfill area and need extra study. To determine the engineering properties, the disturbed samples were taken (Figs. 4, 6) and analyzed in the laboratory. Samples of 1, 6, 7, 8 and 9 were taken from Quaternary alluvium and 2, 3, 4 and 5 were taken from Quaternary soil cover.

Grain size distributions, liquid limits, and plastic limits, as well as the soil permeability of the basement and soil rock units were determined. The results of sieve analyses are reported in Table 1 and Fig. 9. According to unified soil classification system, Quaternary alluvium and soil cover are classified as CL (inorganic clays).

To identify soil types, undisturbed samples were taken from the waste disposal area and tested to define liquid limits and plastic limits by using the cone technique. Results are presented in Table 2 and Fig. 10. The mean values of liquid limit, plastic limit, and plasticity index of Quaternary alluvium and soil cover are 35.12, 19.73, and 15.39%, respectively. Due to their Atterberg limits, the soil of the landfill has also been classified as CL (inorganic clays).

The other important engineering parameter to be defined in the waste disposal area is permeability of soils. The coefficients of permeability for these lithologic units were determined for the undisturbed samples by using the falling head permeability technique. The results are presented in Tables 3 and 4 (Uzuner 1998), respectively. Permeability of the Quaternary cover varies from 1.2×10^{-6} to 3.11×10^{-6} m/s, and it is much higher than 1×10^{-8} m/s, which is defined as the

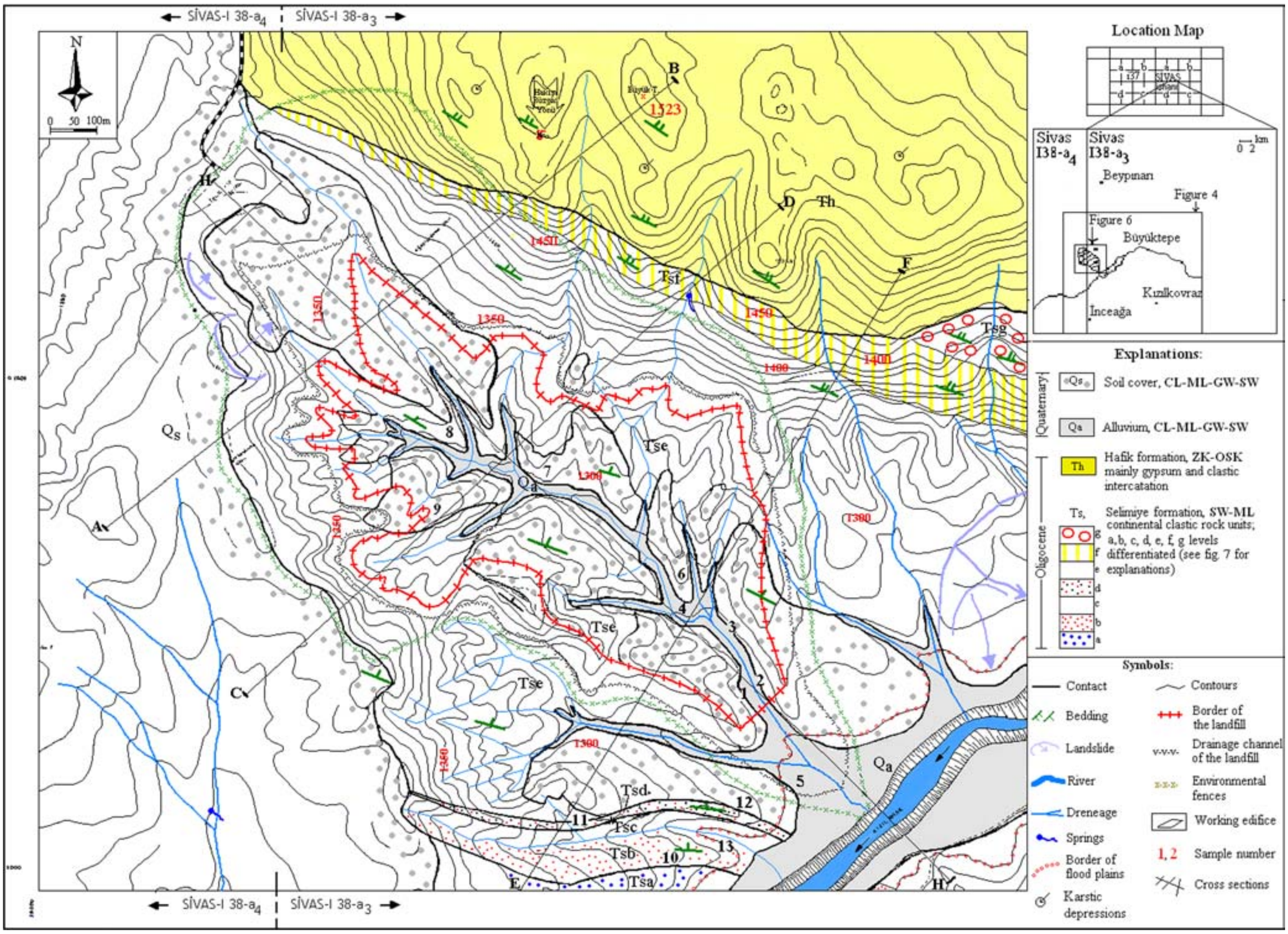


Fig. 6 Detailed engineering geologic map of the Sivas city disposal area (see Fig. 4 for location, geo-engineering classification has been submitted at Fig. 2)

waste disposal standards in Turkey. On the basis of permeability values, the Quaternary soil is classified as "lowly permeable".

These characteristics indicate that seepage waters have limited pollution potential to the ground water. However, the Kızılırmak River, which is situated 500 m southwest of the waste disposal area, is at very high risk of pollution. Because of site attributions, the waste disposal area of Sivas City landfill must be covered by a clay layer or an impervious artificial membrane to international waste disposal standards. In addition, after draining to an impervious man-made pool, the seepage waters should be removed.

Other properties of the area

The landfill area and surrounding region are not at the risk of natural hazards; there are no active faults or landslides which can directly affect the waste disposal area (Fig. 4). There is also no flood risk in the area. Flood potential of the Kızılırmak River has been evaluated for a 100-year flood frequency. The landfill is not at any serious risk resulting from naturally triggered hazards.

Because the basement units are thick and strong enough to carry the burden of the solid wastes, there is no need to determine strength of the lithologic units in the disposal area.

The climate of the Sivas area is semi-arid and arid continental climate. The weather during the summer is usually dry with little precipitation, and it is cold in winter. Precipitation in the region falls mainly during spring. Therefore, decomposition and weathering of the wastes are major effects.

Water quality and GWT of the region were studied on the basis of general standards. The results of water parameters are presented in Table 5. Hardness of ground waters contains 820–1,850 mg/L $CaCO_3$, except for the Pasapınarı fountain. These types of waters are considered to be very hard waters (Samsunlu 1999). The waters around the landfill

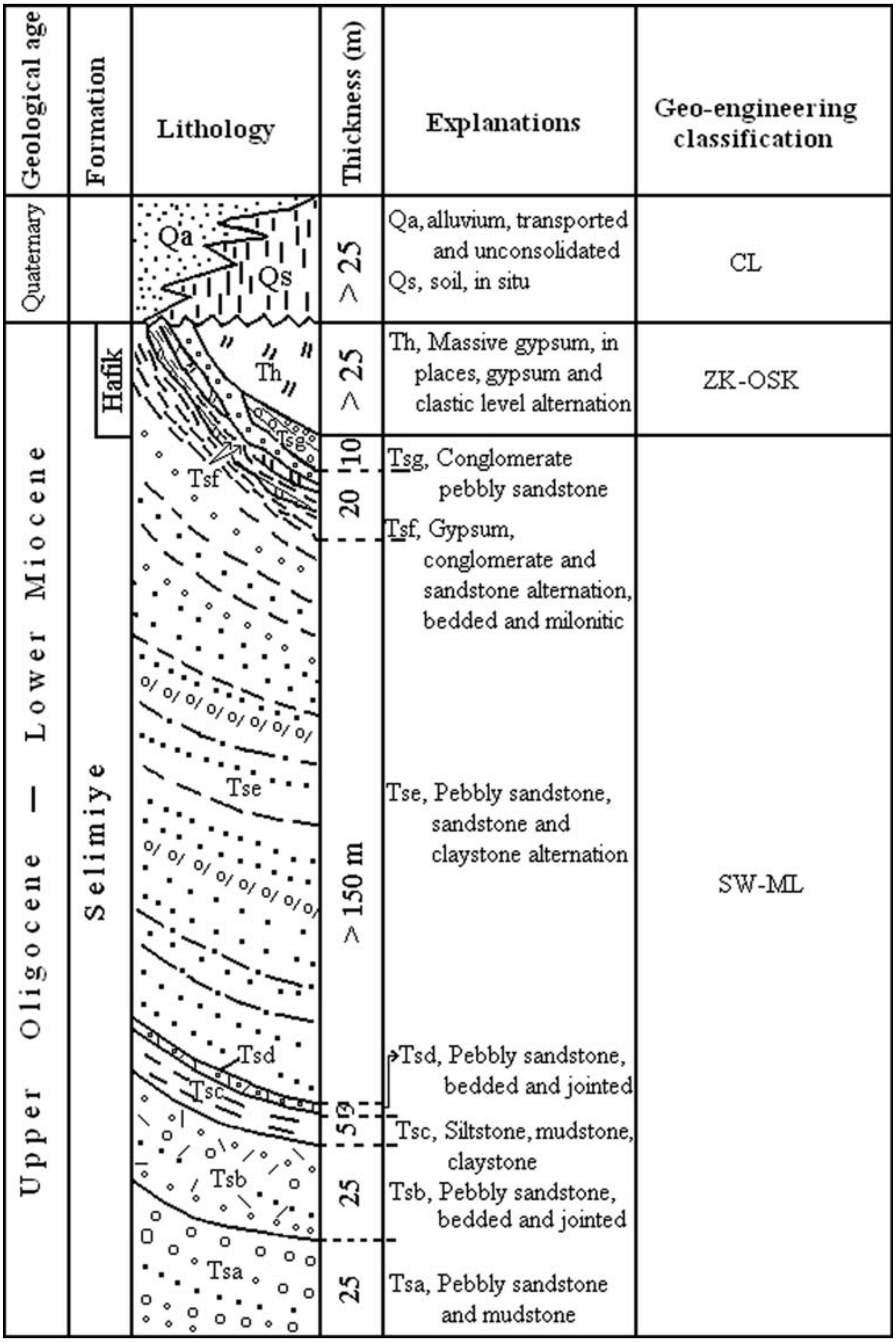


Fig. 7 Columnar section of the Sivas city solid waste disposal area (see Fig. 2 for explanations of geo-engineering classification)

are not suitable for drinking and irrigation purposes. The poor water quality of the region can mainly be attributed to the widespread Oligocene gypsum levels around the Sivas basin (Kaçaroğlu et al. 1997).

Conclusions

The results from geological, hydrogeological and engineering studies on the proposed solid waste disposal site

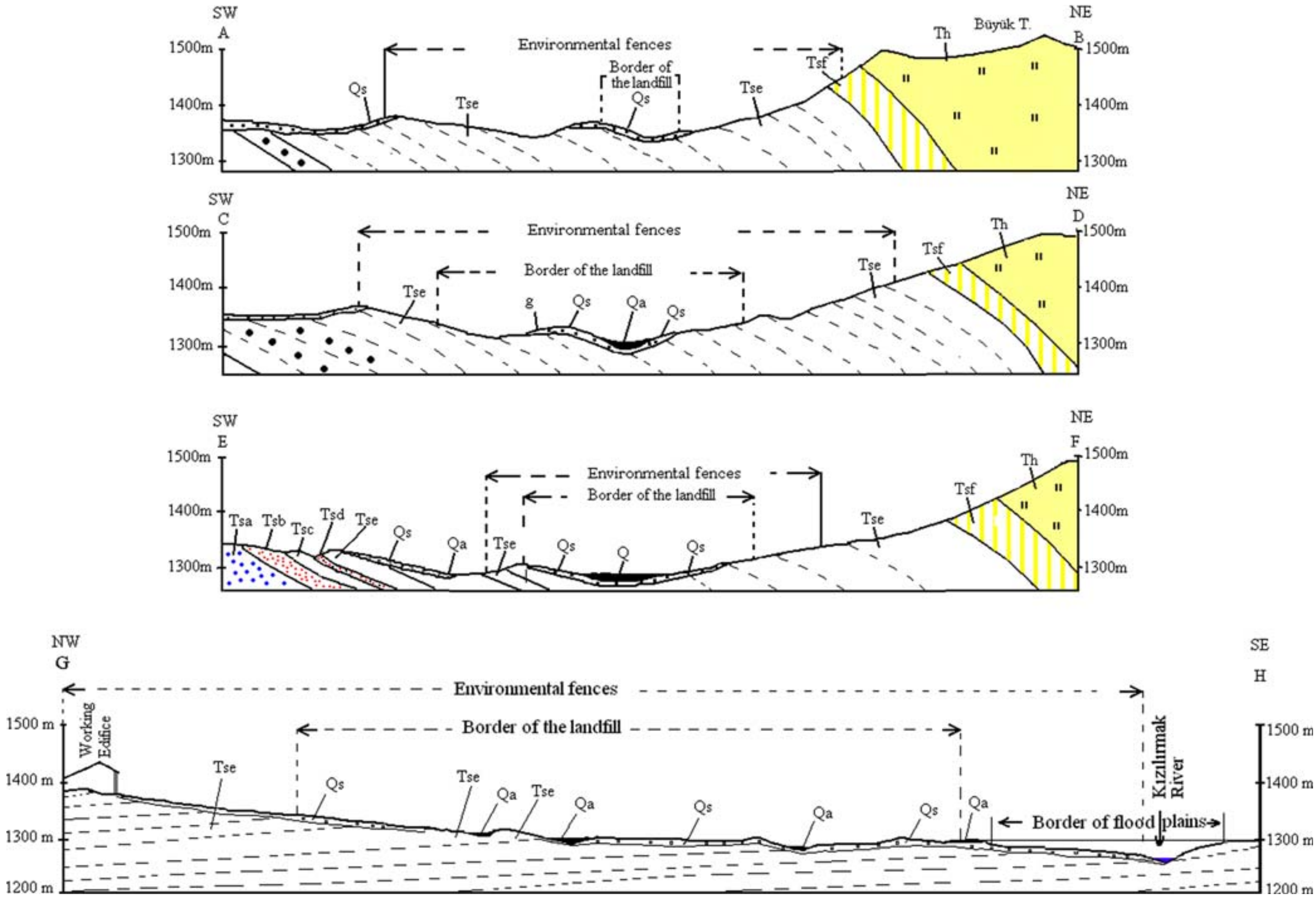


Fig. 8 Cross sections of the landfill area (see Fig. 6 for location)

of Sivas city are presented in Table 6. Oligocene clastic rock units represent the basement of the area, include limited aquiferus levels, and represent SW-ML engineering classification. Some of these levels are also permeable; therefore, the basement units should be protected by impermeable layers.

The soil of the landfill is made up of Quaternary alluvium (Samples 2, 3, 4, 5), which is a poor medium for ground water transport. Quaternary soil cover is represented by samples 1, 6, 7, 9. Quaternary alluvium and soil cover are of CL engineering class and have low permeability.

The Quaternary soil may allow pollutants originated from the waste disposal area to flow through vertically to the basal lithologic units or horizontally at the surface to the surface waters of the Kızılırmak River. The base of the landfill should be covered by an impervious natural clay layer or an artificial membrane.

Table 1 Results of grainsize distribution analyses of the landfill area

Size number	Sieve interval (mm)	Underside of sieve (%)								
		1	2	3	4	5	6	7	8	9
6	3.350	96.10	86.20	96.27	87.07	79.90	97.97	98.70	99.53	87.67
8	1.700	93.73	68.47	93.80	76.37	73.47	96.63	97.80	98.93	85.67
16	1.180	92.47	62.33	91.87	70.57	69.33	95.30	96.80	98.13	83.73
30	0.600	90.27	55.87	87.67	62.67	63.63	93.37	95.53	97.10	81.33
40	0.425	88.13	51.27	83.70	56.93	59.67	89.90	93.10	94.90	77.70
70	0.212	81.87	44.60	75.40	48.73	51.77	80.03	83.77	87.57	67.23
200	0.063	70.03	36.43	60.60	40.57	41.13	65.27	67.87	71.70	52.57

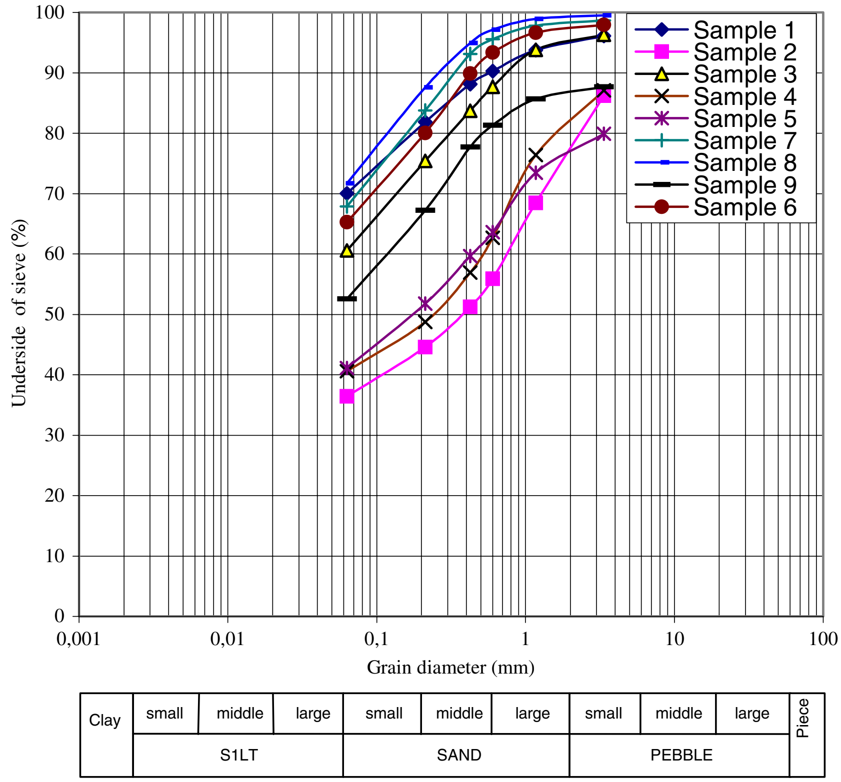


Fig. 9 Results of sieve analyses for landfill area

Table 2 Results of liquid limit, plastic limit, and plasticity index of the landfill area

Sample number	Liquid limit	Plastic limit	Plasticity index IP	Class of soil
1	36.55	18.09	18.46	CL
2	30.00	18.13	11.87	CL
3	35.00	19.22	15.78	CL
4	30.00	18.48	11.52	CL
5	30.70	18.69	12.01	CL
6	39.00	21.88	17.12	CL
7	34.70	20.74	13.96	CL
8	39.80	21.31	18.49	CL
9	40.30	21.01	19.29	CL
Average	35.12	19.73	15.39	CL

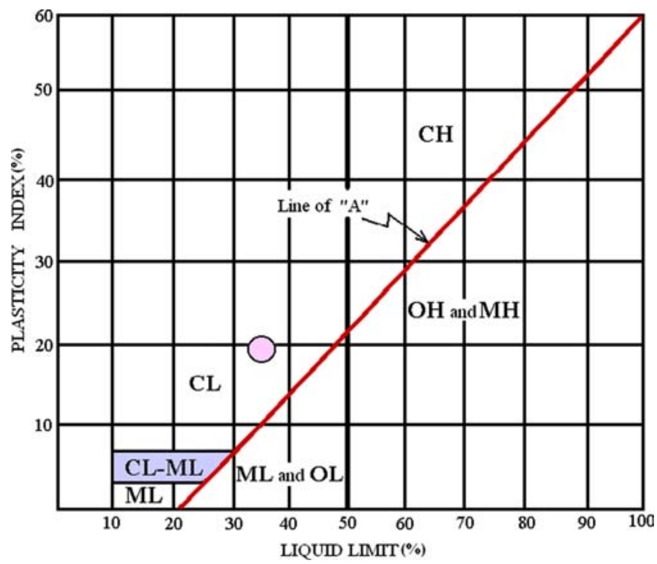


Fig. 10 Results of liquid limit and plasticity index

Other environmental parameters such as climate, strength of the basement rock units, water quality and natural hazards appear to be favorable or neutral to the site selection of the Sivas landfill area.

Table 3 Results of permeability coefficients of the landfill area

Number of sample	1	2	3	4	5	6	7	8	9
Coefficients of permeability (m/s) $\times 10^{-6}$	1.22	2.46	2.85	3.11	1.60	1.32	1.25	1.22	1.54

Table 4 Values of permeability coefficients for various soils (Uzuner 1998)

Kind of soil	*K* (cm/s)	Attitude of permeability
Pebble	> 10	Highly permeable
Sand	$10–10^{-4}$	Permeable
Silt	$10^{-4}–10^{-6}$	Lowly permeable
Clay	$< 10^{-6}$	Very lowly permeable or impermeable

Table 5 Properties of the wells and the ground water around the landfill area

		Pasapınarı	Tavuk Çiftliği	Hesas Helva	Aktes Isı	Sark Gaz	Çiftlik	TS-266
Depth of well (m)			100	80	127	10	15	
Depth of pump (m)			60–65	55	55		10	
Level of ground water (m)			15–20	14–15	33	6	6	
Topographic level (m)		1,290	1,290	1,288	1,305	1,289	1,287	
pH		7.24	7.37	7.13	6.81	6.6	7.15	6.5–9.2
EC (μS/cm)		500	1,585	2,360	2,320	1,900	2,740	
Total hardness	mg/L	270	820	1,850	1,750	1,320	1,030	
	meq/L	5.4	16.4	37	35	26.4	20.6	
Ca^{++}	mg/L	64	300	640	620	468	284	200
	meq/L	3	15	32	31	23.4	14.2	
Mg^{++}	mg/L	26	17	61	48.8	36	78	50
	meq/L	2.2	1.4	5	4	3	6.4	
Na^{+}	mg/L	23	57.5	12	12	17	368	175
	meq/L	1	2.5	0.5	0.5	0.75	16	
K^{+}	mg/L	2.4	1.95	0.78	2.4	1.17	4.3	12
	meq/L	0.0625	0.05	0.02	0.0625	0.03	0.11	
HCO_3^{-}	mg/L	157.38	250	93.5	128	160	149	
	meq/L	2.58	4.1	1.53	2.11	2.61	2.44	
$SO_4^{=}$	mg/L	160	350	1,500	1,400	1,000	800	250
	meq/L	3.33	7.29	31.2	28	20.8	16.6	
CI^{-}	mg/L	13.9	264	160	180	150	584	600
	meq/L	0.39	7.46	4.5	5.06	4.22	16.4	
SAR		0.62	0.87	0.11	0.11	0.20	5	

SAR Ratio of sodium adsorption

Table 6 Geological, hydrogeological, and geo-engineering features of the landfill basement units

Sample no	Geologic features	Hydrogeological features	Jeoengineering features	Results
1	Quaternary soil cover	Surface waters flow over the unit	CL class and low permeability	Needs precaution
2	Quaternary alluvium	Include and transfer water in a little quantity	CL class and low permeability	Needs precaution
3	Quaternary alluvium	Include and transfer water in a little quantity	CL class and low permeability	Needs precaution
4	Quaternary alluvium	Include and transfer water in a little quantity	CL class and low permeability	Needs precaution
5	Quaternary alluvium	Include and transfer water in a little quantity	CL class and low permeability	Needs precaution
6	Quaternary soil cover	Surface waters flow over the unit	CL class and low permeability	Needs precaution
7	Quaternary soil cover	Surface waters flow over the unit	CL class and low permeability	Needs precaution
8	Quaternary soil cover	Surface waters flow over the unit	CL class and low permeability	Needs precaution
9	Quaternary soil cover	Surface waters flow over the unit	CL class and low permeability	Needs precaution
10	Oligocene clastic rocks	Include limited aquifer levels	SW-ML classes and include permeable levels	Needs protection
11	Oligocene clastic rocks	Include limited aquifer levels	SW-ML classes and include permeable levels	Needs protection

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