Management of environmental risks associated with landfills in seismically active regions in the New Independent States of Central Asia

A thesis for the doctor degree submitted to
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submitted by

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Supervisor's foreword

Central Asia consists of the five former Soviet republics of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. For thousands of years, this vast region has been on the cross road of different cultures, e.g. the Greek, Chinese, Turk, Arab and Russian influence. Along the Silk Road, not only goods but also ideas and cultures were exchanged between the east and the west. Under the Russian rule, Central Asia was rarely on the spot light until the Central Asian countries regained their independence in the 1990s. Benefited from the mounting energy demand worldwide, the last decades witnessed unprecedented economic development in this region. The rapid economic development brings noticeable improvement to the living standard. However, some negative impacts for the environment are also observed. One of these environmental problems is concerned with waste management, in particular landfills. The NISMIST Project, funded by the European Commission within its 6th Frame Programme, deals with analysis and management of hazardous landfills in seismically active regions. Started from August 2005, numerous research activities have been initiated and completed. These activities include the site investigation, GIS data base, waste analysis, emission analysis, dynamic modelling, risk analysis and remediation analysis. The project was successfully completed in August 2008. The multidisciplinary and multinational project was managed by Stephen Webb. Stephen has major contributions to the success of the NISMIST Project.

This thesis covers a broad spectrum of topics related to waste and landfill. The in-depth treatment of three representative landfills provides interesting insights into some urgent environmental problems in this region. Large amount of work has been carried out in site investigation and data acquisition. Based on these data, some detailed analyses using the state-of-the-art techniques were carried out. Some specially tailored solutions were presented by considering the local situations. Central Asia is rarely in the public focus. This thesis provides invaluable information on some waste-related problems in this region. I am sure that this thesis will be an important reference for people working in this area.

Our heartfelt thanks are due to our Central Asian partners for their support during the project. The European Commission is gratefully acknowledged for the generous financial support and the flexibility in dealing with some delicate administrative issues.

Wei Wu

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1. Preamble

This dissertation exemplifies that the main reason why environmental investments generally have lower priority on most political agendas is purely the timeframe difference of economical development cycles and the impact of environmental externalities. The external costs to third party stakeholders (citizens and future generations) who do not directly affect economic transactions associated with public projects such as municipal landfills are generally well understood – at least by those with a minimum understanding of the natural sciences and/or civil engineering. However, the acceptance of scientific reason and willingness to take responsibility for management of resources is another issue.

The author has Masters' degrees both in Environmental and Engineering Geology and Business Administration. This dissertation is a culmination of work to date as a geologist, an economist, a marketer and project manager. The scientific research underlying this dissertation is the result of a three-year collaborative project carried out with scientific colleagues from Technical University Hamburg-Harburg (TUHH; Germany), National School of Public Works (ENTPE, France), St. Petersburg State Polytechnic University (SPbSPU) and Scientific Research of the Ecological Safety Russian Academy of Sciences (SRCES), National Centre of Mountain Regions Development of the Kyrgyz Republic (NCMRD), Tashkent State Technical University (TSTU, Uzbekistan), Kazakh National Technical University (KazNTU), National Institute of Desert, Flora and Fauna (NIDFF, Turkmenistan) and the Chemistry Institute of the Tajikistan Academy of Sciences (CHI).

The NISMIST (Management of environmental risks associated with landfills in seismically active regions in the New Independent States of Central Asia) research project focused on assessment of risk and development of remedial recommendations for landfills (municipal solid waste deposits) located in highly active seismic regions of the New Independent States (NIS) of Central Asia. The NISMIST project was funded by the EU Sixth Framework Programme within the International Cooperation (INCO) measures for Russia and the New Independent States (Call identifier FP6-2003-INCO-Russia+NIS-1). The contract (No. 516732) officially began on 01.08.2005, was concluded on 31.07.2008 and had a total EC contribution of 1,139,960 million Euro. The project addressed research priority D.1 (Environmental Protection), as a specific measure in support of international co-operation in developing countries. The details of the addressed call topic reads as follows:

"Management of environmental risks associated with man-made changes, industrial, agricultural and military wastes (excluding nuclear wastes and radiation) including risks to soil, water, air and the food chain and possible remediation."

In response to the call, the following scientific and technological objectives were formulated:

- Development of a GIS database and classification catalogue for landfills in the participating NIS countries.
- Perform dynamic analysis of seismic hazard of landfills for investigation of the mechanical and hydrological properties of waste mass, development of a constitutive model for the behavior of waste mass and three dimensional numerical modeling of the seismic response of landfills.
- Analyze emission potential of landfills will be performed by making use of the Landfill Simulation Reactors (LSR) in climatic chambers.
- Analyze risk of landfills to investigate the potential environmental and associated socio-economic impact of contaminant release, transport, dilution and fate.

- Make recommendations for remediation measures to reduce risk of existing landfills and guidance for site selection and for designing of future landfills

This dissertation concludes three years of joint interdisciplinary research involving geology/ hydrogeology, geophysics, geotechnical engineering, landfill design and operation and waste management. As project manager and participating scientist, it is my pleasure to both thank and congratulate the team on demonstrating a showcase example of international collaborative scientific research under a myriad of cultural and political challenges. My special thanks goes to BOKU Professors Wei Wu (Head of Institute of Geotechnical Engineering) and Jean Schneider (Head of Institute of Applied Geology) for their visionary guidance and scientific coordination of the project and in having the confidence in me to “run the shop”. A mention of thanks also goes to Professor Hanno Schaumburg (TUHH) who played a rudimentary role in setting up and guiding the consortium. My final word of thanks goes to the colleagues responsible for administering FP6 International Cooperation (INCO) projects at the European Commission. Without their financial support, understanding and advisory role as the project progressed, this collaborative project would never had been possible.

Fig. 1.1 NISMIST Consortium, Koi Tash, Kyrgyzstan, May 2008

2. Economic developments and environmental situation in Central Asia

2.1 Soviet Rule of Central Asia

The five Central Asian (CA) republics, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan have a dramatic economic history. Central Asia has suffered traumatic declines in living standards, increased economic uncertainty, and growing inequality and poverty (OECD 2003). In the 18th and 19th centuries the territory of the five Central Asian nations (Fig. 2.1) was absorbed into the Russian Empire (Tsarist era). From then on Central Asia (CA) was effectively treated as a single economic unit. After the 1860s the southern area became specialized in cotton production. Then the construction of railway in Central Asia integrated the region into the Russian imperial economy. After the 1917 Revolution, Central Asia became part of the Soviet Union and in 1930s it was divided into five republics whose boundaries are the basis for today's five CA nations. All five former Central Asian republics were producers of primary products; mainly cotton, energy products and minerals and also suppliers of raw materials to the more industrialized areas of the Soviet Union. The focus on cotton was strengthened, especially after construction began on the Karakum Canal in the 1950s, but it was complemented by the exploitation of energy and mineral resources and by some industrial development. The Soviet economy was planned as a single unit in which goods and services moved without attention to republic borders. At the same time as being open to intra-Soviet trade, the republics were closed to external trade.

Figure 2.1: Political boundaries of Central Asia and neighboring countries. 03.02.2009. Scale: 1:19,000,000 (http://www.indiana.edu/~afghan/maps/central_asia_map.jpg).

2.2 Central Asia since Soviet independence in 1991

After the dissolution of Soviet Union, the Central Asian republics which were among the Soviet successor states mostly subjected to severe economic crisis. None of these state governments had anticipated the rapid dissolution of the Soviet Union and all were totally unprepared for the severing of Soviet ties. Demand and supply networks based quickly collapsed in the early 1990s. The shift to a market economy driven by world market prices substantially benefited the energy exporter states, Kazakhstan and Turkmenistan, but in the short term, even these two republics were also unable to realize these gains due to their dependence on Russian pipelines. All five CA states suffered from disrupted supply chains and higher prices for imports. Imminent economic collapse was signaled in falling output and rising prices in 1991, but it was to become much worse after the formal dissolution of Soviet Union.

Since 1991, political and economic reforms followed different patterns in each of the five new independent states (NIS) in Central Asia. Kyrgyzstan was one of the most liberal and displayed rapidly reforming transition economies; e.g. it was the first Soviet successor state to accede the World Trade Organization (WTO) in July 1998. Kazakhstan is also considered a reformist regime, although this oil-rich country has many similarities to Russia. In Kazakhstan, privatization quickly created powerful oligarchies that distorted and hindered a proper transition to a market economy. Kazakhstan and the Kyrgyz Republic both suffered substantial setbacks during the first half of the 1990s, although the extent is debatable. Both economies have been growing since late 1990s. The Kazakh economy started to grow significantly in the early 2000s especially due to the higher oil prices. Compared to Kyrgyzstan, and Kazakhstan, the other three Central Asian countries were slower to stabilize and benefit from the dynamics of the new market-based economy.

Tajikistan was devastated by civil war which lasted for most of the 1990s. Even after the 1997 peace agreement, the central government did not have control over all of its territory. In the year 2000, Tajikistan with a national per capita income of 180 USD was poorer than most sub-Saharan African countries or the poorest countries of Asia. The economic decline in Tajikistan has been traumatic during first half of 1990s. In this period the living standards had fallen to the levels of the least-developed countries.

Turkmenistan’s regime has become increasingly personalized and autocratic, pursuing a policy based on neutrality and economic independence with minimal economic reform. The unexpected death of the president in 2006 has lead to opening of external relations and international trade (notably in energy) under a somewhat more liberal government elected in 2007. Turkmenistan had also suffered from palpable economic decline, but the energy revenues and political stability have contributed to it being less traumatic than in Tajikistan.

Uzbekistan has been more cautious in reforming but has been the most successful of all Soviet successor states in terms of its economic performance and output. Figure 2.2 illustrates Gross Domestic Product (GDP) changes in former Soviet Union states, including Central Europe, reference year (index) was 1989 = 100. The Uzbek economy genuinely suffered a smaller transitional recession than other former Soviet republics and experienced positive economic growth since the mid-1990s. Figure 2.3 shows the development of the population (in thousands) in five republics of Central Asia in 1950 – 2007.

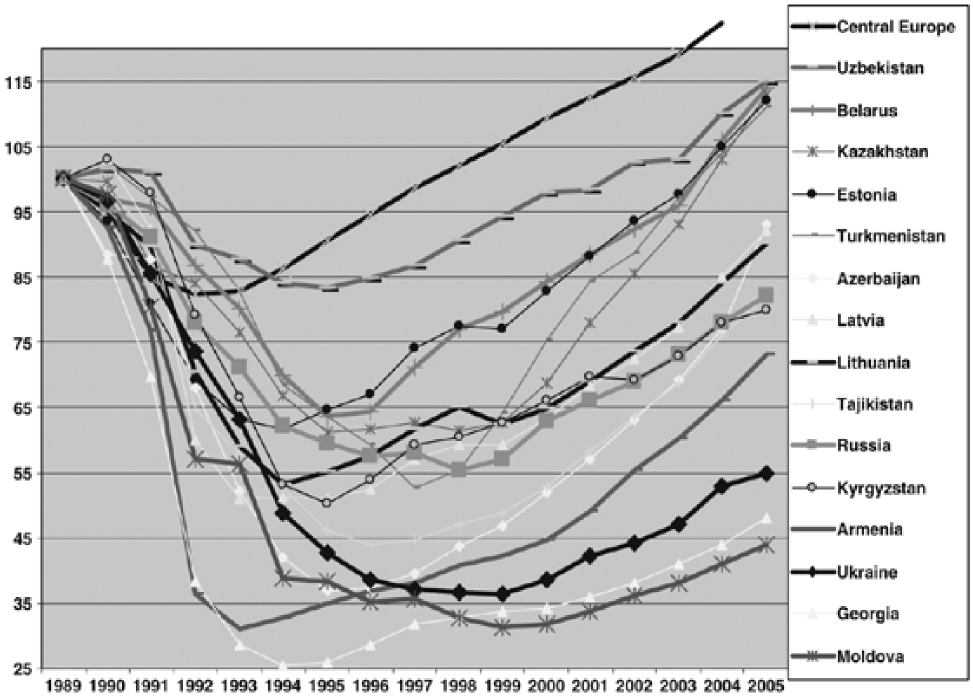


Figure 2.2: GDP changes in post Soviet states and Central Europe (EBRD 2005, Popov V. 2007)

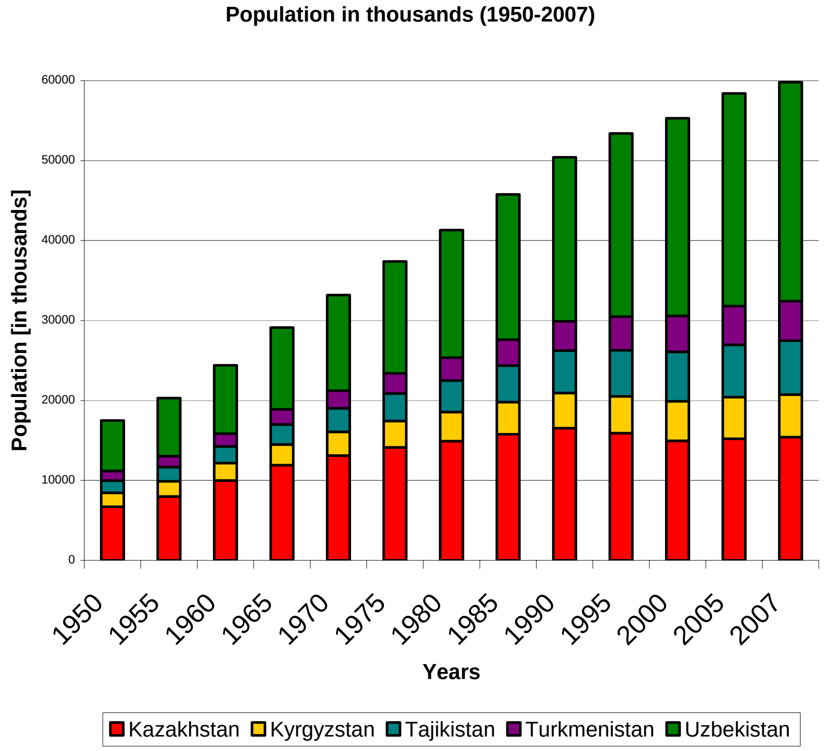


Figure 2.3: Development of the population (in thousands) in five republics of Central Asia (UN 2007)

The following sections offer an overview to the fundamental socio-economic conditions in each of the five Central Asian republics

2.2.1 Kazakhstan

The Republic of Kazakhstan is situated in the northern part of the Central Asia and is bordered by the Russian Federation (6,467 km) in the north, Uzbekistan (2,300 km), Turkmenistan (380 km) and Kyrgyzstan (980 km) in the south and China (1,460 km) in the east. The republic is divided into 14 regions (provinces) and 2 republic cities, and 158 districts (UNECE 2000a). The area of the republic is 2,724,900 km² which makes Kazakhstan the ninth-largest country and the largest landlocked country in the world. The climate of Kazakhstan is continental with cold winters and hot summers, arid and semi-arid with uneven distribution of natural precipitation. Kazakhstan possesses only about 35% of water it needs and 66% of land is subjected to desertification.

Kazakhstan has a population about 15.15 million inhabitants (2005) with about 57.3% of its population live in urban areas (OECD 2007). Being one of the most sparsely inhabited countries in the world it has as overall population density was 5.6 inhabitants per km^2 (2005). Kazakhstan is a bilingual state, the state language is Kazakh spoken by two-thirds of the population and the official language is Russian spoken by most citizens. In the early 1990s Kazakhstan was the only Central Asian republic in which the titular nationality was not in the majority. The population was approximately two-fifths Kazakh, two-fifths Russian and one-fifth other ethnic groups, with the largest ethnic groups being Ukrainian, German, Uzbek and Tartar. Following the dissolution of Soviet Union, Kazakhstan experienced a brain drain as the substantial German population sought to take advantage of Germany's blood-related citizenship law. Many of the Russian and Ukrainian population also chose to emigrate (OECD 2003).

Kazakhstan is rich in oil, gas, and mineral resources, including gold, iron ore, coal, copper, silver and zinc with large-scale commercial exploitation beginning only in the 1960s. Kazakhstan has the world's twelfth largest proven oil reserves (20 billion barrels) and is the world's third largest uranium producers (World Uranium Mining 2007). During the mid-1990s the only distribution routes for Kazakhstan's oil were pipelines through Russia. Accordingly, Russia exploited its monopolistic position by regulating flows and levying high tariffs. The worsening of living standards and the social and economic insecurity impacted human health and life expectancy with heart disease and cancer being the most common causes of death.

In the period 1929-1997, the city of Almaty was the capital of Kazakhstan, which was founded in 1854. In 1997 the national capital was relocated from Almaty in the southeast to Astana (population of exceeding 318,000 in 2000) in the centre towards north at large cost. At present, Almaty is the largest business and cultural centre in Kazakhstan with 1.1 million inhabitants (in 2000). The economic situation in Kazakhstan has improved since 1999 with recovery from the 1998 Russian crisis driven by market forces and good fortune. The sharp real depreciation of the currency stimulated exports and helped to validate policy makers' understanding of market mechanisms. At the same time, buoyant world oil prices in the early 2000s reinforced the positive trade developments (OECD 2003).

2.2.2 Kyrgyzstan

The Kyrgyz Republic is a landlocked, mountainous country bordered by Kazakhstan in the north, Uzbekistan in the west, Tajikistan in the southwest and China in the southeast. The mountainous region of the Tian Shan covers more than 80% of the Kyrgyz Republic, with the remainder made up of valleys and basins. Lake Issyk-Kul in the north-western Tian Shan is the largest lake in Kyrgyzstan and the second largest mountain lake in the world after Titicaca. The highest peaks are in the Kakshaal-Too range, forming the Chinese border. Heavy snowfall in winter leads to spring floods which often cause serious damage downstream. The runoff from the mountains is also used for hydroelectricity. The area of Kyrgyzstan is about 199,900 km² divided into 7 regions (provinces) and 1 republic city (UNECE 2000b). Bishkek is the capital of

Kyrgyzstan which has an administrative status equal to a region (province). Because of its predominantly mountainous topography, relative high levels of precipitation and resulting abundant water Kyrgyzstan is often dubbed the “Switzerland of Central Asia” and there are actually several bilateral agreements in issues of forestry and agriculture, drinking water supply and tourism linking the two countries with the Swiss Agency for Development and Cooperation taking a leading role.

Kyrgyzstan has about 5.16 million inhabitants (in 2005) with 35.8% of the population living in urban areas (OECD 2007). In 2005 overall population density was 25.8 inhabitants per square kilometer. Although the Kyrgyz are in the majority (68.9%) there is a large Uzbek population (14.4%) in the south and a large Russian population (14.4%) in the north of the country, and also other nationals such as Dungan 1.2%, Kazakh 0.8%, Tajik 0.9%, German 0.2%. The reductions in the number of population of other nationalities are due to the emigration. Kyrgyzstan, like Kazakhstan, is a bilingual country having retained Russian as an official language after formally recognizing the Kyrgyz language as a official language after 1991. Kyrgyzstan, like Tajikistan, is a mountainous country. with few natural resources of economic significance. Its economy was tightly linked to the Soviet Union’s economy and it was suffered substantially from the dissolution of the USSR. In the Soviet era, the republic was associated with low economic development and conservatism, although an idiosyncratic step was the appointment in 1990 of a physics professor as First Secretary. In 1993-1998 Kyrgyzstan was by far the most reformist of the Central Asian states. Whether this was because its president was the most liberal or whether he had fewest options is debated. In May 1993, Kyrgyzstan was the first Central Asian country to replace the Rouble by a national currency and this was explicitly part of an economic reform program. Kyrgyzstan received the most support from the international financial institutions. Prices were liberalized, the currency made convertible and tariffs reduced.

In 1998 Kyrgyzstan became the first Soviet successor state to accede to the WTO. Small-scale privatization also progressed rapidly. In other areas, however, reform was less successful. Large-scale privatization also proved difficult in practice, partly due to unrealistic pricing of assets. The only large productive enterprise with a positive output record was the Kumtor goldmine operated as a joint venture with a Canadian company. Kyrgyzstan was successful in cutting inflation, and yet it ran large fiscal deficits as tax revenues fell and public expenditures were not reduced in line. The situation was sustained by substantial IMF and World Bank financial aid, which enabled the central bank to limit inflationary financing of the budget deficit, but which led to a rapid build-up of external debt (OECD 2003). In 2005 due to the "Tulip Revolution", opposition leaders formed a coalition led to the president seeking exile abroad and a change of government.

2.2.3 Tajikistan

Tajikistan is landlocked in the south-east Central Asia by Kyrgyzstan (630 km) in the north, Uzbekistan (910 km) in the north and west, Afghanistan (1,030 km) in the south, and China (430 km) in the east. The area of Tajikistan is about 143,100 km², 93 percent of which is covered by the Tian Shan, Gissar-Alay and Pamir mountain systems. Tajikistan is situated on an active seismic belt that extends throughout the entire south-east of Central Asia. The climate of Tajikistan in general is continental, subtropical and semi-arid, with some desert areas, however, the climate changes drastically with elevation (UNECE 2004).

Tajikistan is divided into four administrative regions as Gorno-Badakhshan autonomous province in the east (45% of the country), Khatlon province in the south, Leninabad province in the north and the Regions of Republican Subordination in the centre. Tajikistan has about 6.51 million inhabitants (in 2005) (OECD 2007). In 2005, the overall population density was 45.4 inhabitants per square kilometer. Although the Tajiks are in the majority (65%), there is a large

group of Uzbek population (25%) and minorities like Russian (3%) and other nationalities (7%), like Tartars, Kyrgyz and Koreans. Since 1989, many Russians emigrated back to the Russian Federation, their numbers have been diminishing ever since.
Tajikistan is the least urbanized republic of the former Soviet republics and in 2005, only 24.7% of its population lived in urban areas. The city of Dushanbe is the capital and the largest city of Tajikistan with 562,000 inhabitants (in 2004). The population in other major cities are: Khujand (149,000 inhabitants), Kulob (78,000 inhabitants) and Qurghonteppa (60,000 inhabitants) (UNECE 2004). The official state language of Tajikistan is Tajik, a Persian based language. Russian is the common language. In Tajikistan also, there are also many Uzbek speakers, mainly in the west and in the south of the country.

The civil war in Tajikistan (1992-97) was one of the most violent internal conflicts of recent Central Asian history during which roads, bridges and other infrastructure were destroyed and many of which have still not been repaired. Since 1997, Tajikistan has sought support from international financial institutions and it has largely followed their policy recommendation. However, implementation has been poor since the central government does not have full control over the national territory. The war and the trade of narcotics have hampered the emergence of civil society. Foreign assistance, mostly from Russia, was mainly military aid, which contributed little to the economy apart from leaving Tajikistan with the highest debt/GDP ratio of any post Soviet republic (OECD 2003). The USA continues to build ties with Tajikistan, especially due to the geographic proximity to Afghanistan.

Agriculture still dominates the country’s economy, with cotton being the most important export commodities. Mineral resources include silver, gold and uranium. Industry is limited to a large aluminum plant, hydropower facilities and small factories specializing in light industry and food processing which are the main contributors in the national economy.

2.2.4 Turkmenistan

Turkmenistan is bordered by Kazakhstan in the northwest, Uzbekistan in the northeast, Iran in the southwest, Afghanistan in the southeast, and the Caspian Sea in the west. The area of Turkmenistan is about 488,100 km², over 80% of which is covered by the Karakum Desert. Turkmenistan divided into one republic city Ashgabat and five regions (provinces) as Ahal, Balkan, Dasoguz, Lebap and Mary. Turkmenistan has about 4.8 million inhabitants (in 2005) (OECD 2007). In 2005, overall population density was 9.8 inhabitants per square kilometer. Ethnic groups are Turkmen (85%), Uzbek (5%), Russian (4%), and other (6%) (CIA, The World Factbook 2008). Turkmen is the official language and regionally recognized languages include Russian, Uzbek and Dari. Turkmenistan has a single-party system and was ruled by President for Life Saparmurat Niyazov until 21st December 2006, when he died of heart attack. Presidential elections were held on 11th February 2007. Gurbanguly Berdimuhammedov was declared the winner with 89% of the vote and was sworn in on 14th February 2007.

The climate mostly consists of an arid, subtropical desert with little rainfall. Winters are mild and dry, with most precipitation falling between January and May. The area of the country with the heaviest precipitation is the Kopet Dag range. Although Turkmenistan historically was one of the poorest republics in Soviet Union, it experienced rapid growth during the final Soviet decades. The construction of the Karakum Canal, begun in the 1950s, which greatly increased the cotton production and in the 1980s natural gas production had been substantially increased. The president’s absolute power is supported by the control over the cotton and the energy revenues. Soon after independence, a strategy of providing free water, electricity, gas, heating, salt and other necessities for citizens up to 2030 has been adopted, still then shortages in supplies and commodities are frequent. Turkmenistan has taken a cautious approach to economic reform, hoping to use gas and cotton sales to sustain its economy (OECD 2003). Half of the country's irrigated land is planted with cotton, making the Turkmenistan the world's tenth-largest producer. Turkmenistan also possesses the world's fifth-largest reserve of natural gas as well as substantial oil resources. The major cities include Ashgabat, Turkmenbaşy (formerly Krasnovodsk) and Dasoguz. The capital Ashgabat located in the southern part of Turkmenistan.

2.2.5 Uzbekistan

Uzbekistan is situated at the crossroads of the ancient Silk Road between China and Europe in the middle of Central Asia between two transboundary rivers, the Amu Darya and the Syr Darya. Uzbekistan is bordered by Kazakhstan (2,203 km), Kyrgyzstan (1,099 km), Tajikistan (1,161 km), Turkmenistan (1,621 km) and Afghanistan (137 km) and covers an area of 447,400 km^2. The Aral Sea in the northwest of the country is divided almost equally between Uzbekistan and Kazakhstan. More than 80% of republic's territory covers by plains. In the south, these plains meet the mountains. This mountainous area is well known for its seismic activity with strong earthquakes up to 10 on the Richter scale (UNECE 2001). This high level of seismicity results from the collision of the Indian subcontinent with the Eurasia (Erdik M. et al. 2005).

Uzbekistan has the largest population among Central Asian republics which is about 26.6 million (in 2005) with annual population growth rate of 2-2.5% and 36.7% of population (in 2005) live in urban areas (OECD 2007). It is the most densely populated region in Central Asia, but population density varies greatly due to the specific natural features like mountains or arid deserts of Uzbekistan. The majority of the population is concentrated in the oases. The average population density is 59.5 persons per square kilometer (in 2005), with a density varying from 452 people per square kilometer in Andijan Region (province) to 6.5 persons per square kilometer in Navoi Region. Over 130 different nationalities are living in Uzbekistan, although the majority of the population is Uzbek (75.8%), followed by Russian (6.0%), Tajik (4.8%) and Tatar (1.6%). The official language is Uzbek.

Administratively, the Republic of Uzbekistan is divided into 12 provinces and one autonomous Republic of Karakalpakstan. The city of Tashkent is the Uzbek capital with a population of 2.4 million people. It is the fourth largest city in the post Soviet Union after Moscow, Saint-Petersburg and Kiev. It situated in the Chirchik River valley at the spurs of Tien Shan Mountains and is the country's administrative and economic-industrial centre. Uzbekistan has a continental climate with hot and dry summers and short, cold winters. Temperatures between day and night, as well as between summer and winter vary extremely. The average annual rainfall on the plains is between 100-200 mm which is lower than the rate of evaporation. Low rainfall, dry and hot air combined with high evaporation leads to rapid mineralization of soils.

Uzbekistan possesses substantial oil and gas resources, being the world's tenth largest gas producer. Uzbekistan is the world's seventh largest gold producer and possesses the world's fourth largest resource of gold. It is the second biggest gold producer in post Soviet countries and first by quantity per capita. Also it has significant resources of copper, silver, lead, zinc, wolfram, coal and is the world's seventh largest uranium producer (World Uranium Mining 2007). Uzbekistan is the world's fifth largest cotton producer and the second largest exporter (UNECE 2001).

According to OECD 2003, Uzbekistan's economic performance since 1989 has been the best of all former Soviet republics, including the rapidly reforming and geographically advantaged Central European countries. It suffered less economic shock from the dissolution of the Soviet Union than did most other former Soviet republics because it produces large amounts of cotton and gold, commodities of value on world markets, and because the government stressed development of import-replacement industries in the post-Soviet era. In the 1990s, oil and gas production increased significantly, providing exports of natural gas and eliminating the Soviet-era need to import oil. In the same period, the expansion of grain cultivation reduced food imports. Another favorable initial condition is Tashkent's position as the regional capital of Soviet

Central Asia and it gained the biggest air fleet, the large aircraft plant and most military equipment in Central Asia. Uzbekistan Airways is the only competitive international airline in Central Asia and remains one of the state enterprises to have been successful in the new economic environment. In the early 2000s, agriculture remained the most important economic sector, but the contribution of industry was rising.

2.3 Environmental situation in Central Asia

Central Asia is rich in natural resources resulting in industries such as mining, oil and gas production and refineries, coal, ferrous and non-ferrous metallurgy, the chemical and petrochemical industry, construction materials industry and light industry. Resource intensive and inefficient production processes, poor waste management and the almost total neglect of environmental protection measures led to the accumulation of high volume of waste of varying hazard levels which pose a significant risk to the population in Central Asia.

The population distribution is mainly around the southern region between Uzbekistan, Tajikistan and Kyrgyzstan. The average density of the Fergana Valley is 100 persons per square kilometer, while in the Uzbek part of the valley it is 300 people per square kilometer. It is mainly in these regions, where the most of the mining and industrial activities, water resources and landfills and dumpsites are located. This situation is further aggravated by high and active level of seismicity. Earthquakes are a major threat to and economic development of Central Asia. The rapid urbanization of earthquake prone Central Asian makes such disasters more deadly and dangerous.

Waste management, in particular landfill practice, is underdeveloped in Central Asia. Often municipal solid waste is disposed together with medical, commercial and industrial wastes. Most of the existing urban landfills can be considered as open dumps, without any kind of protective barriers, safety installations and/or an organized planning for waste deposition which cause severe problems in respect of environmental pollution and public health.

Exceptions of open dump landfill practices are very rare, but can be found for instance in Tashkent, Uzbekistan. The modern equipment, including waste trucks, compactors and excavators has been acquired for Landfill Ahangaranskaya which is currently the main landfill site of the city of Tashkent. Landfill operation is well organized including waste registration, emplacement records and the adequate control of the landfill territory. However, as for all the other sites in Central Asian republics a sufficient monitoring program for determination of the landfill impact is not yet implemented (Kholmatov K. et al. 2007a, Kholmatov K. et al. 2007b, Ritzkowski M. et al. 2007).

Figure 2.4: Aral Sea disaster (http://unimaps.com/aral-sea/aral-pic.gif) (03.02.2008)

Water resources are one of the key factors in the socio-economic and environmental well-being of the Central Asian countries. Practically all water resources of the Central Asian region originate from the regions with year-round snows and glaciers in Kyrgyzstan and Tajikistan. Practice of an irrigated agriculture is concentrated in the populous valleys of the Amudarya and Syrdarya rivers, from which is also carried to Uzbekistan, Kazakhstan, and Turkmenistan. Although providing the population with adequate supplies of drinking water is a priority for Central Asia, the people living on the most river basins have limited access to safe drinking water, especially low-income groups and women. Water for municipal supply and drinking needs is often drawn directly from rivers and canals. Consumers in the middle and lower river reaches are generally supplied with water which is unfit to drink, but there are no alternative sources. Water polluted by heavy metals, phenols and the other toxins is posing an increasing threat to public health and the environment. Poor water and irrigation management has resulted in severe environmental crises and regional tensions. The Aral Sea, located in Uzbekistan and Kazakhstan, has been severely desiccated by overuse of its tributary rivers, a situation recognized as one of the world's worst environmental disasters (Figure 2.4).

The problem of environmental protection in Central Asia is large-scale and in many respects has transboundary aspects. Hence, the solution of the environmental problems demands joint coordinated actions of the Central Asia states. In this connection, multidisciplinary regional projects/programs, mechanisms and the tools of their realization should cover transboundary aspects.

2.3.1 Environmental Legislation in Central Asia

The legislative and institutional framework for environmental protection including waste management in CA is divided between various levels of jurisdiction and liabilities. The environmental legislation system created in the Central Asian states has many similarities and generally made it possible to move away from the administrative control system towards management based on economic incentives and disincentives. The competence to regulate environmental matters in each Central Asian republic is split between State Parliament, the Ministry (State Committee/Agency) of Environmental Protection, and the Regional (Province) and city divisions of the Ministry of Environmental Protection. The Ministry of Environmental Protection is the main coordinator for environment protection activities, among the State entities, in coordinating activities relating to waste management, pollution of water, air, and soil, natural hazards (i.e. earthquakes, landslides and mudflows), and use of natural resources, including managing the Environmental Fund and initiating liability actions.

There are also several non-governmental organizations whose activities focus on raising public awareness, as well as lobbying and representing individuals in environmental decision-making and in defending environmental rights in court. They often have a socio-cultural agenda promoting basic ecological and cultural education of children by organizing tours and field trips, expeditions and festivals. In general, environmental legislation of Central Asian states provides good opportunities for the public and non-governmental organizations to participate in governmental decision-making. The system of legislation in the environmental protection and related issues in Central Asian states comprises a number of primary laws. According to EEA (European Environment Agency, 2007) Central Asian republics have not strategies on municipal waste management. It is still essential to develop a number of legal and regulatory acts for enhancement of economic effectiveness, painless transition to market economy and normal functioning of businesses of various forms of ownership, introduction of economic instruments in waste management, conducting unified technical policy, and creation of unified management system.

Analysis of the operations of local waste companies in Central Asian cities as well as of industrial companies has shown that many new or reviewed policy papers have not yet been conveyed to the implementers and waste management activities and Programs have not been developed. The environmental issues of highest priority in Central Asia are:

- Evaluation of the earthquake, landslide, avalanche and mudflow danger
- Development of the most efficient methods of water use, design water supply and water treatment systems
- Managing, storage and transfer of municipal solid waste and hazardous industrial waste
- Rehabilitation of irrigation systems, intra-farm irrigation, monitoring of pastures etc
- Restoration of the initial ecosystem of the Aral Sea region
- Rehabilitation of the areas of tailing dumps and mining waste piles

The system of legislation in the environmental protection and related issues in Central Asian states comprises a number of primary laws, and it is essential to develop a number of legal and regulatory acts for introduction of economic instruments in waste management, conducting unified technical policy, and creation of unified waste management system.

2.4 Waste management practices in Central Asia

One of the most imposing threats to environmental quality in Central Asia results from poor waste management including insufficient coverage of the collection and/or recycling systems, little to no waste pre-treatment and improper final waste disposal. The majority of the landfills lack the proper equipment and trained personnel necessary for conducting the operation in a controlled manner so that landfills become a menace to the environment and public health. There is generally a lack of reliable data on collection services and their performance in Central Asia. This is mainly because of the lack of a sufficient number of properly trained personnel (both technical and managerial) and need for an acceptable methodology and equipment for obtaining the data.

The majority of Central Asian universities and higher institutions do not offer courses in the waste management resulting in a shortage of properly trained personnel to plan, design and implement waste management systems. In many cases, authorities must rely on the services of local professionals who are not waste management experts and/or on foreign advisors. Furthermore, usual options and technologies that are widely accepted in many industrial countries can be rarely implemented successfully in Central Asia because of the lack of resources and skilled personnel. Furthermore, most efforts to transfer technologies and practices from industrialized countries to developing countries without suitable adaptations are not fully successful due a result of a lack of understanding of the conditions prevalent in developing countries. For instance, a few waste treatment facilities have been built and operated in Latin America with the design and technology of these plants were imported from either North America or Europe. Plant designs imported from industrialized countries tend to be both mechanical and energy-intensive and the plants have either been closed or have fallen into a state of disrepair (Diaz et. al. 2008). An understanding of the conditions requires the collection of basic data, as well as a thorough knowledge of the social, cultural, financial and environmental conditions prior to the preparation of a plan.

The most important data needed for planning and design of waste management systems include quantity, composition, and characteristics of the waste produced in a particular region. This include data on regional waste management practices, methods of storage, types of collection, treatment, final disposal, availability of equipment, maintenance procedure, capital and operating costs, sources of revenue, methods of cost recovery, and availability of human resources. Usually, this data and information should be obtained by experienced and trained personnel so that the personnel can assess the data and pass judgment on the adequacy and quality. If data cannot be collected in the field, then the data should be collected from the reliable sources and be critically evaluated.

A sustainable and effective waste management program cannot be properly designed without information on waste characteristics and waste streams because successful management and processing of waste depends on the types, quantities and composition of the material. The information related to waste composition depends upon the type of treatment to be used for waste processing and the method of final disposal. For instance, if landfilling should be the primary means of final disposal in, then the waste management plan would rely primarily on types (e.g. domestic, commercial and industrial) and quantities of waste to be disposed. If resource recovery and recycling are key components of waste management plan, detailed data on the characteristics of the waste (e.g. composition, bulk density and moisture content) and quantities will also be needed.

2.4.1 Waste collection and transport in Central Asia

Municipal solid waste (MSW) management in Central Asia encompasses the collection and disposal of waste from: domestic, commercial, institutional and industrial sources; city street cleaning; as well as collection and disposal of landscaping waste. MSW is collected at a large variety of points, either in pre-positioned bins or, in their absence, open waste piles using a variety of collection vehicles from compactor trucks to open dump trucks. The MSW collection does not cover all populated areas of Central Asia. The collection service is planned to serve urban areas, however, in fact mainly large cities and regional centers are served. The rural population is not considered as source of significant amounts of MSW to warrant setting up and running MSW collection services.

The authorities responsible for collection of MSW in the Central Asia suffer all the symptoms of transition from a centralized planned to a market economy. The old financing system of these services is not able to respond to inflation and growing prices, which results in declining quality of provided services. Typically, a town in Central Asia is served by collection companies controlled by local municipalities. Although some of them are privatized, they are still under strong influence and control of local municipalities. The basic collection system is functional but rapidly deteriorating. Collection points are poorly maintained with increasingly lack of serviceable bins and are often of limited accessibility to users. A shortage of bins is resulting in waste piles being left for collection and collection frequency depends on vehicles and (available funds for) fuel availability. Failures of collection then results in increased random dumping and burning of uncollected waste. Manual recovery of recyclables from containers is a standard practice in Central Asia and an informal system of separated collection is in place, targeting glass and PET bottles and even dried bread.

Collection fees in Central Asia are set by local municipalities and vary widely. The typical approach is that fees should be kept as low as possible, covering only immediate operational costs. Both the state and private sectors are involved in buying materials separated from MSW. For instance, the state sector in Uzbekistan is focusing on iron scrap and non-ferrous metals with private agents are buying waste paper and plastic. These sectors are competing with the state offering to pay housing and utility debts of population from income of purchased materials, and private sector is offering higher purchase prices. Waste transfer stations were introduced in some of large Central Asian cities, for instance in Tashkent, Uzbekistan where waste delivered to transfer station is compacted and then delivered in special containers to the landfill about 32 km outside of the city. The majority of CA towns are using disposal sites relatively close to their collection area, therefore a transfer stations are often not necessary.

2.4.2 Processing and disposal of waste in Central Asia

After a waste processing plant was put into operation in 1971 in Saint-Petersburg, Russia, similar waste processing plants were constructed in 1977 in Tashkent, Uzbekistan and in Almaty, Kazakhstan. The newest waste processing plant has been commissioned by a private company in Almaty in December of 2007.

Since Central Asia has very limited financial resources allocated to waste management and disposal, most of solid waste generated is disposed in open dumps without any kind of protection barriers, safety installations or organized planning for waste deposition. Almost all waste dumps require upgrading, both in terms of equipment and operating practice. The majority of landfills do not utilize appropriate covering practices, do not maintain recording logs and have high, open tipping faces. Waste compaction is limited to that achieved by bulldozer leveling activities, and intermediate covers are installed very seldom. These practices lead to subsurface fires, especially near the slopes of the tipping area. In addition the low compaction of the wastes reduces the amount of surface runoff and contributes to the acceleration of wash out processes. While some have secure, controlled access and record incoming material by load, there is no routine inspection or weighting of incoming loads, although weight scales are nominally available at some landfill sites. Fences for the prevention of inadmissible entrance are missing just like any kind of litter control.

Scavengers (often children) sorting the incoming wastes and collecting the recyclables are present on almost every landfill. The presence of hazardous industrial waste in the landfills is not commonly observed but in the absence of dedicated management facilities for these wastes, some disposal of these materials most likely takes place. Similarly, biomedical waste is routinely disposed of in the landfills, creating risks to workers and scavengers. Very few landfills have operational monitoring and landfill gases emit from all sites. Surface fires are deliberately lit to reduce waste volume and active fire control by trucked water is ineffective once internal combustion has begun.

Fig. 2.5 Attempted waste separation at source in Central Asia

The waste management system in many Central Asian towns is approaching a state of collapse, largely because of inadequate financial capacity for proper maintenance and capital replacement, although recent ad hoc initiatives by local municipalities are serving to maintain a minimum service level. Attempts to separate at source also require public awareness creation as shown in Fig. 2.5. The majority of urban centers are not properly managing their municipal solid waste therefore an important portion of the waste remains uncollected promoting scavenging and creating a health hazard. Many unauthorized or uncontrolled waste dumps are established inside and outside small towns or cities in Central Asia. The main reasons for uncontrolled waste dumps are:

- Weak legislation on waste management
- The lack of funds for the construction of waste-treatment and disposal facilities
- Insufficient governmental control of waste dumps and the absence of a system of fines for the unauthorized dumping of wastes, including small dumps in residential areas
- A lack of knowledge of municipal waste management practices in local administrations and a lack of responsibility for the implementation of waste management decisions taken by governmental bodies
- The absence of an economic scheme for the collection, transport and disposal of MSW
- Low level of public awareness subject to environmental protection and pollution.

2.4.3 Conclusions on economic development and environmental management in Central Asia

The relationship between economic development and environmental protection policies and implementation is evident in Central Asia as it is for many other countries. Europe and other industrialized nations are steadily increasing waste separation at source thereby reducing the final, non-recoverable fraction and waste disposal by landfill is being substituted by incineration coupled with energy production. Central Asia, however, will be using landfills as the main means of waste disposal for the next 2 – 3 decades at least. During the field work associated with this dissertation, it became apparent that current waste management practices (and associated problems) in Central Asia reflect the standards seen in the 1970’s in Europe i.e. approximately 30 plus years ago. The aim of the project at the basis of this dissertation, was to assess the environmental risk associated with waste management in Central Asia for definition of remedial strategies and measures. However, the resulting recommendations can only be of relevance if the status and dynamics of economic development are considered. The benefits envisaged will need to be weighed against the necessary costs, which range from negligible to substantial, which are discussed as a result in of the four individual landfill site investigations covered in Section 5.

3. Use of GIS and simulation models for environmental risk management

Geographic Information Systems (GIS) are defined very diversely in technical literature, but there are two predominant definitions. The first definition describes a pure software package which allows processing of geographic information. This definition states that the GIS comprises a four-component model: input, management, analysis and presentation.

A second definition divides the elements of the GIS into four components: hardware, software, data and user. This definition shows that the software is not necessarily the most important part of a GIS. All components must be regarded as of the same value. Investments into a Geographic Information System do not end with software and hardware. A large part of costs arises when collecting and acquiring the data needed for the application. The technical knowledge and creativity of the user form a central aspect in the whole Geographic Information System.

GIS can be very useful for two aspects of risk assessment of landfills:

- Large-scale: for locating of new landfill sites based on various constraints e.g. distance to surface water etc. This is typically applied to a geographical / political unit e.g. with a county or state
- Small-scale: for ranking existing landfills in term of relative risk to the environment including vulnerability factors such as potential socio-economic impact e.g. impact on centers of human activity

In this study, the additional factor has been included, being the induced risk associated with regions of high seismic activity. MSW landfills in highly seismic regions have a yet undefined increase in risk to groundwater and soil (e.g. through sudden rupture of the natural base), threat to human life or damage to operational facilities through the possible collapse of a landfill slope under earthquake conditions. Central Asia is one of the most seismically active regions in the world. Severe earthquakes in the region have completely destroyed big cities like Ashgabat (1948) or induced debris flows which devastated wide areas and cities like Almaty (1921). The section describes the use of GIS for assessment of the environmental management of the MSW landfills in Central Asia and considers various case study examples.

3.1 Application of GIS for Environmental Risk Management

The broad issue of environmental risk management associated with landfills can only be solved if all necessary information is available in the GIS. The relationships and dependencies between different aspects are very complex e.g. to identify most well suited location for a landfill. Apart from the natural and socio-economic factors, various stakeholders and factors of political decision making cannot be represented in the system. The operation of the research methodology can be presented in the following steps:

1. Decide on the criteria for spatial buffers
2. Acquire data
3. Convert criteria into GIS layer
4. Perform spatial operation
5. Analyze results
6. Identification of potential areas for landfills

A general list of possible criteria for spatial buffers with their descriptions is presented below:

Proximity to surface water. A landfill must not be located near any surface streams, lakes, rivers or wetlands. For this reason, a 100-meter buffer should be placed using the function in GIS software which will be used to generate the buffer around all surface waters such as streams, lakes and wetlands.

Distance from transportation routes. Aesthetic considerations are necessary to reduce opposition based on visual impact. Therefore, landfills shall not be located within 100 meters of any major highways, city streets or other transportation routes. The stakeholders may also want to extend this criterion to include airports with a distance of 5,000 meters.

Distance from environmentally sensitive or protected areas. The location of a landfill in close proximity to sensitive areas such as national parks or fish sanctuaries must be avoided. The mangrove areas and areas dedicated for special protection should also be excluded. Apart from these areas, a buffer of 3,000 meters should also be placed around the environmentally sensitive areas.

Distance from urban areas. Landfills should not be placed too close (e.g. 15 - 20,000 meters) to high-density urban areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This could also be extended to Not in Anybodies Backyard (NIABY) to prevent health problems, noise and/or odor/dust complaints, decreased property values and scavenging. The rapid urbanization as especially in developing countries should consider how the city is likely to develop in the next 20 years, which is typically a minimum lifetime for a landfill.

Distance from rural settlements areas. Due to the same conflicts relating to the NIMBY/NIABY syndrome, development of landfills shall be prohibited within 3,000 meters from village settlements.

Landform and soil type. The permeability of the underlying soils and bedrock will greatly influence how much leachate is escaping from a landfill site. Therefore, preference should be given to a landform that is somewhat located in flat or undulating land.

Land use/land cover. The land use and land cover must be known in order to determine which areas are more suitable for a landfill. Depending upon the land use types such as grassland, forests or cultivated land, an appropriate index of land use suitability are assigned in the GIS system.

Haul distance. Simple practical considerations like good road access are essential to the economics of a landfill site. Of course, the further away a landfill is from the served urban area, the further the waste will need to be transported, significantly increasing operational costs, not to mention contribution to overall environmental impact.

3.2 Data entry and processing

A common problem with setting up GIS, which includes historical data is either manual entry or digitizing of analogue data, both of which require much time and skilled personnel. Furthermore, some data need verification from site visits, which are then complemented thorough field data and/or technical notes or even the introduction of completely new sites. If site maps are not available, high resolution satellite images or aerial photographs could be use for this purpose. The spatial operations for constraint mapping begin by identifying the criteria or conditions, which after identifying should be converted into GIS layers. The spatial operation from the GIS layers is normally performed in conjunction with GIS functionality found in most GIS software to create a buffer surrounding the theme such as river, road and others as described above.

After the construction of a landfill on a selected location, the landfill selection GIS could be adapted for use as a specific GIS application for monitoring environmental risk (i.e. small scale). This adapted GIS would be used as a data repository for analyzes and evaluation according to criteria, (which will also develop over time (e.g. as legislation becomes stricter or land use in the proximity changes) over the life time of the landfill.

For example, the results of groundwater monitoring are the basis for the analysis of quality of water in the surrounding area of a MSW landfill site. The monitoring of water quality is an important component of environmental assessment impact of a landfill. The values of electrolytic conductivity and concentrations of nitrate, sodium and chloride best reflect the changes taking place in water environment as a result of landfill wastes and the presence of landfill site on this area. Isolines of the concentrations of the chosen groundwater quality parameters can be created (Fig. 3.1).

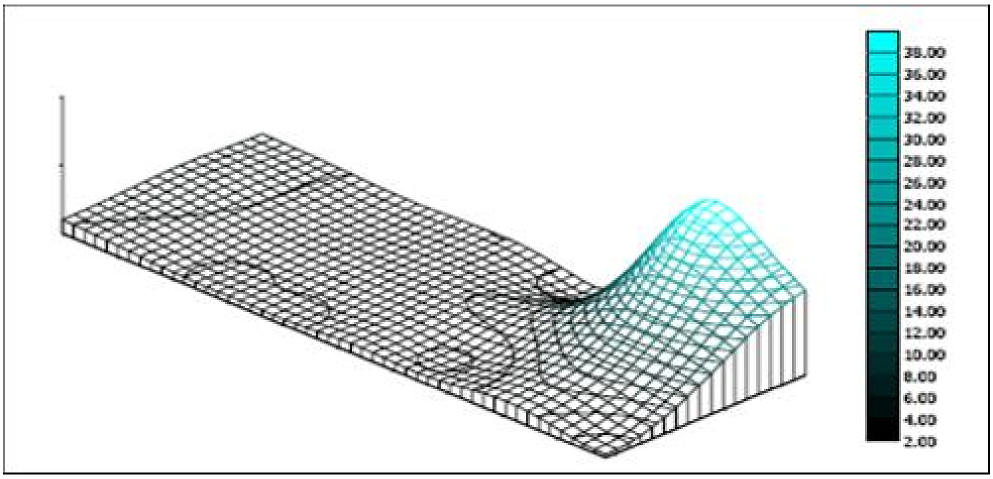


Figure 3.1: Example of isolines of nitrate concentrations in groundwater

Other main planning and monitoring themes for a landfill GIS could be:

- Choice of the location and planning of the landfill
- Landfill topography and geometry development (also subsidence) over time
- Volume determination and residual capacity
- Planning, assistance, monitoring and control of reclamation measures
- Monitoring of landfill gas production (quality and quantity)
- Monitoring of air emissions (noise and dust)
- Documentation of soil samples
- Monitoring of the hydrologic processes in and around landfill
- Monitoring of landfill fires

Suitable methods for the acquisition of data are necessary for every task, if it exists; we are able to ensure a common and global view in analysis and evaluation of the landfill information.

As for any database, the quality of the output (results) is highly dependent on the quality and compatibility of the input data. It was necessary to prepare the data in GIS-supported format and which can be easily loaded. During the data acquisition phase the typical problems arose from trying to incorporate analogue data such as hand-drawn pictures (no scale, orientation, positioning, legend), pictures, photos, schemas etc. It is also way possible, but not without significant effort and the decisions need to be made of what to include and what not. For example valuable background (supplementary) data include political and administrative data –

mixture of old and new names for territories, regions, cities are necessary to document historical aspects.

Two ways to connect (link) data evolved: by feature name or by coordinates. However, sometime only the name of the object (region, city) and sometimes with coordinates, but without any name. The majority of maps were very old and it was assumed that some data on climate and protected areas are as they were defined 15 - 20 years ago.

3.3 GIS Data for Central Asian landfills

Data was collected about the CA landfills to investigate the effects to the environment, the vulnerability of their surroundings due to the emission potential and the vulnerability of the landfill itself due to seismic activity and other natural hazards e.g. flooding. Furthermore, other natural conditions relating to environmental risk such as surface and groundwater, geology, vegetation etc. including population density are entered as various layers in the database. The GIS database was designed and set up in a three-level structure (Fig. 3.2).

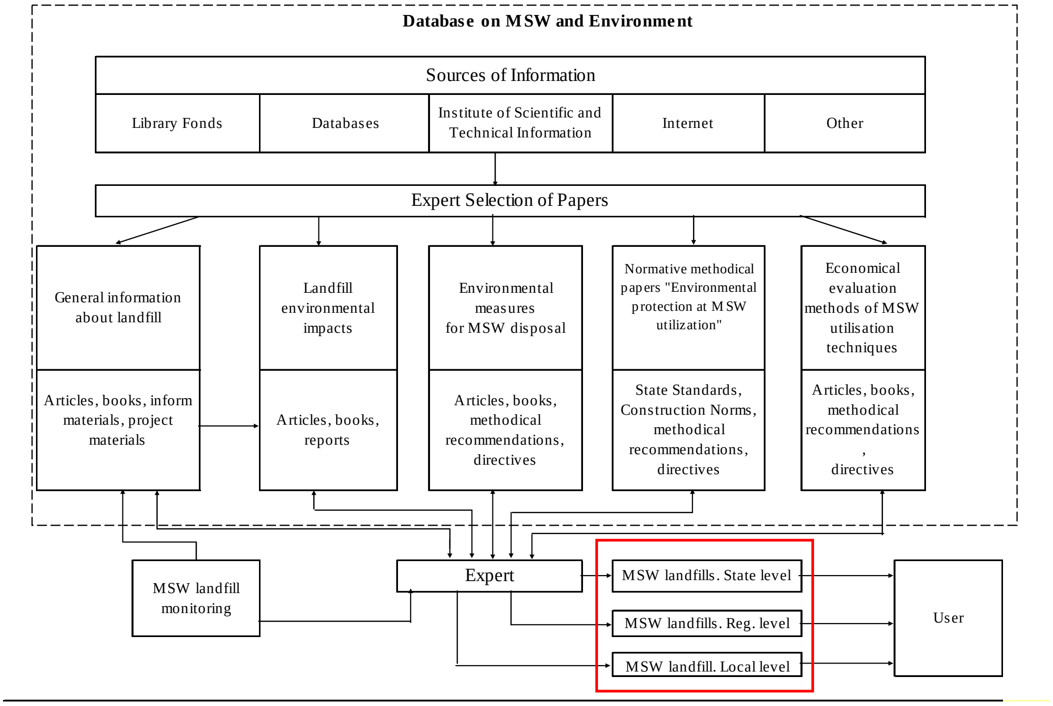


Figure 3.2: Structure and example content of the NISMIST GIS database

The landfill data is divided into three levels which is summarized below and then described in detail:

Level 1 – National (State): includes all registered MSW landfills in the individual Central Asia countries and contains the basic data name, location, volume, operation period, construction type, barriers (if any) and emission collection systems.

Level 2 – Regional: respectively includes 5 representative MSW landfills in each of the 5 NIS countries with more detailed information about size, disposed waste (after European Waste Catalogue (EWC)), emission control, groundwater and monitoring. This level is used for the so-called Landfill Classification catalogue (LCC).

Level 3 – Local: includes all available information about one landfill in the respective country are gathered. This includes data from site investigations like the morphology of the disposed waste, leachate, surface water and groundwater quality, gas quality and quantity, geotechnical, geological and hydrogeological information as well as previous investigations and monitoring programs (see Ritzkowski et al., 2007).

3.3.1 Level 1 – National Data

The general or National level data is based on existing reports, maps and internet data and covers the whole territory of all Central Asian countries.

Landfills descriptive data for this level:
- Landfill (LF) name, location and address
- Beginning of waste deposition
- Date of LF closure
- LF area
- LF capacity (projected and approved)
- Current LF volume
- Existing barriers
- Landfill gas (LFG) collection system
- LF construction type

As specified in Level 1 questionnaires, this level also includes:

I. Cartographical data
- map (scale 1:1,000,000)
- administrative centers
- hydrology
- protected areas

II. Administrative data
- name of the administrative-territorial unit (the state subject)
- area of the territory
- population
- among them urban population

III. Nature and climatic data
- (hydro)geological and seismic conditions
- type of climate
- geo-botanical zone (subzone)
- average annual and seasonal air and soil temperature
- annual and seasonal quantity of atmospheric precipitation
- max temperature
- humidity

IV. Economic data (structure of national economy (%)
- industry
- agriculture
- other types of activity

V. Basic landfill data
- names and locations of MSW authorized landfill
- quantity of generated solid household wastes

- quantity of solid household wastes transported to landfills

3.3.2 Level 2 – Regional Data

The regional level data is mainly collected to fulfill requirements of the Landfill Classification Catalogue (LCC) which references the EC waste classification directive REGULATION (EC) No 2150/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. This can be used to produce a descriptive overview of all the landfill sites in the respective country - which is complementary the EC landfill site classification system - then report to the authorities. The LCC is based on the Level 2 data collected for 5 landfill sites per country, but can be extended with data to register all significant landfills at the national scale. The datasheets for these sites (Table 3.1) are based on the EC directive and available by clicking on the respective landfill site with the GIS.

parameter	completed by the partner
Landfill (LF) name, location and address	**MSW landfill "Ahangaranskaya"** Located 32 km to south-west from Tashkent city. Address: Tashkent region, Ahangaran highway, 32 km. The coordinates of landfills: - 41.05,817 (Latitude) - 69.28,879 (Longitude)
LF operator (responsible organisation)	Mahsustrans
Distance (km) to the nearest location of human settlements (village, town etc.)	1.5-2 km
Beginning of waste deposition [year]	1967 year
LF area [ha]	59 ha
LF height [m]	30 m
LF capacity (projected and approved) [m^3]	7,500,000 m^3
Annual waste acceptance [m^3/a]	290,000 m^3/a
Current LF volume [m^3]	5,250,000 m^3
Anticipated LF operation time until [year]	2014 year
LF construction type (see example for 1st GIS-level)	"combined" LF-type
Waste emplacement method (e.g. compaction)	compaction 2 m of waste compacted by compactors ("TANA", Finland) and 30cm of in-place loess
Type of landfilled waste (according to the European Waste Catalogue, EWC) → specify the respecting numbers (6 digits)	20 01 01 20 01 02 20 01 08 20 01 10 20 01 11 20 01 33 20 01 38 20 01 39 20 01 40 20 01 99 20 02 02 20 03 01 20 03 02 20 03 03

Guidelines for LF operation? If any, please specify (and ad copies)	Normative technical documentation, SanPiN 0157-04 from 12.07.2004
Waste acceptance control ? (yes / no)	yes
If yes, please specify	weight scale
Existing barriers (if any)	
Base liner (specify type)	compacted clay soil
Surface cover (specify type)	compacted soil
Landfill gas (LFG) collection system (if any)	
Number of gas wells	n/a
Other LFG collection system (specify)	n/a
Amount of collected LFG [m^3/h]	n/a
Leachate collection system (if any)	
System type (specify)	n/a
Leachate treatment system (specify)	n/a
Existing data on leachate quality available?	n/a
Specify available leachate data	n/a
Groundwater (GW) characteristics	
Distance (average) between LF base and GW [m]	5-25 m
Number of GW monitoring wells (upstream)	1
Number of GW monitoring wells (downstream)	n/a
Existing data on GW quality available?	yes
Specify available GW data	
LF monitoring records (if any, and in addition to the requested data on LFG, leachate and GW) → specify	According to the data given by Company Shimizu 397.000 CO_2 tons/year. Annual rainfall 338 mm/year.

Table 3.1: Landfill Classification Catalogue (LCC), Level 2 data

Besides the tabular data as shown in Table 3.1, the GIS allows a combination of e.g. geological, hydro-geological and seismic information of a certain political territory with landfill specific information. The combination of GIS and LCC covered the following two different scales:

1. Large scale - general information regarding regional natural and socio-economic conditions, zone of various seismic activity levels, surface water bodies, metrological data, topography and geology, population density, industry including information layer with landfill positions.

2. Small scale - detailed information regarding local natural and socio-economic conditions relating to the specific landfill site and – of special interest for the planned risk assessment – to

implement detailed data regarding the nearby surroundings of the landfill, such as localized information on geological and hydro-geological situation, small water bodies, vegetation, houses or villages (pattern of utilization) for a distance of only a few (1 to 2; max. 5 km) around the landfill.

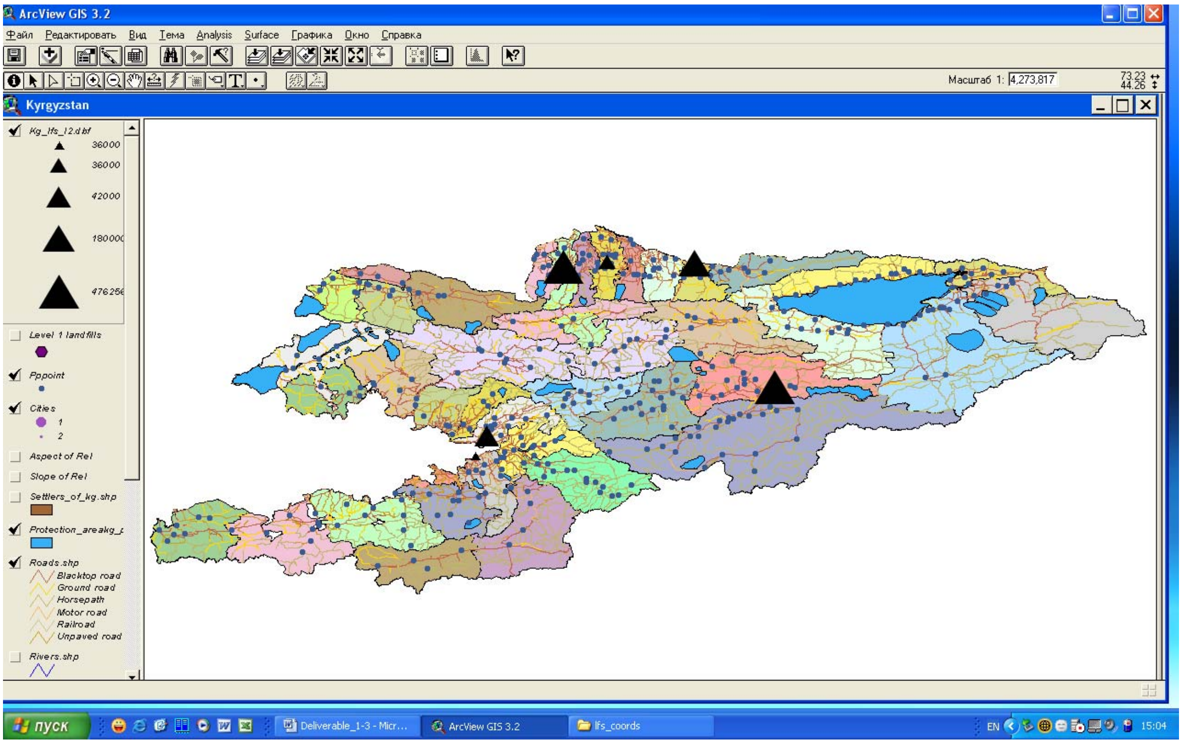


Fig. 3.3 Level 2 data example for Kyrgyzstan. **300 Km** **(approximate)**

The datasheets for these sites are based on the EC directive. The specific landfill data is available by clicking on the respective landfill site on a map (Figs 3.3 and 3.4).

Please note: Figures 3.3 to 3.8 are screen shots directly from the GIS system. North is always up unless otherwise indicated and the scale is only approximate as the diagrams have been trimmed to fit the page size.

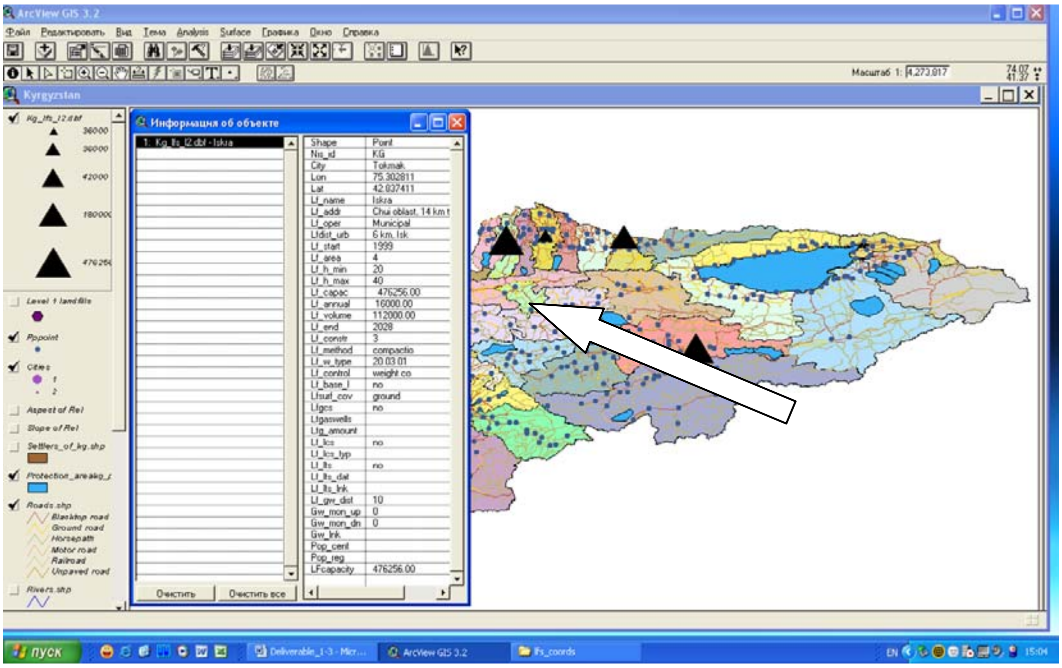


Fig. 3.4: Level 2 information navigation tool for a specific landfill site in Kyrgyzstan.

3.3.3 Level 3– Local Data

Level 3 data layers contain precise imagery and detailed information for selected landfills:

- List of settlements, located in (or nearby) the sanitary buffer zone of MSW landfill, population (in thousands)
- Geotechnical and geophysical data and results of landfills investigations.

This part of GIS was mainly filled in with data from site investigations. Spatial resolution of imagery used formation of the basic layers was 1m. The GIS has also functionality to store photographs, graphics and text from the individual landfill site investigations (Fig. 3.5).

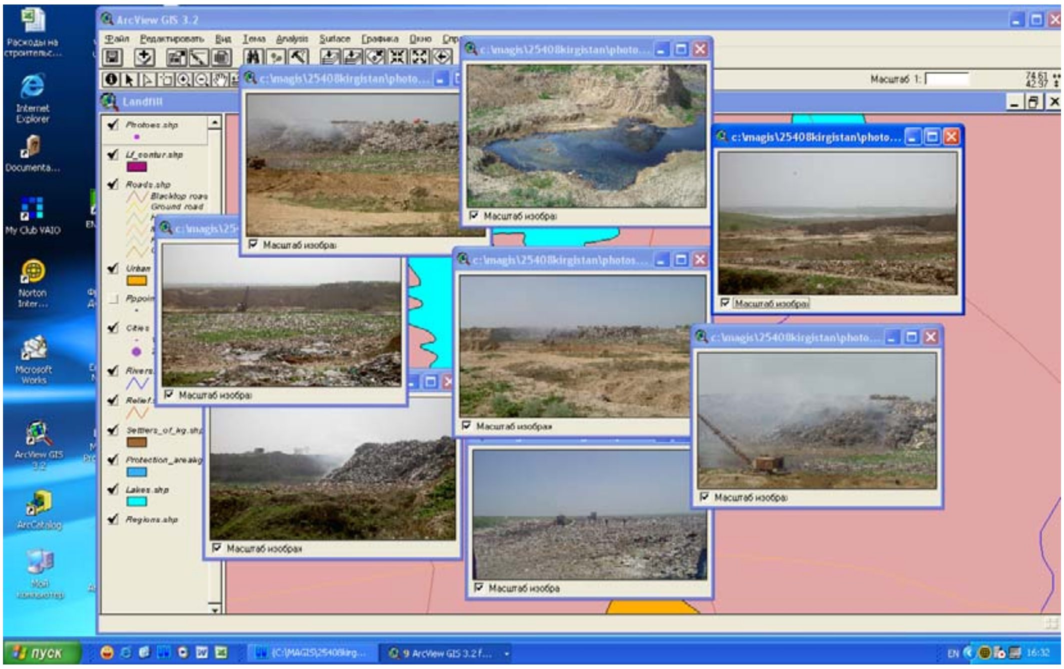


Figure 3.5: Landfill site investigation photos within the GIS

3.4 Applying the GIS for risk assessment of the CA Landfills

An essential part of the research concerned development of the GIS database for risk assessment of the Central Asian landfills which incorporated various cartographical layers of national and regional data as well as local data from the individual landfills. A general risk screening by means of this information was performed for the set of landfill data and a complete risk analysis was carried out for four selected landfills on the basis of more detailed data. The data were gathered by on-site measurements and investigations and include emission potential with respect to gas and leachate, geotechnical and geophysical properties, seismic hazards and slope stability.

3.4.1 Comparative Risk Screening

Comparative risk screening methodology is applied and used for ranking the location suitability of new or existing landfill sites. The main goal of the methodology is to produce a priority from the entire database of Central Asian landfills. Then the Analytical Hierarchy Process (AHP) developed by Saaty (1980) is used to rank the suitability of areas for the construction of new landfill sites (see Sener et al., 2005 and Gemitzi et al., 2006). Hächler (2006) describes the AHP also as a good solution for rating of existing landfills.

As access to detailed geographical data, especially in high resolution (1:25,000 and less) in Central Asia is very limited and the demand of input data for the AHP could not be fully met, a simpler approach was implemented using the GIS to mathematically rank individual sites. The methodology comprises two major interlinked components:

- The environmental landfill location indexing component, which involves the identification, scaling and weighting of environmental sensitivity factors (proximity to the surface water (drainage), protected areas, population distribution);

- The impact analysis component, which involves the superimposition of the pollution generation impacts (rainfall leading to leachate generation, uncontrolled fires and seismic activity, slope factor).

Each landfill is defined by a square grid GIS which is used to calculate key environmental sensitivity factors and the possible pollutant effects. The analysis of the results and identification of environmental hot spots is done by a simple rating algorithm in 4 steps:

1. Evaluation of the selected criteria values for the landfill location by GIS operation: The GIS calculates the exact value for each landfill location, for example the proximity to surface water.

2. Sorting the landfills by criteria values and setting the rank for each landfill equal to the position in a sorted list. For example, proximity to surface water: the landfill with the shortest distance gets the highest rank number 1, the second landfill number 2 etc. This is done for all criteria.

3. Generation of a total rank as the sum of the individual criteria ranks. The individual criteria ranks for the distance to surface water and protected areas, probability of uncontrolled fires, population distribution, slope factor, leachate generation (runoff) and seismicity are summarized. This sum is the rating for the respective landfill. The landfill with the lowest rating is the location with the highest risk

4. Identification of environmental hot spots by setting boundary criteria, for example top 20% of the rating table.

3.4.2 Site Specific Risk Assessment

The GIS supports site specific (small scale) risk assessment by providing necessary geographical, geological and hydro-geological information, the visualization of gathered field data from site investigations and pre-processing of input data for simulation of transportation processes. The landfills selected for detailed investigation were situated in the vicinity of surface water bodies and/or rural settlements. All are in mountainous areas in zones of high seismicity. Therefore not only the emission potential of the landfill must be taken into account but also the hazards to the landfill due to natural disasters such as earthquake, subsequent debris flows and flooding. Thus two different approaches to hazard classification were applied:

- Hazards of potential emission from the landfills
- Hazards of natural disasters to the landfills

The latter hazard can clearly be identified at the old landfill in Dushanbe. The landfill is situated directly next to the Shuraksaiy river, which discharges into the Kafirningan River close to Dushanbe City. Together with the Varzob River the Kafirningan River is the main source of water supply for Dushanbe (Safarov et al., 2000). The steep slopes of the landfill adjacent to the river (Fig. 3.6) could collapse during an earthquake and block the river, which might result in forming of temporary, instable reservoir of water with a high leachate content. Sudden collapse of reservoir represents a serious hazard to downstream settlements. A second (and more probable) hazard is undercutting of the toe of the landfill slope, again potentially causing collapse especially in flooding condition after heavy rainfall. Several techniques were applied for investigation of the landfills covering a combination of geotechnical, geophysical, as well as characterization of the waste at each respective site. Further details about these investigations are covered in later sections and/or site reports by Doanh et al. (2007), Kholmatov et al. (2007) and Ritzkowski et al. (2007). The field data were evaluated and entered into the GIS database to complement the already collected cartographic data, which was the basis for further evaluation and calculations. The database can also provide input data for the calculations of the surface runoff, leachate infiltration, groundwater and air transport phenomena.

Figure 3.6: Old Dushanbe Landfill: Slope (height 25 m) at the river side (looking downstream)

3.5 Use and further development of the GIS

The Level 1 GIS is a comprehensive database of the landfills in Central Asia. The Level 2 GIS contains landfill description compliant to the EC waste management directive to compiling a Landfill Classification Catalogue (LCC) for 5 landfills per Central Asia country . The Level 3 GIS has contains field data, graphics and interpretive reports from each of the fours detailed site investigations performed.

After project completion, the GIS is established as basis system, which has the potential to be extended to become a high quality tool for stakeholders and decision makers and shall be the basis for the risk assessment of the landfills in this region. Risk assessment was carried out during for selected, representative landfills in the respective countries leading to recommendations for an investigation procedure, remedial actions and for the improvement of the waste management strategies.

Commercial GIS software was used for the development of the database however, the GIS can be run at the user level with non-commercial freeware to reduce user costs and avoid copyright violations. In general, high resolution maps of the Central Asian region are classified and were difficult to obtain. The available data for the investigations was initially limited, but then public databases (e.g. Google earth and commercially produced satellite imagery was used to achieve the necessary resolution for Levels 2 and 3.

The investigated MSW landfills in Central Asia were classified using risk screening with the GIS and ranked to identify sites with the relatively highest risk. As the available geographical data was not very detailed, a simple algorithm for the risk screening was used, which still provided a good overview about the landfills with a high hazard and enables the selection of the primary targets for more detailed investigations. Moreover the GIS database, which is produced as an extendable tool, offers support to decision makers in environmental issues.

The Level 3 GIS database provides the necessary data for the risk assessment at the specified locations and can be the basis of operational and remedial recommendations and further planning. However the idea of environmental and public health hazards from landfills is not widely acknowledged at a political level in Central Asia and hence investigation and monitoring results rarely exist for the landfills. Hence, public money to fund the necessary funding for detailed investigations, monitoring and remedial work is generally lacking with current priorities in regional investments.

4. Landfill emission processes and migration

From open dump, controlled dump, sanitary landfill to sustainable landfill, landfill strategies have undergone continuous development since the 1960s. Until now, no waste management policy can exist without landfill. Figure 4.1 shows the overview of waste management and treatment system. Although source reduction, reuse, recycling, biological treatment and thermal treatment can divert a large proportion of waste from final deposition in a landfill, there are still some inert, hazardous wastes and/or residues from other waste treatment methods, e.g. incineration or biological treatment that need to be disposed of by landfilling.

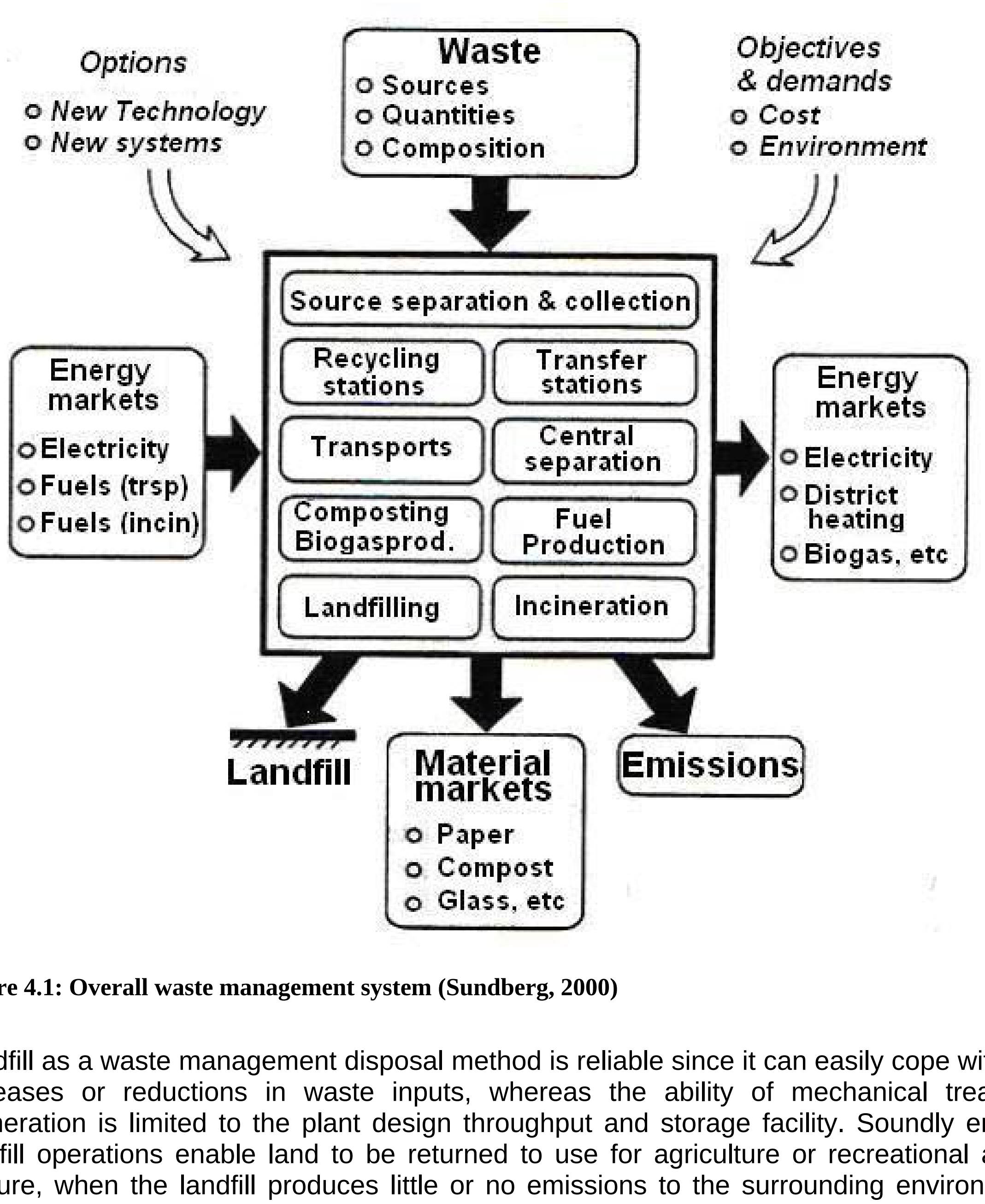


Figure 4.1: Overall waste management system (Sundberg, 2000)

Landfill as a waste management disposal method is reliable since it can easily cope with sudden increases or reductions in waste inputs, whereas the ability of mechanical treatment or incineration is limited to the plant design throughput and storage facility. Soundly engineered landfill operations enable land to be returned to use for agriculture or recreational area after closure, when the landfill produces little or no emissions to the surrounding environment and pose no harm to human health.

Amounts of municipal solid waste generated per capita can vary significantly between countries. The stage of economic development is one primary determination of solid waste amount. Figure

4.2 shows the waste generation rates of more than 50 countries. It is obviously that rising Gross Domestic Product (GDP) results in higher rate of waste generation. However, the increase in waste generation is much less than the rising of GDP. With the economic development of developing countries, there will be more and more waste produced. Under the limited administration and technological conditions, most of the newly produced waste will be still landfilled in developing countries. This will burden existing landfill sites and will require new landfill sites to be found and established in the future.

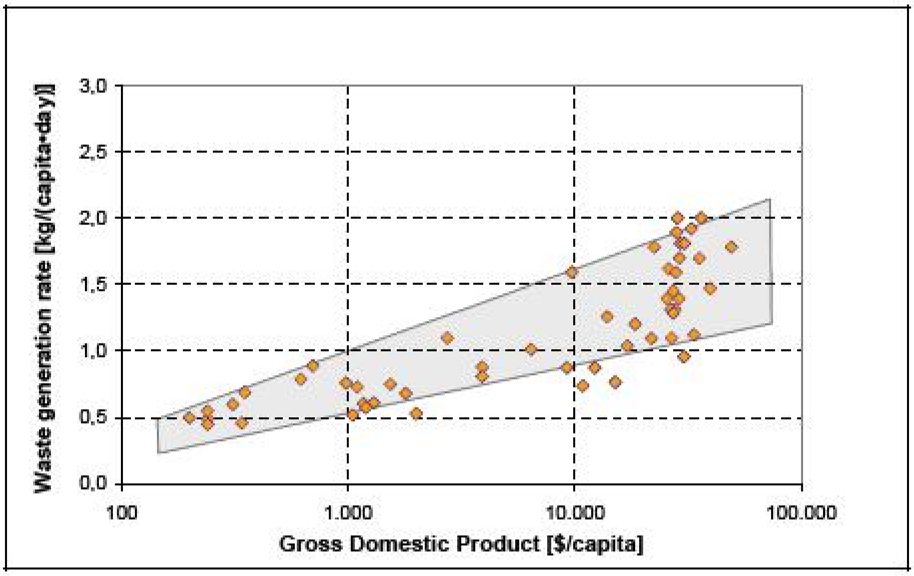


Figure 4.2: Waste generation rates versus Gross Domestic Product (GDP) (World Bank, 1999; METAP, 2000; OECD, 2005)

Despite the positive developments of landfill technology, the performance of landfills, their variation over long periods of time and the question whether the demand for an aftercare-free landfill can be fulfilled are still unclear and unanswered today.

4.1 Landfill Emissions and Potential Hazards

Landfill sites take up valuable ground resources in the world, especially in poor and developing countries, where open dumps or landfill is the only way of waste treatment. With growing population and increased urbanization or industrialization, the ground resources are more and more limited. So the better use of landfills, to increase their capacity of waste volume is an important issue. Landfills not only take up valuable land, they also cause air, water and soil pollution, thus endanger human health. In the past, it was generally believed that leachate from waste is purified by soil and groundwater, and hence contamination of groundwater was not an issue (Bagchi, 1990). In the late 1960s, landfills became under scrutiny and study results showed that landfills significantly contaminate groundwater (Anderson & Dornbusch, 1967; Noering et al., 1968), soil and surrounding surface water resource by leachate containing various chemicals like halogenated hydrocarbon and heavy metals. Settlements and livestock near landfill sites are in danger through drinking or eating polluted water, grasses and vegetables. The overall impact path of landfill waste to human health is summarized in Figure 4.3.

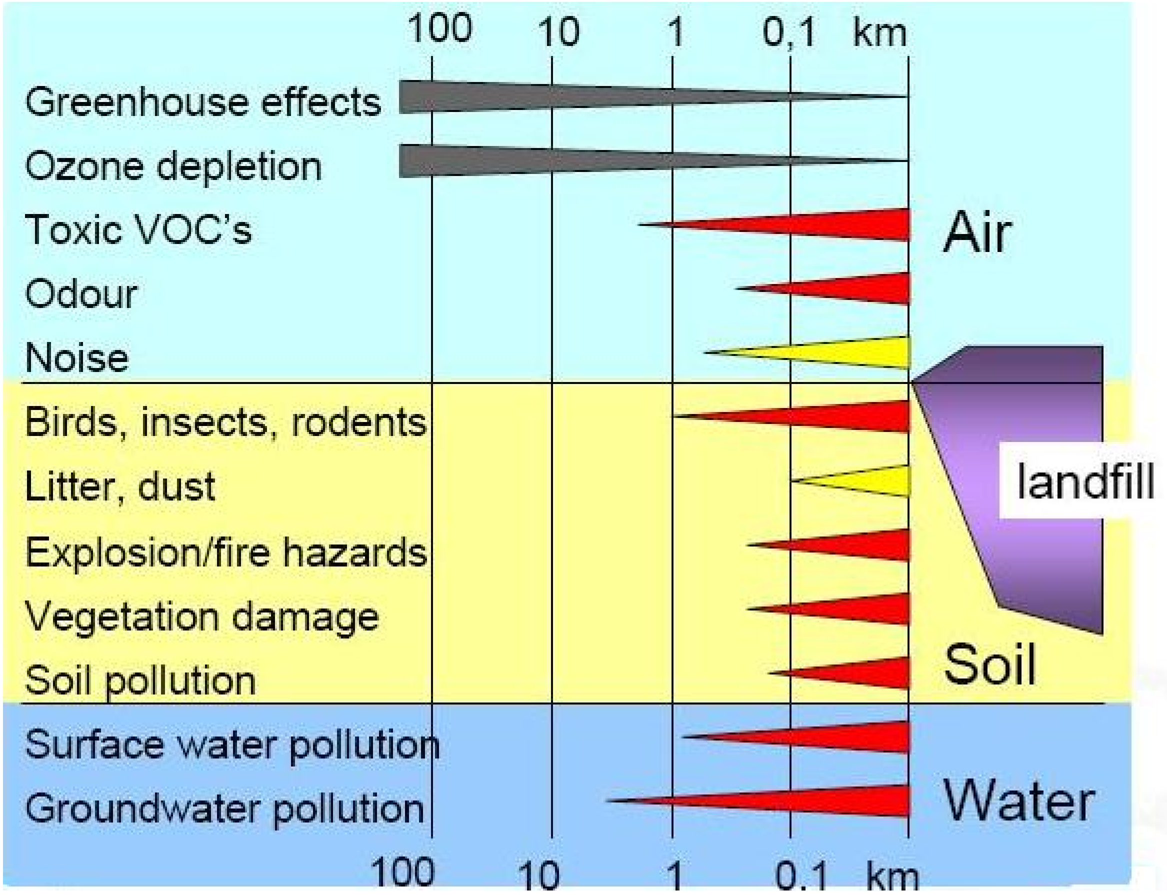


Figure 4.3: Environmental impact of landfills (Ritzkowski et. al. 2007)

Landfills are breeding grounds for vermin, insects and scavenging animals, which raises the chances of illness and disease. Therefore, through the food chain, landfills are a threat to human health, as well as to plants and animals.

Decomposition of organic material in a landfill generates landfill gas, which typically consists of 45-60% methane, 40-60% carbon dioxide and traces of other organic compounds (less than 1%) (Fellner, 2005). If landfills are not well controlled, dust and volatile organic compounds in waste can cause odor and even suffocation. Escaping landfill gas can reduce the oxygen content in soil to limit plant growth. Another risk potential is the high risk of fire and danger of explosion because of the flammable and the explosive landfill gas methane. An explosion potential can arise if there is an explosive gas mixture by penetration of air into a closed gas-system. On landfill sites, fire and explosion is more probable when there is an ignition source i.e. hot surfaces, open flame, spark emitting work (grinding), electrical apparatus (drilling machine) or electrostatic charge etc. The landfill fire can also be caused by increased heat through chemical oxidation and biological decomposition in waste, waste materials are heated to reach the point of ignition. Landfill gas contributes towards the global greenhouse effect. The impact of methane for destruction of ozone layer is about factor 23 times of carbon dioxide (Watson et al., 1996). So in landfill strategies, methane as main landfill gas is more emphasized. The migration of landfill gas and its concentration at near surface areas can cause explosions in nearby buildings and toxic effects on humans, animals or plants.

In developing countries, some poor scavengers dwell on landfill site. The waste piled up in an uncontrolled manner might slip and cause property damage and injury or loss of life in neighboring communities. The buildings near landfills have a higher risk of structural instability and collapse especially in areas of high seismicity. There are numerous closed landfills all over the world. Since at the time of the landfills establishment, most of the landfills were built with low technological design or even no safety consideration (baseliner, fences, drainage basin etc.), significant leachate and gas production continues for long periods of time after closure. So aftercare leachate treatment can be necessary for several decades or even centuries, thus the operational costs continue long after landfill closure. The problem of long term aftercare of landfills is not all solved because of political, financial, administrative and technological deficiencies.

4.2 Landfill processes

As shown in Figure 4.4.4, there are several processes around landfill: waste decomposition, formation of dust and noise, animal's feeding upon waste, landfill leachate formation and possible infiltration to groundwater, water (possible recirculated leachate, precipitation, surface water) infiltration to landfill, landfill gas emission, ground surface evaporation and evapotranspiration, and surface runoff. All these processes correlate with each other and influence in between.

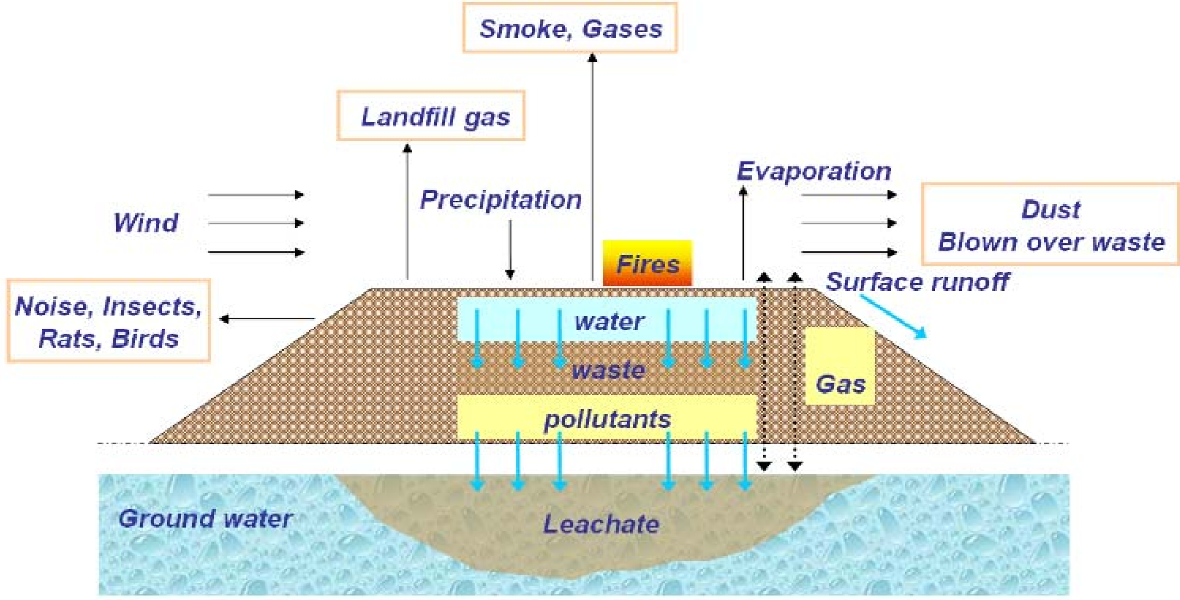


Figure 4.4: Landfill mass transfer and emissions (Ritzkowski et.al. 2007)

Leachate is the liquid that has percolated through or drained from solid waste and that has extracted from it dissolved or suspended materials (Stegmann, 2005). The source of the liquid is primarily the water already present in the waste, produced from biochemical processes, decomposition loss, and any water induced from an external source such as rainwater, drainage and ground water.

Landfill gas is produced by three processes: bacterial decomposition, volatilization, and chemical reactions. Landfill gas is a mixture of different gases. By volume, landfill gas is composed of about 50% carbon dioxide and 50% methane. Landfill gas also contains a smaller percentage of nitrogen, oxygen, ammonia, sulphides, hydrogen, carbon monoxide, and non-methane organic compounds (NMOCs), such as trichloroethylene, benzene, and vinyl chloride.

The quantity and quality of formed leachate and landfill gas at a specific site depend on the characteristics of the waste (composition, age etc.), presence of oxygen and moisture in the landfill, morphology of the underground, the design and the operation of the landfill (extent of compaction, soil cover or sealing and the vegetation) and the climatic conditions (temperature, precipitation, air humidity, wind speed and evapotranspiration). Contrary to factories or industrial plants, emissions from landfills are not restricted to the operational period only. For instance leachate emissions from municipal solid waste landfills can stay on an environmentally incompatible level for hundreds of years (Belevi & Bacchini, 1989; Kruempelbeck & Ehrig, 2000).

An understanding of waste decomposition processes in landfill environment is essential in order to provide a basis for the successful design, construction, operation and closure of landfills. Through long periods of monitoring and control of numerous landfills, an increasing understanding of the complex series of chemical and biological reactions that initiates with burial of waste in landfills has been developed. Figure 4.5 and Figure 4.6 show the five different phases during the stabilization process in landfill body and the gas and leachate composition as refuse decomposes (Andreottola und Gannas, 1992).

Phase I: The first aerobic process

Limited amount of oxygen will be trapped inside the upper layer of the landfill after the capping liner covers the waste. Due to the high oxygen demand of waste, waste in the upper layer of landfill will undergo an aerobic metabolism. In this aerobic phase, proteins are degraded into amino acids, thus into carbon dioxide, water, nitrates and sulfates, typical catabolites of all aerobic processes. Carbohydrates are converted to carbon dioxide and water and fats are hydrolyzed to fatty acids and glycerol and are then further degraded into simple catabolites through intermediate formation of volatile acids and alkalis. Cellulose, which constitutes the majority of organic fraction of wastes, is degraded by means of extracellular enzymes into glucose, which is used subsequently by bacteria and converted to carbon dioxide and water. This stage, due to the exothermal reactions of biological oxidation, may reach elevated temperatures if the waste is not compacted. Usually the aerobic phase is quite short and no substantial leachate generation will take place.

Phase II: Acid fermentation process

During the acid fermentation process, high amounts of volatile acids, and high partial pressure of CO_2 cause a decrease of leachate pH. Concentration of inorganic ions such as Cl^-, SO_4^{2} Ca^{2+}, Mg^{2+}, Na^+ increases. This is caused by the lixiviation of easily soluble material including that originally available in the waste mass and that made available by degradation of organic substances. The initial high content of sulfates may slowly be reduced as the redox potential drops. The generated sulfides may precipitate iron, manganese and heavy metal that dissolved by the acid fermentation. In this anaerobic stage, a population of mixed anaerobic microbes consists of strictly anaerobic bacteria and facultative anaerobic bacteria. Facultative anaerobic bacteria not only break down waste but also reduce the redox potential so that methanogenic bacteria can grow. Facultative anaerobic bacteria are very sensitive to the presence of oxygen and require a redox potential below -330mV in order to carry on their functions. BOD_5 values in this phase are commonly greater than 10,000 mg/L. The ratio of BOD_5/COD normally is larger than 0.7. PH value is in the range of 5 to 6. Concentration of ammonia, generated through hydrolysis and fermentation of protein compounds, is often in the range of 500-1000 mg/L. The time frame of Phase I and Phase II is about 2 to 5 years.

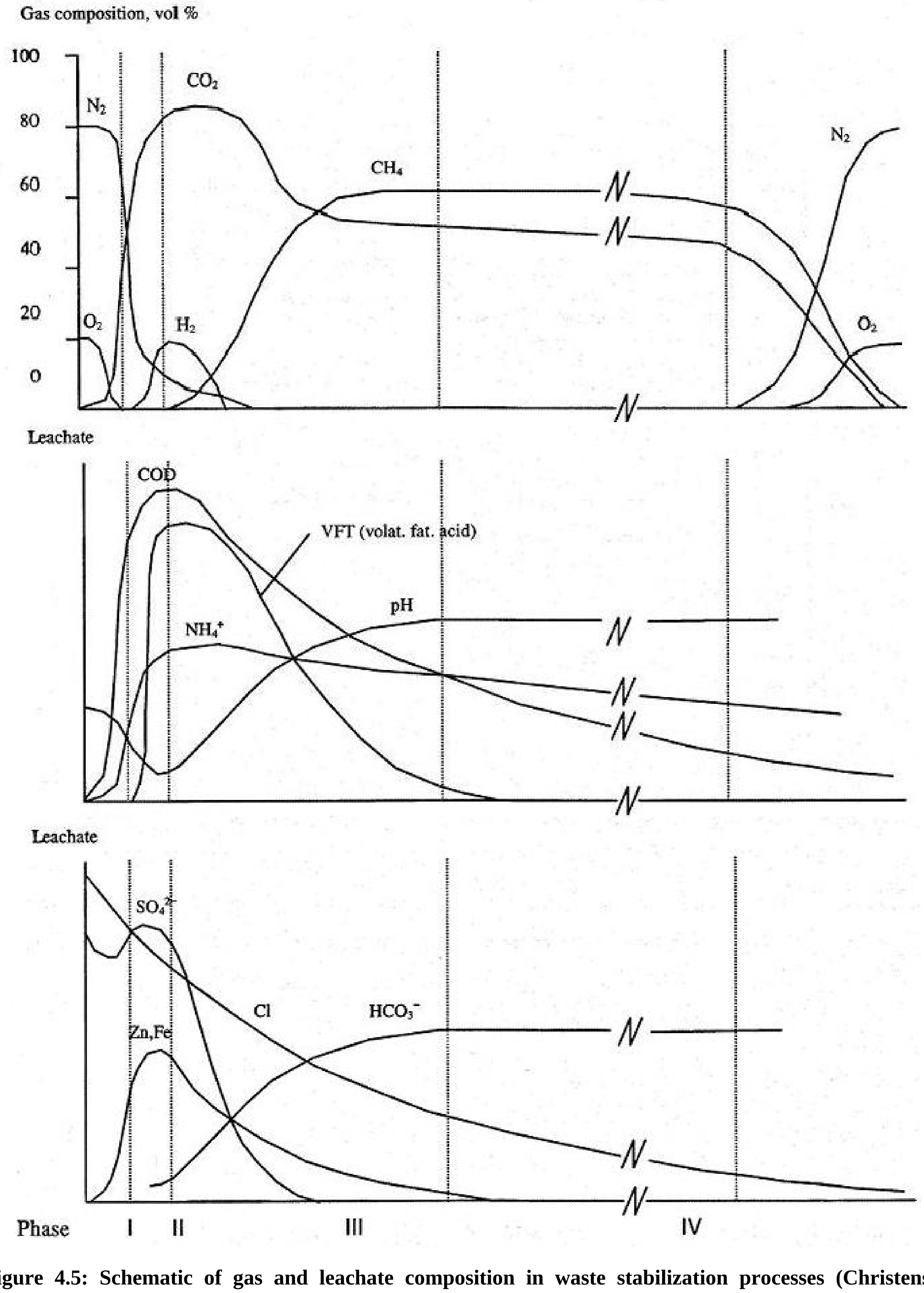


Figure 4.5: Schematic of gas and leachate composition in waste stabilization processes (Christensen & Kjeldsen, 1989)

Phase III: Intermediate anaerobic process

This stage starts with slow growth of methanogenic bacteria. But the process may be inhibited by the excess generation of volatile acid, which are toxic to the methanogenic bacteria at a concentration range of 6000-16000 mg/L. Methane concentration increases in the gas, while hydrogen and volatile acid decreases. Concentration of sulfate also decreases due to biological reduction. Lowered pH and alkalinity caused by the conversion of fat acid, will in turn decrease the solubility of heavy metals. Ammonia is released and is not converted by an anaerobic environment.

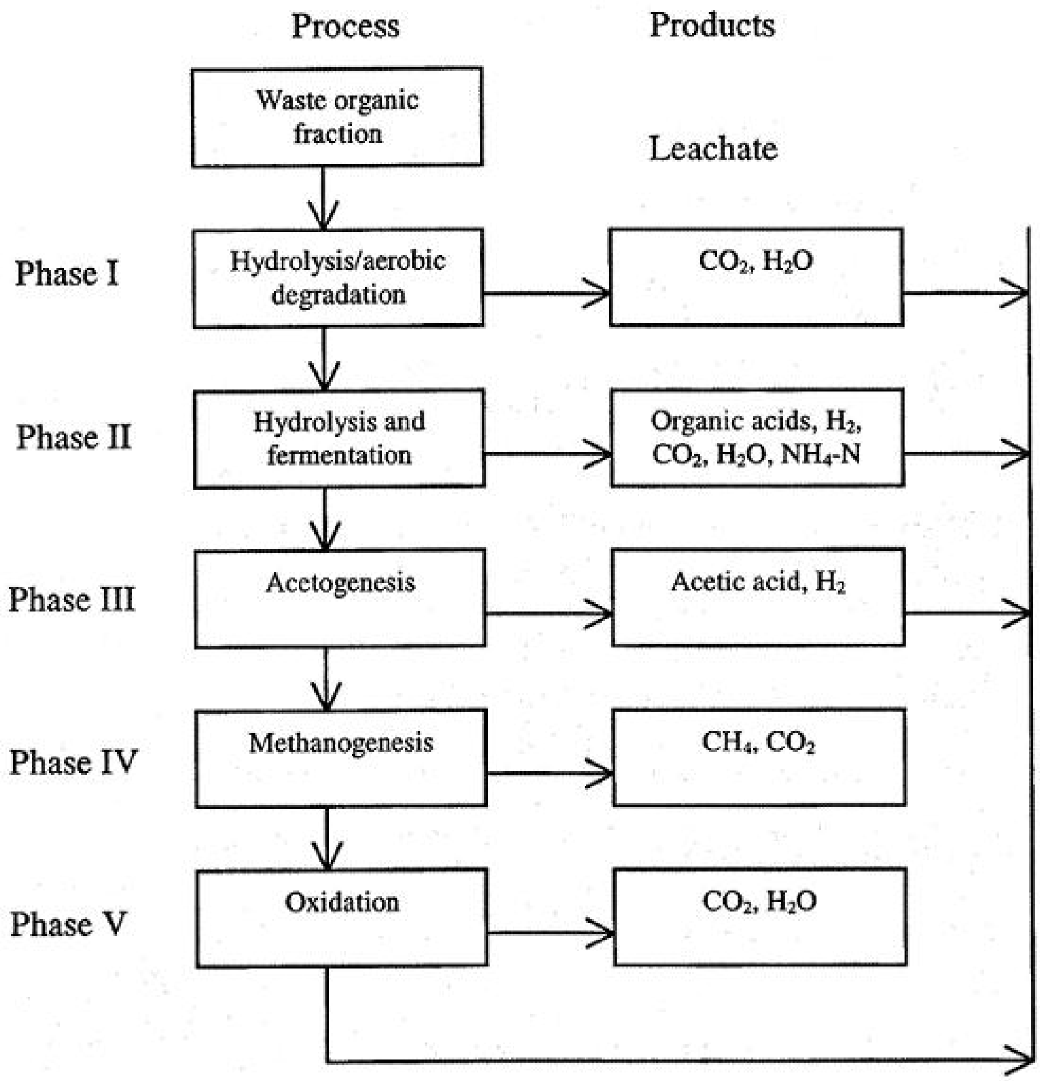


Figure 4.6: Schematic of waste stabilization processes (Li, 2003)

Phase IV: Methanogenic process

This phase is characterized by methanogenic fermentation elicited by methanogenic bacteria. Methanogenic bacteria are very sensitive to the change of pH value. The optimal pH for methanogenic bacteria is in the range of 6 to 8. Composition of leachate in this stage is characterized by neutral pH value, low concentration of volatile acid and dissolved solid. Methane in the landfill gases presents more than 50%. In this phase the concentration of COD and BOD are drastically decrease to a range of 2000-3000 mg/l and 100-300 mg/l respectively;

this indicates that most degradable organics namely BOD are degraded in this phase. Ammonia continues to be released by the first stage acetogenic process.

Phase V: Second aerobic process (mature phase)

In old landfills, once available organic matter is degraded and only the more refectory organic carbon remains in the landfilled wastes, a second aerobic phase will appear in the upper layer of the landfill and subsequently in the landfill body. In this stage, methane production rate is low enough that air will diffuse from atmosphere into the landfill body (Christensen & Kjeldsen, 1989).

However, waste characteristics, environmental conditions and landfill technologies have a significant impact on the rate of refuse decomposition, and subsequently the time required for decomposition to proceed to the point where methane production decreases to zero.

During the stabilization processes, the temperature in landfill increased due to chemical reactions and biological degradation. One case in Figure 4.7 shows that the temperature in the landfill increased continuously from around 30°C to over 40°C in three years, while in the same period the ambient temperature is between 0°C and 20°C. Phase III and Phase IV will take several decades. During this period significant emissions have to be expected.

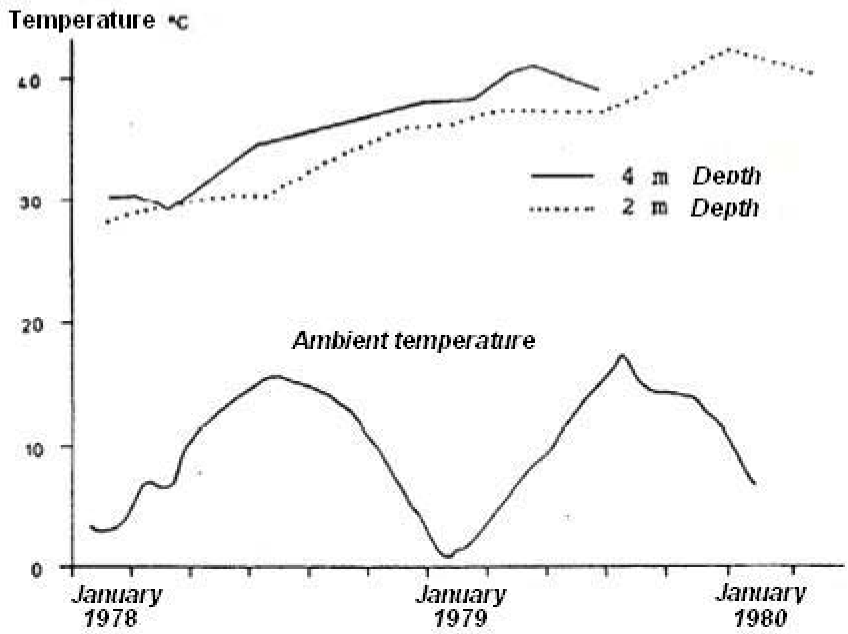


Figure 4.7: Temperature profiles in a landfill (Christensen & Kjeldsen, 1989)

4.3 Simulation of Landfill Processes in the Laboratory

A simulation of landfill processes can take place in so-called Landfill Simulation Reactors (LSR), whereby a process which takes decades in the field can be simulated within a few months in the lab. A scheme of the LSR and a photo of the LSR lab in St. Petersburg is depicted in 4.8. Within a very short time period, compared with the processes taking place in the real landfill, the emission potential in respect to gas and leachate can be determined.

Figure 4.8: LSR Scheme and set up laboratory

The reactor is filled with waste material. The waste material is usually collected from the landfill through means of representative sampling at specified depths. Alternatively, the waste can be sorted off site and an replica sample also assembled in the lab, though this decreases the reliability of the results. It is absolutely air tight to guarantee anaerobic conditions and installed in an environmentally controlled chamber at the temperature of 35°C. Water is added and regularly circulated. These are the optimal conditions for the methanogenic bacteria, which degrade the organic substances in the waste material to mainly methane (CH_4) and carbon-dioxide (CO_2). The recirculation of the leachate accelerates the leaching process. By exchanging leachate with fresh water the infiltration of water and the release of leachate formed is simulated. The gas and leachate is chemically analysed on a regular basis.

The aim of LSR experiments is to gain information about the emission potential of the sampled waste material through changes in chemical composition of the emitted gas and liquid (leachate). The parameters BOD_5 and COD are indicators of the contamination of the water with organic compounds. Where the BOD is sum parameter for the biochemical oxygen demand, which indicates the readily biodegradable contamination. The COD (chemical oxygen demand) is a sum parameter for the amount of organic compounds in water. It includes the easy degradable and persistent organic compounds. A decrease of the BOD and COD shows that the biodegradation is taking place and biodegradable compounds are degraded by the bacteria. The decrease of the BOD/COD Ratio is an indication that the remaining organic compounds are not biodegradable and only decrease by the wash out effects.

The LSR is relatively simple and cheap to build, but the accuracy and reliability of the results are highly dependent on the highly consistent operation conditions and experience of the scientist for both running the experiment and interpreting the results. A LSR lab was constructed in Tajikistan (local samples) within this project and LSR experiments were run in St. Petersburg (waste from Bishkek and replicated sample for Ashgabat).

4.4 Characteristics of Landfills in Central Asia

The landfills in Central Asia are characterized by a lack of ordinances, directives and regulation; poor waste management practices and education; without or with low level of technological design; with little or no monitoring and control systems with the potential of serious pollution and a hazard to human, flora, fauna and environment.

Currently there are not many well rounded norms, legislation or regulation concerning waste storage and waste treatment established in developing countries. Many countries do not have the relative ordinance at all or only refer to some aspects which can not effectively prevent or solve current waste process or landfill problems. Under this unsatisfactory condition, even existing regulations are not followed by all waste treatment sites. Economic development is considered much more important than environmental protection so the problems of waste management and disposal are to a large extent, neglected.

As industrialization takes place, economically developing countries typically display resource intensive and inefficient production processes that leave high volumes of waste of varying hazard levels. Generation of total waste is bound to increase in the future due to introduction of a market structured economy, which has the affect of promoting consumerism. Furthermore, the management and treatment of waste are not improved with the same speed as the economy evolves. It is quite normal that a lot of waste is dumped and stockpiled in an uncontrolled manner. While specifically designated city dump sites exist, they are usually not well organized and the waste is not collected regularly. The accumulation of solid waste in cities can bring along many problems as a source of air and water contamination, vermin and transmittable diseases.

The landfill sites themselves are sources of high health risks for animals, livestock and landfill workers, since they are contact with hospital waste, chemical waste and other hazardous waste. Dust and smoke can be carried by great distances polluting the air, soil, vegetative cover and water basin, damaging flora and fauna, as well as impairing the public health. It results in distribution of infectious diseases. The public awareness concerning environmental problems, principles and protection measures as well as danger to the own health is generally low. There is inadequate effective education of the general public and in specific curricula at higher education level. Scavengers are commonly found on the landfills digging out and collecting potential recyclables (Figure 4.9) and are directly affected by the emissions (gas, dust and smoke) and the hazard of getting into contact with toxic materials and hazardous waste.

Figure 4.9: Scavengers at work

For most cases in these countries, collected waste is not separated before disposal. There is normally no separation, pre-treatment or utilization of waste due to low level of waste management, limited technologies and economical limitations. Accumulated waste is removed for disposal even without compaction directly to landfill. In the absence of adequate waste treatment i.e. hazardous waste landfill, incineration etc. most hazardous waste also ends up in municipal landfills along with industrial, mining and medical wastes.

Landfill sites in economically developing countries vary significantly in size, volume and operational status. Not many of them have equipment like bulldozers or waste compactors. There are usually no base liners, monitoring systems, collection and utilization systems for leachate and landfill gas etc. Landfill fire is quite common, which causes air pollution and is harmful to vegetation, animals and human health. The administration of landfill site is generally not effective, without detail information of landfill site utilization, waste composition, quantity, and lack of continuous records.

4.4.1 Landfill technologies and strategies

Landfill engineering and strategies keep improving with the cognition of existing landfill problems. The ultimate goal of waste disposal is to dispose unwanted substances safely, so called final storage landfill or sustainable landfill. It means that the landfill requires little aftercare and creates low short and long term risks. Closed landfills do not need supervision after 30 years (one generation) and there is no transfer of waste problems from today to future generations (Stegmann, 2005). Figure shows the historical development of waste disposal with incremental improvement to reach the landfill objectives.

Figure 4.10: Development of landfill strategies (Rushbrook & Pugh, 1999)

The different landfill development stages are summarized and explained in detail by Fellner (2005) as follows:

Open dumping

Open dumping (Figure 4.11) is the uncontrolled land disposal of waste. The site is not managed and there are no controls over access of unauthorized persons (e.g. scavengers), animals or environmental pollutions. Additionally no consideration has been given to the geological or topographical suitability of the site. Most likely, the location of the dumpsite was chosen because it was the cheapest land available that did not affect interest groups within the municipality. No preparatory earthworks or site engineering has taken place and almost no control is exercised over the site operations or the manner in which the waste is deposited. Fires, pests, unconstrained horizontal spread of the landfill surface and slope failures are commonplace.

Figure 4.11: Open dumping (scavengers and grazing animals)

Controlled Dumping

A controlled dumpsite is basically an open dump with some operational or administrative improvements. The main features of a controlled dumpsite (Figure 4.12) are:

- Reduction of the disposal area of the site to a smaller and more manageable size
- Soil cover of exposed waste on unused or closed parts of the site
- Prevention of fires
- Rules of on-site work with workers, drivers and scavengers

The advantage of these operational improvements (in comparison to the open dumps) are that they can be introduced quickly, need little or no additional investment. But controlled dumping is not preferable as the emissions of the landfills overall remain unchanged. Landfill gas is not collected nor treated and no leachate control systems exist.

Figure 4.12: Controlled dumping delivery

Engineered Landfill

An engineered landfill (Figure 4.13) is characterized as a disposal site where engineering techniques are applied to control one or more of the following points:

- Collection of surface water wastes by installing a surface drainage system
- Extraction and spreading of soil materials to cover wastes
- Spreading and compacting wastes into thin layers
- Collection and removal of leachate away from wastes into lagoons or similar structures
- Isolation of wastes from the surrounding geology
- New parts of the landfill are prepared before receiving wastes

This means that planning has to be done before construction, which includes beside the design of construction elements such as liners or the leachate collection system, also waste disposal plans showing how the site will be filled with waste and closed, subsequently.

Figure 4.13: Engineered landfill (preparation of base sealing and waste compaction)

Sanitary Landfill

Compared to engineered landfills sanitary landfills (Figure 4.14) are characterized by an increasing complexity in engineering design and construction techniques. Sanitary landfills typically have many additional features to those found on engineered landfills, for example:

- Pre-planned installation of landfill gas control and utilization systems
- Extensive environmental monitoring
- Well-qualified work force
- Detailed record-keeping about the deposited waste and the environmental monitoring
- Leachate treatment
- Specialized mechanical equipment
- Complex lining systems to isolate waste from the surrounding geology
- Post-closure plan
- Aftercare management

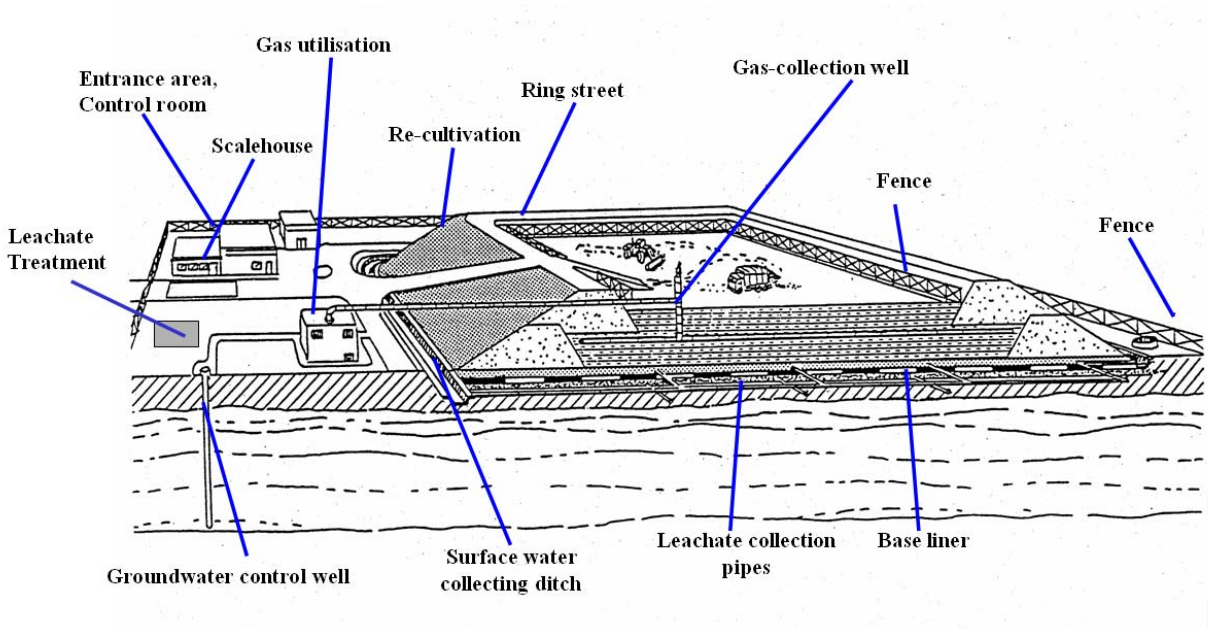


Figure 4.14: Sanitary landfill scheme (Bilitewski et al., 1997)

Although emissions are controlled and properly treated at the sanitary landfill, this disposal strategy has still the major drawback that the treatment must be continued over decades or even centuries. This time of necessary treatment of emissions is called aftercare period. In order to minimize aftercare measures, the reactivity potential of the waste deposited needs to be reduced. Such reduction is achievable by waste pretreatment prior landfilling. Sanitary landfills can be operated according to different concepts, for instance as flushing bioreactor i.e. forced water entry into the waste (Figure 4.15).

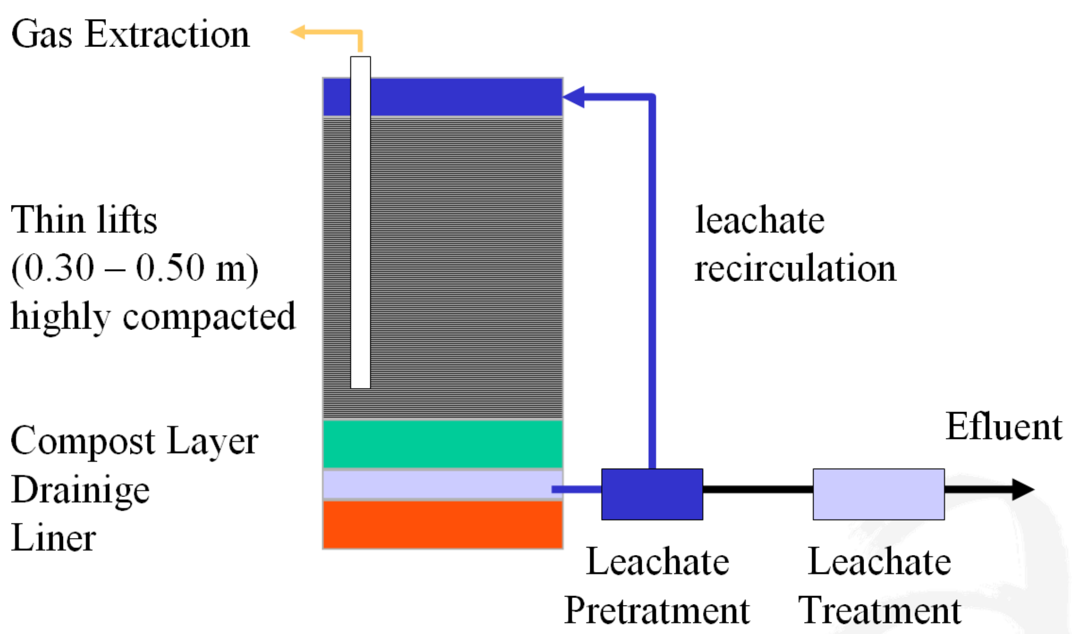


Figure 4.15: Scheme of a bioreactor landfill (Ritzkowski et. a. 2007)

Sanitary landfills for pre-treated waste

The strategy of pre-treating waste before landfilling is derived from the claim of long-term maintenance-free landfills, where, contrary to municipal solid waste (MSW) landfills, there will be no aftercare necessary once the landfill is closed. The predominant forms of waste treatment prior disposal are incineration or mechanical biological pre-treatment. The residues of both processes show lower reactivity than fresh municipal solid waste. However, emissions from sanitary landfills filled with residues from waste incineration or mechanical biological pre-treatment plants are still not "environmentally sound" and need therefore proper treatment. Nevertheless, aftercare measures are reduced compared to MSW landfills. Additionally landfill equipment can partly be omitted, for instance at a landfill for incineration residues no gas collection system is required.

Final Storage Landfill

A final storage landfill's emissions into water, soil, and air are "environmentally sound" in the short and long run (i.e. thousands of years). In order to become a final storage landfill, a landfill has to fulfill the following prerequisites:

- Wastes have to be mineralized and transformed prior to landfilling so that they become immobile, non-soluble, "stone-like" materials that cannot be transformed to soluble substances in a landfill environment.
- The landfill has to be located in an area that is not subject to heavy erosion or other geological and tectonic activity.

According to Brunner (1992) anthropogenic flows (emissions) can be described as "environmentally sound" if they have no impact on geogenic material flows and storage, which means that they must be smaller by two orders of magnitude than natural flows. Such final-storage landfills are able to accommodate pollutants and residues that either cannot be recovered or that are products from waste management not suitable to enter subsequent economic cycles (Brunner, 2005). One possibility is in-situ treatment in a reactor landfill with leachate recirculation and in-situ aeration after landfill closure. The second possibility is a pre-treatment either by incineration or mechanical-biological (MBP) as shown in Figure 4.16.

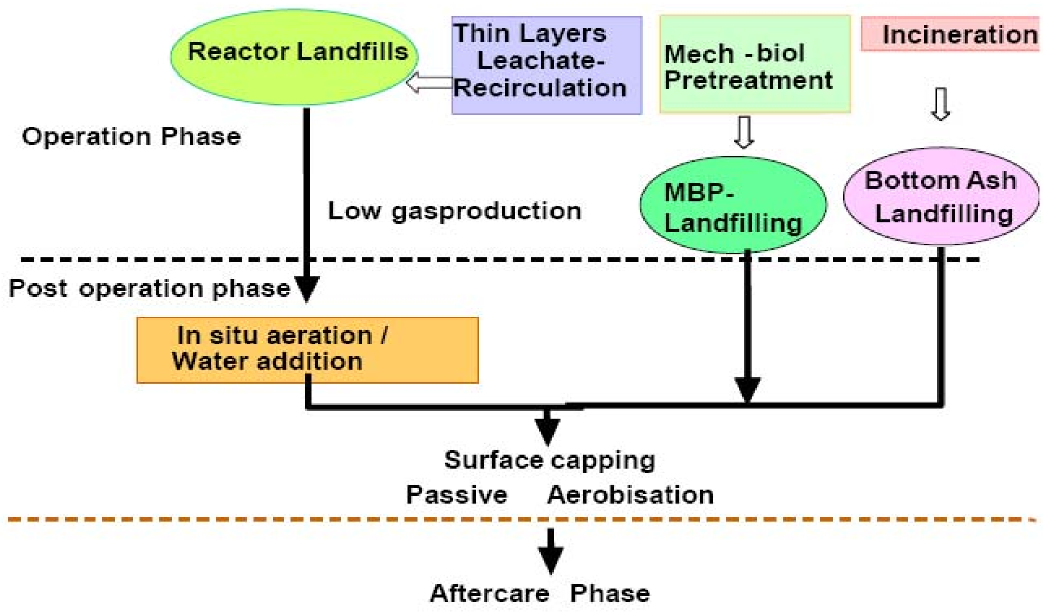


Figure 4.16: Sustainable Landfill Concept (Stegmann, 2005)

A summary of the above discussed landfill development stages (without waste pre-treatment prior landfilling) is given in Figure 4.17.

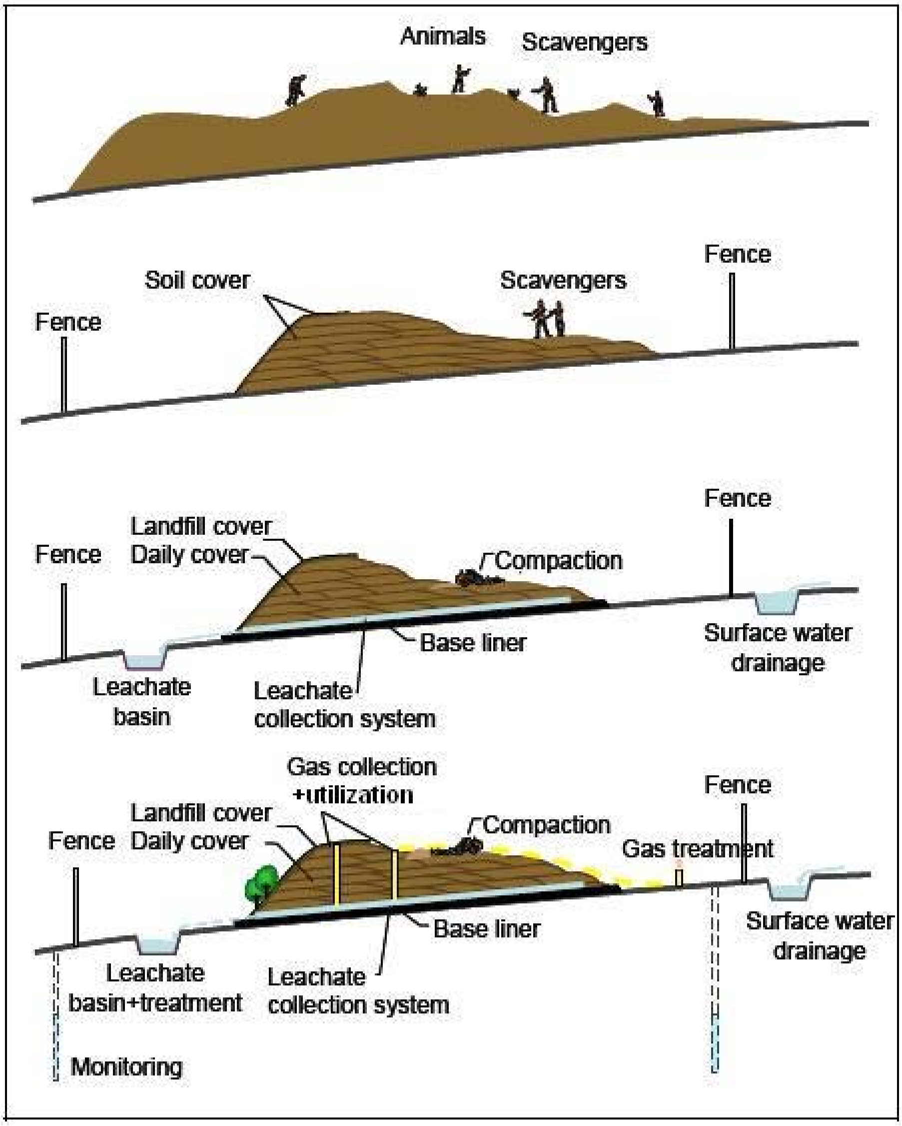


Figure 4.17: Summary of landfill strategies (open dumping, controlled dumping, engineered landfill and sanitary landfill) (after Fellner, 2005)

4.5 Conclusions on status of landfill techniques in Central Asia

The technological development of landfills is directly related to the investment level that is able to be made. Often the necessary investment funds are not available due to the lack of financial resources of the communities or due to the lack of motivation to spend money for environmental purposes. Hence the predominant types of landfills in Central Asia are open and controlled dumps, but as discussed in Section 5, there possibilities to develop landfills to encapsulate and utilize the gas emissions for energy production, but more importantly, as a source of economic return through carbon trading within the Clean Development Programme (CDM) as established under Kyoto protocol. The following section looks at four representative Central Asian landfill, describes their characteristics, prioritizes remedial recommendations and their suitability for development as a CDM landfill.

5. Landfill Site Investigation Techniques and Applications

Four Central Asia municipal (Almaty, Tashkent, Bishkek and Dushanbe) landfill sites were investigated over a two year period as the basis for the research (Fig. 5.0). The investigated sites are generally representative of Central Asian landfill standards i.e. no base liner, little access restriction and limited or no gas leachate and/or gas extraction or collection system. All sites mainly receive municipal solid waste (MSW) but also all other kinds of waste.

Figure 5.0: Overview of the four Central Asia landfill locations investigated (03.02.2009) (http://grad.econ.ubc.ca/mberka/kg/cismus.gif)

Data was collected and information about the landfills was acquired from the respective municipalities and the landfill operators. A variety of site investigation techniques was applied on the landfills according to availability of existing information (e.g. from previous investigations) and suitability of the site e.g. to address the main hazard identified. The three main types of site investigation cover were:

- Waste characterization with solid, liquid and gas sampling and analyzes
- Geotechnical and hydrogeological investigation site survey, drilling, sampling and laboratory analysis of the soil and groundwater
- Geophysical investigations to gather geological and hydrogeological information as well as parameters for the modeling of the influence of seismicity to the landfill sites

The landfill sites are listed in Table 5.1 and are described for each respective country in the following sections.

Portable equipment was transported from Europe to Central Asia to perform the investigations and soil, waste and liquid samples were transported to Europe for analyzes. Furthermore, due to the impossibility to transport large amounts of waste material from Central Asia to Europe or St. Petersburg, a Landfill Simulation Reactor (LSR) laboratory was installed at the Chemistry Institute of Tajikistan (CHI) for the investigation of the long term emissions of the waste from the landfills in Tajikistan. Waste samples from Almaty, Kazakhstan landfill were modelled at the SPbSPU LSR laboratory (St. Petersburg) to simulate gaseous and liquid emission potentials of these two respective landfills.

This section summarizes the status of the landfills and highlights the identified problems for each of the sites. The conducted investigations and the risk analysis are the basis for the elaboration of possible remediation measures and recommendations for the individual landfill sites. The respective investigations and analysis results are described, the problems and possible impacts are listed and possible solutions for improvement and remediation of the individual landfills are made.

Table 5.1: Overview table of the SI techniques used at the four investigated landfill sites

No.	Landfill site name and city	Summary of site/laboratory investigations
1	Karasai landfill, Almaty, Kazakhstan 43 º25.833' N 76 º59.667' E Elevation: 764 m to 869 m	a) Waste characterization Excavation of trial pits in the landfill, waste sampling, groundwater sampling, Waste sorting analysis, gas measurements, LSR test (in St. Petersburg) b) Geotechnical investigation Site assessment and surveying, soil sample collections, geotechnical testing at laboratory, installation of runoff sampling station (NB: No geophysical investigation was possible because of the steep topography of the site)
2	Ahangaranskaya landfill, Tashkent, Uzbekistan 41º5.5090' N 69º28.5400' E Elevation 456 – 482 m	a) Waste characterization Excavation of trial pits in the landfill, waste sampling, groundwater sampling, waste sorting analysis b) Geotechnical investigation Site assessments and GPS surveying, drilling and soil sample collections, geotechnical testing at laboratory, installation of two observation wells c) Geophysical investigation Vertical Electric Sounding (VES), Seismic Refraction (SR), Ambient noise
3	Krasnyi Stroitel landfill near Bishkek, Kyrgyzstan 42º57.4148' N 74º35.2642' E Elevation 577 m	a) Waste characterization Excavation of trial pits in the landfill, waste sampling, surface and groundwater sampling, waste sorting analysis, gas measurements b) Geotechnical investigation Site assessment and GPS survey, drilling and soil sample collections, geotechnical testing at laboratory c) Geophysical investigation Vertical Electric Sounding (VES), Ambient noise
4	Dushanbe "old" landfill, Tajikistan 38º33.0464' N 68º52.4061' E Elevation 840 m	a) Geotechnical investigation Site assessment and GPS survey, drilling and soil sample collections, geotechnical testing at laboratory b) LSR test (in Dushanbe) c) Geophysical investigation Vertical Electric Sounding (VES), Ambient noise

5.1 Karasai Landfill, Almaty, Kazakhstan

The Karasai solid waste landfill site for Almaty city is located in Karasai region of Almaty oblast at coordinated 43 º25.833’ N, 76 º59.667’ E at elevantion 764 to 869. The landfill is located 2.3 km to the north of 34th km of the Almaty-Bishkek motorway, approximately 3 km to the west of Itey village (Fig. 5.1). The site terrain is a grass-covered, sub mountain-valley part of steep relief.

The Karasai landfill site was constructed in 1988-1989 by Almaty City Development Department and was put into operation on 29th of December 1989. The area of the site is 23 ha with 18 ha used for waste disposal until 2007. The filled waste consists of typically unsorted household waste, construction and demolition waste as well as bulky waste. The organic waste content appears to be relatively low. Operational equipment includes a weighbridge at the landfill entrance and 2-3 bulldozers used for the distribution and light compaction of the delivered waste. The entrance is secured by a gate and permanent staff. However, the site is only partially fenced on the upper side facing the next village (7 km). Leachate is collected in an insecure pond (currently approximately 70 m^2) at the landfill base, the deepest point of the natural gully.

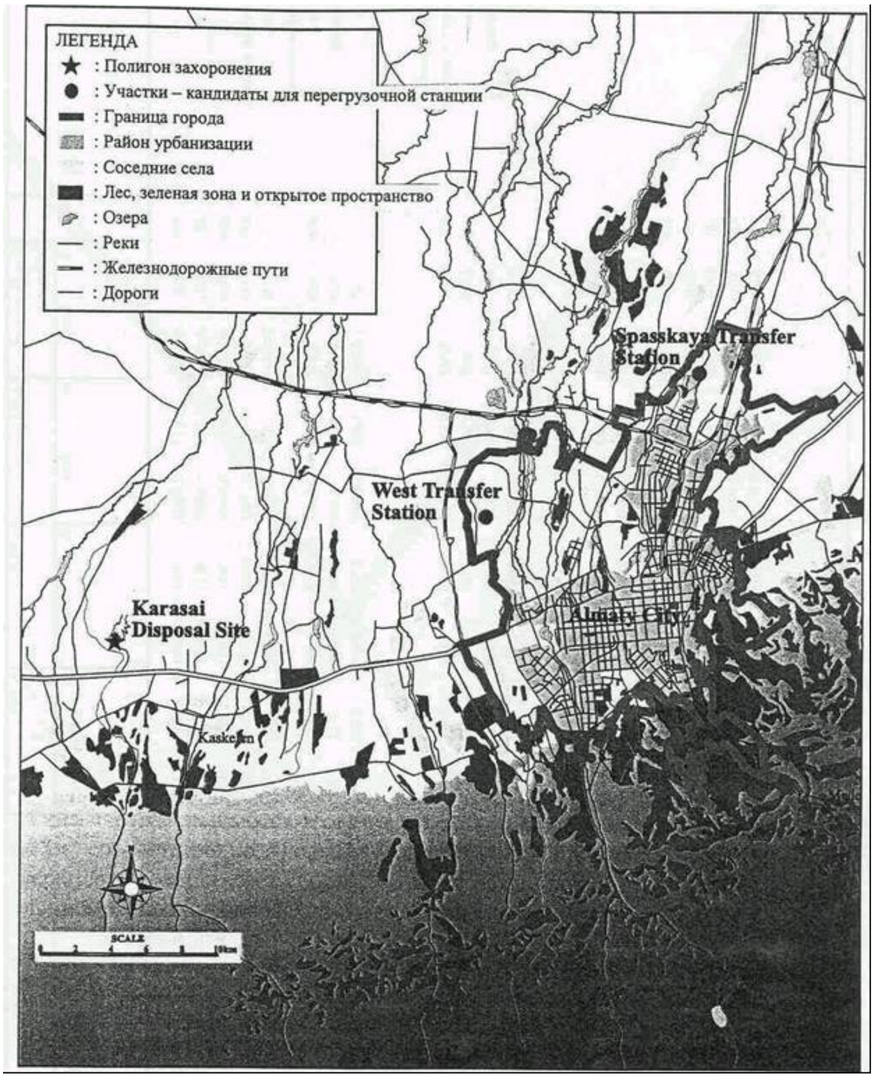


Figure 5.1: Overview of the Karasai landfill location (Source: Karasai Landfill Monitoring report, Almaty City Development Department, 2005)

5.1.1 Waste characterization

The waste characterization investigations carried out included:

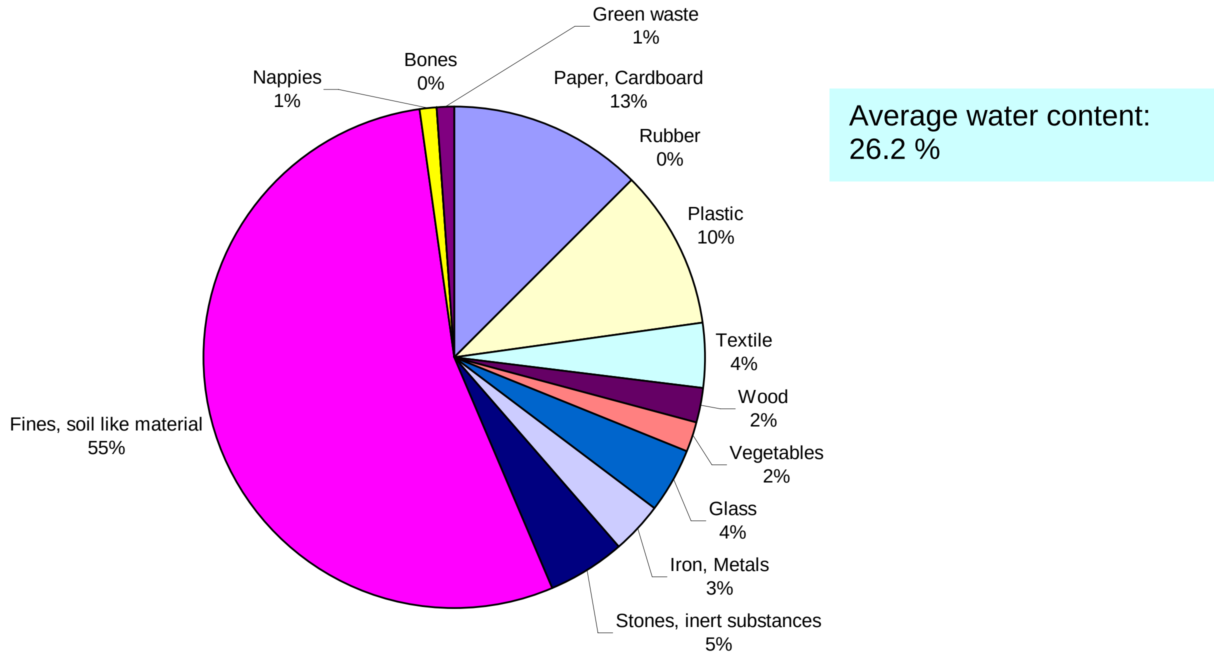
- Excavation on different spots on the landfill
- Waste sampling
- Surface and groundwater sampling
- Sorting analysis of excavated waste samples
- Gas measurements

The pit excavations (Fig. 5.2) were carried out at two different locations - one in an older part of the landfill and one in an area with rather fresh waste. For the excavation a backhoe with the possibility to dig to a depth of 5 meters was used.


Figure 5.2: Excavation at the Karasai landfill

Samples were taken from each level (i.e. 1 m intervals) for lab analysis as well as for the sorting analysis. The temperature of the different levels was measured and optical and olfactory impressions noted. The first excavation pit released the smell of organic fatty acids. Hence (at least) the upper layers seem to be in the acidic phase, i.e. early phase of anaerobic biodegradation processes. At the older part at Pit No. 2 anaerobic waste material (black in color, LFG smell) was excavated and the same investigations as Pit No. 1 were undertaken. The results are shown in Figures 5.3.

The comparison of the different waste compositions found at the sampling pits showed higher amounts of fines and vegetables for the relatively young waste whereas for the older waste had a significantly higher the plastic fraction. This might be attributed to both the further biodegradation of organic substances with time (thus a reduction in the organic rich fine fraction and in the vegetable fraction) as well as a less effective sorting of plastic components in the past (as the value of this fraction increased significant during recent years). The moisture contents found at both pits are relatively low but remain within the range allowing a sufficient biodegradation under the prevailing anaerobic conditions.



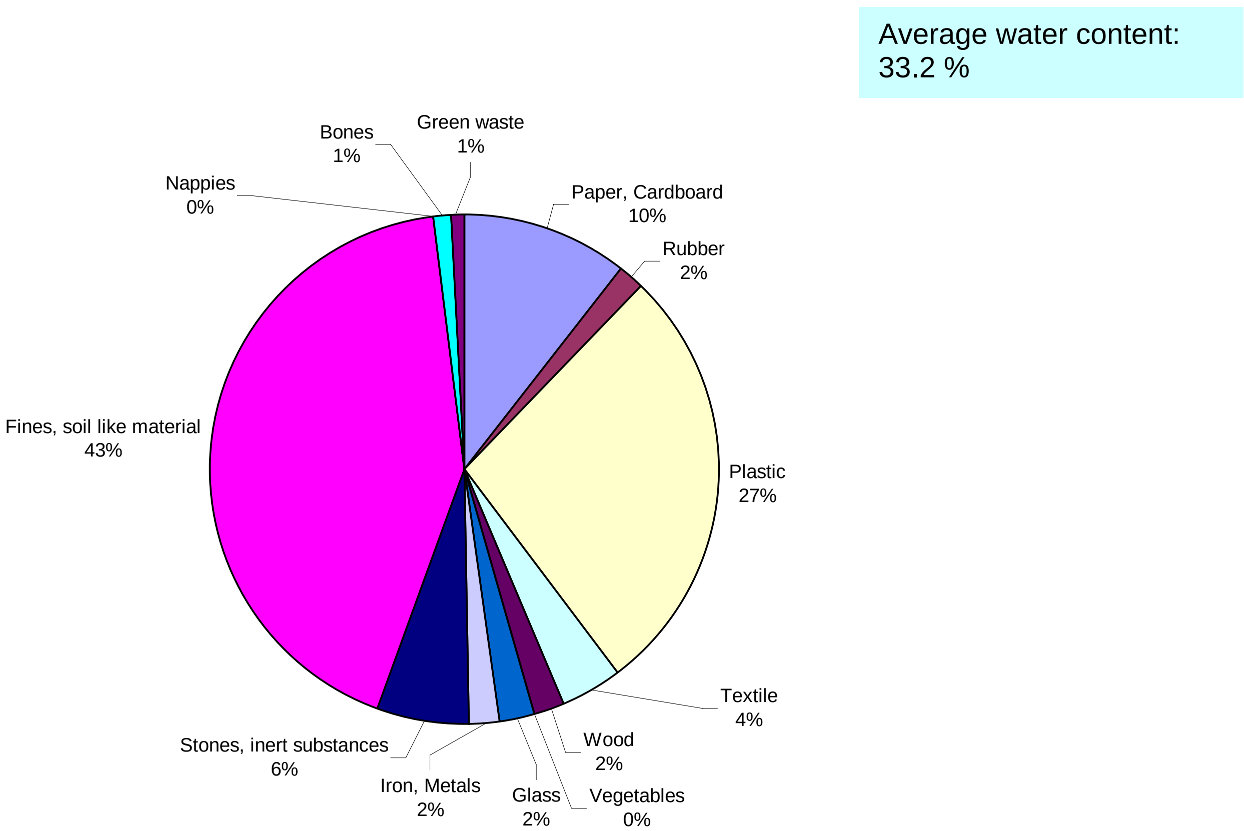


Figure 5.3: Karasai Landfill sorting analyses Pit No.1 "fresh" waste, without coverwaste (above) and Pit No. 2, age > 3 years (below)

There are 3 groundwater monitoring wells within the Karasai landfill area and one leachate pond in the northern part of the landfill. Water levels and temperatures were measured and samples taken from the monitoring wells. Leachate samples were also taken from the pond.

All samples were analyzed *in situ* for temperature, pH, redox potential, conductivity, dissolved oxygen, total suspended solids and stored in flasks for later laboratory analysis. Further results derived from different investigations conducted by various organizations including the investigation by a Japanese company in 2006 and investigations undertaken by KazNTU (2005, 2006 and 2007), the landfill operator (2006), the State Sanitary Department (2000 – 2006) and KAZGIIZ (1999). Table 5.2 shows the average concentrations measured in the leachate.

Table 5.2: Concentrations of contaminants in the leachate (average of the measurements)

pH	NH_4	Cl	SO_4	HCO3	Cond.	Redox	BOD	DOC	AOX
	mg/l	mg/l	mg/l	mg/l	mS/cm	mV	mg/l	mg/l	µg/l
8,32	1360,0	10780,0	62,74	9568,0	42,5	-383,0	4921,0	4210,0	4522,0

Fe	As	Hg	Pb	Cr	Ni	Zn	Cd	Cu	Mo	Mn
mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
10,0	0,037	0,0014	0,383	3,2	0,45	1,215	0,021	1,165	0,026	0,21

The concentrations of organic and inorganic leachate pollutants are relatively high and exceed the average values found for MSW landfills in Germany and Western Europe several times. Lead and chromium concentrations are significantly elevated. This is probably due to the common practice to landfill hazardous wastes (e.g. industrial waste) together with MSW.

The groundwater quality in the surrounding was checked by the analysis of three ground water wells in the vicinity of the landfill. Additionally, results were available from other drinking water wells in the villages near the landfill which were produced by the State Sanitary Department. According to the available analysis results these groundwater aquifers do not seem to be negatively influenced by the landfill leachate.

With a portable landfill gas analyzer (GA 2000, Geotechnical Instruments) and a portable FID (PORTAFID, Sewerin) the gas composition in the upper layers of the landfill body (the depth depends on the length of the lances and the possible penetration depth) and on the surface of the landfilled waste were measured on more than 50 locations. The detected components were CH_4, CO_2, O_2, CO and H_2S. Waste temperature was also measured by means of a portable thermometer. As the portable FID allows the detection of methane mass concentrations and fluxes (leaving the covered landfill surface) a rough estimation of current LFG production rates can be made. For landfill sections showing no or only insufficient covering, the FID method has only limited significance. Furthermore this calculation does not consider a possibly methane oxidation during the passage through the landfill top cover (i.e. soil layer), which might lead to slight underestimations of the actual gas productions rates. However, according to the mentioned above method, a total LFG production rate exceeding 5,500 m^3/h was calculated for the Karasai landfill. Calculated hourly gas production rates for the different sections of the landfill (according to Fig. 5.1) are summarized in Table 5.3.

Table 5.3: Calculated hourly gas productions per section by means of the FID measurements

Section	Area (ha)	CH4 (ppm)	LFG ($l/(h*m^2)$)	LFG (m^3/h)
I	4.24	948	18.96	803.904
II	1.45	948	18.96	274.92
III	1.94	2084	41.68	808.592
IV	2.02	1300	26	525.2
V	3.92	2084	41.68	1633.856
VI	4.08	2084	41.68	1700.544
total	17.65			5747.016

5.1.2 Geotechnical / Hydrogeological

In the pretext of geotechnical/hydrogeological site investigation, the circumference of the landfill and its different elevation levels were surveyed with a portable GPS-device in WGS84 coordinates and height above sea level. Ninety four positions were recorded during the survey and additional positions from the different sampling and measurement activities were already available from past studies. Distinctive locations were also documented with photos.

The soil samples for permeability tests were taken from the site. From the test results it is found that loamy (clay) soil permeability (water conductivity) is approximately $1*10^{-6}$-10^{-5}cm/sec. Based on the laboratory analysis the physical characteristics of loamy soil are reported in Table 5.4.

Table 5.4: Characteristics of loamy soil

Physical Characteristics	Unit	Average Values
Plastic limit, W_p	%	17.30
Plastic index, PI	%	8.70-9.20
Water content, W_n	%	20.50-21.40
Liquid index, I_l		0.37-0.47
Degree of saturation, S_r	%	99-99.8
Void ratio, e		0.54-0.56
Unit weight, γ_m	t/m^3	2.10-2.12
Dry unit weight, γ_d	t/m^3	1.73-1.76
Elasticity modulus, E	MPa	4.60-4.70
cohesion, C_v	kPa	22-38
Internal friction angle, ϕ	degrees	22-23

Topographical aspects

Almaty Karasai landfill site is located on the steep valley of the northern lower slope of the Zailiyskiy range. This site is a natural Y-shaped broad gully, extending from the north to the south. The steep sides of gully are turf-covered and the width and depth of broad gully decreases to the north. The width of gully varies from about 350 m to 150 m and depth varies from 90 m to 35 m. The relief of the disposal site is extremely indented and its surface is a combination of the broad gullies, hills and ridges with flat tops inclined to the north. Geomorphologically, this site is an alluvial-proluvial plain. In this context, the Karasai landfill site terrain and relief conditions are favorable for its operation.

Geological aspects

The most ancient deposits in the region are of Palaeozoic age. According to geophysical data, rock foundation has a common downwarping from the South to North. Hard rocks are laid at the depth about 1000 m. Palaeozoic foundation is overlapped with a thick series of Neogene and Quarternary sedimentary deposits. The thickness of the Quarternary deposits reaches 400 m.

Karasai disposal site is characterized by lower-quaternary alluvial-proluvial (i.e. secondary transported) loess-like loams. These loams are overlapped with non-saline topsoil of 0.2–0.3 m thickness. Loam subsidence ground conditions' type is subsidence (II), except the loams forming the sides and the bottom of the broad gully, which are non-subsiding. Filtration coefficient (permeability) of subsiding loams is varying around a mean value of around 10-7 m/sec whereas the non-subsiding loam is nearly impermeable. The alluvial-proluvial loess is better sorted than aeolian loess and is characterised with more stratification. The aoiliean loess tends to be more homogeneous fine sand to silt and clay that is stiff in character. It generally has a low vertical permeability, but can have localised zones (lenses) of higher sand- gravel content and thus, increased horizontal permeability. The stratified surfaces can result in slumping of dip slips.

Clay loams are not subsiding, from solid to mushy consistency with inclusion of shells, gypsum crystals and efflorescent carbonaceous salts. The clay loams in the vicinity of the landfill site can be subdivided into two engineering-geological units: clay loams above an altitude of ca. 762.0 m a.s.l, and clay loams below that altitude.

The bedrock in this area is characterized by large deep fractures on the underlying blocks with differential vertical movements. The Almaty region, north-western part of Karasai landfill had highest seismic activities in the past with relatively frequent destructive earthquakes. The Zailiiskii and Kungey Alatau range is an especially active seismic zone which can experience earthquakes of 8.6 - 8.8 in magnitude and has been classified in a MSK zone IX (destructive) by the Kazakhstan authorities. However the vulnerability associated with the landfill site can be classified as low with the main identified risk being collapse of the landfill working face.

Hydrogeological aspects

Hydrogeologically, Karasai disposal site is in the part of Iliyskiy artesian basin. The groundwater reserve is recharged by glaciers and snowfields on Zailiyskiy Alatau mountain range. The water-bearing strata are composed of modern upper-quaternary, middle-quaternary and lower-quaternary deposits. Perched groundwater occurs in the modern alluvial deposits at 2.2 m to 7.2 m below the surface. The aquifer within the middle-upper quaternary alluvial-proluvial deposits occurs at about 200 m which is a source of drinking water. Perched groundwater at the Karasai disposal site is at a depth of 1.5 m at the bottom of the broad gully, at the Northern part of the landfill at a depth of 0.5-1.52 m and in the Southern part at a depth of 8.95-16.32 m. The highest (perched) groundwater level appears between May and June durning the snow melt. The groundwater from the lower-quaternary deposits with gravel-pebbles bedding with loam layers are used as the source of water supply for Karasai landfill site itself. The water at this source contains sulfates, hydro-carbonates, sodium, calcium and chloride within the acceptable ranges. The water complies with the Russian GOST 2874-80 standard for drinking water.

Filtration coefficients of lower-quaternary clay loams (non-subsiding) underlying the landfill were determined by means of pump and slug tests in boreholes and found to be in the range of 10^{-9} m/s, and according to laboratory tests performed, even as low as to 10^{-10} m/s i.e. ideal subsurface material for a landfill. There are no watercourses, tapering out springs in the shallow gullies and depressions adjoining to the landfill site or downstream from the main broad gully.

Along the broad gully between the two small earth dams (both failed) were constructed to catch runoff water (leachate) from the landfill (See Fig. 5.5). Currently, water collected from Kaskelen River is used for household and technical needs of the landfill site. This water meets sanitary and hygienic requirements in terms of its macro-elements composition, biogenic and oxygen mode, pH reaction, but this water is contaminated with fluorine, copper, zinc and suspended particles.

Considering the present situation of the landfill site, there is only a possibility of contamination of surface water sources and the perched groundwater up to the depth of 7.2 m. The main aquifer is sufficiently to be considered safe from contamination.

Meteorological aspects

The climate in the area is moderately continental with dry air and many sunny days. The maximum weight of snow blanket is 70 kg/m^2. Normative frost zone of the loams is 126 cm. The average annual precipitation is 509 mm and average annual evaporation is equal to 452.2 mm. Average air temperature of the coldest month (January) is minus 9.9°C, average air temperature of the hottest month (July) is 29.5°C. Considering the amount of precipitation, the probability of contamination to the water bodies due to runoff water from landfill site is very low.

Summary of hydrogeological / geotechnical investigations

The hydrogeological / geotechnical investigations were a joint effort between the BOKU and the local partner KazNTU with assistance from on-site staff from the Karasai landfill over six days in January 2007. The site investigation work was designed to complement information from already available extensive reports and it was agreed that the potential benefits from additional drilling was not justified due to limited accessibility and costs The aims of the site investigation included: acquiring existing hydrochemical data from three former monitoring and seven drinking water wells in the vicinity; digging two trial pits in the gully downstream of the landfill, conducting a seepage test in one of them and constructing a runoff sampling device in the other one as well as auger drilling a shallow observation well nearby (Figure 5.4) ; an additional water and leachate sampling campaign for hydrochemical and isotopic analyzes; and geotechnical analyzes of some ten loess and loam samples taken from the rock faces present on the site.

The following site investigation work program was defined:

- Hydrogeological / geotechnical

- Ca. 10 loess samples: Ca. 5 according to list; rest for missing parameters only
- Two refractive seismic sections (total length ≤ 300 m) on loess plateau and in gully (for dry and saturated conditions, respectively), or lab measurements
- Runoff sampling (in the gully)
- Seepage test in trial pit (incl. one soil sample)
- Runoff sampling device (custom made – see diagram below)
- Shallow observation well (auger drilling; ca. 3,0 m; location within pond)

- Hydrochemical investigations

- Drinking water monitoring data from relevant authority (Kaskelen)
- Additional sampling: leachate pond, site monitoring well, runoff sampler, gully observation well

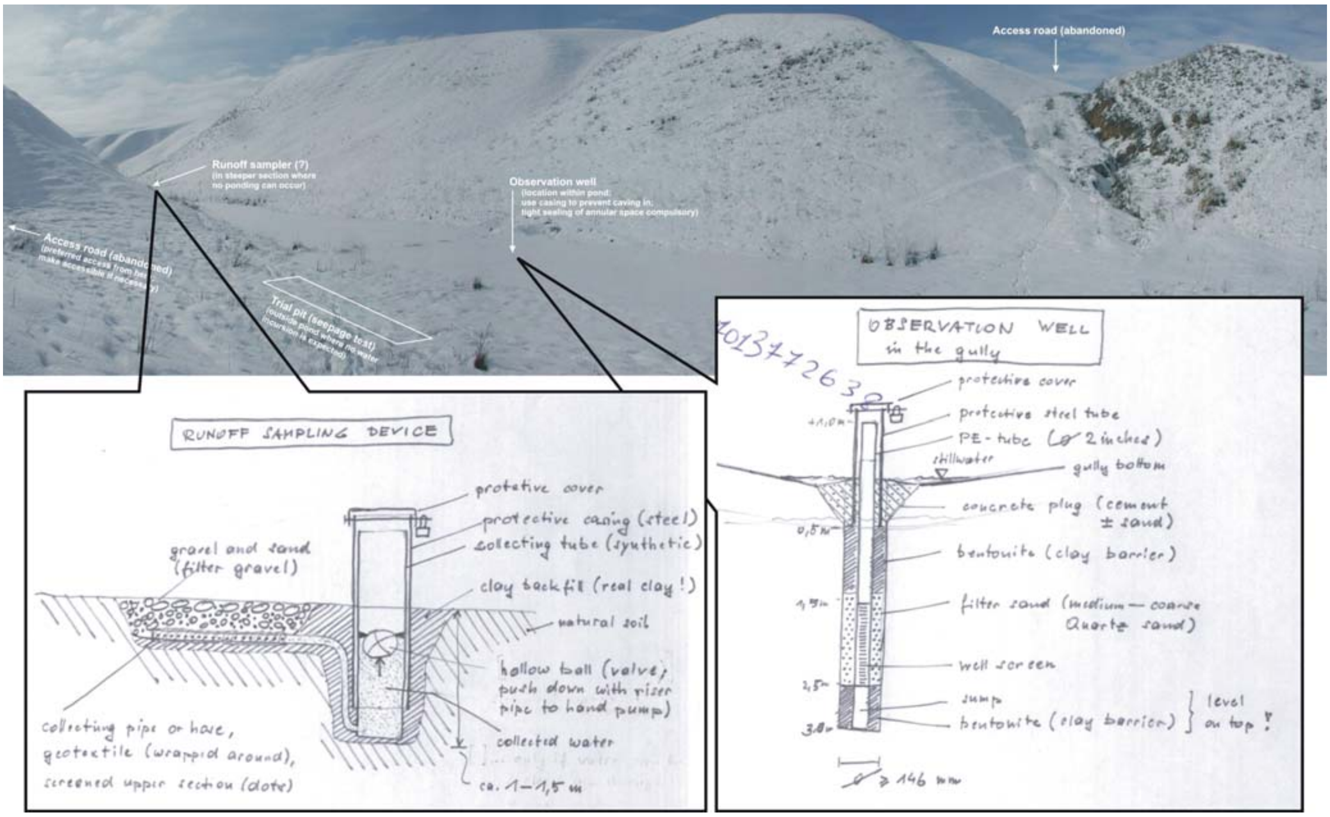


Figure 5.4: Location and drawings of the installed runoff sampling devices – view from below the landfill looking down the gully NNE. (W. Straka, IAG, BOKU, unpublished NISMIST project report)

5.1.3 Geophysical investigation

Due to the steep morphology of the site, it was not feasible to perform any geophysical investigation within the stipulated time at this landfill.

5.1.4 Identification of problems and possible impacts

Leachate

Leachate is collected in a pond (currently approximately 70 m^2) at the landfill base, the lowest point of the natural gully. Two small earth retention embankments (made by loess material) have collapsed after heavy rainfall. The accumulated leachate from here flows and disperses in the gully and drains away. The leachate is strongly polluted. The values for chloride, sulfate, BOD, COD and AOX even exceed several times the maximum concentrations measured in the leachate of comparable German landfills in the 1980’s (Table 5.3.5) as this as used is as a de facto comparison standard for many landfills.

Table 5.3: Parameters exceeding maximum values for German Landfills of the "Karasai" leachate

Element	Exceeding	Max concentration (mg/l)
Chloride	2 to 4 times	10780
BOD	10 times	4921
DOC	2 to 3 times	4210
AOX	1.5 times	4522

The leachate also contains high concentrations of heavy metals. It is therefore highly contaminated and poses a hazard to the soil and perched groundwater.

Groundwater

The perched water table in a depth of 1.5 to 4.5 m below surface in the gully is highly contaminated with heavy metals and oil products (Table 5.4) which definitely originates from the landfill. The landfill operator draws its water from the aquifer in a depth of approximately 200 m; this water is not affected by the landfill yet. The perched groundwater downstream from the landfill has a high risk of contamination, which is why the surface runoff sampling device was installed.

Table 5.4: On site Boreholes: parameters exceeding recognized limit values

Parameter	WHO	German DWO	GSPO	Max. concentration (mg/l)
Arsenic	1 to 5	1 to 5	1 to 5	0.046
Lead	-	8 to 40	3 to16	0.4
Chromium	2 to 4	2 to 4	2 to 4	0.21
Nickel	3	3 to 4	up to9	0.18
Zinc	-	-	1 to 2	0.87
Manganese	8	63	-	3.17
Fe	-	Up to 865	-	137
Oil products	-	-	3	0.6

Landfill Fires

Wide areas of the landfill are burning. The extent of the deep seated fires is difficult to predict. Smoke emerges from nearly all slopes and border areas of the lower part. Figure 6 indicates the locations of visible fires or smoke discharging from the landfill while the big symbols indicate intense fires with heavy formation of smoke. The combustion process is taking place inside the landfill. The waste material (plastics, paper, organics) is combusted uncompleted due to under-stoichiometric oxygen supply and too low temperatures, which might cause the formation of dioxins and carbon monoxide (CO). People working on the landfill or nearby and residents might be affected by the toxic substances in the air. Especially the workers on the landfill, who are sometimes sleeping on the ground, are exposed to high CO values.

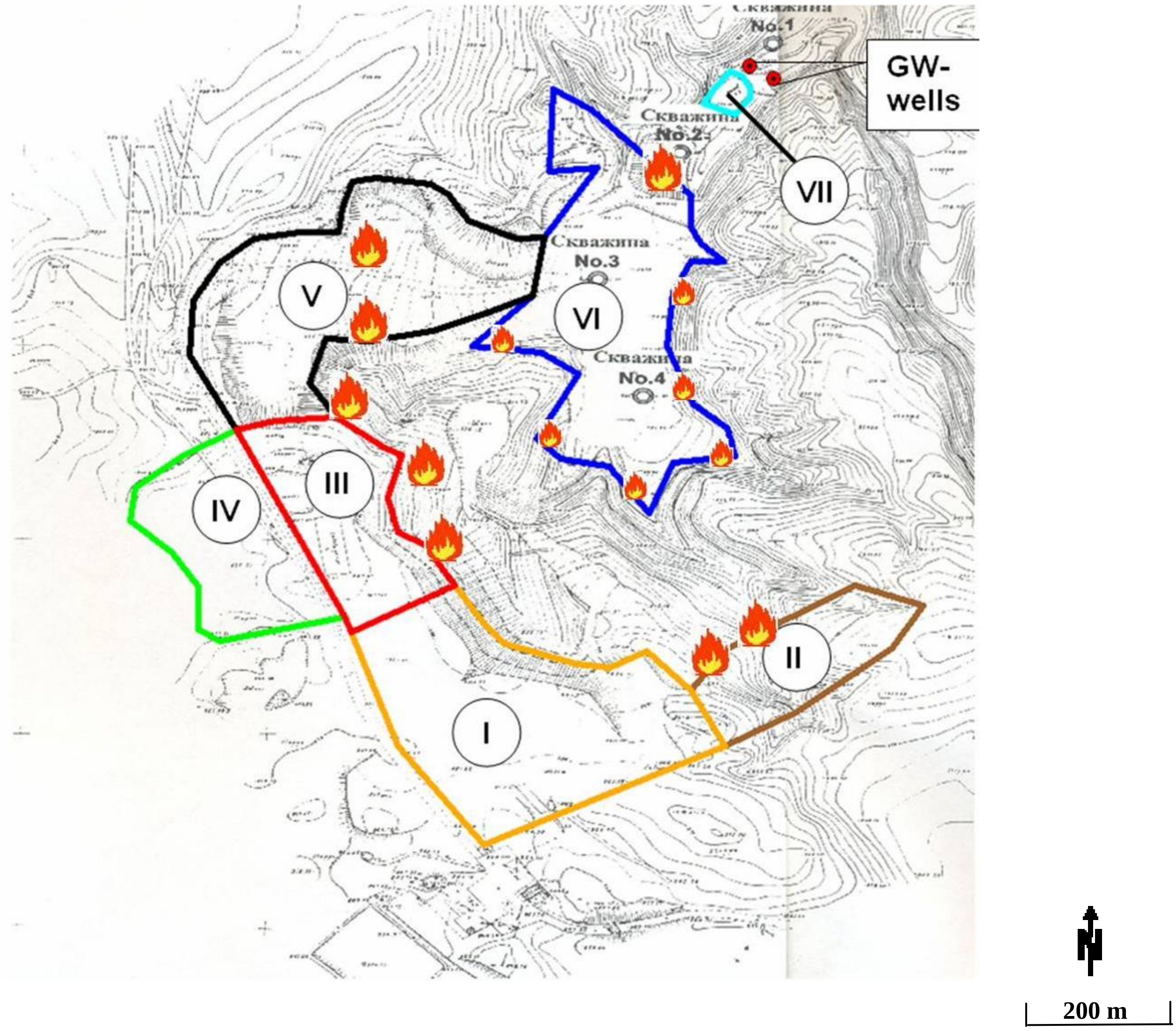


Figure 5.5: Location of landfill fires (big symbol = strong fires, small symbol = small fires). (Source: adapted from Karasai Landfill Monitoring report)

Gas emissions

Younger parts of the landfill emit significant amounts of landfill gas to the atmosphere. It can be estimated, that the average composition of the gas is 50 to 60% methane (CH_4) and 40 to 50% carbon dioxide (CO_2). A landfill of this size is likely to emit several hundred up to several thousand m^3 of landfill gas every hour. As the global warming potential of methane in the atmosphere is 21 (based on a theoretical retention time of 100 years), a manifold of this volume in terms of CO_2-equivalents is emitted to the atmosphere. It is therefore necessary to capture and treat the methane in order to protect the climate. Additionally the energy content of the biogas can be utilized for the production of electricity and heat. Based on a rough estimation 1 m^3 LFG is equal to approx. 5 kWh. This means, that for LFG capturing rates of 2,500 m^3/h (< 50% of the theoretical LFG production rate) approx. 12,500 kWh can be generated, thus enabling the complete energy supply for the landfill (including periphery) and heating of offices and other related buildings in winter.

Ground/soil contamination

Karasai landfill site is located on the steep valley of the northern, lower slope of Zailiyskiy Alatay over the loess-like loams soil layer. The results of the chemical test on the soil show that, the present soil contamination falls on hazard class I and II. According to the chemical hazard class I, the maximal lead content of site is 134.9 mg/kg. This is about 4.2 times the maximum permissible amount of lead. Similarly, the zinc content is 3.6 - 8.8 times maximum permissible concentration (MPC). A contamination with cadmium was observed in two samples. No contamination with arsenic and mercury was found. According to chemical hazard class II, the maximal copper content exceeds 1.4 – 214 times the MPC amount. The copper content of the background soil is about 1.2 – 164.7 times more than MPC. There was no chromium contamination found.

5.1.5 Waste/landfill operation and management

The area of the Karasai landfill which is covered by waste is approximately 17ha in 2007. Most of the area (approx. 12-14 ha) is still actively used for waste disposal. There is no organized plan of waste disposal. Waste is apparently unloaded where it is currently most suitable. The lower areas (V and IV) are often not accessible during winter time due to whether conditions. The disposal during that time is taking place in the upper areas. During summer time also the lower areas are used for waste disposal. The waste is transported to the place of disposal on the site by the incoming waste transportation vehicles and unloaded on the landfill. A couple of bulldozers are distributing the unloaded waste. Most of the waste is moved to the edge of the disposal area and pushed down a high and steep disposal slope.

Through this procedure the waste material gets only slightly compacted. There is a weigh bridge at the entrance, so the weight of the delivered waste is controlled. Still it is unclear, whether there also recordings of the delivered waste material. Other inspection of the waste is not taking place. The kind of waste is not controlled, so basically all kind of waste can enter the landfill. Scavengers are working on the landfill, collecting recyclables (plastic, glass bottles, metals) from freshly delivered waste as well as from the older already disposed waste. The workers are not protected at all, sorting the waste bare handed. The landfill is freely accessible, so anybody can enter the landfill. The landfill has extensive surface and sub-surface fires. The waste material is usually uncovered with only an old area (IV) and the burning part of area II are covered with local loess material.

The leachate is collected in two small leachate ponds (currently approximately 70 m^2 each) at the landfill base (VII in Fig. 5.5), the lowest point of the natural gully in the north of the landfill. Two small earth retention embankments (made by loess material) have broken after heavy rainfall. There is no active leachate management. Three boreholes in the immediate downstream from the landfill allow sampling of the perched ground water, which is only a few meters under the surface. The access to the boreholes and leachate ponds is limited as there is no intact road. The area is only accessible on foot.

5.1.6 Geotechnical/seismic hazards

From the lessons learned from past earthquakes, modern solid waste landfills have generally shown a good ability to withstand strong earthquakes without impairment to human health and the environment. Experience has shown that well-constructed landfills can withstand moderate peak accelerations up to at least 0.2g (~ magnitude of M6.2 Richter scale) without harmful effects. However, in case of Karasai landfill (poorly compacted waste, tipped at very steep slopes, no baseline or foundation) a strong to major earthquake (M6.0 -7.9 Richter) one or more of the following failures could occur:

- Sliding or shear distortion of landfill or foundation or both
- Landfill settlement
- Transverse and longitudinal cracks of cover soils
- Cracking of the landfill slopes
- Disruption of the landfill by major fault movement in foundation
- Differential tectonic ground movements
- Liquefaction of landfill or foundation

These failure mechanisms are not necessarily independent of each other. Once the landfill fails it can create many problems to the surrounding environment. Therefore, some precautionary measures are required in case of strong to major earthquakes.

5.1.7 Specific Recommendations

The main problems of the Karasai landfill are:

- Extensive fires
- Emission of leachate into the environment
- Emission of greenhouse gases (GHG)
- Hazards due to seismic activities

Except the GHG emissions these problems pose a direct risk to the people working on the landfill, the environment in the vicinity and consequentially the flora and fauna, the agriculture and the residents in the surrounding. Several simple and cost effective solutions can be applied to improve the situation on the landfill. Others mentioned here will need additional and maybe external funding, but are essential for modern landfill management.

Leachate

The leachate of the landfill accumulates in the lowest point in the northern gully. The pond which was constructed to retain the leachate is neither fortified or sealed nor intact. Leachate flows and disperses in the gully and drains away. The earth retention embankments (made by loess material) must be restored to prevent more leachate from leaving the pond in an uncontrolled way. The pond should be fortified so that a collapse of the retention dam is not possible. A liner e.g. a geo-membrane should be installed to prevent leachate infiltration. The volume of the existing leachate pond has to be verified and enlarged if necessary, based on leachate volume calculations. The collected leachate demands treatment. Leachate recirculation is a recommendable option but should be combined with a certain pre-treatment, either in the pond or at an external treatment plant.

A pump could be installed in the leachate pond and the fluid could be pumped through hoses onto the landfill. A rather high difference in elevation has to be overcome at the Karasai landfill, which might result in needing strong pumps. Alternatively, a tank vehicle with an implemented spraying unit could be used, provided that the access road to the basin is usable. The leachate should be pumped out of the pond and spraying should be conducted when no people are on-site e.g. in the evening. It is the best to close off the sprayed area to prevent people accessing the area to allow spraying in the morning to and thereby achieving a higher evaporation level.

It is also possible to treat leachate in aerated lagoons, which could be constructed at the base of the landfill between waste and the retention embankment of the existing leachate pond is about 3200 m^2 (see Figure 5.6). This area could be developed as a fortified basin with a base liner (geo-membrane), acting as an aerated lagoon. As a reliable calculation of the amount of leachate reaching the basin at the lowest point is not possible, the volume of leachate needs to be assessed by monitoring for correct dimensioning of the lagoon. The simplest option is a naturally aerated lagoon, which does not need additional installations and needs only a depth of a few decimeters. Mechanically aerated systems and multiple basin systems, which are more effective, though require substantially higher investment.

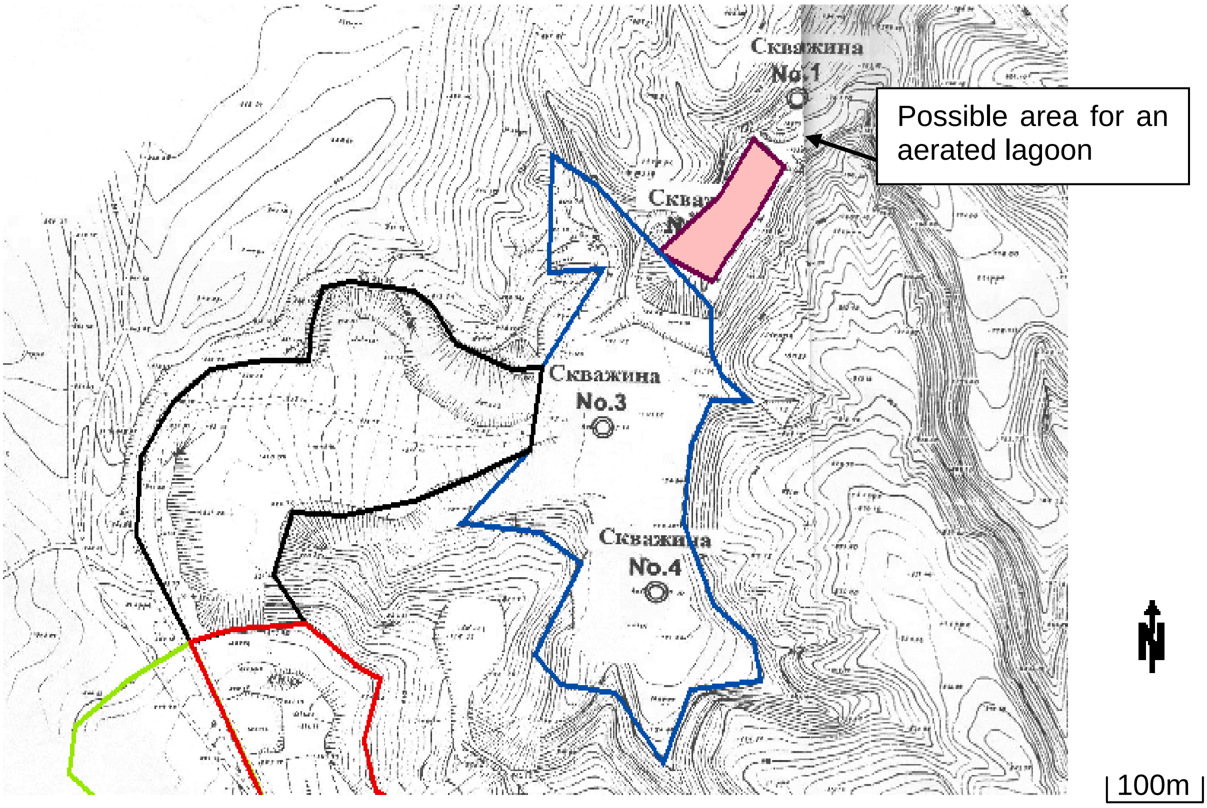


Figure 5.6: Possible area for an aerated lagoon. (Soure: adapted from map from the Karasai Landfill Monitoring report)

Landfill Gas

The Karasai landfill does not have any gas collection system. To prevent greenhouse gas emissions discharging into the atmosphere and to recover the energy, it is necessary to collect and treat/utilize the gas. This is usually done by means of vertical gas wells, because they can be installed easily in an existing landfill. The gas is flared or utilized for energy and heat production in gas engines. The installation of this system needs some investment for gas wells, collection pipes and a flaring / utilization unit. It is however possible in Kazakhstan to start a so called "Clean Development Program" (CDM) project under the scope of the Kyoto Protocol. This enables developing countries to reduce their emission of carbon dioxide into the atmosphere and receive "carbon credits" in exchange. These carbon credits can be sold on the international market. This makes the installation of a gas treatment system attractive as it is possible to generate income. The Karasai landfill consists of different areas which are more or less suitable for the gas extraction. The lower part VI (4 ha) seems to be suitable for the gas extraction. This part is quite even, the waste is relatively fresh and no intense fires have been observed in 2007. The suitability of the other parts needs to be verified. The elaboration of such projects is complex and needs specialists for the application. There are companies are specialized in this field and have such programs running. Further investigations and calculations have to be conducted to estimate the possible gas production, gas yields and CO_2 reductions. In this process a detailed analysis of the needed technical and structural preconditions and investments as well as the potential economical efficiency will be made. Overall a CDM project is a good opportunity to finance the improvement of the landfill site.

Waste slope stability

As the landfill is not well compacted and constructed properly, there is a serious risk of landfill slope failure and subsidence of landfill in case of a large earthquake. As there is no liner at the base of landfill, there are greater chances of contamination to underground soil and groundwater. In such situations, the containment of the body of the landfill and compaction of landfill is very important. Similarly, the standard construction and operation practice of landfill (refer to country norms on “Landfill construction and operation”, if not refer to relevant European Commission’s norms and guidelines) should be followed strictly to avoid the hazard due to large earthquakes. The tipped waste (Figure 5.7) should be compacted in layers with adequate side and top cover. The spread waste should be put together to form an embankment.

Figure 5.7: Loosely dumped waste should be placed in layers with proper compaction and side/top cover.

5.1.8 Summary of remedial recommendations for the Karasai Landfill

As per the results of the site investigations and other information from the previous studies the Karasai disposal site is favorable for landfill operation. The terrain conditions are also favorable for its operation, however, the landfill lies in seismic zone IX and therefore, precautionary measures on the landfill should be taken against possible earthquake hazards. As the landfill operations are not carried out as per the standard landfill construction practices, there might be geotechnical hazards related to slope failures and subsidence of landfills. Steep landfill slopes may collapse under earthquake and it will danger to the people working on the site and damage to the surrounding environment. Table 5.6 summarizes and prioritizes the recommended measures according to the various problems to be addressed.

Table 5.5: Recommended remediation measures for the "Karasai" landfill.

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Employ security personnel	uncontrolled access	restrict access to landfill	very high	immediately	personnel, uniform		low
Special garment or ID-cards for workers	uncontrolled access	restrict access to landfill	very high	immediately	ID-cards, uniform		low
Protective clothing for workers	staff security	protect workers from harmful substances	very high	immediately	safety gloves, safety shoes protective clothing, gas masks		low
Implementation of a pre-sorting area on the landfill	people on the landfill, waste control	keep people from the landfill, better waste control, hazardous waste, inflammable waste and other different kinds of waste could be sorted out and disposed / treated separately.	high	immediately	existing bulldozers can be used		very low
Stop the disposal at the steep disposal face	landfill fires, low compaction	prevent fires if waste is disposed in prepared areas and compacted.	very high	immediately	no		no
Define disposal area with a maximum height of 2 m, change location after reaching the height, cover and do not operate other areas during that time	landfill fires, low compaction	prevent fires if waste is disposed in prepared areas and compacted.	very high	immediately	no	soil for temporary cover	low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Avoid steep slopes	landfill fires, low compaction	prevent oxygen entering the landfill	very high	immediately	no	no	no
Flatten existing slopes	landfill fires, seismic hazards	prevent oxygen entering the landfill, reduce hazard of collapse	high	immediately	no	no	no
Purchase a Sheepsfoot roller compactor	landfill fires, low compaction	prevent landfill fires by preventing oxygen entering the landfill, reduce hazard of collapse	very high	funding needed	Sheepsfoot rollers compactors	no	high
Compact waste in layers of 0.3 to 0.5 m with Sheepsfoot roller compactor	landfill fires, low compaction	prevent fires, better compaction	high	after purchasing a compactor	Sheepsfoot rollers compactors	no	no
Flatten, compact and cover existing slopes	landfill fires, low compaction	prevent landfill fires by preventing oxygen entering the landfill, reduce hazard of collapse	very high	after purchasing a compactor	Sheepsfoot rollers compactors	soil	low
Construct and fortify access road to the lowest point of the landfill and the leachate ponds	accessibility	all areas are accessible at every time	high	funding needed	construction company to prepare the road		middle
Control and record waste at the entrance	waste control	spot unwanted and hazardous waste material, separate treatment disposal	high	immediately	personnel		low
Control accepted waste at the location of disposal	waste control	spot unwanted and hazardous waste material, separate treatment disposal	high	immediately	personnel	no	low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Record volume, the origin and the kind of the delivered waste	waste control	organization of landfill	high	immediately	personnel	personal computer, software	low
Implement a landfill register, which is divided into a grid squares. The place of the disposal of all of the registered waste should be recorded here. The disposal should be planned according to that register.	organization of the landfill	organization of landfill	high	immediately	personnel	personal computer, software	low
Develop organization al and safety instructions, conduct trainings for the personnel conducted to ensure a safe and controlled disposal.	organization of the landfill	organization of landfill	high	immediately	personnel		low
No smoking or deliberate on the landfill	organization of the landfill	organization of landfill	high	immediately			no
Cover burning areas with clay or clay like material	landfill fires	confine and extinguish landfill fires	high	immediately		clay	middle
Restore loess retention dam	Leachate flows and disperses in the gully and drains away	collect leachate	very high	immediately		soil	low
Fortify dam and install a liner (e.g. plastic sheet)	Leachate flows and disperses in the gully and drains away	collect leachate	high	immediately	building material	concrete, cement, plastic sheet	low
Recirculation of the leachate with a pump and hose	Leachate treatment	treat leachate	high	immediately	pump, hose		low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Recirculation of the leachate with a tank vehicle	Leachate treatment	treat leachate	high	after purchasing a tank vehicle and build an access road	tank vehicle		middle
Install passively aerated lagoon	Leachate treatment	Treat leachate	high	After determination of Leachate volume	Building material, pump, hose	Concrete, cement, tubes etc.	Middle to high, depending on the type
Install gas collection and flaring / utilization unit	Gas discharges into the atmosphere	Treat gas, prevent greenhouse gas emissions	High	After finding funding, e.g. CDM project	Gas extraction system, flare / gas engine	Misc.	Low to high depending on funding
Install monitoring wells on each side of the Landfill for perched and deep groundwater table	Monitoring of Groundwater	Monitoring, natural attenuation	High	immediately	Monitoring wells		Low to middle
Implement Monitoring Program (groundwater, surface water, air) and prepare hazard action plans	Monitoring of emissions	Monitoring, natural attenuation	High	Immediately	Data storage (PC), Measuring equipment		Low to middle
Educate staff about hazards and proper behavior on the landfill	Awareness of hazards	Create awareness	High	Immediately	Education material		Low

5.2 Ahangaranskaya landfill, Tashkent, Uzbekistan

Ahangaranskaya is the main MSW landfill of Tashkent city located about 32 km south-west from the limits of Tashkent City along the Ahangaran highway at coordinates 41º5.5090’ N, 69º28.5400’E with elevation 456 – 482 m) occupies an area of about 59 ha. It was put into operation in 1967 with projected capacity of about 7.5 million m³. Irrigation channels surround the landfill area. The landfill territory is almost completely fenced, with some irrigation channels forming borders. The site terrain represents a relatively flat hilly region of quaternary stiff and thick loess deposits. The thickness of this alluvial, pro-alluvial loess layer is of about 200 m. The groundwater level is about 50 m below the natural surface. An existing groundwater well of about 200 m depth (upstream of the groundwater flow) is situated near the main entrance, although with no borehole log available. A swamp is located along the left side of the access road, near the main entrance, where the truck drivers usually washed their machines after unloading their waste content. Two boreholes were drilled during the site investigations at the landfill border. Borehole No. 1 in the west of the landfill with a depth from surface of 13 m and Borehole No. 2 in the east of the landfill with a depth from the surface of 30 m (see Fig. 5.8).

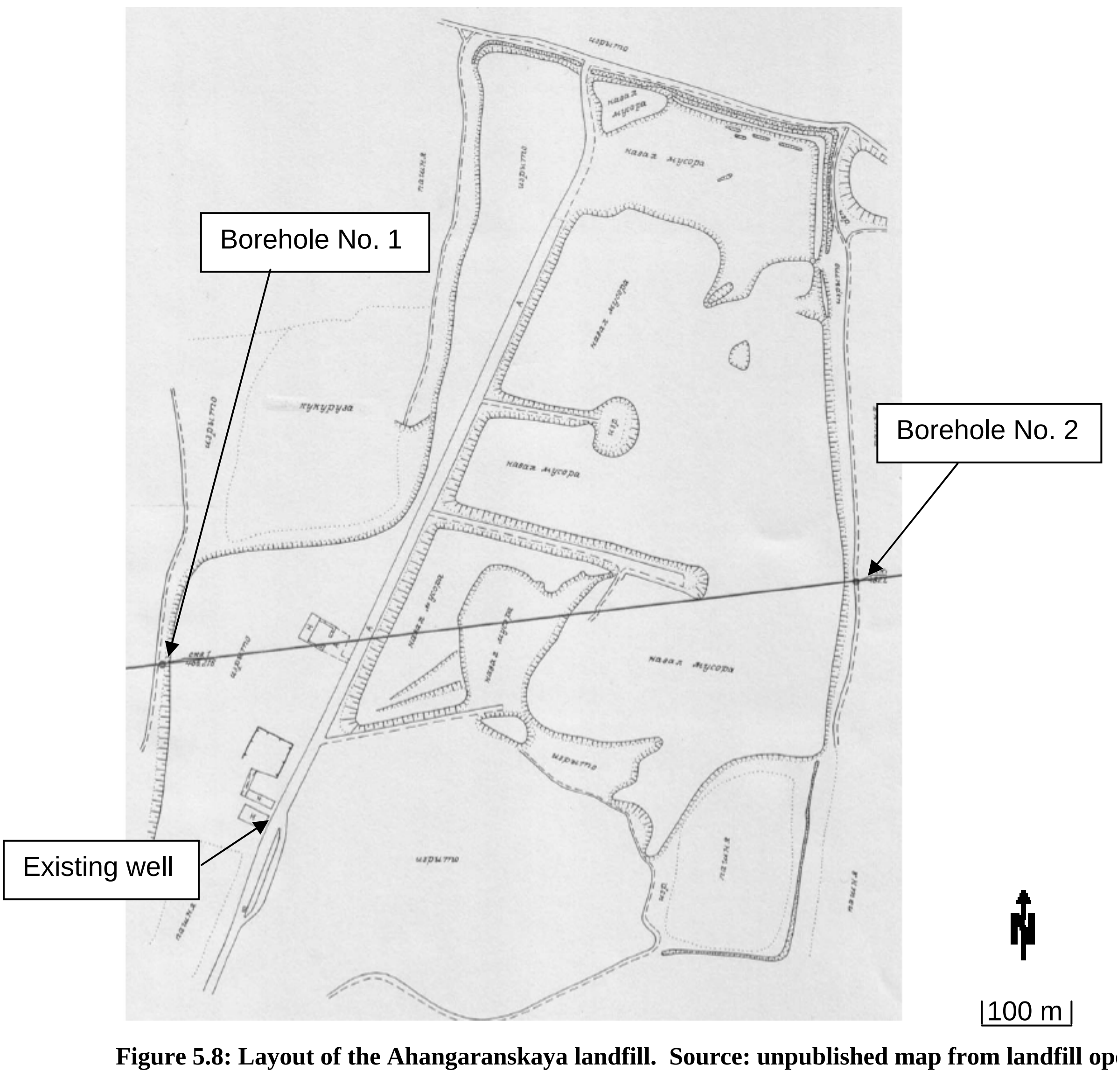


Figure 5.8: Layout of the Ahangaranskaya landfill. Source: unpublished map from landfill operator.

5.2.1 Waste characterization

The waste characterization investigations carried out on Landfill Ahangaranskaya included:

- Excavation on different spots on the landfill
- Waste sampling
- Leachate sampling
- Groundwater sampling from new installed observation wells
- Sorting analysis of excavated waste samples

One pit with depth of 6 meters was excavated (Fig. 5.9) in an older part of the landfill and second pit also with depth of 6 meters was excavated in an area with rather fresh waste.

Figure 5.9: Pit excavation on the Ahangaranskaya Landfill

Waste was sampled at 2 m intervals for sorting analysis, as well as for the further lab analysis. The temperature was measured at different levels and optical and olfactory impressions were noted. The results of the sorting analysis are listed in Table 5.6.

Table 5.6: Results from the sorting analysis

Type of waste	Pit No. 1 (%)	Pit No. 2 (%)
Fines, soil like material	76.4	4.2
Stones	4.4	7
Construction materials	2.3	5
Iron, Metals	2.1	1.5
Glass	1.1	4
Vegetables	0.1	38
Wood	0.8	6
Textile	2.7	3
Plastic	9.1	3
Rubber	0.5	1.5
Green waste	0	1.6
Paper, Cardboard	0.2	25
Bones	0.3	0.1
Nappies	0	0.1
Average water content	20.8	21.5

Description of samples from each pit

Pit No1. Waste age 3-5 years; Covered on top by 25-30 cm of loess; Typical anaerobic waste material (black colour, landfill gas smell); Waste sampling with interval 2 m, total depth 6 m

Pit No. 2: Relatively "fresh" waste; No top cover; Smell of degrading organics; Waste sampling with interval 2 m, total depth 6 m

There is one existing groundwater well of about 200 m depth and two new groundwater wells installed within the framework of the site investigations on the landfill. Water levels and temperatures were measured and samples were taken from all 3 groundwater wells. Leachate samples were also taken from Platform 1 and Platform 4 (see Figure 5.10). All samples were analyzed in-situ for temperature, conductivity, pH, and stored in flasks for later laboratory analysis at Department of Environmental Engineering, Tashkent State Technical University. Additionally solid waste, leachate and groundwater samples were delivered to Germany for lab analysis by colleagues from Institute of Waste Management, TUHH in close cooperation with two Uzbek scientists.

The concentrations in the leachate do not much differ from the concentrations measured in the leachate of German MSW sites in the 1970's and 1980's. The measured values generally are above the average values but only exceed the maximum BOD concentration 5 times. The concentrations of contaminants measured in the leachate are displayed in Table 5.7.

Table 5.7: Concentrations of contaminants in the leachate

Location	NH_4	NO_3	NO_2	Cl	SO_4	PO_4-P	HCO_3	Cond.	BOD_5	DOC
	mg/l			mg/l	mg/l	mg/l	mg/l	mS/cm	mg/l	mg/l
Platform 1	2466.0	0.0	0.0	7365	272.0	27.0	16597	40.2	2394	3430
Platform 4	1804.0	0.0	0.0	13613	344.0	13.0	17485	58.5	2873	4000

Location	As	Hg	Pb	Cr	Ni	Zn	Cd	Cu	Mn	Fe	AOX
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l
Platform 1	1.056	0.0023	0.2	2.5	0.65	1.37	0.0043	0.25	0.67	22.3	2695.0
Platform 4	0.192	0.0011	0.058	0.88	0.32	0.35	0.0012	0.084	0.15	5.78	2368.0

Waste at Ahangaranskaya Landfill is compacted and covered with intermediate covers made of loess. Some parts of the landfill have been finally covered with loess. The climate is comparable with Kazakhstan and Kyrgyzstan. Therefore for the estimation of leachate production 15% of the precipitation is used. Based on an average annual precipitation of 446 mm, the possibly generation of approx. 67 mm leachate might be expected. As the landfill covers an area of 59 ha this sums up to a theoretical annual leachate production of approx. 39,530 m^3.

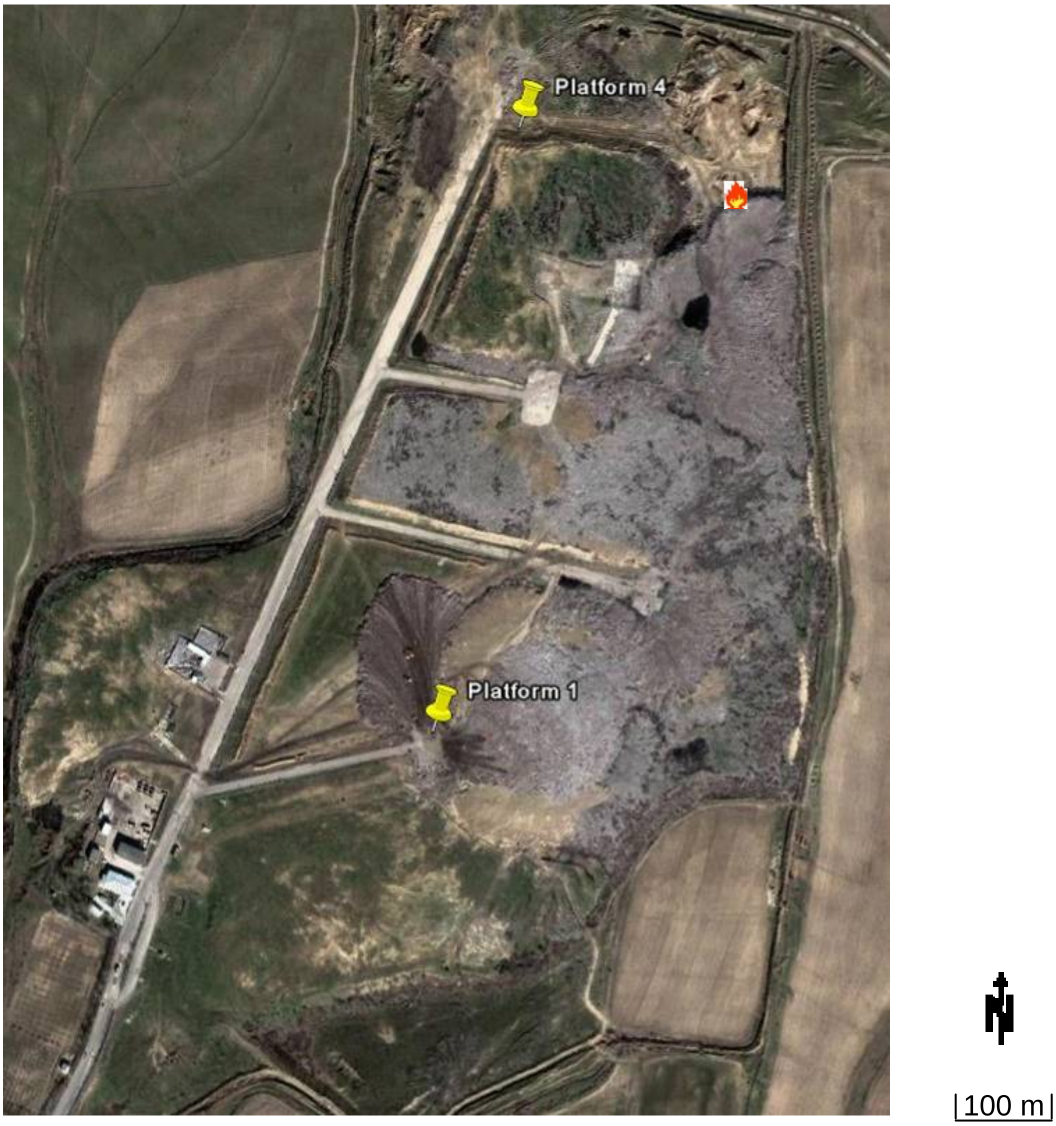


Figure 5.10: Satellite image of the landfill show sampling locations and landfill fire (Source: Google Earth, 2006)

Two boreholes were drilled in the framework of the site investigations on the landfill territory and were retained as groundwater monitoring wells: One in the west (Borehole 1) and one in the east (Borehole 2) of the landfill. Generally the contamination levels of the samples from Borehole 2 were significantly higher then those sampled from Borehole 1. This seems to disprove the assumption of a groundwater flow from east to west. The overall contamination level of the analyzed samples was very low. Considering that the groundwater level is only 3 to 4 meters below the base of the landfill, it can be assumed that the groundwater flow direction is in the north-south direction and the eastern and western areas are therefore not affected. Also there is an irrigation channel in the west of the landfill which might influence the groundwater quality as the well is very close to the channel.

It is planned that the Ahangaranskaya Landfill will remain in operation until 2014. Calculations by means of the “Tabasaran-Rettenberger model” were carried out with different wastes decomposition coefficients, k. The results are displayed in Figure 5.11. The peak production is expected in the year 2015 with values between 9,700 and 10,800 m^3/h. The end of significant gas production is expected between 2035 and 2045.

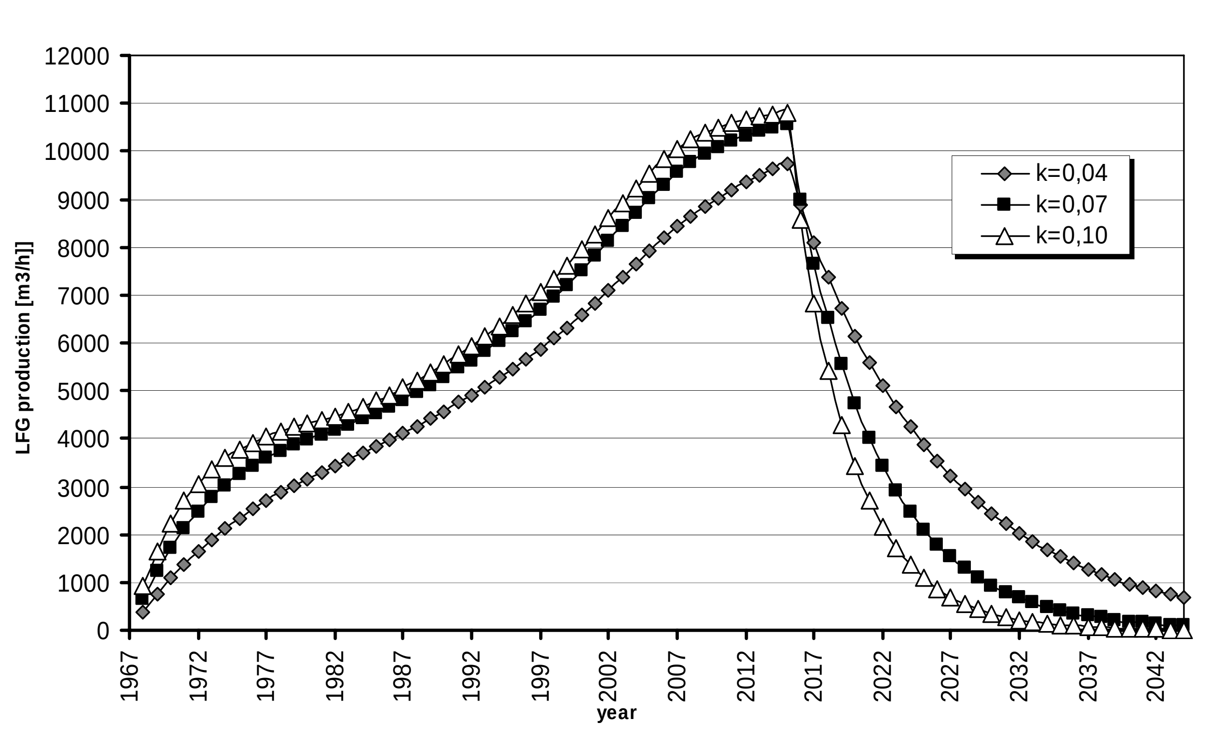


Figure 5.11: LFG production on the Ahangaranskaya landfill with different decomposition coefficients.

5.2.2 Geotechnical / Hydrogeological Site Investigation

The following site investigation programmed was planned for the Ahangaranskaya landfill:

- Drilling of two boreholes d-250 mm with loess sampling and installation of observation wells for ground water monitoring
- Construction and installation of safety cylinders with lid and lock for the two wells
- Cementing of the area around the observation wells and safety cylinders up to 0.5 m from the surface
- Construction of landfill plan and landfill cross-section
- Compression tests of soil by the two-curves method
- Shear test of soil
- Determination of physical properties, permeability, pre-consolidation pressure and compression index
- Statistical treatment of the laboratory test results

Two boreholes were drilled during the site investigations at the landfill border. Borehole No. 1 in the west of the landfill with a depth from surfaces of 13 m and Borehole No. 2 in the east of the landfill with a depth from the surface of 30 m.

Undisturbed loess samples from the boreholes were tested and analyzed to determine the physical properties, strength properties, deformation behavior, slump properties in the laboratory. In addition, information about the site was collected from various reports from the earlier site investigations and assessment. The summarized results of the physical properties of soil samples from the landfill site are found in Table 5.10 and the borehole logs are found in the appendix.

Table 5.8: Physical properties of soils at Tashkent landfill site

Physical states	Symbols	Units	Values
Natural unit weight	γ	kN/m^3	18.88
Saturated unit weight	γ_{sat}	kN/m^3	19.54
Specific gravity	Gs	kN/m^3	2.70
Void ratio	e		0.715
Permeability	K	m/s	$1,4 * 10^{-6}$
Water content	W	%	22.1
Liquid limit	W_{LL}	%	28.8
Plastic limit	W_{PL}	%	19.8
Compressibility			
Compression index	C_c	-	0.237
Swelling index	C_s	-	0.036
Preconsolidation stress	σ_p	kPa	0.183 – 0.216
Shear strength			
Natural state			
Friction angle	Ø	º	26 º3’ – 29 º5’
Cohesion	C	kPa	4.00 – 35.00
Saturated state			
Friction angle	Ø	º	26 º5’ - 28 º2’
Cohesion	C	kPa	3.00 – 18.00

Topographical aspects

Tashkent is situated in the Chirchik River valley at foot of Tien Shan Mountains. Landfill site Ahangaranskaya is the main MSW landfill of Tashkent city located on 32 km south-west from the City along the Ahangaran highway and occupies an area of about 59 ha. It was put into operation in 1967 with projected capacity of about 7.5 million m^3. Irrigation channels surround the landfill area. The landfill site area is characterized by ravine relief on gentle hills in Golodnaya Steppe at the altitude between 456 m and 482 m. The investigated area is situated on the plain at the left bank of the river Chirchik. The topography is represented by alluvial-proluvial plains. On watersheds the relief of these plains is slightly-hilly, and in band of foothills is aslope- corrugated, which is divided by wide fluvial valleys and shallow lateral arid dales. There are ravines in some sites of plain as well as canals, drainages and collectors within the irrigated tracts of lands.

Geological aspects

The landfill is located on slightly hilly territory of foothill plains with no hydrographic net inside of landfill area. The site terrain represents a undulating region of Quaternary stiff and thick loess deposits. The thickness of this alluvial, pro-alluvial loess layer is of about 200 m. The subsurface at the landfill site is represented by three Quaternary strata. The first stratum is the upper Quaternary sediment of Golodnaya Steppe complex QIII (gl) and consists of loam and loamy sand with gravel bands down to 10-15 m. This layer is followed by the mid-Quaternary sediment of Tashkent complex with two sections: the top section QII (ts2) and the bottom section QII (ts1). These two sections consist of loess loams with gravel bands of 60-70 m total thickness. The third layer is under Quaternary sediment of Soh complex QI (sh1) and consists of proluvial and dealluvial stony loam, pebble stone with sandy-argillaceous filler, conglomerates on argillaceous cement with marl with of 150-200 m. The Quaternary sediments are followed by the upper Pliocene sediment of Neogene consisting of compact plastered light-brown aleurolite (siltstone), marl, argillaceous sandstone.

Hydrogeological / hydrological aspects

The water table in the shallow Quaternary sediments is only about 1-3 m below the ground surface. However, this groundwater in the Quaternary sediments is not hydraulically connected with groundwater in deeper Mesozoic and Paleozoic carbonate sequences. This perched groundwater in the loess sediments is frequently contaminated and therefore not used as drinking water. Drinking water is usually tapped in the deeper sequences. A thick clay sequence of Neogene and Paleogene age lies below the Quaternary loess and gravels and protects the deeper aquifers. The underground at the landfill site Ahangaranskaya is represented by three quaternary strata.

The average groundwater level is about 50 m below the natural surface. Readings from the installed Boreholes No. 1 and 2 indicate a groundwater table level at the depth of 7.4 m (Borehole No. 1) and 24.68 m (Borehole No. 2), but these perched water tables are not hydraulically connected to deep seated aquifer. In addition to these two boreholes, an existing groundwater well of about 200 m depth (upstream of the groundwater flow) is situated near the main entrance but no borehole record is available for this well. The average permeability of the soil sampled from boreholes is $6.0*10^{-4}$ m/s.

Hydrological aspects of consideration include the contrete.lined irrigation channels which partially run around the perimeter of the landfill site. These channels form an entry barrier (though not really effective) but also a risk of leakage into the landfill site. Furthermore, the swamp near the site entrance just to the south of the site is used for washing the waste trucks.

Meteorological aspects

The climatic conditions of Tashkent Region are similar to that of sandy deserts with low humidity and in high air temperature reaching 42°- 44°C in shade during July. In the coldest periods of winter the temperature can reach minus 22°C. Average monthly temperature of the air ranges from –7.2°C (January) to +42.8°C (July). The hottest season is the period from May to September with the coldest period being from November to February. Duration of frost-free period in a year in average is 224 days with average duration of daylight hours being 12 hours 12 minutes.

The annual average of relative air humidity is 58%. The absolute air humidity ranges from 12.8 to 13.4% (June-August), minimal absolute air humidity is 4.3-7.0% (November - March). Atmospheric precipitations during the year are irregular. Blanket of snow lies 38 days annually in average. Average height of snow blanket is 16 cm, and sometimes up to 23.2 cm. Maximal depth of soil freezing is 0.66 cm.

Seismicity

Tashkent is located in the most seismically active region in Central Asia. Since 1868, there were about 27 earthquakes with magnitude greater than 4.5 on the Richter scale. The seismicity is dictated by the two major thrust zones, the Tian Shan and Pamir, which move in response to stress release resulting from the collision of Indian with Asian plates. The city of Tashkent was devastated by a strong earthquake in 1966. The probability of at least one earthquake with seismic intensity VI (Strong) , VII (Very strong) and VIII (Damaging) (MSK-64) with a 50-year period is equal to 0.92, 0.58, 0.39 respectively.

5.2.3 Geophysical site investigations

A combination of three geophysical site investigation techniques were perform at the landfill:

- Vertical electrical sounding (VES)
- Seismic refraction (SR)
- Ambient noise (AN)

The vertical electrical sounding (VES) was conducted to investigate the following:

- Apparent resistively profile and the ground water table of the landfill
- Waste thickness and loess thickness totally contaminated by the leachate under the waste layer and its vicinity (leachate survey)
- Groundwater level within the landfill higher than the ground water level in the surrounding loess (territory)
- Prepare and cross-sections of landfill.

Seismic refraction (SR) technique was applied to determine the shear wave velocities (Vs) and compressive wave velocities (Vp) inside the waste mass, in contaminated and uncontaminated loess-type loamy soils and identify the geological structure of loess-type loamy stratums and their thickness.

Figure 5.12 gives an overview of the points and lines of the VES and SR measurements taken.

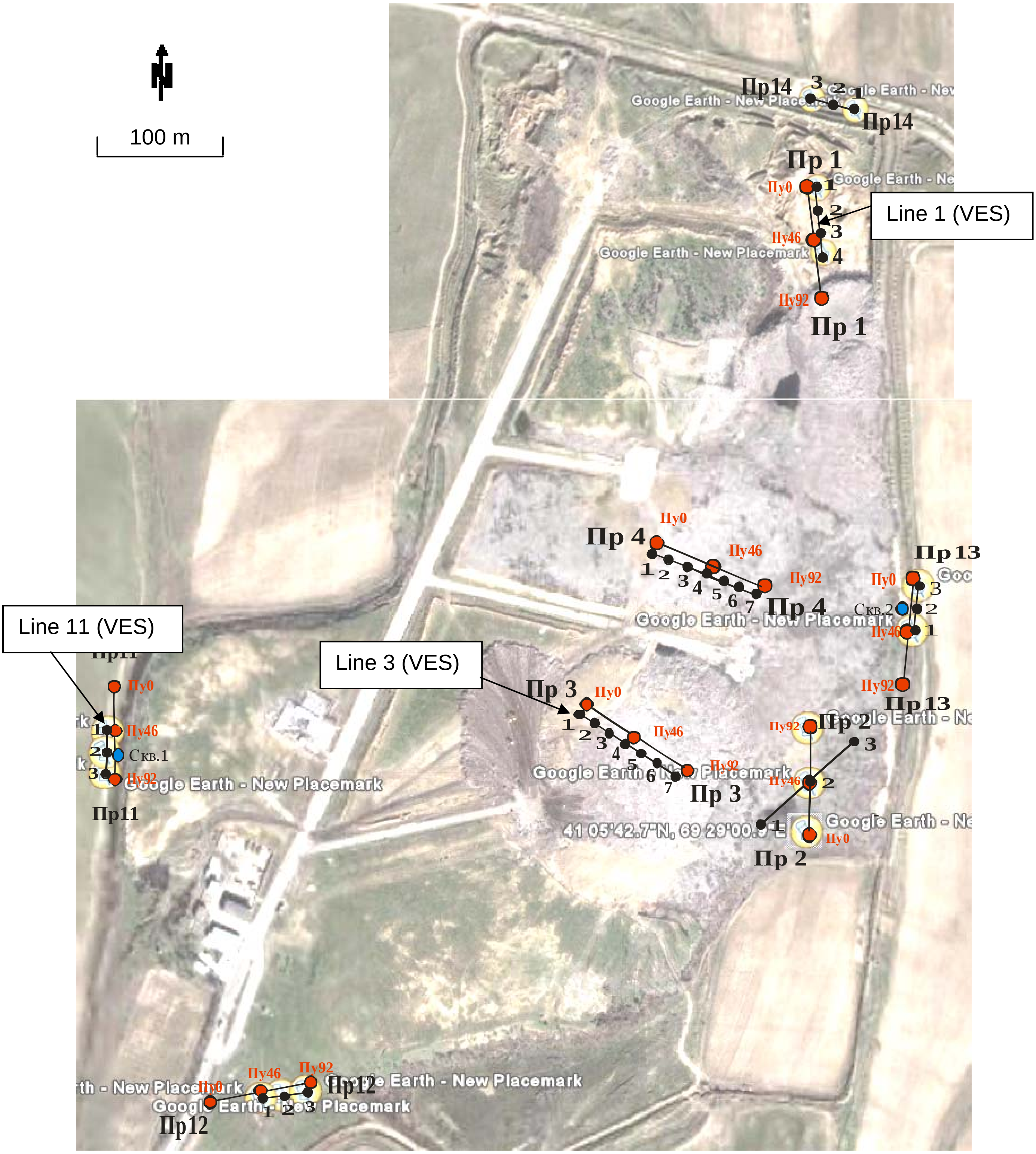


Figure 5.12: Measurement points and lines using VES (black) and SR (red) techniques. (Source: Google Earth, 2006)

The profiles along lines 1, 3 and 11 are shown in Figs. 51.3 and 5.14 below.

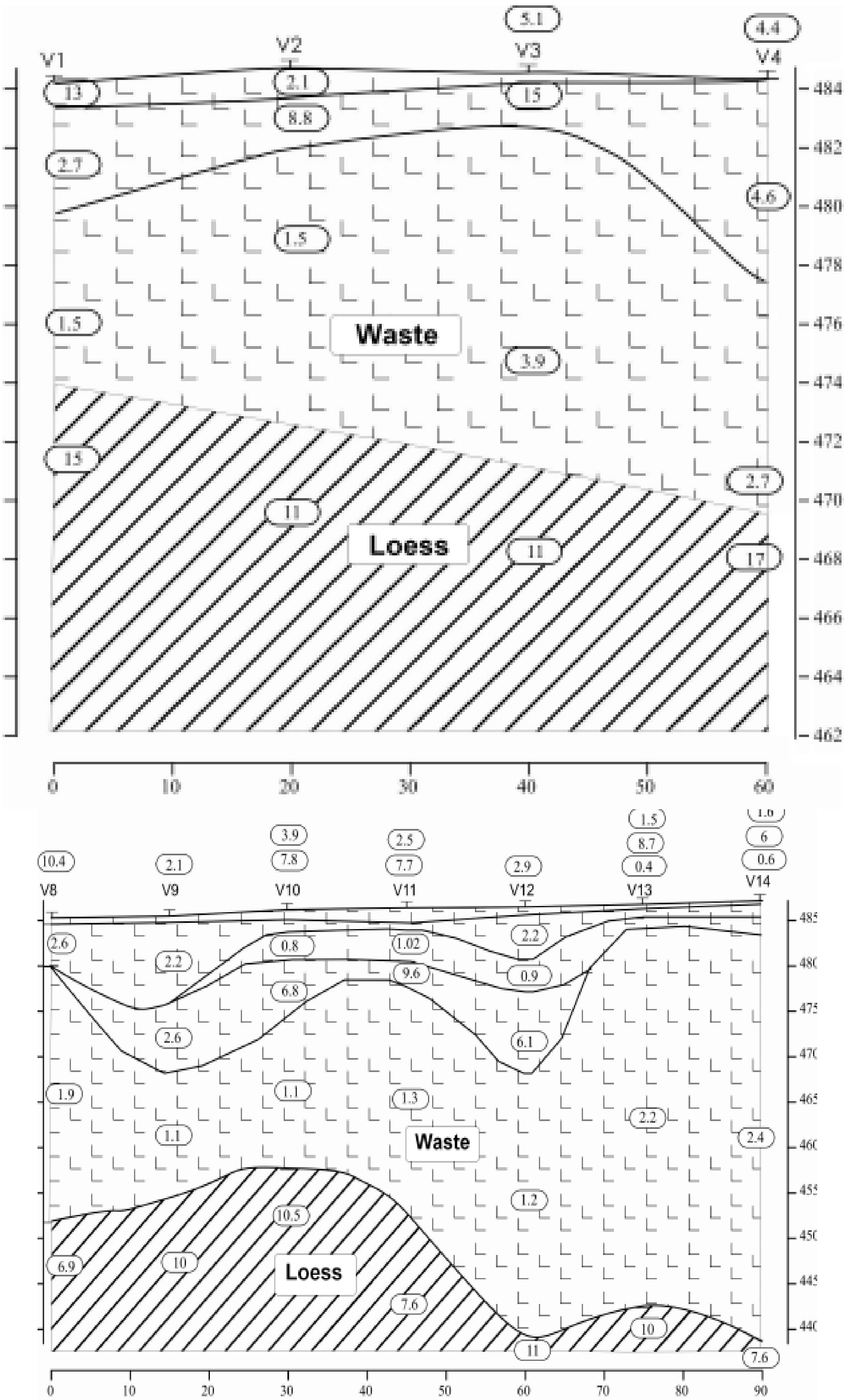


Figure 5.13: Soil profiles along lines 1 and 3 with resistively in fresh waste (above) and old waste (below). Y-axes scales in elevation (m.a.s.l.) and x-axes in metres (length of profile)

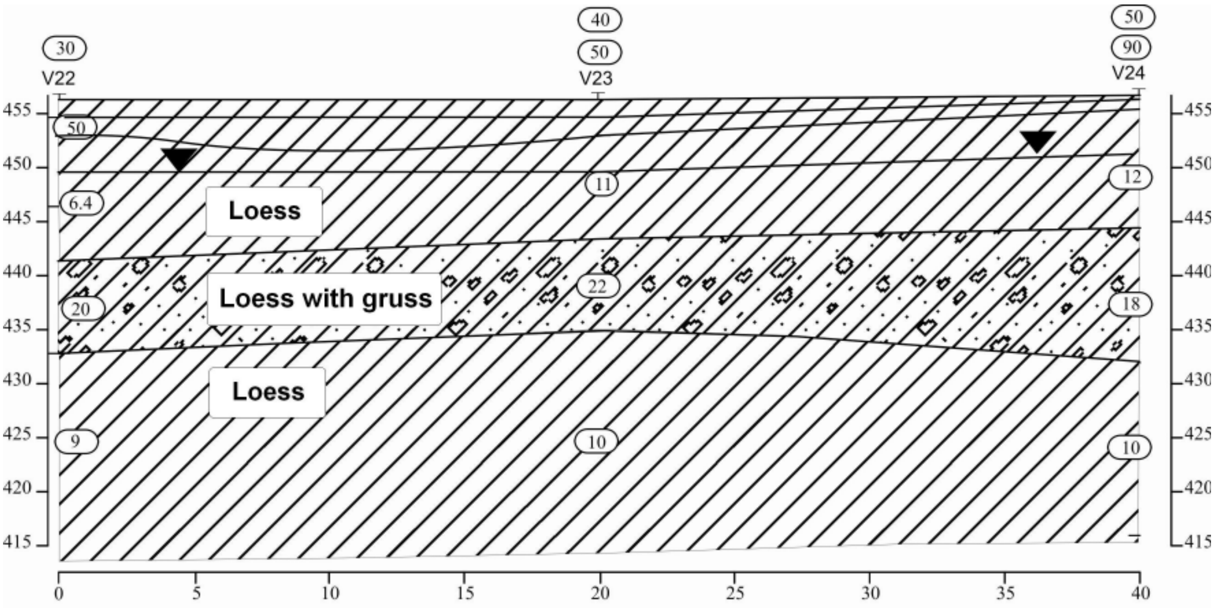


Figure 5.14: Soil profile at line 11 with VES

Ambient noise investigations were conducted in November 2006 by ENTPE and TSTU to characterize the dynamic response of the landfill site (i.e. both the waste body and the underlying natural loess) in terms of fundamental resonance frequency and the seismic amplification. Two concurrent ambient noise measurement systems were used:

- A Chinese system consisting of one portable 3-component velocimeter JC-V104 and one digital data acquisition station EDAS-3.
- A Russian system with three short-period seismometers CM-3KB with one American digital acquisition station Webtronics (See also for details Doanh et al. 2008).

Although the two systems mentioned above showed that the ambient noise measurement technique did indeed function in terms of differentiating between waste the surrounding loess, the exact results gained were see to be too inaccurate because of the age and condition of the equipment. This led to finalising the decision to purchase the new, mobile ambientg noise equipment which was subsequently used on the Dushanbe and Bishkek landfills, after which the shear wave veloicities were as a basis for modelling of the dynamic behavior of the landfills under earthquake conditions (see sections 5.3.3. and 5..4.3). Importantly, the results of the first VES, SR and AN field mesurements proved the viability of geophysical techniques for landfill investigation.

5.2.4 Identification problems and possible impacts

Leachate

The landfill neither possesses a leachate collection system nor ponds for the collection of natural drained leachate. Leachate occurs in various low-lying locations within the landfill where it is left to evaporate or seep away into the soil beneath the landfill as there is no base liner. The vertical permeability of the subsoil is approx. 0.12 m/d (ca. $2.3*10^{-8}$ m/s). This means that in the worst case, the leachate might reach the perched groundwater table (which is only 5-10 m below the landfill bottom) within less than 2 months which could lead to contamination.

Ground- and surface water

Groundwater samples from the boreholes showed no significant contamination. As stated above, it is assumed that the perched groundwater under the landfill is significantly polluted. The values measured do not seem to reflect the real situation of the contaminated groundwater which exists under the landfill. This could have several reasons, such as the influence of water from an irrigation channel or a different groundwater flow direction than assumed. Further investigations are therefore recommended to define the extent of contamination of the perched groundwater.

The contrete-lined irrigation channels partially making up the perimeter of the landfill are clearly not water tight. Leakage into the landfill site increase the production of leachate, which may not be significant at a normal daily rate basis, but is a channel is broken open by accident for through sudden ground movement (i.e. earthquake) would likely lead to a rapid, inflow of water into the landfill producing a flushing effect. Initially, a small lake wouldl be formed in the lower sections of the landfill and any overflow run-off water in to the low-lying swamp near the site entrance just to the south of the site currently used for washing the waste trucks. The swamp is probably already in a contaminated state (it was not part of the permitted investigation progrmme), but this generally an unacceptable situation.

Landfill Fires

The extension of landfill fires is limited to the slopes of the tipping area. Some minor subsurface fires seem to exist, but generally the fire situation is not a significant problem.

Gas emissions

The Ahangaraskaya landfill has a size of about 59 ha. Significant amounts of landfill gas are discharged to the atmosphere with an estimated average composition of 50 to 60% methane (CH_4) and 40 to 50% carbon dioxide (CO_2). A landfill of this size is likely to emit several hundred up to several thousand m^3 of landfill gas every hour. As the global warming potential of methane in the atmosphere is 21 (based on a theoretical retention time of 100 years), a manifold of this volume in terms of CO_2-equivalents is emitted to the atmosphere. It is therefore necessary to capture and treat the methane in order to protect the climate.

Waste/landfill operation and management

The operational management of the Ahangaranskaya landfill is outstanding compared to other Central Asian landfills. Access to the landfill is generally restricted and controlled. The landfill has new machinery including compactors and the waste is disposed and compacted in layers with intermediate covers. Steep disposal slopes are avoided. Still the safety of the scavengers can be improved and the disposal of the waste could be better organized. Hazardous waste is not separated. Also the remaining fires should be extinguished and new fires avoided.

Seismic hazards

The results of the site investigations and information from previous studies generally support the suitability of Ahangaranskaya site for landfill operation. However, the landfill area lies in a zone subject earthquakes of XIII (Damaging) MSK intensity thereby some precautionary measures could be justifiable. The low to medium compaction of the landfill leads to the risk of subsidence of landfill, but due to the flat terrain, there is no risk of slope failure. As there is no landfill base liner, there are greater chances of contamination to underground soil and groundwater. The stiff loess may rupture due to earthquake which can open new and rapid routes of leachate into groundwater. But considering the depth to the real groundwater, there is a very low risk of groundwater contamination. The usual building codes for public administration buildings in a seismic zone of this type should be observed. In sum, it can be said that the probability of a significant seismic event is relatively high, but risk and associated vulnerability i.e. potential impact is low.

5.2.5 Summary of Recommendations for the Ahangaranskaya Landfill

The landfill construction and operations are of a high standard in comparison with most landfill sites in Central Asia. However, there are still some weaknesses in landfill construction like: insufficient compaction and no proper placement of wastes and soil in layers. In the case of a large earthquake, there might be geotechnical hazards related to consolidation (subsidence) of the landfill and, because there is no base liner, there is a greater chance of contamination of the underlying soil and groundwater. Since the site is located in flat to undulating terrain, the risk of slope failure of the landfill due to earthquake is low. But because of the low-medium density of waste there is high risk of localized consolidation of the landfill in the mid to long term, even without a seismic event. The operation buildings on the landfill should be safe against earthquake. More compaction should be applied to the disposed waste and increased use of intermediate soil covers would help stabilize the landfill body. Additionally the slopes of the landfill should be flattened and compacted to prevent their collapse and currently unused areas should be temporarily covered (see Figure 5.15). In the fresh landfill site use of base liner/geomembrane is suggested to avoid ground contamination and to control leachate. Table 5.11 summarizes and prioritizes the recommended remedial measures according to the various problems to be addressed.

Figure 5.15: Slopes of the landfill should be flattened and compacted. Areas currently not used for disposal should be covered temporarily.

Table 5.9: Recommended remediation measures for the Ahangaranskaya Landfill

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Protective clothing for workers	staff health and saftey	protect workers from harmful substances	very high	immediately	safety gloves, safety shoes protective clothing	None	low
Implementation of a pre-sorting area on the landfill	people on the landfill, waste control	keep people from the landfill, better waste control, hazardous waste, inflammable waste and other different kinds of waste could be sorted out and disposed / treated separately.	high	immediately	existing bulldozers can be used	None	very low
Define disposal area with a maximum height of 2 m, change location after reaching the height, cover and do not operate other areas during that time	landfill fires, low compaction	prevent fires if waste is disposed in prepared areas and compacted.	very high	immediately	no	soil for temporary cover	low
Avoid steep slopes	landfill fires, low compaction	prevent oxygen entering the landfill	very high	immediately	no	None	no
Flatten, compact and cover existing slopes (increase use of compaction equipment)	landfill fires, low compaction	prevent landfill fires, reduce hazard of collapse dust / odor and wind transport of waste	very high	immediately	existing	Diesel, soil	low
Control and record waste at the entrance	waste control	spot unwanted and hazardous waste material	high	immediately	Personnel training	None	low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Control accepted waste at the location of disposal	waste control	spot unwanted and hazardous waste material, separate treatment disposal	high	immediately	Personnel training	None	low
Record volume, the origin and the kind of the delivered waste	waste control	organization of landfill	high	immediately	Personnel training	computer, software	low
Implement a landfill register, which is divided into a grid squares. The place of the disposal of all of the registered waste should be recorded here. The disposal should be planned according to that register.	organization of the landfill	organization of landfill	high	immediately	Personnel training	personal computer, software	low
Develop organizational and safety instructions, conduct trainings for the personnel conducted to ensure a safe and controlled disposal.	organization of the landfill	organization of landfill	high	immediately	Personnel training		low
Cover burning areas with clay or clay like material	landfill fires	confine and extinguish landfill fires	high	immediately	None	Clay	middle
Locate and monitor the leachate emission	Control leachate accumulation	Locate leachate emission points	very high	immediately	None	None	low
Build sealed leachate ponds according to the amount of leachate and direct the leachate there by channels or pipes	Control leachate emission	collect leachate, reduce impact induced by breakage of the irrigation channels	high	After knowing leachate occurring locations	building material	concrete, cement, plastic sheet	low
Recirculation of the leachate with a pump and hose	Leachate treatment	treat leachate	high	immediately	pump, hose		Low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Relocate irrigation channels away from site perimeter	Risk of water inflow to site	Reduce risk through trickle and/or breakage leading to sudden inflow	Med-high	After designing an alternative water routes	Engineered solution, contractors	Concrete, cement, pumps?	Medium to high
Recirculation of the leachate with a tank vehicle	Leachate treatment	treat leachate	high	after purchasing a tank vehicle	tank vehicle		Medium
Install passively aerated lagoon	Leachate treatment	Treat leachate	high	After determination of leachate volume	Building material, pump, hose	Concrete, cement, tubes etc.	Medium to high
Install gas collection and flaring / utilization unit	Gas discharges into the atmosphere	Treat gas, prevent greenhouse gas emissions	High	After finding funding, e.g. CDM project	Gas extraction system, flare / gas engine	Misc.	Low to high
Install monitoring wells on each side of the landfill for perched and deep groundwater table.	Monitoring of groundwater	Monitoring, natural attenuation	High	immediately	Monitoring wells		Low to middle
Implement Monitoring Program (groundwater, surface water, air) and prepare hazard action plans	Monitoring of emissions	Monitoring, natural attenuation	High	Immediately	Data storage (PC), Measuring equipment		Low to middle
Install base liner and leachate collection system for the future disposal area	Leachate drains into the soil	Avoid soil and groundwater contamination	High	Immediately	Base liner, leachate collection	Misc.	Middle to high
Install gas collection and treatment system for the future disposal area	Landfill gas discharges to the air	Capture gas, avoid greenhouse gas emissions, possible energy recovery and CO_2-credits	High	Immediately	Gas collection and treatment system	Misc.	Middle to high
Train personnel about hazards and proper behavior on the landfill	Awareness of hazards	Create awareness	High	Immediately	Personnel training		Low

5.3 Old Landfill, Dushanbe, Tajikistan

The so-called “Old” (closed and recultivated) Dushanbe landfill site is locate about 8.5 km east of Dushanbe, the capital of Tajikistan, northeast of the 191 Dushanbe district situated directly next to the small river Shuraksaiy, which feeds into the Kafirningan River. It has the coordinates 38º33.0464’ N, 68º52.4061’ at anelevation of 840 m. Together with the Varzob River, the Kafirningan River is the main source of water supply for the city of Dushanbe. The landfill features steep slopes towards the river. A loacational map of the old Dushanbe landfill with sampling pits 1 and 2 is shown in Fig 5.16. The landfill was built on natural ground and was developed to a simple trapezoidal embankment of waste deposit above the ground with an average waste thickness of about 6.5 m. The landfill has neither a geomembrane base liner nor gas or leachate collection system. The landfill operation ended in 1979 followed by the covering with moderately compacted loess soil cover of approximately of 1 to 2 m thickness. The landfill site is freely accessible and currently used as pasture land for cattle.

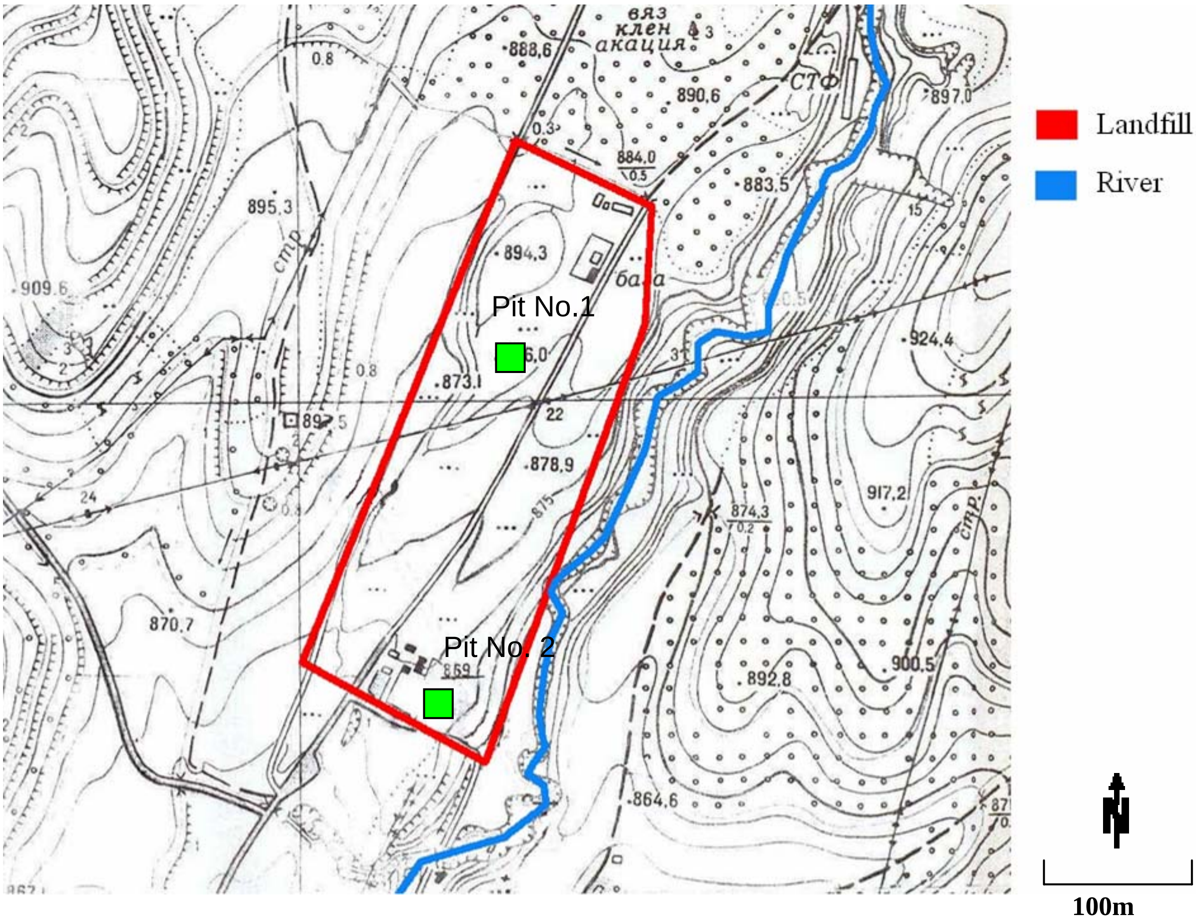


Figure 5.16: Area of the old Dushanbe landfill (red) situated directly next to the Varzob River (blue) and the positions of the 2 excavation pits (green). (Source: Adapetd from Tajik Geological Survey 1:5000 map)

5.3.1 Waste characterization

Investigations of the gas and leachate emissions were carried out on the old landfill. These include waste sampling, sorting analysis, leachate sampling and analysis and the long term investigation of waste samples in a Landfill Simulation Reactor (LSR) at the CHI Laboratory. Samples of the landfilled waste were taken from two pits located on northwest and northeast parts of the landfill as shown in Fig. 5.16. A sorting analysis was conducted in line with the sorting analysis in the other NIS countries. The results of the waste sorting analysis are summarized in Fig. 51.7.

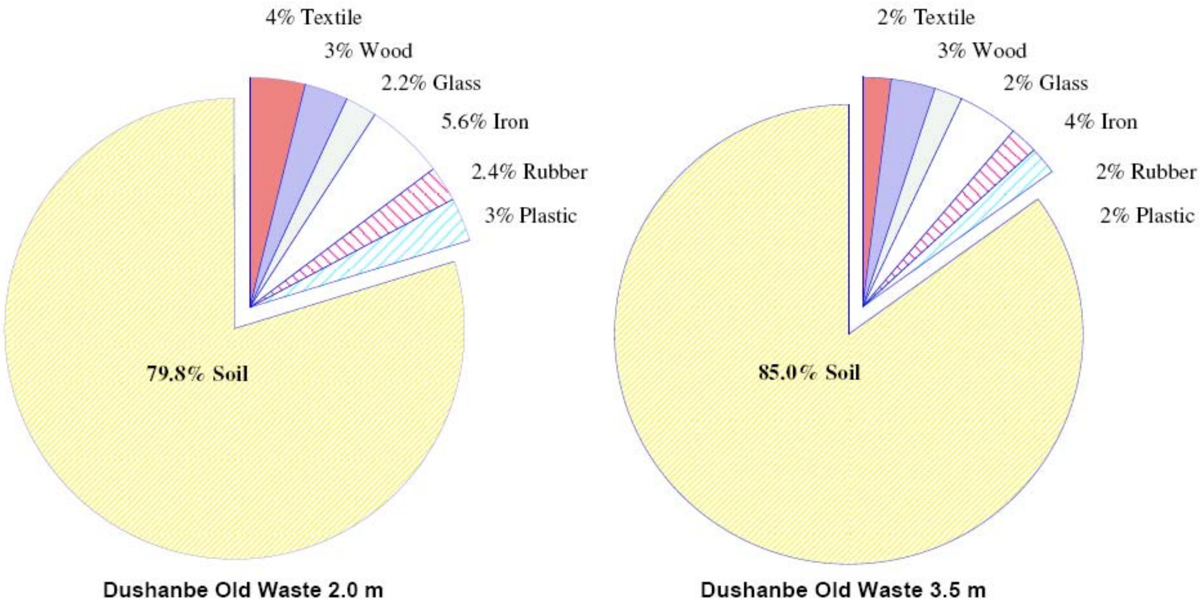


Figure 5.17: Waste partitions at 2.0 m and 3.5 m depth of Dushanbe old landfill

Both waste samples confirm the advanced status of biodegradation which occurred during landfill operation and since its closure back in 1979. Organic material has been widely decomposed by microbial processes leaving a significant amount of "soil like" material. Residual organics are allocated to hardly or slow or non-degradable fractions (e.g. rubber, plastic, textiles) thus further degradation (and emission formation) seems unlikely.

Further samples were taken and analyzed in the LSR-Laboratory. Leachate and gas quality were analyzed. Overall no significant emissions were found from the old landfill.

5.3.2 Geotechnical / Hydrogeological Investigation

The recultivated landfill site was surveyed and information was also collected from various reports from the earlier site investigations. The geotechnical and hydrogeological site investigations results are summarized in the following paragraphs.

Topographical aspects

The old landfill site is located at about 8.5 km east of Dushanbe city on right bank of the Shuraksaiy small river. The landfill borders on the river and undercutting of the landfill slope toe can be observed, as can the highly erosive nature of the loess material exposed on the opposing river back (Figure 5.18). This erosion will clearly be accelerated under flood conditions. The landfill area extends approximately 700 m in the north-south direction and

230 m in the east-west direction and occupies a contiguous area of about 16 ha of agricultural land. The landfill was closed in 1979 and had an estimated volume of about 1 million m^3 of municipal solid waste (MSW) deposited.

Geological aspects

Geologically, the area is composed of alluvial fan deposit of medium quaternary age and presented by loess-like loam with a depth of more than 30 m. However on Shuraksaiy site modern deposit combined with loams and transferred clays are observed. In general, the geological conditions observed at this landfill are very similar to that at Karasai landfill near Almaty. The immediate subsoil at the site is loess of varying thickness (40 m –100 m). The alluvial-proluvial loam soil is typically pale - yellow to brown colour with a pelitic texture, massive texture including lime concretios from hard to plastic consistence. The plastic to stiff loess loam has coarse layers of gravel of up to 40-80 mm in diameters.

Seismicity

According to the regional seismic map, the Dushanbe landfill site is located in the zone of highest a seismic risk which has been subject to frequent earthquakes of magnitude 5 – 6 M and up to 8 M or up to intensity IX (Destructive) on MSK-64 scale. Geotechnical failure processes are already appeared in the form of mudflow on Shuraksaiy which can erode the slope. There is a high possibility of undercutting of the slope by the river which can cause slope failure. Due to the interference from the local people, a bulk of old landfill and waste pile on a slope of Shuraksaiy rivulet has been exposed which has a negative impact in the local environment.

Drilling, sampling and testing

Two boreholes to a depth of 18 m were drilled in July 2006 by means of a truck mounted drilling ring during the site investigation in accordance with Tajikistan and EN Technical Specifications. Samples taken during field work were delivered to the OJSC Institute for Architecture and Civil Engineering (GIINTIZ) in Dushanbe and to the Institute of Geotechnical Engineering, University of Natural Resources and Applied Life Sciences, Vienna for laboratory testing. Disturbed and undisturbed samples were tested for index properties, soil classification, shear strength test and deformation test. Atterberg limits tests were performed for the classification of soil and sieve analysis for the determination of grain size distribution. In addition, the natural water content, natural unit weight, specific gravity and the definition of soils with respect to unified soil classification system was also determined. In order to determine the shear strength parameters, unconsolidated - undrained (UU), triaxial compression tests were performed on undisturbed (UD) samples. Consolidation tests have been performed on undisturbed samples to determine the compressibility properties of the soil layers. The drill logs are found in the Appendix and the location of the boreholes is shown in Fig. 5.19.

Summary of geotechnical site investigation results

The soil permeability was calculated to correspond to 1.4 – $2.0*10^{-8}$ m/s. The water content varies from 4.6 - 20.7%. Large variation in water content is due to different composition of the soil and also related to the depth of soil layer. The liquid limit of the soil varies from 23.1 - 32.1. The pre-consolidation stress in natural condition is about 2.4 - 5.8%. The mean values deformation module in natural condition varies from 10.8 - 34.5 MPa. Large variability in values is due to heterogeneity of natural composition of the soil and its physio-mechanical behavior. The average frictional angle of soil is 27 - 29 degrees.

Figure 5.18: Loess erosion and undercutting of landfill slope toe in Shuraksaiy river (looking downstream)

Hydrogeological aspects

The landfill is located in the undulating hills southern of the Hissar Mountains. In this area, the hills are topped by a flat surface that slopes abruptly down to the Shuraksaiy rivulet. The groundwater is 73 m depth in a gravel bed within the alluviall fan in a borehole north of the nearby new landfill. In the old landfill site, drilling and geophysical investigation did not identify (perched) groundwater at shallow depths (up to 18 m). Pools of water on the surface in the landfill cover due to surface water pipes breakage show the relative low permeability of the cover material.

5.3.3 Geophysical Site Investigation

The geophysical site investigation at this landfill was conducted on the second week of April 2007, with the help of local scientists from CHI. The interpretation of the whole geophysical survey was supervised by ENTPE. The landfill site and underlying natural loess was investigated using the ambient noise technique. This investigation aimed to evaluate the dynamic characteristics of waste and loess deposits, mainly for the determination of fundamental resonance frequency and seismic amplification as well as to compliment the borehole logs to establish stratigraphic cross sections.

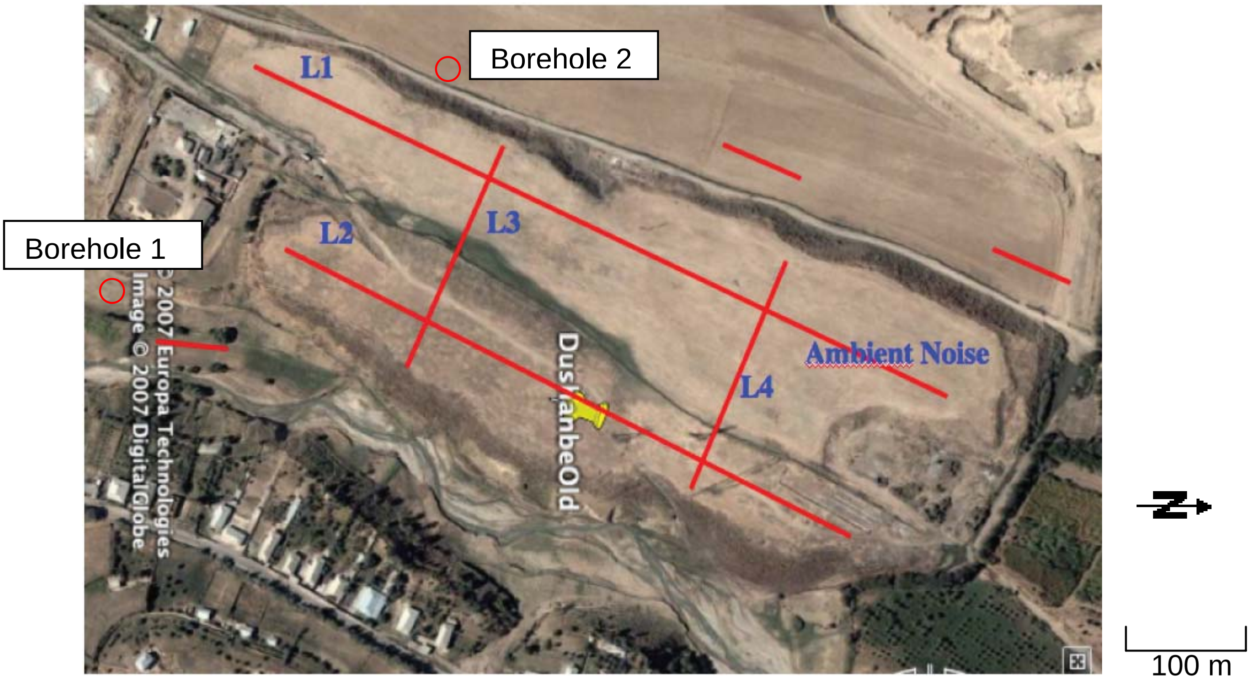


Figure 5.19: Ambient noise measurement lines on (long) and nearby (short) the old landfill (Source: DigitalGlobe)

To facilitate the ambient noise measurements, the old landfill site was divided into two elongated zones parallel to the broken water pipe in the middle of the landfill, visible in the aerial view shown in Fig. 5.19. The orientation of these two zones is approximately 10° north-northeast. Four measurement lines (L1 to L4), inside the landfill area totaling 32 points and 6 measurement points of 3 short measurement lines on natural loess outside the landfill area were made. An additional 20 points were measured inside Dushanbe city giving a total of 124 ambient noise measurement points during the investigation using the two Tromino sensors. The main dynamic characteristics of the old Dushanbe landfill using noise ambient technique are summarized in Table 5.11.

Table 5.10: Ambient noise site investigation results of Dushanbe old landfill

Material	f_0, Hz	AH/V (f0)	Frequency range, Hz	V_s, m/s
Waste	1.2 - 2.2	2.0 – 5.5	1.0 - 2.7	230 - 240
Loess	1.4 - 1.6	4.0 – 5.0	1.0 - 2.5	320 – 350

The shear wave velocity Vs of the (bedrock-like) substratum at about 60 m depth below the loess is about 650 m/s. The resonance (or fundamental) frequency (f_0), being the maximum amplitude of oscilation of a layer, was identified at about 1.5 Hz in intact loess along a secondary road outside the old landfill site and 4.0 Hz inside Dushanbe city. These parameters were used for perfoming the dynamic analysis of the landfill to simulate its behaviour under earthquake conditions.

A profile of the landfill was produced through combined interpretation of knowledge gained through drilling and the geophysical meaurements which is shown in Figure 5.20. The horizontal axis is not to scale to emphasize the details of the subsoil. The compacted final loess top cover is indicated with dark green colour. This shallow soil layer has a higher velocity than the main waste body due to presumably from compaction effort.

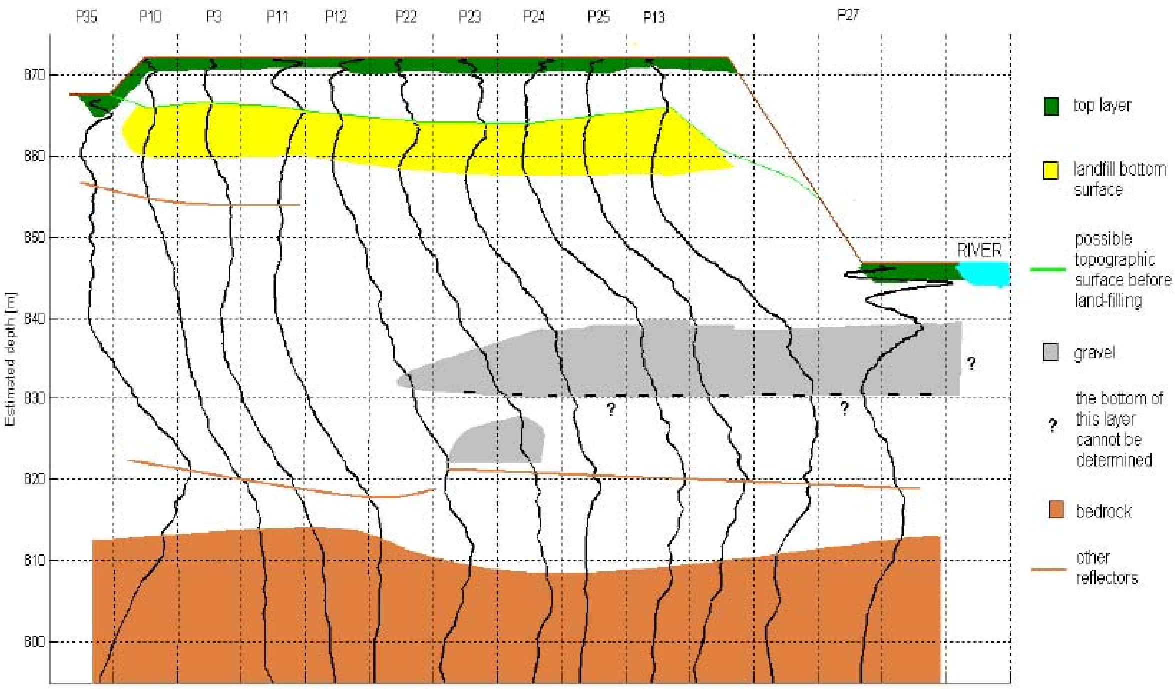


Figure 5.20: Interpreted profile of Ambient Noise Line 3 of Dushanbe old landfill (WNW to ESE)

The ambient noise technique was shown to adequately resolve the problem of geophysical methods in identifying multiple strata with relatively low contrasts between two adjacent layers as in the case of waste deposits on loess.

5.3.4 Dynamic Analysis for Old Dushanbe Landfill

Dynamic analysis modeling using the QUAKE/W software was performed at the BOKU using field data obtained through the geophysical methods (ambient noise) as well as the GPS survey. Figs 5.21 – 5.23 shows a simulated dynamic loading (earthquake) and resulting displacement on the x and y axes over time.

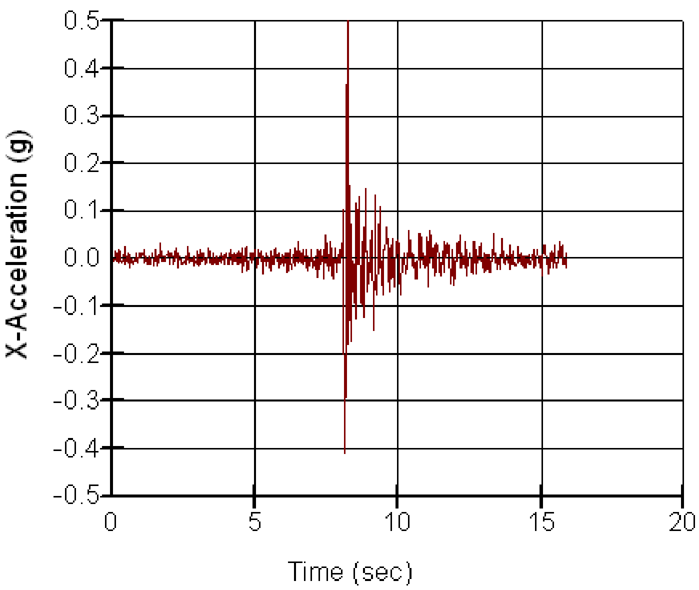


Figure 5.21: Absolute acceleration at the base of the slope

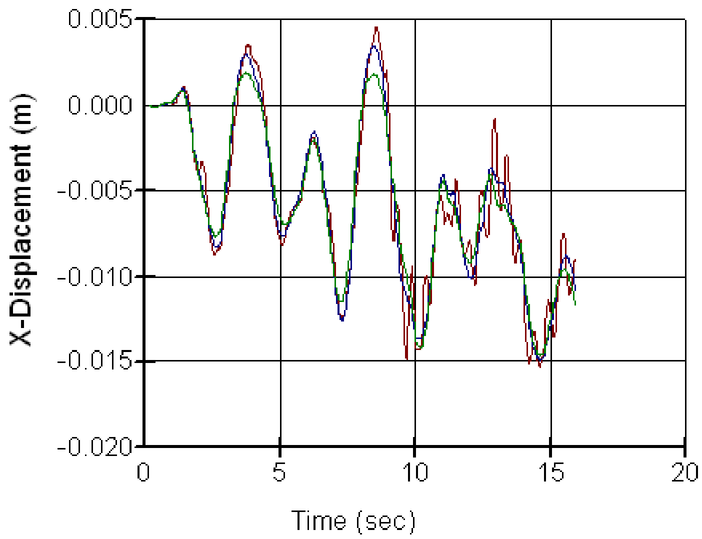


Figure 5.22: The displacements in the x-direction of the Dushanbe slope (red line represents the surface)

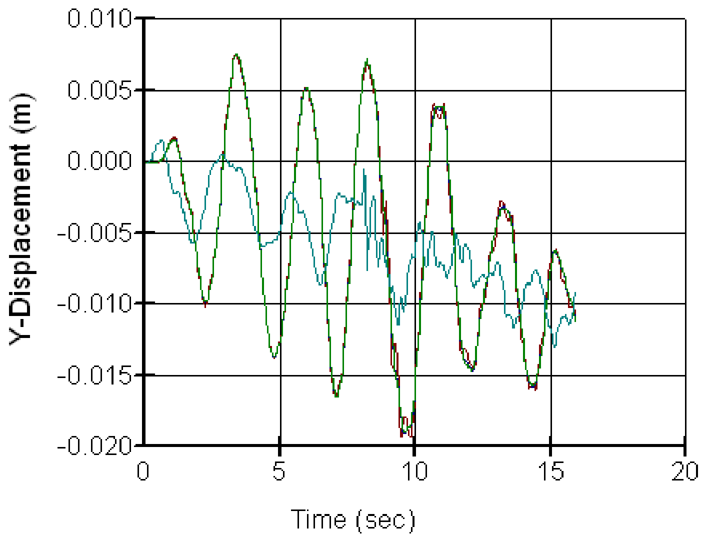


Figure 5.23: The displacements in the y-direction of the Dushanbe slope (red line represents the surface)

The modeling showed a maximum resultant displacement of 2.5 cm in the old Dushanbe landfill. The maximum horizonal displacement of about 1.8 cm occurred at the bottom of the slope of the landfill. Figure 5.24 shows deformation of the slope mass under maximum dynamic loading and the Figure 5.25 shows the effective vertical stress in different soil layers. An important condition that needs to be known is whether the investigated soil layers amplify or attenuate the acceleration during an earthquake. This was defined in this case by simulating the horizontal acceleration response at locations at both the top and bottom of each layer.

A stability analysis of Dushanbe landfill during the earthquake of an equivalent magnitude of 0.5g was carried out by means of numerical anaylsis shown in Figure 5.26. A factor of safety of 0.58 resulted from the analysis which means a complete failure of the landfill slope in case of an earthquake having a magnitude equal to or greater than 0.5g. Gravitational force (g) used in modelling can not be accurately expresses magnitude on the Richter scale, but generally this would relate to a medium to strong (e.g. 6 to 7) seismic event.

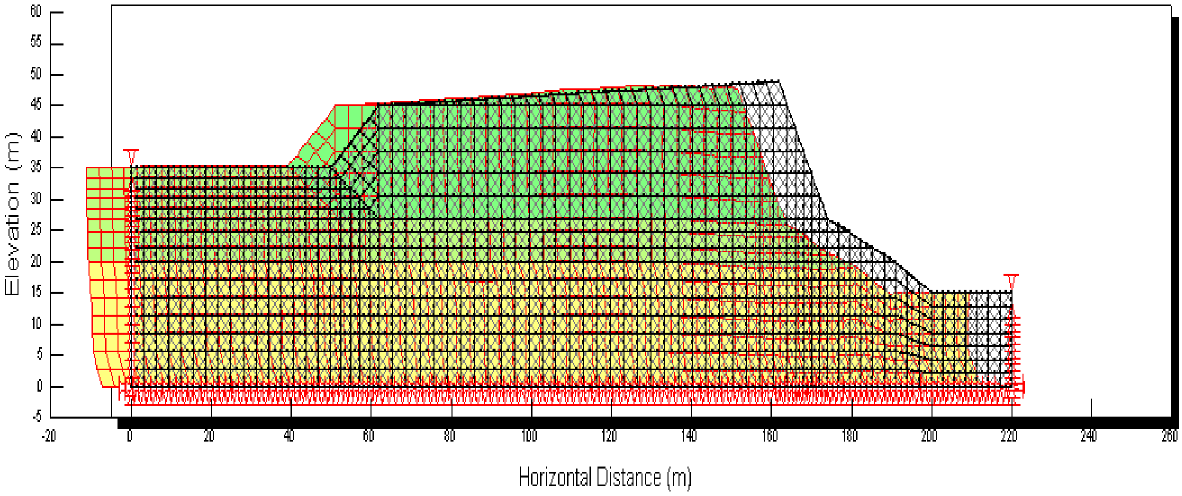


Figure 5.24: Deformations of the Dushanbe landfill at the last time step (end of simulation)

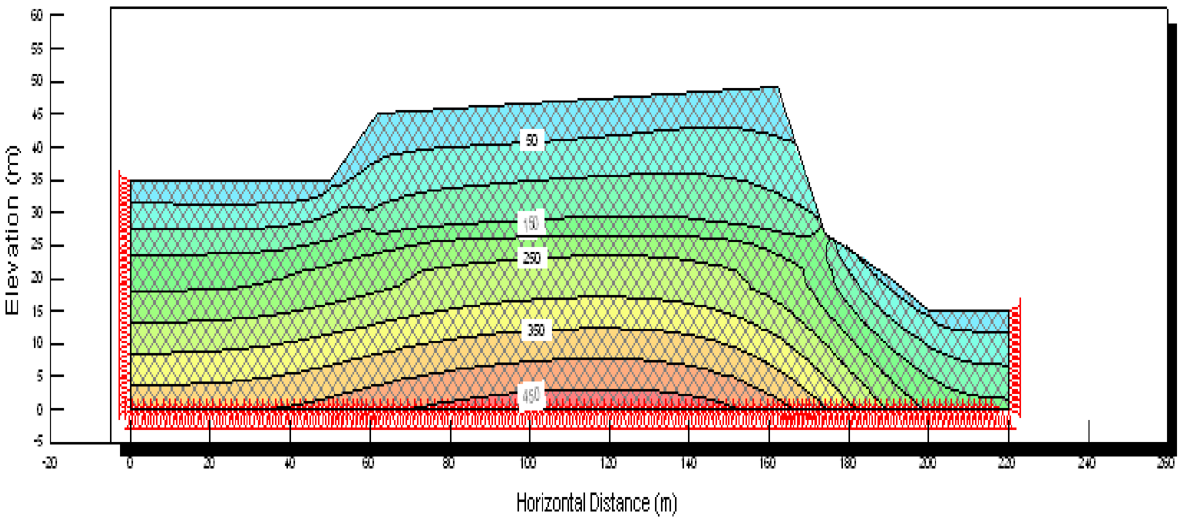


Figure 5.25: Effective vertical stress at different layers of the Dushanbe landfill

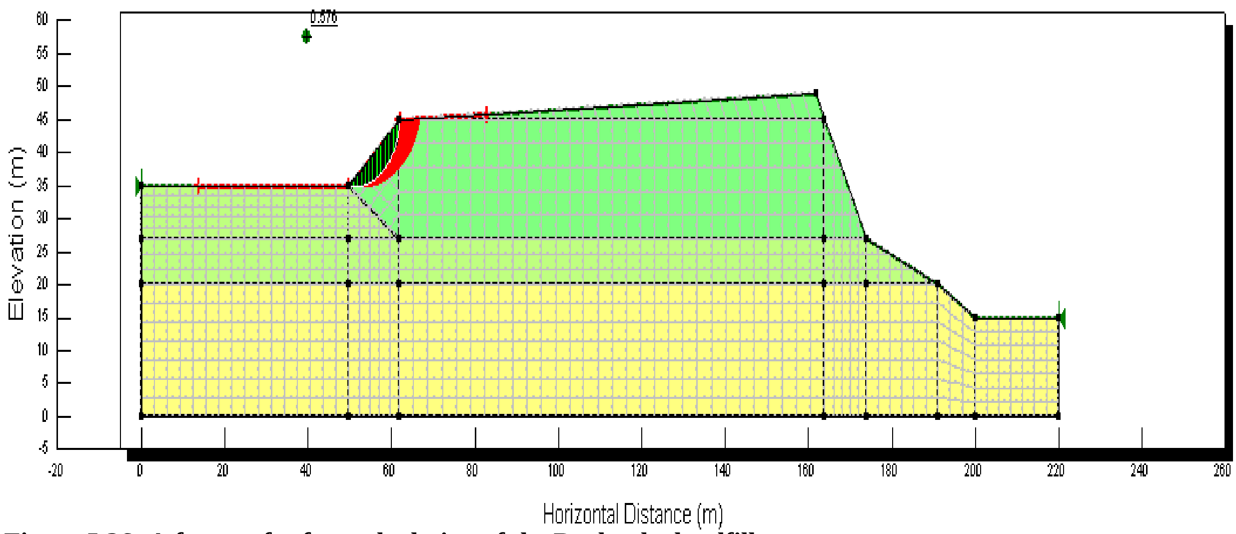


Figure 5.26: A factor of safety calculation of the Dushanbe landfill

5.3.5 Identification problems and possible impacts

Leachate

As the landfill is situated directly next to a river, there is a possibility of leachate seepiing directly into the surface water. Based on the results of the LSR tests and considering the average waste age, as well as dilution effects, leachate emissions might not cause severe environmental problems, as it seems likely that most of the leachate has already been washed out, essentially leaving the landfill in a relatively "dry" condition. To be absolutely sure that there is no risk from the leachate seepage, the leachate from deeper layers of the landfill could be analyzed, but in general the leachate hazard seems to be quite low.

Groundwater and soil

Groundwater could have been contaminated by substances washed out of the waste during disposal and subsequently as leachate after closure. The extent spreading of contaminants (leachate plume) is unknown i.e. the soil under the landfill body could be contaminated. Just 300 meters downhill to the south of the landfill there are some settlements (see Figure 5.27). Their use of groundwater as well as the groundwater flow direction is still not fully determined because the drilled boreholes did not reach groundwater level.

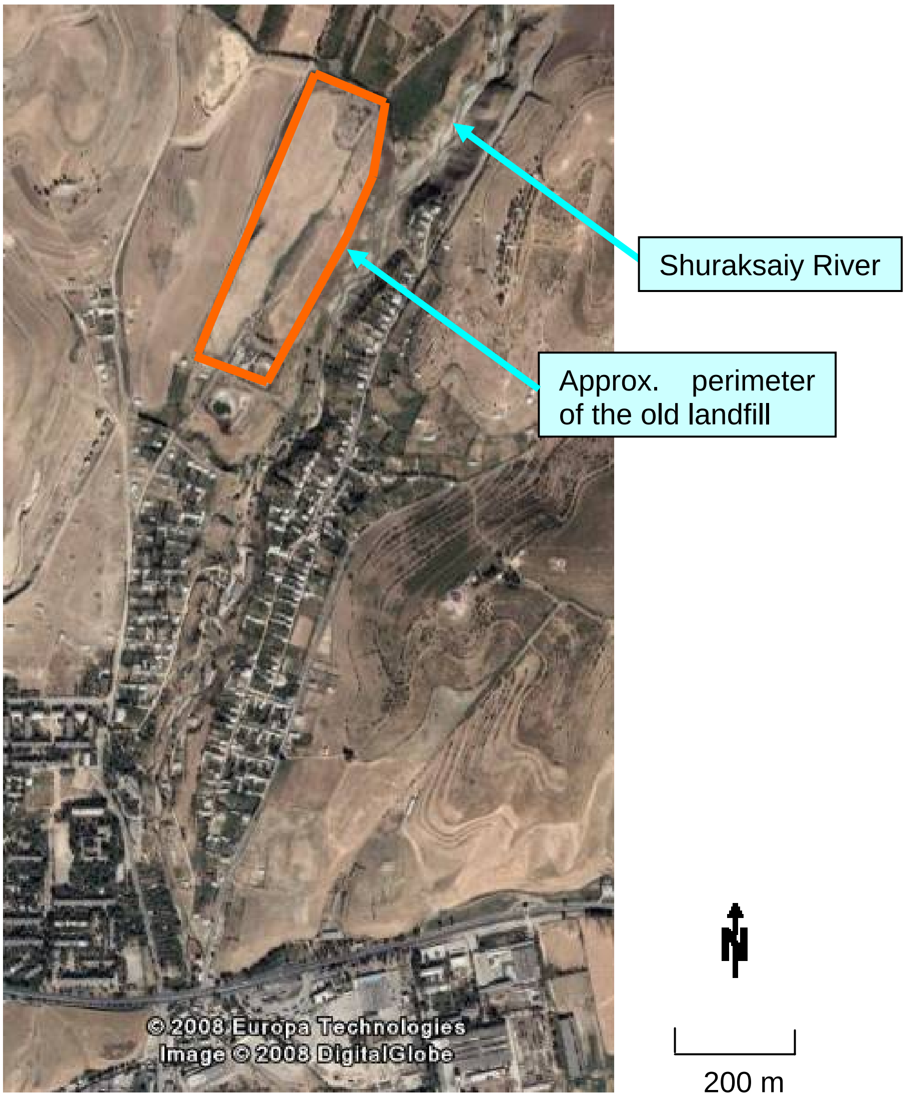


Figure 5.27: Satellite view of the landfill with settlements in the vicinity (Source: Google Earth, 2008)

Waste/landfill operation and management

The landfill is no longer operated and the top cover now supports pasture for cattle and is freely accessible. It could be said that the site is no longer mamaged as an old landfill, rather it apears to be unmonitored in all aspects e.g there is a leaking waterpipe running running lengthwiase across the surface and the tope cover isroded at some places clearly exposing decomposed waste-. Scavenges are excavate the riverside slope for any useable resources from the waste and the degraded material is locally used as a fertilizer.

Geotechnical/seismic hazards

The landfill site is located in the southern part Hissar valley in territory of so-called Adirs (hills) to the east of Dushanbe. This territory cosnists primarly of loess and has a hilly and smoothed relief and there are signs of highly active erosion and landslide processes. The site is situated in Central Tadjik depression and hosts seismically active structures including the Hissar-Kokshaly fault in the North and Ilak fault zones in the South. According to the seismic zone map of Tajikistan territory, Hissar- Kokshaly zone can experience earthquakes of magnitude 7.5 on Richter scale and on the zone of Ilak fault it can reach up to 6.5 Richter. The site is located in seismic active zone IX on MSK-64 scale.

There is a significant risk of collapse of the landfill riverslope during flooding and / or major earthquake. In case of flooding, the river can undercut the slope and the waste material can be exposed or washed out by river. This is worsened through excavation of the slope by people recovering plastic and other materials for recycling, fertilizer of fuel (Fig. 5.28). The excavation cavities are quickly enlarged after rainfall, accelerating erosion and subsequent instability of the slope. Erosion will be greatly accelerated through excavation of the slope and surface of the landfill as shown here at the upper edge of the slope facing the river.

A collapse of the river slope could then form a dam, temporarily blocking the river until the pressure of the restrained water causes a sudden collapse, which can be can have catastrophic results further downsteam depending on the size of the formed reservoir. Similar situations can occur in high alpine regions, known as a GLOF (Glacial Lake Outburst Flood).

Figure 5.28: Undercutting of slope and excavation by people and exposure of waste possibly through excavation and erosion at the top of the riverside slope

5.3.6 Specific Recommendations for the Old Dushanbe Landfill

Landfill operation and organization

The degraded material is used as a resource (fertilizer, fuel, re-use?) by anybody, as the site is easily accessible. The origin of the waste and its contamination level is not clear. There was and still is no separation of hazardous waste in Tajikistan, therefore parts of the waste could be highly hazardous. It is therefore not advisable to use the fine fraction of the waste as fertilizer or to handle it with bare hands. Especially the fine fraction usually contains the highest contamination. As the waste is heterogeneous, the analysis of randomly selected samples cannot guarantee that the material is safe and does not pose a hazard. The material would be most likely be used for growing edibles and the resulting oral intake could cause severe health hazards. The degraded waste material should not be used as fertilizer.

Leachate

To verify leachate pollution in deeper layers, samples should also be taken from there as well as from the foot of the slope at the river and analyzed. Measures to prevent leachate flowing into the river should be taken if necessary. If there is contaminated leachate, it should be collected in channel (drainage) between landfill and river and directed to a small pond which could be installed on the flat area just south of the landfill for aeration treatment. Recirculation of the leachate is not a recommendable option, as the landfill is already covered and utilized for agricultural pasture. The simplest option is a naturally aerated lagoon, which does not require additional installations and needs only a depth of a few tens of centimeters. More advanced are mechanically aerated systems and multiple basin systems, which are more effective. To plan a lagoon system for the landfill, more data are necessary to determine the necessity, size and kind of lagoon system.

Mitigation measures for geotechnical and seismic hazards

There were clearly some weaknesses in landfill construction such as low or no compaction, no proper placement of wastes and soil in layers, thin top cover etc. In such situations, there might be geotechnical hazards related to slope failures and localized subsidence of landfill in case of large earthquakes because it is located in a seismically active zone. As there is no base line of the landfill, there are greater chances of contamination to underlying soil and groundwater in case of foundation failures. Since the landfill site is adjacent to the river site, the slope of the landfill should be protected from the river. Considering the site conditions of the landfill and other aspects, following mitigation measures are recommended for geotechnical and seismic hazards.

Protection of river side slope

The slope of landfill should be protected from erosion and river undercutting. For this purpose construction of vegetated gabion walls or vegetative crib walls at the toe of the slope are recommended. The slope could be reinforced with geosynthetics and vegetation planted on the slope to reduce slope erosion and excavation. Various soil bioengineering techniques are shown in the Figures 5.29 – 5.33 from Florineth, 2004. These “soft-engineering” techniques are often good alternatives to conventional (and expensive) reinforced concrete for use in low income countries. Higher frequency of labor-intensive maintenance is generally required and it is possible these structures may not withstand extreme events, especially in the early years after construction before the plants have set deep roots.

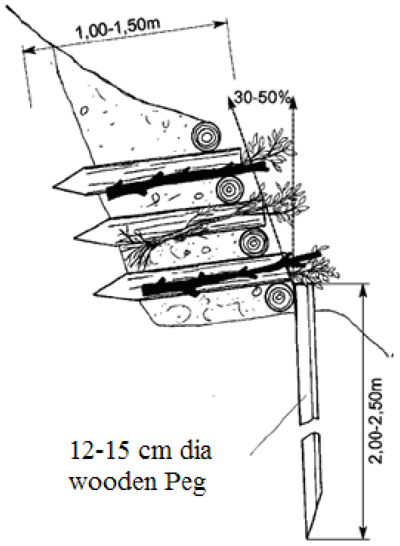


Figure 5.29: Typical section of a vegetated wooden log crib wall at the toe of the slope (Florineth, 2004)

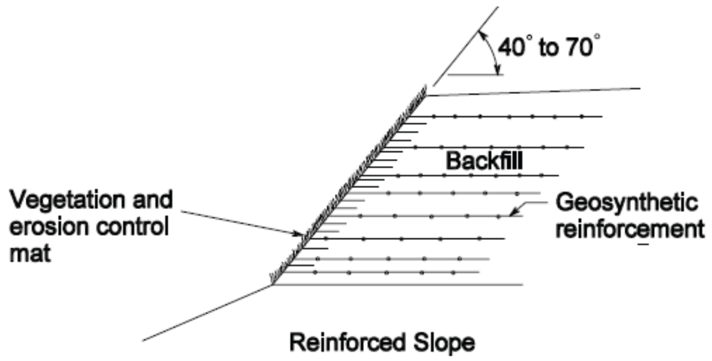


Figure 5.30: Reinforcement of slope using geosynthetics and slope protections with vegetations, typical example (source unknown)

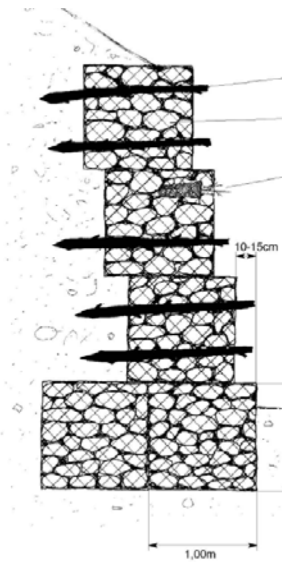


Figure 5.31: Typical example of vegetated gabion wall suitable for the use to prevent from river cutting (Florineth, 2004)

Vegetation in the form of brush layers will reduce the slope erosion and risk of slope failure.

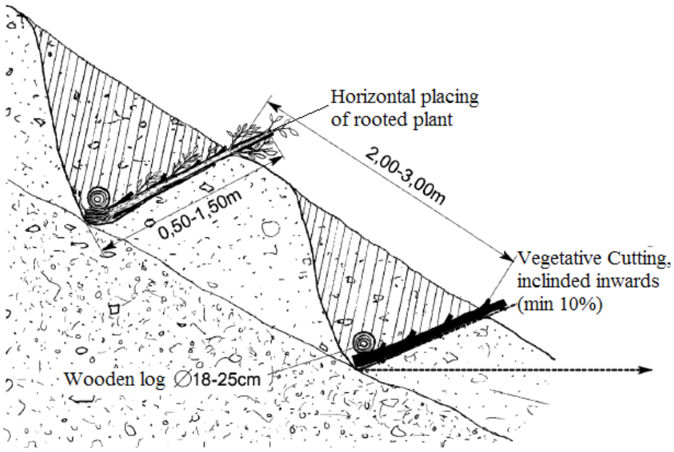


Figure 5.32: Typical example of brush layering/hedge brush layering to prevent slope erosion (Florineth, 2004)

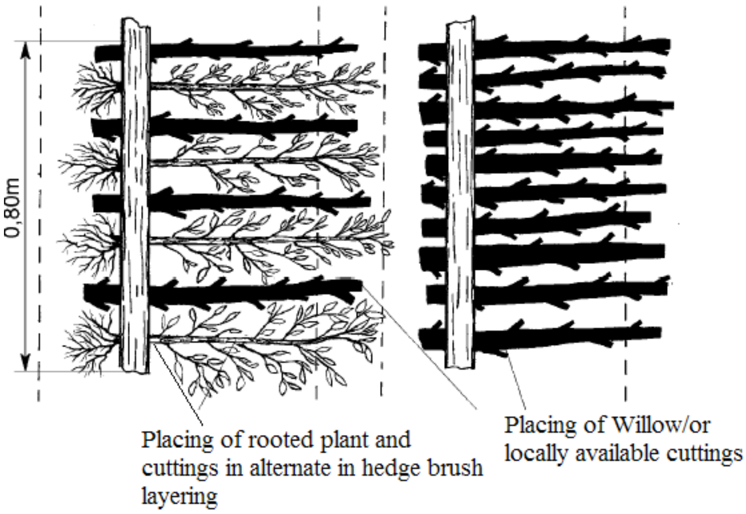


Figure 5.33: Example of hedge brush layering and brush layering (Florineth, 2004)

As mentioned, the suggested soil bioengineering techniques are low cost techniques and are particularly well suited for use in developing countries. For example, the following table shows a comparative cost of vegetative crib wall, gabions and stone masonry walls in Nepal. The best solution however would be, to fortify the slope toe against torrent erosion and subsequent undercutting, it is recommended to use stoned-filled gabions to a minimum height of 1.5 metres above the riverbed and to use bioengineering techniques for the rest of the slope.

Table 5.11: Comparative cost of vegetative crib wall, gabions and stone masonry walls in Nepal

Wall Type	Minimum width of wall required/used in practice in metres	Unit	Quantity	Rate in NRs	Total amount in NRs	Cost per running metre in NRs
Vegetated bamboo crib wall, 30.5 m long	1.2 m	m^3	54.90	450.20	24716.00	810.36
Stone masonry *(L=30.5, B= (0.5+0.9)/2, H=1.5)*	0.5m at top 0.6 H at bottom	m^3	32.02	1800.00	57636.00	1889.70
Gabion wall (30.5 m)	1 m	m^3	45.75	1200.00	54900.00	1800.00
Dry stone masonry *(L=30.5, B= (0.5+1.12)/2, H=1.5)*	0.5 m at top 0.75 H at bottom	m^3	36.45	800.00	29160.00	972.00
Cost saving per running metre (compared to gabion wall)						**989.63**

Note: 1 € = NRs 100 (Nepalese Rupees)

Placement of additional top cover and tree/bush plantation: The exposed surface area of the landfill should be covered by putting additional soil from the nearby area. Then, plantations of some trees or other suitable plants are recommended to avoid soil erosion and to protect from scavengers.

Monitoring

The analysis results of the leachate taken from the landfill from a depth of 3.5 meters did not show any significant contamination. The landfill is rather old and operation ended 1979. The concentrations of contaminants in the upper landfill layers should be very low due to wash out and degradation processes. Still there is a possibility the contaminants have reached the groundwater used by the population downstream. A consistent monitoring of the groundwater should be carried out to determine the actual contamination and take care of hazards to the environment and people due to a spreading of contaminants through the groundwater.

Lessons learnt for the new landfill

Overall, the new landfill is more suitably location because there is neither significant surface water (river) nor settlements nearby. However, as with most Central Asian landfills, there is no base liner and poor operational management i.e. freely accessible to scavengers, little/no separation / sorting, no monitoring of waste delivery or environmental conditions and no compaction equipment. Clearly, nothing can be done about the absence of a base liner and the a compaction machine is capital intensive investments, the costs can be offset by the increase in capacity (i.e. lifetime) of the landfill, as well as reduction of fires, which are highly hazardous and difficult to extinguish. Establishing landfill operational management and a monitoring programme (waste delivery downstream boreholes etc.) for the landfill is does not require large investments and can help identify and mitigate reduce hazards before becoming a long-term “hidden” problems.

Table 5.13 lists and prioritizes recommended measures and the problems which they address for the Old Dushanbe Landfill.

Table 5.12: Recommended remediation measures for the old Dushanbe landfill

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Prevent usage of waste from the landfill as fertilizer	Waste material is used as fertilizer	People are protected against the intake of hazardous substances	High	Immediately	Information material, personnel		low
Investigate whether there is leachate from the landfill flowing into the river	Leachate emersion from the landfill is unsure	Clarification whether leachate discharges into the river	High	Immediately			Low
Collect and analyze possible leachate emissions from the landfill	Leachate is possibly contaminated	Find out about hazard from possible leachate contamination	High	If there is leachate emitted from the landfill	Sampling devices, chemical analysis		low
In case there is a significant amount of contaminated leachate, collect leachate at the foot of the landfill and direct leachate to a leachate pond.	Possible leachate flow into the river	Prevent leachate flowing into the river	High	If there is contaminated leachate from the landfill	Collection channel, leachate pond	Building material, pipes	Middle
Investigate the hydrogeological conditions (aquifers, depth and thickness)	Groundwater situation unclear	Get knowledge about the groundwater situation	High	Immediately	Boreholes and wells	Misc.	middle
Install monitoring wells on each side of the Landfill for each aquifer and downstream in some distance	Groundwater contamination is not monitored	Monitoring, natural attenuation	High	immediately	Monitoring wells		middle
Implement monitoring Program (groundwater, surface water) and prepare hazard action plans	Emissions from the landfill are not monitored	Monitoring, natural attenuation	High	Immediately	Data storage (PC), Measuring equipment		Low to middle
Determine the use of groundwater by the settlers in the immediate	Settlers might use	Protect population from harmful substances	High	Immediately	Personnel		low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
vicinity	contaminated groundwater						
Determine the use of surface and groundwater by the settlers in the immediate vicinity	Settlers might use contaminated water	Protect population from harmful substances	High	Immediately	Personnel		low
Awareness creation to settlers as to why they should not excavate the landfill	Destabilization of riverside slope, avoiding health hazard	Reduce risk of slope failure and increased erosion. Reduce health risk	High	Immediately	Personnel, prepare basic information leaflet, local info event, Put up signs around site, especially where excavation is carried out.	Warning Signs	Low
Perform feasibility study for design of bioengineering measures on the riverside slope	Stabilization of the riverside slope, particularly against flooding	Reduce undercutting at the toe of the slope	High	Immediately	Personnel	To be determine d in feasibility study	Low
Replace eroded top soil cover at the head of the riverside slope and plant suitable stabilizing vegetation	Reduce erosion, reduce introduction of rainfall into landfill	Stabilize the slope, reduce leachate production	High	Immediately	Personnel,	soil, tree seedlings and their support/ protection	Low

5.4 *Krasnyi Stroitel Landfill, Bishkek Kyrgyzstan*

The Bishkek landfill is located 15 km north of the city at a former brickworks site, where loess was excavated for brick production at coordinates 42º57.4148’ N, 74º35.2642’ E and elevation ca. 577m (Fig. 5.34). The landfill is operated since 1974 and is surrounded by grassland. There is no technical barrier (base liner) between the waste and the loess subsurface. The prevailing loess shows a finer texture in comparison to the other NIS landfill sites, as it has been re-deposited as fluvial sediment and contains approx. 12 – 25% clay-sized particles. Due to the relatively high clay content a permeability of approximately 10^{-8} - 10^{-9} m/sec can be estimated.

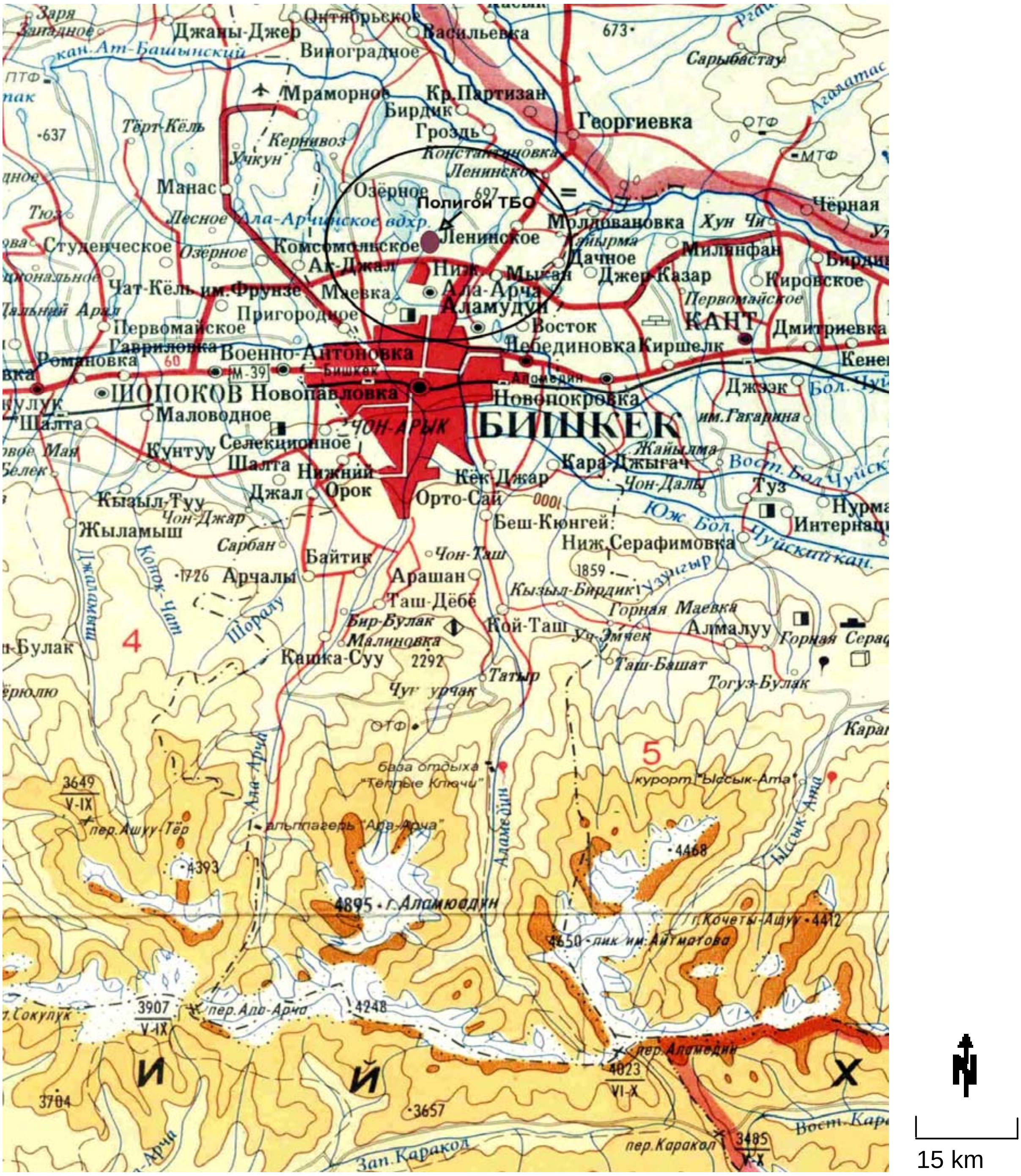


Figure 5.34: Location of Krasnyi Stroitel landfill (marked in oval) north of Bishkek city (Source: adapted from 1:200,000 Topographic map, Kyrgyz Geological Survey)

The deposited waste is typically unsorted household waste, construction and demolition waste as well as bulky waste. Organic waste content appears to be relatively low. Operational procedures include a mechanical weighbridge and two bulldozers used for slight compaction and surface shaping. A compactor on the site is in need of repair and/or new compaction rollers. There is no fencing around the site (i.e. it is freely accessible), however, only few people are scavenging at the landfill. A new landfill manager was employed in February 2006 and keenly pursued improvements in operational management and layout of the site. The manager closely cooperates with the Bishkek Municipal Administration.

One very significant characteristic of the landfill at the time of the investigations were the 5-6 meters wide and up to 8 meter deep trenches in the southern part of the landfill (Figure 5.35). These trenches are made to allow scavengers to search for valuable material (e.g. metals) inside the landfill body. The southern part of the landfill is the old part of the landfill. Due to the active burning of the waste material after disposal and the smoldering fires in the landfill body, the waste material in this area is slag like.

Figure 5.35: Trench in the old part of the landfill, depth approx. 6 meters

There are two leachate ponds at the Krasnyi Stroitel Landfill. No groundwater monitoring wells are installed, but there is one drinking water well about 2 kilometers south of the landfill and a river which is retained in winter and spring to an irrigation water reservoir is nearby in the north-east.

5.4.1 Waste characterization

The waste characterization investigations included:

- Excavation on different spots on the landfill
- Waste sampling
- Surface and groundwater sampling
- Waste sorting analysis
- Gas measurements

Two waste excavations including one sorting analysis were conducted and waste samples were taken from the top layers (3m) and out of the trenches and the temperature was measured. The excavated material in the upper layers was very dry and there was no odor. In the lower layers of the trench (5-8 meters) typical anaerobic waste material (black in color, H_2S & Ammonia smell) was excavated and the lowest layer (8 m) was water saturated. As the original groundwater table lies much deeper, a perched water table seems to exist at 7 - 8 meters depth. The results are displayed in Figure 5.36.

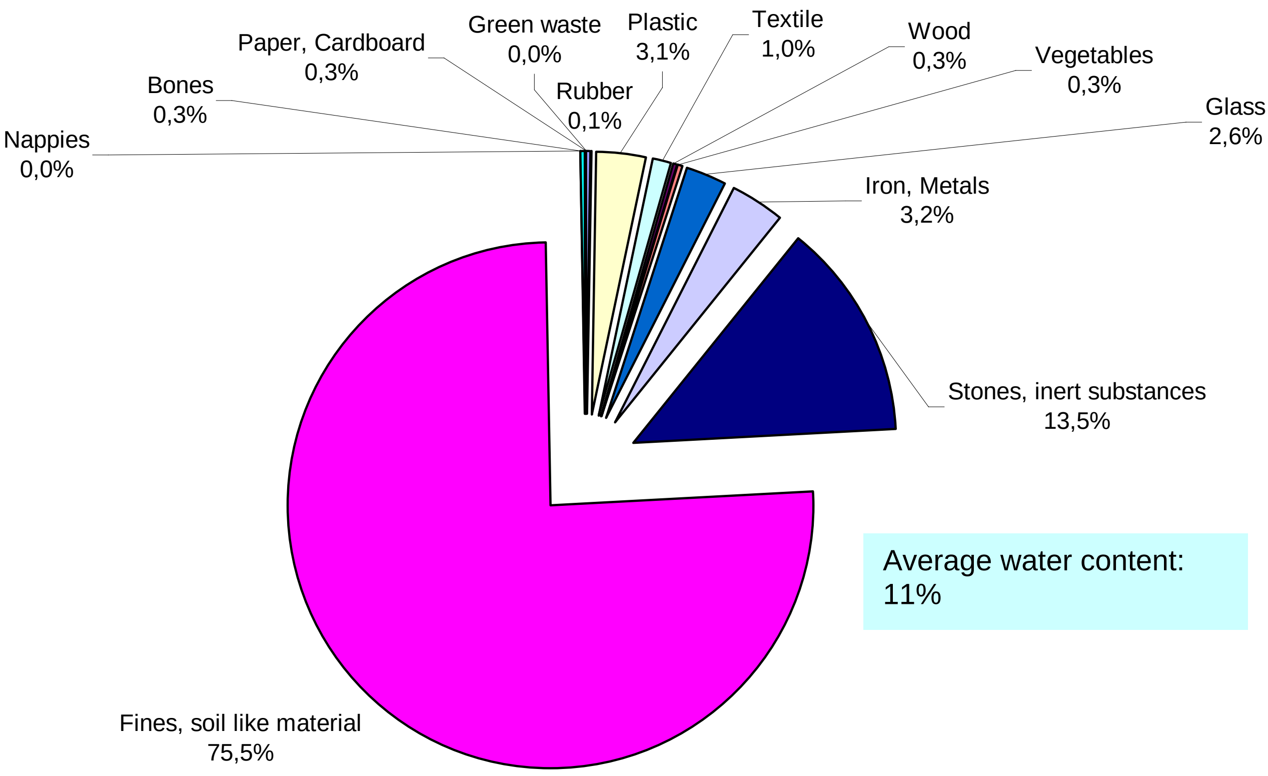


Figure 5.36: Waste sorting analysis of old waste sample, Bishkek landfill.

Water samples were taken from the two leachate ponds, the drinking water well about 2 kilometers south of the landfill and the river. The samples were analyzed *in situ* for temperature, pH and redox potential and stored in flasks for later laboratory analysis. The average measured contaminant concentrations are shown in Table 5.13.

Table 5.13: Concentrations of contaminants in the leachate (average of the measurements)

Location	Temp	pH	Cond.	BOD_5	DOC	AOX	NH4
	°C		mS/cm	mg/l	mg/l	µg/l	mg/l
Pond 1	°C	7,43	85,0	48146	24000	16,1	2376,0
Pond 2	°C	8,24	41,8	1010	1420	3,746	1166,0

Location	NO_3	NO_2	Cl	SO4	PO_4-P	HCO3	TKN
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Pond 1	0,0	0,0	25625,0	1538,0	10,0	23259,0	3355,0
Pond 2	0,0	0,0	9638,0	2946,0	3,0	9616	1446,0

Location	As	Hg	Pb	Cr	Ni	Zn	Cd	Cu	Mn	Fe
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Pond 1	0,108	0,0032	1,75	3,61	1,19	4,64	0,017	1,76	9,12	68,9
Pond 2	0,02	0,002	0,13	1,63	0,74	0,95	0,017	1,09	0,38	10,2

The landfill is divided into two parts to estimate the leachate emissions: The southern part with the old waste and the northern part with relatively fresh waste. The analysis results from leachate pond No. 1 are therefore used to determine the leachate quality of the new part of the landfill. The analysis results from leachate pond No. 2 are used for the leachate quality of the old part. The annual rainfall is 442 mm/a, but no evapotranspiration data was available. Leachate production was estimated to be 25% of the annual precipitation, which gives an annual leachate production of 1105 m^3/ha. Table 5.14 shows the respective values.

Table 5.14: Leachate production of the old and the new part of the Bishkek landfill

	Area	Leachate production
Old part	15 ha	16575 m^3/a
New part	13 ha	14365 m^3/a

With the portable gas analyzer (GA2000, Geotechnical Instruments), the FID (PORTAFID, Sewerin) and a portable digital thermometer gas and temperature measurements (see Table 5.16) were conducted in three areas: the Old landfill, uncovered waste in the “recent area” (age > 3 years) and the operation area. Only the measurements on top of the landfill were considered for the calculation, which came to a total hourly gas production of approx. 3600 m^3/h for the Year 2006.

Table 5.15: Results from the FID measurements in Kyrgyzstan

Parameter	Old landfill	> 3 years old	Operation area
Area (ha)	15	11	2
Methane (av.)	26 ppm	1410 ppm	1350 ppm
Number of Measurements	19	4	3
Max	210 ppm	5500 ppm	2800 ppm
Min	0 ppm	0 ppm	51 ppm
CH_4 prod (l/m^2h)	2.9	28	27
Landfill gas (LFG) (m^3/h)	76	2970	562

5.4.2 Geotechnical / Hydrogeological

A topographic survey of the landfill was carried out with a GPS during site visit. In addition to this, the following field and laboratory investigations were carried out:

- Drilling of boreholes d-250 mm with loess sampling
- Installation of observation wells for ground water monitoring
- Construction and installation of safety cylinders with lid and lock
- Cementing of the area around the observation wells and safety cylinders up to 0.5 m from the surface
- Construction of landfill plan and landfill cross-section
- Compression tests of soil by the two-curves method
- Shear test of soil
- Determination of physical properties, permeability, preconsolidation pressure and compression index of the soil samples.

Undisturbed loess samples from the boreholes were tested and analyzed to determine the physical properties, strength properties, deformation behavior, slump properties of loamy soils. Strength properties were determined by means of slow (sluggish) shear with previous compression (pre-compression) and water saturation at loadings P = 0.1, 0.2 and 0.3 MPa.

Slump properties and deformation behavior of loamy soils were determined on compression tests by the two-curve method. Compression tests were conducted at final loading 0.3 MPa. Pre-consolidation pressures of soils were determined. Compression indexes (coefficient) of soils were also determined in the laboratory. Table 5.17 presents summarized results on geotechnical and geophysical data from within and around the Bishkek landfill.

Topographical aspects

Bishkek is the only major city in Kyrgyzstan with an area of around 16,000 ha. Bishkek landfill is situated in the northern part of the Chu River valley, located on foothill plain at an elevation of 725 - 800 m above mean sea level. It is about 15 km away from the city at a former brickworks site where loess was excavated for the brick production. The landfill is in operation since 1974 and is surrounded by agricultural grasslands.

Chui River valley is limited from the south by Kyrgyz Mountain range. The highest point of this mountain range is located between origins of the rivers Ala-Archa and Alamedin and has the maximal elevation is 4855 m above mean sea level. The mountain range slopes are cut by numerous deep gorges with the Chui valley being limited in the north by Zailiyski Ala-Too, an outlier of the Kastek range. The valley extends towards northwest and passes through sandy plain area of Muiun-Kum on left-bank of Chu River and stony desert of Betpak-Dala on right-bank of Chu River.

Table 5.16: Summarized results on geotechnical and geophysical data in and around the Bishkek landfill

№	Data name, properties	Symbols	Unit	Actual value
1	General information			
	Subsoil water level	GWL	m	8 – 14 m below the surface
	Ground type – loam loess-like	pl – al Q_{III}		Proalluvial and alluvial
	Thickness of deposit	H	m	Up to 120 m
2	Geotechnical properties			
2.1.	Physical property			
	Soil / ground consistency	g	g/cm^3	2,70 – 2,72
	Natural density	g	g/cm^3	1,50 – 1,62
	Volumetric weight of ground skeleton	g	g/cm^3	1,41 – 1,50
	Porosity coefficient	E		0,83 – 0,92
	Permeability	k	m/sec	$(3,3 – 37,1)*10^{-8}$
2.2.	Granulometric composition			
	Sand particles (1 – 0,05 mm)		%	3,0 – 9,0
	Silt particles (0,05 – 0,002 mm)		%	65,0 – 70,0
	Clay particles (<0,002 mm)		%	10,0 – 20,0
2.3.	Moisture	w	%	9,0 – 13,0
	Liquid limit	w_L	%	26,5 – 27,7
	Plasticity limit	w_P	%	18,5 – 19,5
	Maximal molecula moisture capacity	w_m	%	14,0 – 25,0
2.4.	Soil compressibility			
	Compressibility coefficient in dry condition	C_c	kg/cm^2	< 0,06 (6 kPa)
	Compressibility coefficient in wetted condition		kg/cm^2	0,06 – 0,8
	Relative slump coefficient	I_e		0,01 – 0,17
2.5.	Shearing resistance			
	Angle of internal friction	Φ	degrees	21 – 27
	Cohesion	c	kPa	2 – 6
	Angle of internal friction	Φ	degrees	6 – 17
	Cohesion	c	kPa	1 – 2
3	Geophysical properties			
	Loam loess-like in natural condition	V_P	m/sec	350 – 800
	Water-saturated loam	V_P	m/sec	1500 – 1900
	Bedrock	V_P	m/sec	4500 – 5000 и более
	Waste	V_P	m/sec	n /a
	Transverse velocity			
	Loam loess-like in natural condition	V_S	m/sec	170 – 250
	Water-saturated loam	V_S	m/sec	170 – 250
	Waste	V_S	m/sec	N / a
	Peak ground acceleration	PGA	g	0,2 – 0,3

Geological aspects

Chui valley is an ancient valley filled with heavy overlaying strata with neogenic and Paleozoic formations. Paleozoic overburdens are found on the top surface which is made of grit stones with carbonate cement. These formations are interstratifying with dense argillite, which are left on the surface by Chu River at the north-east part of the landfill. The slope of deposits is abrupt (at an angle of 35°- 40°) inclined to southwest direction. The depth of these ancient deposits varies from 600m to 900 m below the surface. Figure 5.37 provides a regional overview with proximity to the irrigation reservoirs to the north, the right of which extends back close to the landfill (marked by a red arrow) upon filling. The location cross section between the two boreholes (1096 and 1097) running approximately north south is show in Figure 5.38.

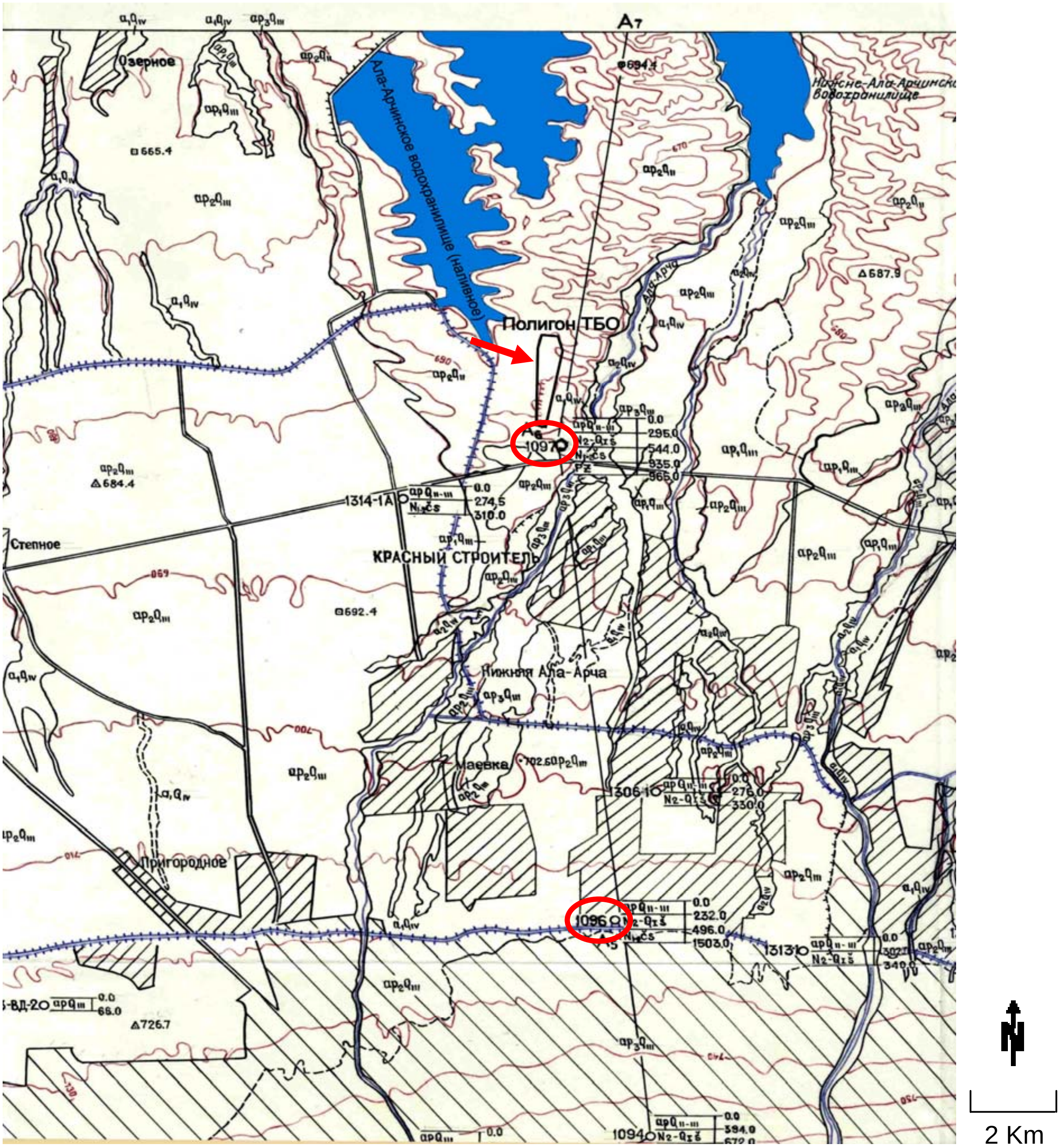


Figure 5.37: Regional overview of landfill (marked with red arrow) and existing deep boreholes (red ovals) area with cross section. Adapted from 1:25,000 map (Source: Kyrgyz Geological Survey, 1976)

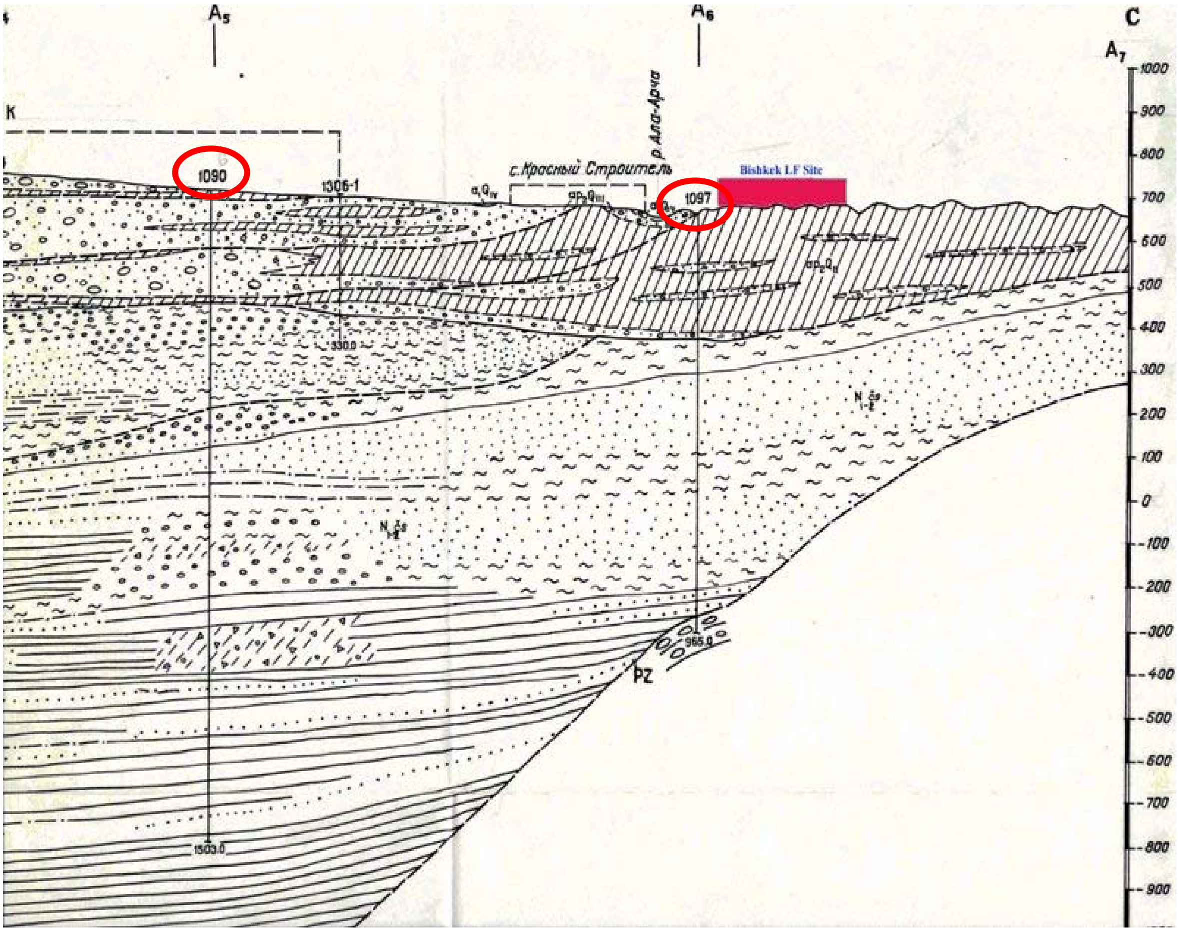


Figure 5.38: N-S Geological section of landfill area. The borehole on the left should be numbered 1096 and the one on the right is 1097. (Source: Kyrgyz Geological Survey, 1976).

The investigation area is situated within the limits of flat to slightly inclined proalluvial-alluvial plain as a continuation of the Kyrgyz Range. The low-lying relief is caused by alluvial deposits in late quaternary time resulting from uplifting of material from surrounding hills of Chui valley. Prolluvial-alluvial plain are formed by subsequent denudation, deposits and cuts on the surface by the present river networks. There are two genetic relief types in the investigation area: denudation sites, where accumulative processes have stopped at the moment and represent the most ancient formation made of accumulation surfaces (Q2III) and accumulative sites with prevalence of accumulative processes proceeding till now. The first type of watershed denudation surface is formed by prolluvial-alluvial deposits of early quaternary age. The second is an accumulation terrace of the Ala-Archa River.

Hydrogeological aspects

The landfill area is located in the Chui artesian basin, which hosts a very good aquifer system for Bishkek's potable, domestic, industrial and district heating water supplies. The city overlies a thick laterally heterogeneous fluvioglacial and alluvial multi-aquifer system that fines laterally northwards away from coarse clastic piedmont deposits into more stratified deep alluvial plain sediments. The coarse deposits forming the aquifers have high significant horizontal and vertical permeability and the urban wells abstract water from different depths. The landfill is located at an area showing a relatively high ground water table, thus possessing the risk of potential contamination due to infiltrating leachate. Near the landfill an artificial freshwater reservoir is situated which is of trans-boundary importance for irrigation

(Kazakhstan and Kyrgyzstan). The aquifer is however, naturally protected by the clay-rich loess loam of very low permeability.

Seismic aspects

Bishkek city is located on a fault formed by Chui valley and Kyrgyz Range. This area is located on the south of Tian-Shan seismic belt. In accordance to seismic zoning map of Kyrgyz Republic the landfill falls into the zone with possible earthquakes of magnitude ranging 6.5 – 7.0 on the Richter scale. The present formation of Chui valley is an accumulative result of powerful tectonic movements, epeirogenic uplifting, erosive and deposition processes. Chui depression represents a deflection of Paleozoic foundation, is deep buried under thick layers of mesa Neozoic deposits. The depth of Paleozoic deposits in landfill area is about 1 km, and in crest part of Kyrgyz Range Paleozoic rocks are lifted to a height of 3 km, i.e. the amplitude of movements exceeded 4 km. The vertical movements of the mountain range were accompanied by lowering the bottom of Chui valley. Annual average rate of immersing in the middle of the hollow to Neogene is about 0.3 – 0.4 mm.

The Chui valley, especially the south and southeast parts, is subject to earthquakes of destructive nature. The intensity of the first recorded earthquake in Belovodskoe village (to the west of the old landfill) in 1770 was about XIII (Destructive) to IX (Ruinous) on the Modified Mercalli (MM) scale. There was another large earthquake in 1865 in Merke village which had a magnitude of VII (Very Strong) to VIII on the MM scale. The “Yssyk-Ata“ fault which delineates the Chui valley from the foothills has a penetration depth of 25 - 30 km and it is about 100 km long is relatively close so the landfill is classified as being in a very seismically active area.

5.4.3 Geophysical site investigations

The geophysical site investigation was conducted by ENTPE with the help of local scientists from NCMRD during the last week of June 2007 to evaluate dynamic characteristics of waste and loess deposits, mainly the first fundamental resonance frequency and the seismic amplification.

Ambient noise (AN) measurements: the ambient noise technique was used to dynamically characterize the landfill site, i.e. to differentiate between the waste body and the underlying natural loess. Two digital seismic noise measurement systems from Micromed, Tromino TRS-019/01-06 and TRS-019/01-06, were used. Each digital tomograph consists of one portable 3 orthogonal high-resolution electrodynamic sensor and one integrated high resolution digital data acquisition and preprocessor.

The landfill was separated into two north-south oriented zones along a depression close to the middle of the site. Three measurement lines were established inside the landfill area totaling 16 points. Furthermore, 6 measurement points across 3 short measurement lines on natural loess outside the landfill area (Figure 5.39). The majority of the measurements points of all lines were simultaneously performed with two digital tomographs, separated by a distance of only 1m, to check the validity of the ambient noise measurements directly on waste, without any loess cover.

Figure 5.39: Ambient noise measurement lines (Source: Google Earth, 2007)

The main dynamic characteristics of the Bishkek landfill using the ambient noise technique can be summarized as follows:

Waste: On the waste, an average resonance frequency of about 0.91 Hz was identified on point P5 of line L1 and 1.25 Hz on point P8 of line L2. The amplitude of the spectral ratio ranging from 2.5 to 2.7 was found in the waste. An anisotropy effect was identified in the waste.

Loess: On loess situated in the immediate vicinity of the landfill, an average resonance frequency of about 1.0 Hz was identified on measurement point P17. The amplitude of the spectral ratio of 2.0 was found on loess. No anisotropy effect was found on loess.

The main dynamic characteristics of the operational Bishkek landfill using noise ambient technique can be summarized as follows : low impedance contrast between the waste and underlying loess layers, globally small spectral ratio peak, the 1D structure and nearly isotropic response of old waste, the heterogeneity and highly anisotropic response for the younger waste. The actual values are found in Table 5.18.

Table 5.18: Ambient noise site investigation results of Bishkek landfill

Material	f_0, Hz	AH/V (f0)	Frequency range, Hz	V_s, m/s
Waste	0.6 – 1.3	1.3 - 8.1	0.1 – 2.0	150 - 200
Loess	0.9 - 1.2	2.1 – 2.5	0.8 – 1.3	270 – 340

5.4.4 Dynamic Analysis of Bishkek Landfill

As for Dushanbe, the BOKU performed a dynamic analysis modeling of the Bishkek landfill using QUAKE/W. Figure 5.40 shows the horizontal acceleration at the history nodes i.e. at the time points of monitoring of the simulated seismic wave. The Figures 5.41 and 5.42 show the x-displacements and y-displacements of the Bishkek landfill and the figures 5.43 – 5.44 show a simulated the dynamic loading and the resulting horizontal and vertical displacements.

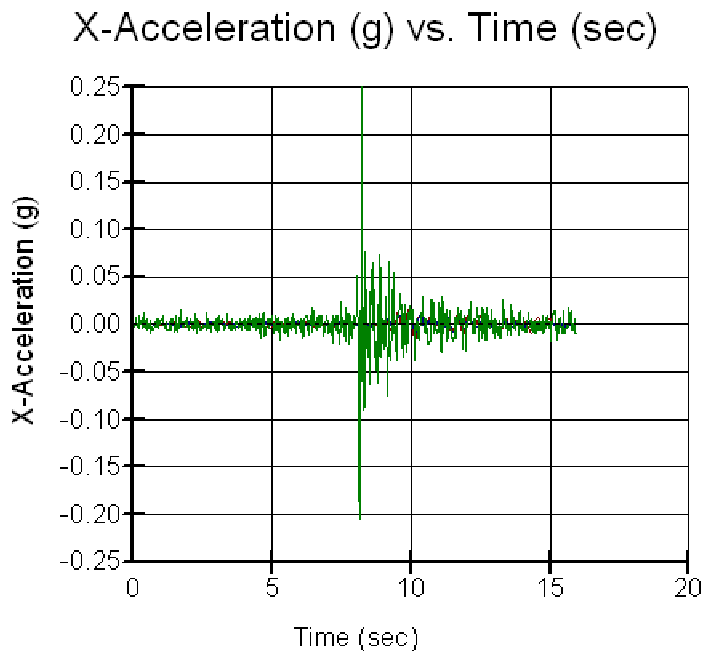


Figure 5.40: Absolute acceleration at the history nodes

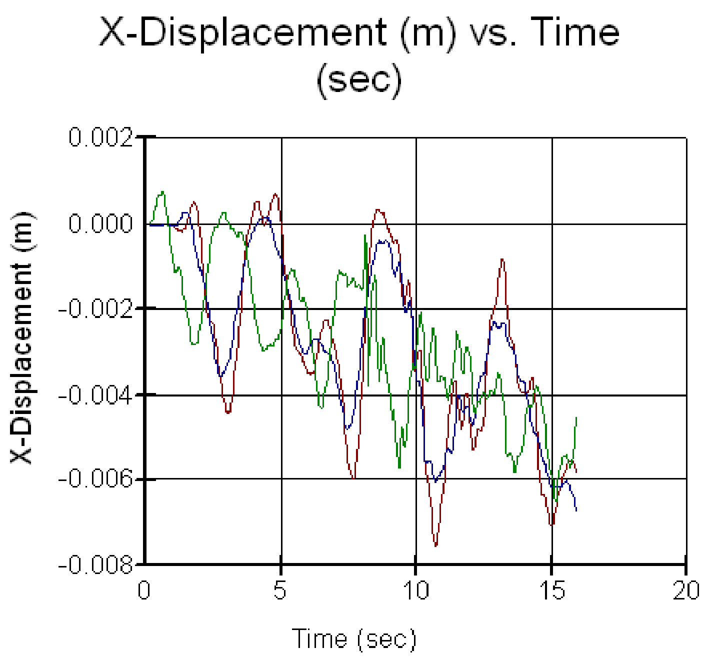


Figure 5.41: The displacement in x-direction of the Bishkek lanfill at the history nodes (red line top)

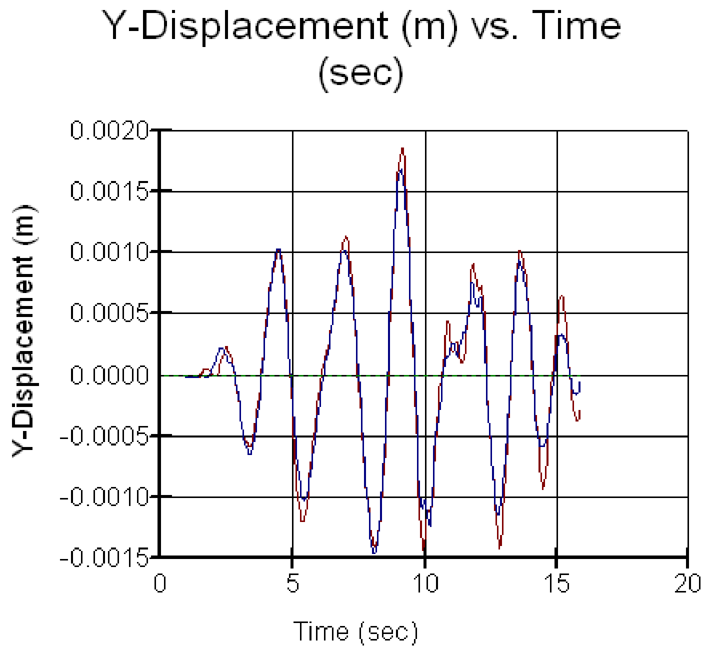


Figure 5.42: The displacement in y-direction of the Bishkek landfill at the history nodes (red line top)

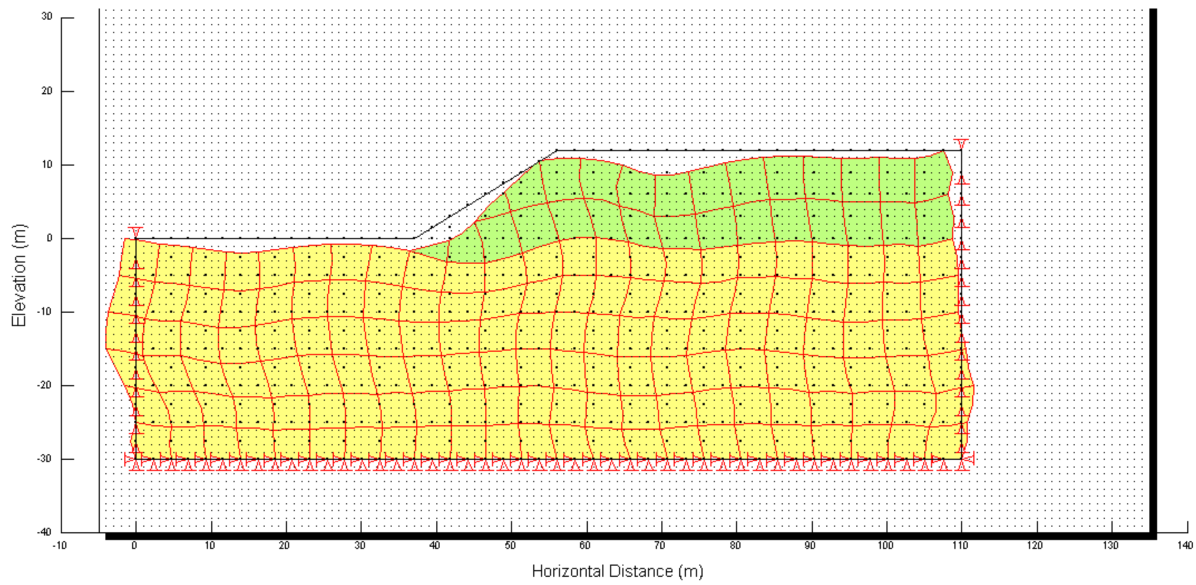


Figure 5.43: Deformations of the Bishkek landfill at the last time step

The maximum displacement in x-direction (horizontal) at the bottom of the landfill is about 1.8 cm. The maximum settlement of 1.7 cm occurred in the middle of the modeled landfill body. The deformation of the body of the landfill is shown in Figure 5.43 and the effective vertical stress distribution is shown in Figure 5.44.

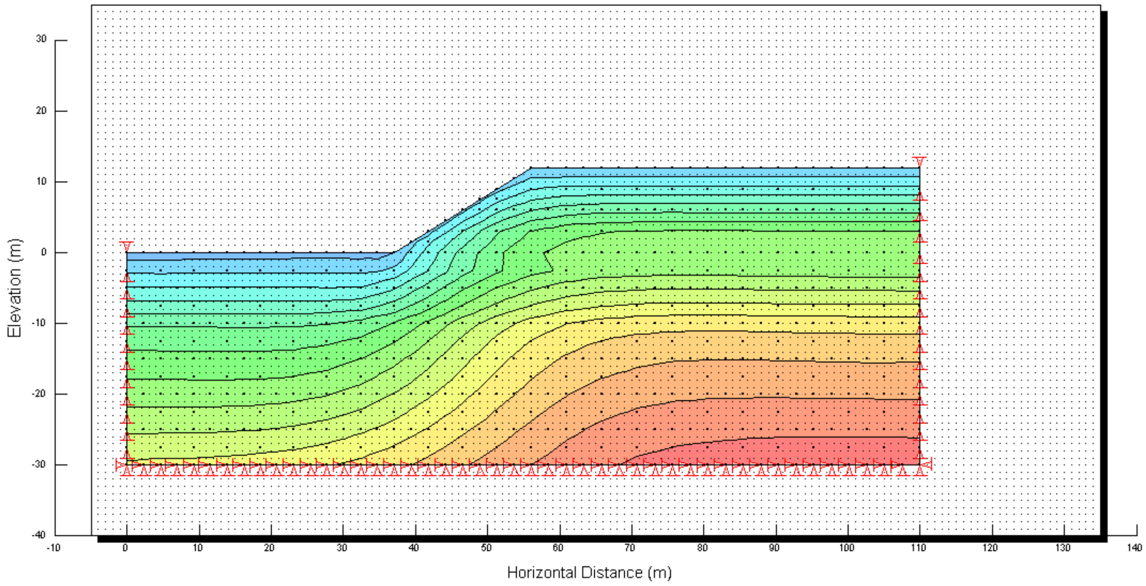


Figure 5.44: Effective vertical stress of the Bishkek landfill at the last time step

The numerical analysis can be used to determine amplification or attenuation characteristics of the soil and landfill layers by measuring the x-acceleration response at the top and bottom of each layer. Figures 5.45 and 5.46 show the acceleration amplitude for the top (red line) and the bottom (blue line) of the waste material and loess material respectively. It can be concluded from this simulation that the loess material attenuates the input motions whereas the waste material amplifies the input motions.

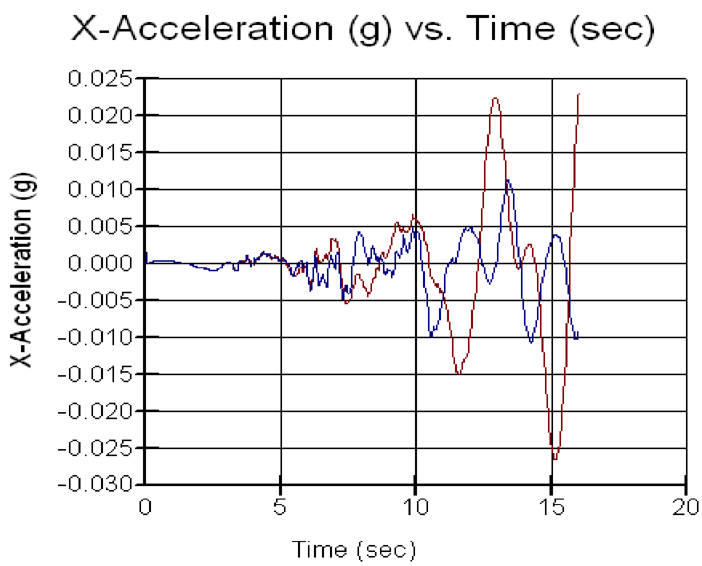


Figure 5.45: Acceleration histories at the top i.e. surface (red line) and at the bottom of the landfill (blue line)

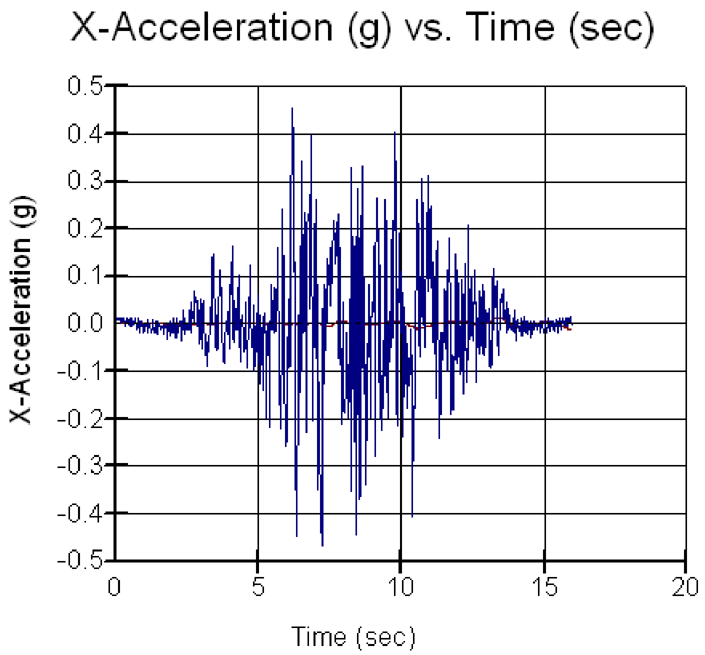


Figure 5.46: Acceleration histories at the top (red) and at the bottom of the loess deposit (blue line)

In support of the findings on amplification / attenuation characteristics described above, the following response spectra curves representing the energy content of the seismic wave and its response are described. Figure 5.47 shows the response spectra for the input acceleration (0.55g). The response spectra of the loess layer (Fig. 5.48) and waste layer (Fig. 5.49) show that the waste has a higher response (0.063g) than that the loess (0.044g). Althouhgh the input acceleration has been attenuated by both materials, but to a lesser extent by the loess. As the wave goes from the underlying loess into the waste, the wave engery has been amplified from 0.044g to 0.063g.

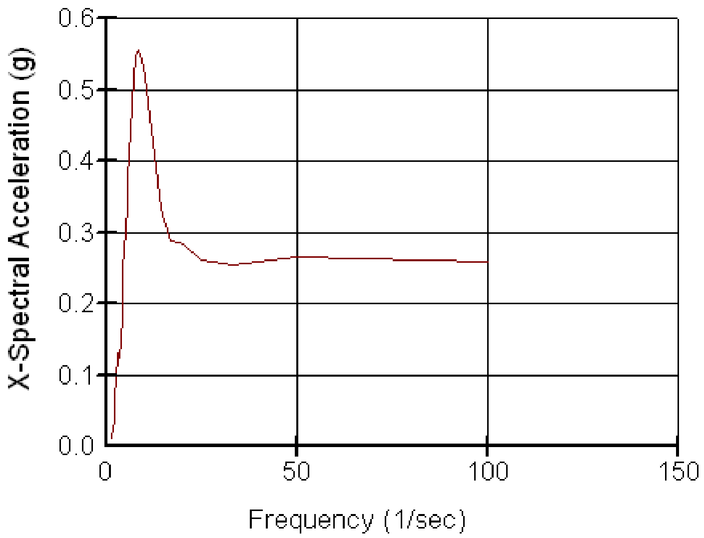


Figure 5.47: Response spectra of the input motion

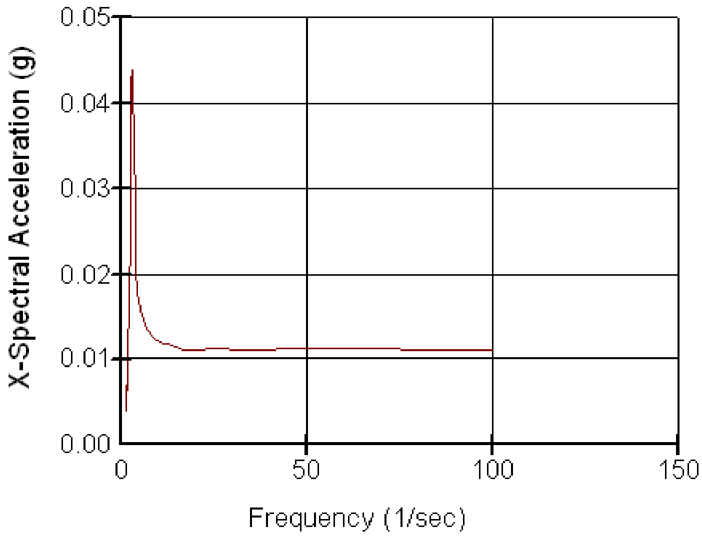


Figure 5.48: Response spectra of loess layer

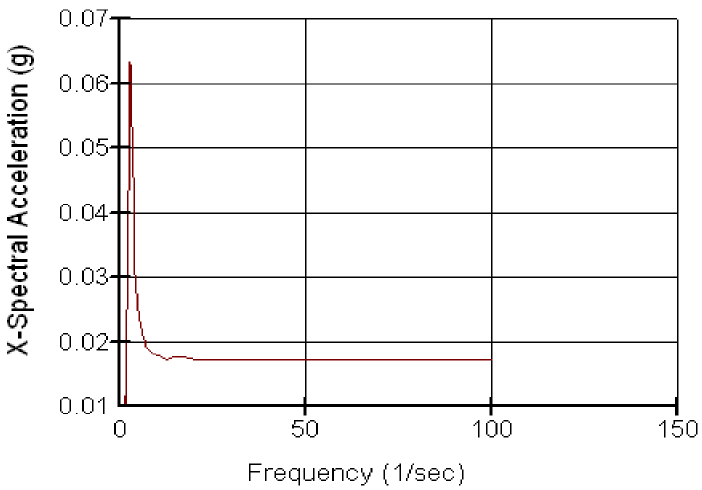


Figure 5.49: Response spectra of landfill layer

As decribed the response spectra of loess layer clearly shows that the higher frequencies of the input motions, above 15 Hz are nearly damped completely by the loess, which could be attributed to the low base frequency of the loess. In the combined result, the fill material has exerted an amplification of the motion of the loess material.

Although the Bishkek landfill shows that significant displacement would take place during an earthquake of medium to strong magnitude (e.g. 6 – 7 on the the Richter scale) and that the waste layer would amplifiy the accelerlation, there is still no real danger of collapse except for at the steep working face. A factor of safety analysis at for a seismic event correlating to 0.5 g showed that the landfill would not collapse. Furthermore, the landfill is constructed in an area of low relief and the associated vulnerability associated with seismicity is considered to be low.

5.4.5 Identification problems and possible impacts

Surface water

On the east side of the landfill in the immediate vicinity flows the Ala-Archa River, which is retained in winter and spring in an irrigation water reservoir in the north-east. Several samples were taken and analyzed from different spots of the river and from the reservoir. All samples comply with the German and WHO drinking water standards. They do not show any influence from the nearby landfill. Still there is a possibility of contamination of the river by the landfill's leachate, mainly during seasons with high precipitation. Also there are natural gullies at the east and at the northern end of the excavated area for the future waste deposition (Figure 5.50). It is likely that after strong precipitation or snow melt, the leachate can pass through the gullies and reach the reservoir. Precautions need to be taken to prevent the leachate flowing into the river through the gully.

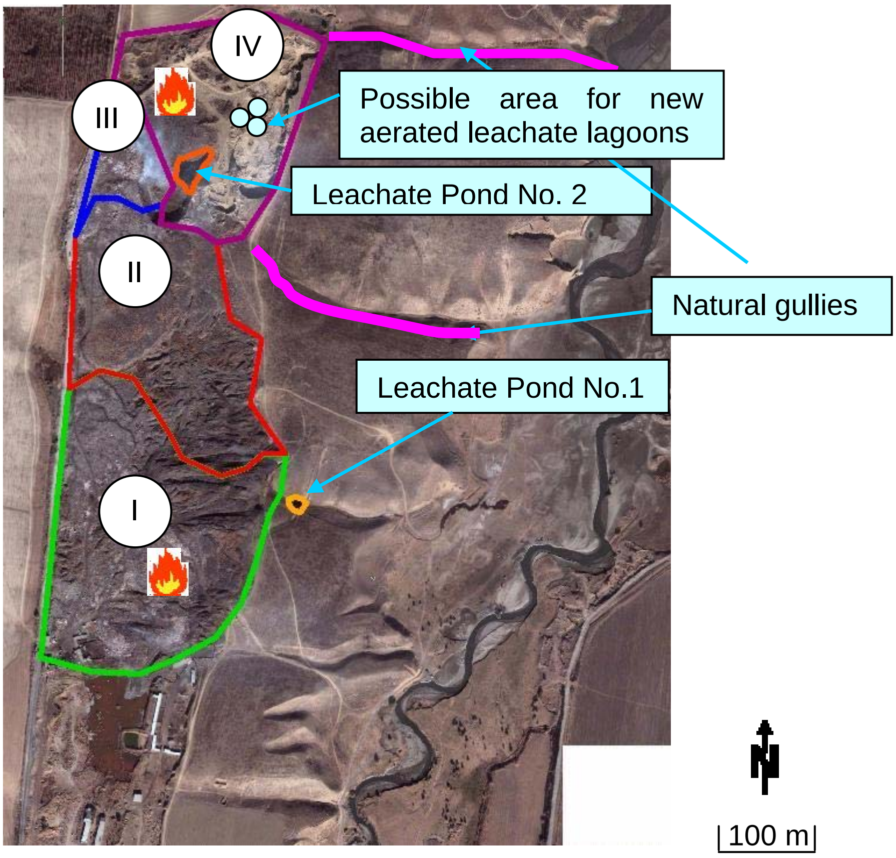


Figure 5.50: Satellite image of the landfill with the 4 different areas (I – IV) and the indication of fires, leachate ponds and natural gullies (Google Earth, 2007)

Leachate

Leachate is collected in two ponds each of approximately 1250 m^2 at time of field work. Earth retention embankments (made by loess material) were built to retain the leachate. The dam at the eastern leachate pond No.1 has collapsed. The accumulated leachate from here flows towards the river and accumulates in the dried riverbed. It is assumed that the water from the leachate evaporates during summer, leaving the contaminants in the soil. The contaminants are then washed out by the river and precipitation during wintertime. The leachate is strongly contaminated. The values for chloride, sulfate, BOD, COD Lead and Chromium exceed several times the maximum concentrations measured in the leachate of comparable German landfills in the 1980's (Table 5.19). A possible location for building new, lined (either concrete of with plastic liner) leachate aeration ponds is also shown in Fig. 5.50.

Table 5.19: Contaminant parameters exceeding maximum values of German Landfills in Bishkek taken from Leachate Pond No. 1.

Parameter	Exceeding by	Maximum Value
Chloride	2 to 5 times	25625 mg/l
Sulphate	3 to 7 times	1538 mg/l
BOD	2 to 87 times	48146 mg/l
DOC	15 times	24000 mg/l
Lead	1.7 times	1.75 mg/l
Chromium	1 to 2 times	3.61 mg/l

The leachate also contains high concentrations of heavy metals. It is therefore highly contaminated and poses a hazard to the river, soil and groundwater. For a detailed analysis of the possible hazards, further investigations are necessary.

Groundwater

The vertical hydraulic conductivity (permeability) of approx. 10^{-8} - 10^{-9} m/s of the loess under the landfill is very low. The groundwater was not reached with the 30 m borehole put down with the site investigation and the available maps and profiles (Kyrgyz Geological Survey, 1976) show that the artesian groundwater is approximately 200 – 250 m below the surface, although with a piezometric surface estimated to be only 20 – 30 m below the suface. In this case, the surface water is at much higher contamination risk from uncontrolled runoff of leachate than the groundwater.

Landfill Fires

The landfill is burning in parts where fresh waste was deposited and intentionally lit. These fires usually extinguish when the combustible materials are completely incinerated. Subsurface fires occur through self incineration of the waste material. These fires mostly appear at the slopes at the working face, as relatively fresh waste and availability of oxygen are necessary for the process. The locations of deep seated fires are marked in Figure 5. with the fire symbol. The waste material (plastics, paper, organics) is combusted imperfectly due to missing oxygen underground and too low temperatures, which might cause the formation of dioxins and carbon monoxide (CO). People working on the landfill or nearby and residents are affected by the toxic substances in the air. Especially the workers on the landfill, who are sometimes sleeping on the ground, are exposed to high CO values, dioxins and odorous smoke.

Settlements

People have recently built houses and have settled deliberately next to the western border of the landfill erroneously assuming that the landfill gas extraction project, initiated by the Danish Environmental Protection Agency (DEPA), will provide the cheap energy. The status of the people's fresh water supply is unknown. If they are using the groundwater in the vicinity of the landfill, they might be accessing a contaminated perched groundwater table. Further investigations about the groundwater tables and the flow direction are necessary. The settlers are also exposed to the possible landfill gas migration, which might cause explosions. Another hazard to the health might be caused by smoke from landfill fires.

Landfill gas emissions

Landfill gas is emitted to the atmosphere from the younger parts of the landfill. It can be estimated, that the average composition of the gas is 50 to 60% methane (CH_4) and 40 to 50% carbon dioxide (CO_2). As the global warming potential of methane in the atmosphere is 21 (based on a theoretical retention time of 100 years), a manifold of this volume in terms of CO_2-equivalents is emitted to the atmosphere. It is therefore necessary to capture and treat the methane in order to protect the climate.

The investigations showed that the gas emissions of area I and area II (as shown in figure above) are comparably low due to past subsurface fires, which have combusted the deposited waste material to a large extent. However, at least in the deeper waste layers residual LFG production occurs. Considering the whole landfill, the main source for landfill gas emissions is identified with area III. Here fresh waste is deposited, occupying an area of approx. 2 ha. For the future gas emissions the excavated area north of the landfill (approx 11 ha) should be taken into account. If this area is filled it might cause major landfill gas emissions. A gas extraction system could be installed during the filling of this landfill section.

Waste/landfill operation and management

The area of the Krasnyi Stroitel landfill which is covered by waste is approximately 28 ha. Most of the area is not actively used for the waste disposal. There is one major tipping area in area III. But waste is sometimes also deposited in area I. These areas are also characterised by burning waste material and strong smoke. There is no organized plan of waste disposal. Waste is unloaded on these areas where it fits. The waste is transported to the place of disposal on the site by the incoming waste transportation vehicles and unloaded on the landfill. Bulldozers exist to distribute the waste. Most of the waste is moved to the edge of the disposal area and pushed down a high and steep disposal face. The waste material is not compacted at all.

There is a weigh bridge at the entrance, so the weight of the delivered waste is controlled. Still it is unclear, whether there are active recordings of the delivered waste material. Other inspection of the waste is not taking place. The kind of waste is not controlled, so basically any kind of waste can enter the landfill. Scavengers are working on the landfill, recovering recyclables (plastic, bottles, metals) from freshly delivered waste as well as from the older already disposed waste. The workers are not protected at all sorting the waste bare handed. In the old part of the landfill there are 5-6 meter wide and up to 8 meter deep trenches. They were dug with bulldozers to enable the scavengers to reclaim more materials even from the deeper parts of the landfill.

The landfill is freely accessible, so anybody can enter the landfill. Pigs are brought to the landfill to feed them with the organics in the freshly delivered waste. The landfill is burning at the slopes of the disposal face and other areas where waste is disposed. Surface fires are set deliberately to reduce the waste volume. Dark black smoke emerges from these fires into the air (Figure 5.51). The waste material is usually uncovered.

Figure 5.51: Intentional burning of freshly disposed waste

5.4.6 Specific Recommendations for the Krasnyi Stroitel Landfill

The main problems of the Krasnyi Stroitel (Bishkek) Landfill are the emission of leachate into the environment, the extensive fires, the hazards due to seismic activities and emissions of greenhouse gases. Except the latter these problems pose a direct risk to the people working on the landfill, the environment and settlements in the vicinity and consequential the flora and fauna, the agriculture and the residents in the surrounding. A comprehensive collection of possible measures to improve the situations on landfills is presented. These options are more or less applicable for the Krasnyi Stroitel Landfill. Several simple and cost effective solutions can be applied to improve the situation on the landfill. Others mentioned here will need additional and maybe external funding but are essential for a modern landfill management.

Landfill operation and organization

The waste is tipped at steep faces with heights up to 20 meters, hence a large surface area is exposed to ambient air and the compaction of the waste is very low. This permits the air to enter the landfill easily and creates the basis for the fires. The disposed waste is not compacted. The available machinery on the landfill basically only distributes the waste and it is not suitable for compaction, hence the compaction effect is rather low.

It is therefore recommended to stop the tipping at the steep faces and disposal should only take place at specific times within defined open areas. Other areas should not be operated during that time and temporarily covered. After a certain height (approx. 2m) has been reached, the area should be changed to another location. Existing slopes should be flattened to minimize the impact of collapse during an eventual seismic event. These measures can be implemented immediately and do not need additional funding.

Very important to prevent new fires is the compaction of the waste during the disposal. Compaction equipment is needed for this purpose and sheepsfoot roller compactors are usually used to compact the waste on landfills. This kind of machine is essential for the controlled operation of a landfill. The waste is disposed in layers of 0.3 to 0.5 m and compacted afterwards by rolling over the layer several times. As it is not available at the Krasnyi Stroitel landfill, a sheepsfoot rollers compactor should be set on the investment list with very high priority. In general the equipment of the Krasnyi Stroitel landfill is not sufficient for the controlled operation and the infrastructure does not meet the necessary standards.

The volume, origin and type of the delivered waste should be controlled and recorded at the entrance of the landfill. The actual type of waste in the transport vehicles should also be controlled during the disposal on the field. Pre-sorting areas as previously described could help to separate special wastes. The place of the disposal of all of the registered waste should be recorded in a landfill register, which is divided into a grid squares. The disposal should be planned according to that register.

The landfill is freely accessible and it is recommended to control the access to the landfill and only allow authorized people. Personnel should be informed about safety regulations and instructions of the landfill management. This is advisable for their own safety and to prevent fire hazards and unwanted material on the landfill. The landfill area is about 28 ha. and fencing of the landfill will be quite costly to construct and maintain. Also building material might be stolen and the fence therewith destroyed. Still a fence is a very good measure to control the access to the landfill. Security personnel should be employed to guard the landfill and fences and to expel unauthorized people and to report fresh fires and other safety-relevant events, as well as to guard technical equipment. Special garment or ID-cards could be developed and introduced for the identification of the workers and other staff on the landfill.

Leachate

The landfill leachate accumulates in two ponds. Leachate pond No. 1 in the east of the landfill which was constructed to retain the leachate is neither fortified, sealed nor intact. The retaining dam has collapsed and the leachate flows and disperses in the gully and accumulates in the riverbed. The earth retention embankments (made by loess material) must be restored and fortified immediately to prevent more leachate from leaving the pond in an uncontrolled way. A liner, e.g. plastic foil should be installed to prevent leachate dispersing. The size of the existing leachate pond has to be verified and enlarged if necessary. The second pond (Pond No. 2) is situated in the area which is planned for future disposal of waste material. Here also loess embankments were constructed to prevent the leachate dispersing on the area. This pond again is neither fortified nor sealed. As the pond is situated in the future disposal area a fortification of the pond next to the progressing waste body does not seem to be reasonable. Rather a planning of a fixed area on the site for the accumulation and treatment of the leachate should be carried out. The leachate should be directed to this area by channels or pipes.

The disposal area should be sealed with a base liner and a leachate drainage system should be installed. As this measure is quite cost intensive, it is difficult to implement. The collected leachate needs to be treated or recirculated by pumping or transporting the leachate back onto the landfill. Recirculation of the leachate is in this case a recommendable option. A pump could be installed in the leachate pond and the fluid could be pumped through hoses onto the landfill or a tank vehicle with an implemented spraying unit could be used. The leachate should be pumped out of the leachate pond and transported to the location on the landfill for the application. The spraying should be conducted only if people are not on-site e.g. in the evening. If possible it is the best to close off the sprayed area to prevent people accessing the area. Spraying could then also be conducted in the morning time to allow more water to evaporate. Direct human contact with leachate must be avoided.

The treatment of the leachate is also possible in aerated lagoons. As mentioned above, an area for leachate treatment fortified basins with a base liner, working as an aerated lagoon could be developed. As a calculation of the amount of leachate reaching the ponds is not possible, the volume of leachate needs to be verified by monitoring. With this knowledge the aerated lagoon can be planned. The simplest option is a naturally aerated lagoon. It does not need additional installations, but the depth should not exceed a few 10 centimeters. More advanced are mechanically aerated systems and multiple basin systems, which are more effective. To plan a lagoon system for the Krasnyi Stroitel landfill, more data are necessary to determine the size and kind of lagoon system. A recommended location is found in Fig 5.50.

Landfill gas emissions

To prevent the greenhouse gas emissions discharging into the atmosphere it is necessary to collect and treat the gas. This is usually done with vertical gas wells, because they can be installed in an existing landfill. The gas is flared or utilized for energy production. The installation of this system needs some investment for gas wells, collection pipes and a flaring / utilization unit. It is however possible in Kyrgyzstan to start a so-called “Clean Development Program” (CDM) project under the scope of the Kyoto Protocol. This enables developing countries to reduce their emission of carbon dioxide into the atmosphere and receive “carbon credits” in exchange.

A pilot landfill gas capturing and utilization project has been initiated at the Krasnyi Stroitel (Bishkek) landfill by the Danish Environmental Protection Agency (DEPA) in cooperation with company AAEN A/S of Denmark in 2006. The vertical wells, a pump station and flare have been installed and test pumping for volume, methane and oxygen content carried out. The Final Report suggests that the test results were positive and an Emission Reduction Purchase Agreement (ERPA) was suggested which should then be completed with a business plan to construct a full scale gas capturing and utilization plant.

However, the full scale plant seems not to have been implemented. Our investigation showed that the Krasnyi Stroitel landfill consists of areas of various suitabilty for the gas extraction and utilization. As the southern part (Part I, 15 ha) has been subjected to severe subsurface fires the remaining gas production potential tends to be very moderate and originates only from the very deep waste layers. Gas quantities are expected to be lower than demanded for regular flaring, i.e. only temporarily operation might be possible. The northern parts of the landfill are more suitable as the waste material is younger. The suitability of the respective areas needs to be verified in any case.

Residential Settlements

There are residential settlements directly next to the landfill site. The inhabitants are exposed to the hazardous smoke, gas and odor of the landfill. The houses were illegally built and should be relocated, as there is a severe health hazard to the residents. In general the area 500m around the landfill should be clear from settlements. A plan for the resettlement of the people should be elaborated.

Mitigation measures for geotechnical and seismic hazards

Since the landfill site is located in relatively flat terrain, the risk of foundation failure of the landfill due to earthquake is low. But because of low density of waste and existing slope angle there is high risk of localized slope failures of the landfill deposits in case of large earthquakes, although the result of the dynamic analysis of the landfill showed that it will not fail at the existing conditions and with less magnitude earthquakes. Because of the location of the landfill in seismic active zone, there exists a geotechnical hazard related to slope failures and subsidence of landfills in case of large earthquakes. As there is no liner at the base of landfill, there are greater chances of contamination to underground soil and groundwater in case of foundation failures. Considering the site conditions of the landfill and other aspects, following mitigation measures are recommended for geotechnical and seismic hazards:

- Reduce the slope angle of the landfill deposits by shifting the toe of slope outwards or top inwards.
- Increase the density of waste materials by improving the compaction or increasing the thickness of soil layers
- Place the wastes in layers with adequate side and top covers.

Monitoring

The site investigations showed that the hydraulic conductivity of the soil is low, but the groundwater situation is only partially understood and there are settlements in the immediate vicinity. Groundwater, surface water and air quality should be analyzed on a regular basis. For this purpose the installation of facilities like monitoring wells and the purchase of appropriate sampling and storing equipment might be necessary. Detailed and accurate recordings of the conducted works as well as additional data (climate conditions, time etc.) and the execution by educated personnel are made. Records of the monitoring results are kept, updated and evaluated to ensure immediate actions in case of hazards determined. Groundwater wells should be installed around the landfill. The number and depths of aquifers needs to be verified and wells to each aquifer need to be installed on each side of the landfill. The groundwater flow direction has to be determined. And at least one groundwater well in the groundwater table should be installed also downstream in a further distance to observe the spreading of contaminants. A sampling and analysis of the groundwater, as well as the river and reservoir needs to be conducted on a regular basis. Also the impairment of the vicinity due to the strong air pollution needs to be monitored.

Table 5.20 summarizes and prioritizes the recommended remediation measures.

Table 5.20: Recommended remedial measures for the Krasnyi Stroitel landfill

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Employ security personnel	uncontrolled access	restrict access to landfill	very high	immediately	personnel, uniform		low
Special garment or ID-cards for workers	uncontrolled access	restrict access to landfill	very high	immediately	ID-cards, uniform		low
Protective clothing for workers	staff security	protect workers from harmful substances	very high	immediately	safety gloves, safety shoes protective clothing, gas masks		low
Implementation of a pre-sorting area on the landfill	people on the landfill, waste control	keep people from the landfill, better waste control, hazardous waste, inflammable waste and other different kinds of waste could be sorted out and disposed / treated separately.	high	immediately	existing bulldozers can be used		very low
Stop the disposal at the steep disposal face	landfill fires, low compaction	prevent fires if waste is disposed in prepared areas and compacted.	very high	immediately	no		no

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Define disposal area with a maximum height of 2 m, change location after reaching the height, cover and do not operate other areas during that time	landfill fires, low compaction	prevent fires if waste is disposed in prepared areas and compacted.	very high	immediately	no	soil for temporary cover	low
Avoid steep slopes	landfill fires, low compaction	prevent oxygen entering the landfill	very high	immediately	no	no	no
Flatten existing slopes	landfill fires, seismic hazards	prevent oxygen entering the landfill, reduce hazard of collapse	high	immediately	no	no	no
Purchase a Sheepsfoot rollers compactor	landfill fires, low compaction	prevent landfill fires by preventing oxygen entering the landfill, reduce hazard of collapse	very high	funding needed	Sheepsfoot rollers compactors	no	high
Compact waste in layers of 0.3 to 0.5 m with Sheepsfoot rollers compactors	landfill fires, low compaction	prevent fires, better compaction	high	after purchasing a compactor	Sheepsfoot rollers compactors	no	no
Flatten, compact and cover existing slopes	landfill fires, low compaction	prevent landfill fires by preventing oxygen entering the landfill, reduce hazard of collapse	very high	after purchasing a compactor	Sheepsfoot rollers compactors	soil	low
Control and record waste at the entrance	waste control	spot unwanted and hazardous waste material, separate treatment disposal	high	immediately	personnel		low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Control accepted waste at the location of disposal	waste control	spot unwanted and hazardous waste material, separate treatment disposal	high	immediately	personnel	no	low
Record volume, the origin and the kind of the delivered waste	waste control	organization of landfill	high	immediately	personnel	personal computer, software	low
Implement a landfill register, which is divided into a grid squares. The place of the disposal of all of the registered waste should be recorded here. The disposal should be planned according to that register.	organization of the landfill	organization of landfill	high	immediately	personnel	personal computer, software	low
Develop organizational and safety instructions, conduct trainings for the personnel conducted to ensure a safe and controlled disposal.	organization of the landfill	Safety for workers, controlled landfilling	high	immediately	personnel		low
Prohibit smoking or deliberate burning on the landfill	organization of the landfill	Avoid surface fires	high	immediately			no
Cover burning areas with clay or clay like material	landfill fires	confine and extinguish landfill fires	high	immediately		clay	middle
Restore loess retention dam	Leachate flows and disperses in the gully and drains away	collect leachate	very high	immediately		soil	low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Fortify dam and install a liner (e.g. plastic sheet)	Leachate flows and disperses in the gully and drains away	collect leachate	high	immediately	building material	concrete, cement, plastic sheet	low
Plan a fixed area for the leachate collection	Leachate collection	Collect leachate	high	immediately	Personnel		Low
Recirculation of the leachate with a pump and hose	Leachate treatment	treat leachate	high	immediately	pump, hose		low
Recirculation of the leachate with a tank vehicle	Leachate treatment	treat leachate	high	after purchasing a tank vehicle and build an access road	tank vehicle		middle
Install leachate collection ponds and transportation pipes or channels	Leachate is not collected	Collect leachate	High	Immediately	Building material	Pipes, concrete, cement, foil, etc.	
Install passively aerated lagoon	Leachate is not treated	Treat leachate	high	After determination of Leachate volume	Building material, pump, hose	Concrete, cement, tubes etc.	middle to high
Install a base liner and leachate collection system for the future disposal area	Leachate drains into the ground	Collect leachate	High	After planning and acquiring funds	Leachate collection system	Misc.	high
Make sure, that no leachate is leaving the landfill area and flows into the river. Possibly install dams	Leachate might flow through the gullies into the river after strong precipitation	Avoid contamination of the river by leachate	Middle	Immediately	Building material	Misc.	low

Measure	Problems addressed	Effect	Priority	When is the implementation possible	Equipment / Investment needed	Material needed	Costs
Install gas collection and flaring / utilization unit	Gas discharges into the atmosphere	Treat gas, prevent greenhouse gas emissions	High	After finding funding, e.g. CDM project	Gas extraction system, flare / gas engine	Misc.	low to high depending on funding
Install gas collection and treatment system for future disposal area	Gas discharges into the atmosphere	Treat gas, prevent greenhouse gas emissions	High	After planning and acquiring funds	Gas collection system	Misc.	high
Investigate the hydrogeological conditions (aquifers, depth and thickness)	Groundwater situation unclear	Get knowledge about the groundwater situation	High	Immediately	Boreholes and wells	Misc.	middle
Install monitoring wells on each side of the Landfill for each aquifer and downstream in some distance	Groundwater contamination is not monitored	Monitoring, natural attenuation	High	immediately	Monitoring wells		middle
Implement monitoring Program (groundwater, surface water, air) and prepare hazard action plans	Emissions from the landfill are not monitored	Monitoring, natural attenuation	High	Immediately	Data storage (PC), Measuring equipment		Low to middle
Educate staff about hazards and proper behavior on the landfill	Awareness of hazards	Create awareness	High	Immediately	Education material		Low
Relocate illegally build houses next to the landfill	Settlers are exposed to toxic gas, smoke and odor	Protect population from harmful substances	High	Municipality needs to make a relocation plan.			

6. Concluding recommendations

The four landfills in Central Asia investigated for emission potential and seismic risk during the three-year NISMIST research project funded under the FP6 INCO Programme (Contract No. 516732) formed the basis of this dissertation. All investigated sites are municipal solid waste landfills, but as no real waste separation takes place, all other kinds of waste are also disposed on the sites. Although the overall situation of the landfills in the five Central Asian countries seems to be quite similar, the investigated sites differ in the age, size, but also operational advancement. The old Dushanbe landfill in Tajikistan is already closed and covered, while the others are still in operation. The Kazakh “Karasai” landfill and the Kyrgyz “Krasnyi Stroitel” landfill are having quite similar conditions as they both face the same problems of uncontrolled waste disposal, low compaction, extensive deep seated fires, uncontrolled gas and leachate emissions and uncontrolled access as well as unprotected workers and scavengers on the site. Most of the Central Asian landfills in operation seem to be similar to these landfills. The Uzbek “Ahangaranskaya” landfill takes an outstanding position in Central Asia, as a significant foreign investment into equipment and waste processing units was made there and the operation of the landfill is better organized. Still, there are deep seated fires (even if they are less), uncontrolled gas and leachate emissions and unprotected workers and scavengers. Also all landfills have in common that they have no base liner, no leachate collection and no gas collection system.

6.1 Georisks associated with landfills

From the lessons learnt from past earthquakes, modern solid waste landfills have generally shown a good ability to withstand strong earthquakes without damages to human health and the environment. Experience has shown that well-built waste landfills can withstand moderate peak accelerations up to at least 0.2g (~ 4 - 5 Richter scale) with no harmful effects. To deepen understanding about the impact and hazards deriving from these landfills in question, each site was subject to its own specifically designed investigation program. Boreholes were drilled, soil samples were taken and geotechnical tests were carried out, and groundwater levels determined where groundwater was reached (wells for monitoring were also installed). Waste, leachate, groundwater, surface water and landfill gas were sampled and chemically and biologically analyzed and the landfill and the surrounding were investigated with various geophysical techniques. Using the numerical analysis, stability analyzes of Bishkek and Dushanbe landfills during the earthquake of an equivalent magnitude of 0.5g (~ 6 – 7 Richter scale) were carried out. An extensive dataset was established for each site from existing material and site investigations, which was interpreted to identify problems and potential hazards.

Typical open dump landfill problems are contaminated soil, groundwater, surface water and air pollution as well as the emission of greenhouse gases and health risks to the people working on the landfill or living in the vicinity, to the flora and fauna or to the world’s climate. The investigated landfills are no exception. The added factor of seismic risk is usually rather low, but the numerical analysis resulted in a factor of safety 0.58 in case of Dushanbe, which means that the Dushanbe landfill slope will fail completely. From these results, it can be concluded that (for other landfills also) in case of large earthquake having a magnitude exceeding 7 in Richter scale, there is a high risk of collapse of landfill. In case of a large earthquake, the municipal solid waste landfills could fail in any of the following ways:

- Sliding or shear distortion of landfill or foundation or both
- Landfill consolidation and subsidence
- Transverse and longitudinal cracks of cover soils

- Cracking of the landfill slopes
- Disruption of the landfill by major fault movement in foundation
- Differential tectonic ground movements
- Liquefaction of landfill or foundation
- Failure additonally induced by flooding and / or erosion

The collapse of the landfill's slopes could bury workers and scavengers, destroy buildings and machinery. In the case of the Old Landfill in Dushanbe, a large portion of waste material could slide into the adjacent river causing pollution as well as flooding. The river would likely be temporarily blocked, which leads to the next hazard of a flash flood and widespread distribution of the waste material when the temporary dam collapses. Furthermore, the deposited waste and accumulated leachate will be exposed at the slip surface upon collapse and will be further dispersed through rain into river

From the geotechnical results, it could be concluded that the loess-loam subsoil (although with its regional differences) relevant to the risks under consideration, can be treated as sufficiently similar to be characterized by a single set of design values. These design values may be input to any geomechanical or geohydraulic risk analysis concerning possible earthquake-triggered collapse as well as pollutant transport in the subsurface. This conclusion is brought about by the facts that the thickness of the loess-loam deposits is such that underlying gravel or rock strata are not relevant to the problem of geotechnical failure, however groundwater contamination, although not observed, cannot be excluded altogether. The major factor affecting soil (and soil-like material i.e. decomposed, compacted waste) is water content i.e. water saturated horizons (perched groundwater), could be subject to sudden pore water overpressure in case of an earthquake, which could induce liquefaction and subsequent collapse.

The set of design values and/or ranges was developed for the relevant geomechanical parameters to consider when selecting a new landfill site or the risk associated with an existing landfill (Table 6.1). Furthermore, a set of geophysical design values was also established (Table 6.2) for this purpose. As stated, these are guideline values only and require peer-reviewed scientific verification before being used in practice.

Table 6.1: Landfill geotechnical design values

No.	Parameter	Sym-bol	Unit	Design value	Range
2.1.	Physical property				
	Specific gravity	G		2,7	2,70 – 2,72
	Natural density	ρ	g/cm³	1,55	1,50 – 1,62
	Volumetric weight of ground skeleton	$ѳ_s$	g/cm³	0,35	0,0 – 1,0
	Porosity coefficient	n		0,9	0,83 – 0,92
	Filtration coefficient (conductivity)	k	m/sec	$1*10^{-7}$	$(3,3 – 37,1)*10^{-8}$
2.2.	Granulometric composition				
	Sand (1 – 0,05 mm)		%	-	3,0 – 9,0
	Silt (0,05 – 0,002 mm)		%	-	65,0 – 70,0
	Clay (<0,002 mm)		%	-	10,0 – 20,0
2.3.	Water content				
	Natural	w	%	12	9,0 – 13,0
	Liquid limit	w_L	%	27	26,5 – 27,7
	Plasticity limit	w_P	%	19	18,5 – 19,5
	Maximum moisture capacity	w_m	%	25	14,0 – 25,0

2.4.	Soil compressibility				
	Compressibility coeff. – dry	C_c	kg/cm²	0,05	< 0,06 (6 kPa)
	Compressibility coeff. – saturated		kg/cm²	0,80	0,06 – 0,8
	Relative slump coefficient	I_e		-	0,01 – 0,17
2.5.	Shear strength				
2.5.1	Natural state				
	Angle of internal friction	φ	deg.	23	21 – 27
	Cohesion	c	kPa	5	2 – 6
2.5.2	Water saturation condition				
	Angle of internal friction	Φ	deg.	10	6 – 17
	Cohesion	c	kPa	1	1 – 2

Table 6.2: Geophysical design values

Vp: compression wave velocity, Vs: shear wave velocity, ρ: electrical resistivity

No.	Title of soils and their characteristics	Vp (m/s)	Vs (m/s)	ρ (Ωm)
1	Waste a) unsaturated b) saturated	 277 – 333 314 – 357	 105 – 222 166 – 250	 3 – 15 1 – 3
2	Loess-loam a) dry b) moist c) water saturated d) under the waste body e) consolidated f) with gruss (intercalations)	 312 – 682 122 – 294 1800 – 1818 364 – 630 769 – 1000 1500 – 2857	 200 – 382 89 – 180 235 – 266 222 – 364 - 267 – 382	 40 – 150 15 – 20 5 – 12 7 – 10 15 – 20 14 – 18
3	Gravel–pebble (with loamy filler) a) unsaturated b) saturated	 - 1410 – 2000	 - 303 – 348	 28 – 45 18 – 32
4	Rock	4500 – 5000	-	-

6.2 Mitigating environmental risks through improved landfill operation and management

6.2.1 Landfill fires

The biggest hazard on the landfill is the deep seated fires and the resulting toxic substances, gases and particles in the air to which the workers are exposed and significantly harm the environment. Two different approaches are possible to protect these people. The first is to keep the people off the landfill and allow only those workers on the landfill who are essential for the landfill operation. It is necessary to protect the people working on the site e.g. with protective clothing and gas masks as long as there is the strong formation of smoke gas due to the fires. A possibility to keep the scavengers off the landfill is to shift the location of recovering i.e. a separate collection point for recyclables and pre-treatment of the waste as it is done in developed countries. This demands a highly developed waste management system which is not yet available in Central Asia. A simpler possibility is the implementation of a pre-sorting area on the landfill territory, where the waste is deposited temporarily. The recyclable material can be recovered there before the waste is relocated to the landfill for long term disposal. This is accompanied by another advantage: The delivered waste can be controlled much better and hazardous waste, inflammable waste and other different kinds of waste could be sorted out and disposed / treated separately.

The second approach is to extinguish or confine the existing fires and to prevent new fires. Several options exist to prevent new fires by changing the landfill operation and organization. The basis for the landfill fires is the supply of oxygen. By preventing the ambient air to enter into the landfill body spontaneous ignition and the generation of deep seated fires can be prevented. The waste is often disposed uncontrolled at steep, loosely tipped slopes with heights between 5 to more than 20 meters. Hence a large surface area of waste is exposed to ambient air and the compaction of the waste is very low. This permits the air to enter the landfill easily and creates the conditions for the fires.

6.2.2 Waste compaction

The disposed waste is not compacted. Most sites are poorly equipped with suitable compaction machinery hence the compaction effect is rather low. It is therefore highly recommended to stop the disposal at the steep disposal face immediately. Disposal areas should be clearly defined and the open area limited. The disposal during a certain period should only take place at that area. Other areas should not be operated during that time and covered temporarily. After a certain height (approx. 2m) has been reached, the operation area should be changed to another location. Steep slopes and disposal faces need to be avoided. Existing slopes should be flattened. This also minimizes the hazard due to seismic impacts. These measures can be implemented immediately and do not need additional funding. Very important to prevent new fires is the compaction of the waste during the disposal. Compaction equipment is needed for this purpose. Sheepsfoot rollers are usually used to compact the waste on landfills. This kind of machine is essential for the controlled operation of a landfill. The waste is disposed in layers of 0.3 to 0.5 m and compacted afterwards by rolling over the layer several times. As it is not available at the Karasai landfill a tamping sheepsfoot rollers should be set on the investment list with very high priority. Also the existing slopes of the landfill should be compacted and covered to prevent oxygen to enter the landfill body. This can also confine the existing fires.

6.2.3 Waste delivery recording

The volume, the origin and the kind of the delivered waste should be controlled and recorded at the entrance of the landfill. The actual kind of waste in the transport vehicles should also be controlled during the disposal on the field. Pre-sorting areas as described before could help to separate special wastes. The place of the disposal of all of the registered waste should be recorded in a landfill register, which is divided into a grid squares. The disposal should be planned according to that register. Filling sections should be planned in general. Desirable would be the installation of an operation log. If possible this could also be done with a PC, but a daily data backup is absolutely essential. It should be updated daily and contain the following entries:

- Data about the accepted waste (kind, volume and origin)
- Results of the waste control
- Serious incidents, including disruptions, causes and solutions
- Construction and maintenance measures
- Monitoring results
- Planning of filling sections
- Volume and kind of waste disposed per filling section
- Meteorological data (precipitation, wind, etc.)

6.2.4 Access restriction

The landfill is freely accessible to everybody. It is recommendable to control the access to the landfill and only allow authorized people. They should be informed about safety regulations and instructions of the landfill management. This is advisable for their own safety and to prevent fire hazards and unwanted material on the landfill. Fencing of landfills can be quite costly to build and maintain. Also building material might be stolen and the fence therewith destroyed. Still a fence is a very good measure to control the access to the landfill. Therefore a security-team should be employed to guard the fences and the landfill and to expel unauthorized people. The guards should also report fresh fires and other safety-relevant events and guard the technical equipment. Special garment or ID-cards could be developed and introduced for the identification of the workers and other staff on the landfill.

6.2.5 Leachate control

The leachate of the landfill accumulates wherever it seepage allows it, although some site made attempts to control leachate, this was generally not successful. Fortified and sealed leachate ponds should be installed and the leachate should be directed to the ponds by channels or pipes. The size, number and the locations of possibly leachate ponds have to be determined by identifying and monitoring the preferred emission points. The treatment of the leachate is also possible in aerated lagoons. As a calculation of the amount of leachate reaching the ponds is not possible the volume of leachate needs to be verified by monitoring. With this knowledge the aerated lagoon can be planned. The simplest option is a naturally aerated lagoon. It does not need additional installations, but the depth should not exceed a few 10 centimeters.

6.2.6 Landfill Gas

The landfill site investigated did not have any gas collection system at present, with the exception of the Bishkek site, which had some “exploration” gas wells drilled in 2007. To prevent greenhouse gas emissions into the atmosphere it is necessary to collect and treat the gas. This is usually done with vertical gas wells, because they can be installed in an existing landfill. The gas is flared or utilized for energy production. The installation of this system needs some investment for gas wells, collection pipes and a flaring / utilization unit. It is however possible in investigate the feasibility to initiate a so-called “Clean Development Program” (CDM) project under the scope of the Kyoto Protocol. This enables developing countries to reduce their emission of carbon dioxide into the atmosphere and receive “carbon credits” in exchange. These carbon credits can be sold on the international market. This makes the installation of a gas treatment system attractive as it is possible to generate income from the disposition of the credits. Such a CDM feasibility project has been launched in Ashgabat, Turkmenistan in July, 2008. The elaboration of such projects is complex and needs specialists for the application. Certain companies are specialized in this field and have such Programs running. Further investigations and calculations have to be conducted to estimate the possible gas production, gas yields and CO_2 reductions. In this process a detailed analysis of the needed technical and structural preconditions and investments as well as the potential economical efficiency will be made. Overall a CDM project is a good opportunity to finance the improvement of the landfill site. For the future the disposal area should be sealed with a base liner and a gas collection system should be installed to capture and utilize the gas.

6.2.7 Monitoring

The site investigations and the risk assessment suggest that the immediate hazard to the ground water and settlements is relatively low. The groundwater level is relatively deep and the hydraulic conductivity is low. The degradation of contaminants can take place in the soil by natural processes. This is called “natural attenuation”. The use of natural processes within the context of a carefully controlled and monitored site cleanup approach is called “monitored natural attenuation”. Long-term monitoring is an important component of a remedy where natural processes are to be relied upon to achieve cleanup objectives.

Monitored natural attenuation is quite simple and cheap to install and operating costs for monitoring and analyzes are rather low. Ground water, surface water and air quality should be sampled and analyzed on a regular basis. For this purpose the installation of facilities like monitoring wells and the purchase of appropriate sampling and storing equipment might be necessary. Detailed and accurate recordings of the conducted works as well as additional data (climate conditions, time etc.) need to be kept. All works must be executed by educated personnel. Records of the monitoring results are kept, updated and evaluated to ensure immediate actions in case of hazards determined. Groundwater wells should be installed around the landfill and the deep groundwater as well as the perched groundwater table should be monitored regularly. Therefore at least two (three would be better) groundwater wells should be installed on each of the sites of the landfill; one reaching the deep groundwater and one reaching the perched water table. Their operability has to be checked and restored if necessary. The groundwater flow direction has to be determined. And at least one groundwater well in the perched groundwater table should be installed also downstream in a further distance to observe the spreading of contaminants. A sampling and analysis of the groundwater needs to be conducted on a regular basis.

6.3 Education and awareness creation

The basis of a sustainable waste management is the knowledge about the importance of environmental protection and the protection and the efficient utilization of resources. The awareness about possible hazards deriving from improperly disposed waste is also an important factor. This knowledge should not only be with people working on higher levels in the field of waste management but also to the whole population, starting with children in kindergartens and schools. For a start the workers of the landfill and in the waste collection should be informed about environmentally sound waste disposal and the possible hazards posed not only to the environment but also to their own health. Workers should be trained, how to avoid these hazards and how to protect themselves. Campaigns are necessary to create awareness among the population about sustainable management of resources and the consequences of improper waste handling and disposal, as well as the possible contaminations of soil, air and water and the hazards to the health. Furthermore, the international cooperation in science and research should be intensified and expanded to enable a know-how transfer of state of the art waste management and environmental protection. With the support of international experts waste related and environmental orientated studies should be implemented in the universities to train qualified personnel and decision makers in the field of environmental topics for the future.

6.4 Future development

Due to the limited resources of raw materials for energy and products there is a great need to deal with waste as a resource. In many countries waste recycling is a real business where the product value of recycled materials, is steadily increasing. With improving mechanical sorting techniques it is already – an will be more in the future – possible to separate the different kinds of plastics which have a high value and can be used for new plastic production. Where it is not economical and/or ecological feasible organic waste fractions can be used as a fuel where tailor-made compositions should be provided in the future. For future waste management in Central Asia, especially in the big cities, the foundation has to be laid for a comprehensive recycling of waste materials. Therefore it is necessary to plan and install a separate collection system and corresponding recycling plants. All materials which can be recycled should be recycled. A material recovery is working best if the material is not contaminated by other waste products. High calorific fractions, such as plastics, wood and paper can be used as refuse derived fuel (RDF) in power plants or cement works. Bio-waste (kitchen and yard waste) should be treated separately in aerobic (composting) or anaerobic (biogas) plants. High quality compost and energy can be recovered from this kind of waste. It is very important, that hazardous waste (e.g. highly toxic material, medical waste) is not mixed with other wastes and treated and disposed separately.

Even though a “zero waste strategy” should be followed, which means that the amounts of waste for disposal should approximate to zero, landfilling will be most widely used practice for waste disposal all over the world, especially in developing countries for several decades. The multi-barrier concept should be followed, when planning and siting a new landfill. This concept for planning, operation and after-care considers more than only base liners or top covers as barriers. “It is the waste to be dumped itself that forms the most important barrier. The other barriers are the geological barrier of the landfill site, base sealing with an effective drainage system, and surface sealing after a landfill section has been completely filled” (Heyer and Stegmann, 2005). Other important elements performing the role of barriers are the controlled post-closure use of the landfill area and the long term monitoring and control of the landfill behavior (Stief, 1990).

Developed countries with a highly developed waste management system pre-treat waste before disposal to minimize emissions from the waste and to reduce settlements of the landfill. This is also an essential factor to create a geotechnically sound i.e. stable landfill which essentially becomes part of the landscape. If properly engineered and constructed, the impact and associated environmental risk of the landfill can be minimized and through monitoring, also controlled. It is an inevitable fact that landfills will continue to be used as the main form of waste disposal for decades to come in the less industrialized countries of the world. It is also quite clear that the majority of the governments of these countries will lay higher priority on economical development rather that environmental protection. This is understandable and even justifiable, but only to a certain extent. Unfortunately many of the economical development policies are too short sighted (even limited by electoral periods, if they even exist) and that the long term costs i.e. the external costs of waste disposal go far beyond the designation of “suitable” land for waste disposal. It is hoped that the NISMIST research project and this resulting dissertation have made a small, but meaningful contribution to sustainable development of the Central Asian economies and that the relevant decision makers are better informed on how to couple environmental protection as an integral component of their policies.

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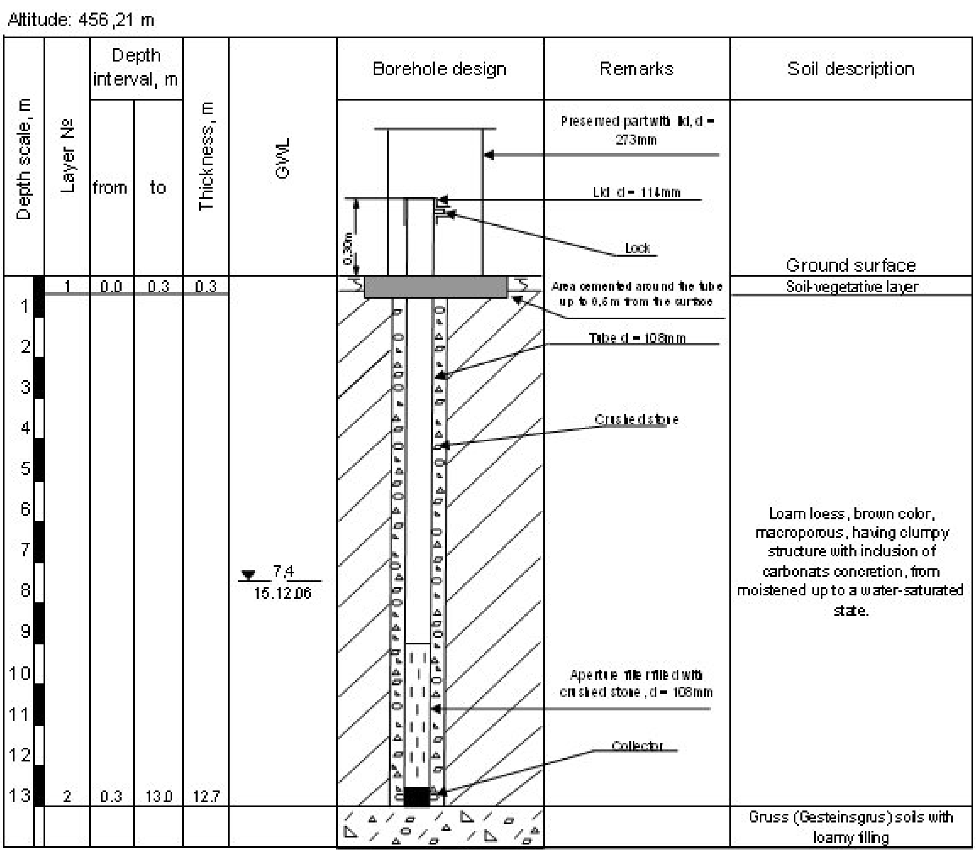
8. Appendix

8.1 Borehole logs – Ahangaranskaya Landfill, Tashkent, Uzbekistan

Lithological units, observations during drilling

No.	Lithologic description of soils	Borehole 1 (depth in m)	Borehole 2 (depth in m)
	Soil-vegetative layer	0.0 – 0.3	0.0 – 0.3
	Loess-type loams, brown, moistened, with inclusion of calcareous concretions	0.3 – 13.0	0.3 – 30.0
	Gruss (Gesteinsgrus) with loamy filling	13.0 – 13.3	30.0 – 30.5
–	Groundwater level (date of measurement)	7.4 (15.12.06)	24.68 (18.12.06)
–	Total depth	13.3	30.5

Lithologic column and constriction of borehole №1

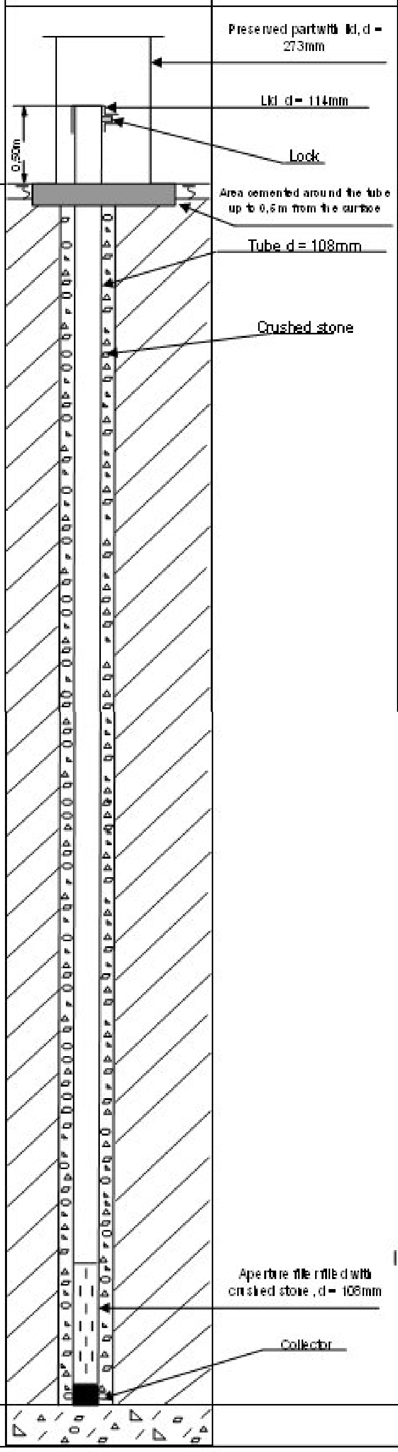


Lithologic column and constriction of borehole №2

Altitude: 482.40 m

Depth scale, m	Layer №	Depth interval, m from	Depth interval, m to	Thickness, m	GWL	Soil description
						Ground surface
	1	0.0	0.3	0.3		Soil-vegetative layer
1–24						
25					24,68 18.12.06	Loam loess, brown color, macroporous, having clumpy structure with inclusion of carbonats concretion, from moistened up to a water-saturated state.
26–29						
30	2	0.3	30.0	29.7		
						Gruss (Gesteinsgrus) soils with loamy filling

Borehole design / Remarks



8.2 Borehole logs – Krasnyi Stroitel, Landfill, Bishkek, Kygyzstan

Borehole No. 1 – Profile description, sampling points

<table>
<tr><td colspan="6">Method: Core drilling with diameter 129 mm
Scale: 1:200</td><td colspan="4">Borehole No. 1, (NISMIST) (at the crossing of profiles II-II x III-III) VES H=690, φ=42°58’07,6” λ=74°35’12,7”</td></tr>
<tr><td rowspan="2">Number of layer</td><td rowspan="2">Geological index</td><td colspan="2">Depth of bedding, m</td><td rowspan="2">Layer’s capacity, m</td><td rowspan="2">Lithological section</td><td rowspan="2">Deposit’s description</td><td colspan="2">Groundwater level</td><td rowspan="2">Group of hand working</td></tr>
<tr><td>from</td><td>to</td><td>Date</td><td>Time</td></tr>
<tr><td>1</td><td rowspan="3">paQ_{III-IV}</td><td>0.0</td><td>23.4</td><td>23.4</td><td>■ 3.2
■ 6.2
■ 9.2
■ 12.2
■ 15.2
■ 18.2
■ 21.7</td><td>1. Loess like loam brown color, hard (solid) high porosity, slump, including separate thin clay concretion, <5%, from 6m depth thin vein carbonate (~1mm). Lower 11.3m loam is semisolid, from depth 12.7m tight plastic, low porosity, not slumped, in interval 13.3-14.1m with layers seams of sand of fine and medium size moisture. From 14.1m – loam in accordance to consistence close to soft plastic, low porosity, not slumped. In the interval of 15.7-20.0m loam is soft plastic, taupe color, with thin layers seams, dusty, watered.</td><td rowspan="3">GWL not reached</td><td rowspan="3">25.05.2007</td><td>II</td></tr>
<tr><td>2</td><td>23.4</td><td>25.1</td><td>1.7</td><td>■ 24.2</td><td>2. Clay sand loess like brown-grey color, plastic, low porosity, not slumped, with thin layers seams (length 3 cm) sand dusty, grey, and watered.</td><td>I</td></tr>
<tr><td>3</td><td>25.1</td><td>30.0</td><td>4.9</td><td>■ 27.2
■ 30.0</td><td>3. Loam loess like, biscuit color, soft plastic, low porosity, not slumped, with thin layers seams (length 3 cm) sand of different size.</td><td>II</td></tr>
</table>

Borehole No. 2 – Profile description, sampling points

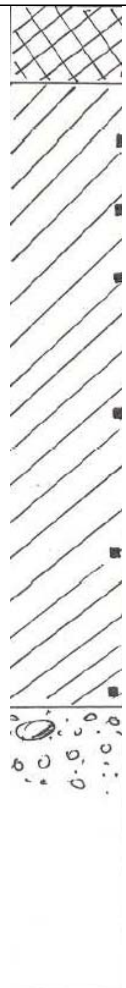
Method: Core drilling with 129 mm diameter Scale: 1:200	**Borehole No. 2,** (NISMIST) (at the 300m distance from chink No1, along ground way) φ= 42° 58’25,1” λ=74°35’02,7”

Number of layer	Geological index	Depth of bedding, m		Layer’s capacity, m	Lithological section	Deposit’s description	Groundwater level		Group of hand working
		from	to				Date.	Time	
1	paQ_{III-IV}				■ 1.2 ■ 3.2 ■ 5.2 ■ 7.2 ■ 9.2 ■ 11.2 ■ 13.2 ■ 15.2 ■ 17.2 ■ 20.2	1. Loess like loam light-brown color, hard (solid) high porosity, homogeneous, in the upper part until 2.5m with root of plants, slump, Lower 5.0m with slots and layer of carbonate, with depth 7.0m loam is low porosity. In interval 10.5-11.5m – is high porosity. In depth of 14.5 loams is tight plastic, not slumped.	GWL not reached	25.05.2007	II

8.3 *Borehole logs – Old Landfill, Dushanbe, Tajikistan*

Borehole No. 1

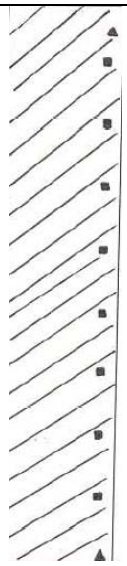
Altitude of well head: 857,50 m Scale 1:100 Date of drilling: 26 July 2006

№	Geological age of stratum	Depth of deposition of stratum		Thickness	GW level first obs.	GW level stable	Geological profile	Category	Lithologic description
		from	to						
1	2	3	4	5	6	7	8	9	10
1	$^{t}Q_{IV}$	0.0	1.20	1.20	Untapped				Banked earth, which is consist from mechanical mixture of clay soil, with beaten brick. Ground is solid, overconsolidated clay
2	Q	1.20	10.20						Loam from pale-yellow till biscuit colour, pelitic texture, clumpy texture with adding of lime concretion of firm consistence
									Pebbles soil predominant size of fragment 40-80 mm, average rounded oval forms, petrographic mixture metamorphic, sedimentary, rarely igneous rock. Fill material – sand of grey colour, medium-sized with less water content. Soil with 15% of tinned.

■ Places of soil monolith sampling
▲ Places of soil sampling

Borehole № 2

Well headed height: 872,00 m Scale 1:100 Date of drilling: 26 July 2006

№	Geological age of stratum	Depth of deposition of stratum		Thick ness	Level of UW	Level of UW Fixed	Geologic profile	Category	Lithologic description of rock
		From	To		Show up				
1	2	3	4	5	6	7	8	9	10
1	Q	0.0	18.0	18.0	Untapped				Loam from pale-yellow till biscuit colour, pelitic texture, clumpy texture with adding of lime concretion from solid till permeability consistence

■ Places of soil monolith sampling

▲ Places of soil sampling