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APPLICATION OF GIS TO AVAILABLE INFORMATION ON THERMAL WATERS IN THE AZERBAIJAN REPUBLIC AND ITS USEFULNESS FOR ENVIRONMENTAL ASSESSMENT

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ABSTRACT

Geothermal resources of Azerbaijan are represented by mineral-thermal water of low to intermediate temperature (35 – 100°C). The geothermal water is extracted from natural sources. It is used in balneology and for heating greenhouses (Greater and Lesser Caucasus, Talysh Mountains and Kura-Araz depression). The reserves of geothermal water were discovered and partially studied during exploration drilling for oil and gas in the Kura-Araz depression and the Absheron peninsula. The total thermal power of geothermal water with temperature 30-110°C has been estimated as 130 MWt in free flow and up to 700 MWt with pumping. High-potential geothermal resources for electricity production have not been identified. A major environmental impact assessment of air and water pollution for oil refineries and chemical and metallurgical industries is needed and poses great challenges to the economic development of the country.

1. INTRODUCTION

Exploration and evaluation in Azerbaijan have shown a high potential for geothermal development. Prospective sources have been recommended for balneological, industrial, and energy applications. The use of geothermal waters for greenhouse heating in the Lyankaran region (Talysh Mountains), Gandja, Yalama-Khudat, and Jaarly regions (Kura-Araz depression), is found to be promising; the high mineral content of these waters (more than 15 g/1) is typical.

This report has been prepared as a part of the Geothermal Training Programme of the United Nations University in 2006 and includes a review of the utilization of geothermal waters in Azerbaijan for balneology and for possible future purposes. The environmental aspects of geothermal development and utilization are receiving increasing attention with a shift in attitudes towards the world's natural resources.

2. PHYSIOGRAPHIC FEATURES

The republic of Azerbaijan borders with the Dagestan Republic of the Russian Federation in the North, Georgia in the northwest, and Armenia in the southwest, while Armenia separates Azerbaijan from the Autonomous Republic of Nakhchyvan which borders Turkey and Iran in the south. The eastern border lies through the Caspian Sea between Russia, Turkmenistan and Iran, the coastline being more than 850 km. The main part of the border is of natural origin (rivers and mountain ranges) but is man made in parts. Azerbaijan occupies the southeast part of the Caucasus isthmus and its small southern part. It covers the southeast part of the Greater Caucasus, a part of the Lesser Caucasus (including A.R. Nakhchyvan), and the Talysh Mountains with the vast Kura-Araz depression in between. Geographically, the republic is located within the part of Eurasia which is closely connected to the Aral-Caspian depression and is located near the traditional border between Europe and Asia.

In addition, the republic's territory also includes several islands located along the Caspian coastline (Nargin, Zhiloy, Bulla etc). Latitudes 38° 25' and 41° 55' North and longitudes 44° 50' and 50° 23' East outline the 86.6 thousand km^2 territory, excluding the islands some of which are located beyond the above mentioned eastern meridian.

The average altitude of the republic is 384 m with the highest elevation being 4466 m (Bazardyuzu) and the lowest point - 27 m on the Caspian coastline. Of the territory, 18% is located below sea level; plains and lowlands consist of more than 39%; low and average hills (up to 2500 m), 39.5%; high mountains (higher than 2500 m), 3.5% of the republic's territory. The four main relief features are: the Greater Caucasus (part of the Main Caucasus range); the Lesser Caucasus (including the eastern part of the Lesser Caucasus range and AR Nakhchyvan); the Kura-Araz depression and the Talysh Mountains together with the Lyankaran depression.

The river network of Azerbaijan accounts for more than 8350 rivers of different sizes with an overall length of 33,665 km. The Kura River is the biggest waterway in the entire Caucasus.

2.1 Tectonic setting

The Azerbaijan territory is located within the central part of the Mediterranean mobile belt which is characterized by high level seismicity, active modern magmatic volcanism, mud volcanism, widely developed landslides, flooding and other active geological processes (Shikhalibeyli et al., 1984). Therefore, recent geological processes both slow and fast, have occurred widely throughout the Azerbaijan territory. The present structure of Azerbaijan's territory was generated during the last stage of the formation of the Alpine folded area. In this connection, the structures generated during the neotectonic stage were important in establishing its present structure alongside ancient structural elements. At present, the territory is a region of active folding, diapirism, faulting, active seismicity, mud volcanism, with a wide distribution of geothermal sources etc. (Guliyev and Panakhi, 2004).

Tectonically, the southeast subsidence of the Great Caucasus passing through the Absheron-Prebalkhan zone of uplifts in western Turkmenistan could probably be considered an eastward continuation of the meganticlinorium depression. The Gusar-Kelkor trough, representing the main marginal tectonic element of the joint zone of the epihercynian Skif-Turan platform and the Alpine folded area, adjoins this zone on the northern side. The Earth's crust is thick in Azerbaijan, varying from 38 to 55 km (Rahmanov, 1978).

2.2 The climate – forming factors

Azerbaijan is situated on the northern extremity of the subtropical zone, in southeast Caucasus and the northwest part of the Iran plateau. Its climatic diversity is caused by the complicated geographical location and the landscape, the proximity of the Caspian Sea, the effects of the sun's radiation, air masses of different origin, etc. The Greater Caucasus, situated in the north and stretching from the northwest to the southeast, protects the country from direct influences of cold air masses coming from the north. That leads to the creation of a subtropical climate on most foothills and plains of the country. Other mountain chains surrounding the country also have a great impact on air circulation. The complexity of the landscape causes non-uniform climate zones.

The territory of the Azerbaijan Republic, as well as all the territory of the Caucasus, is in a subtropical zone and this influences the climatic subtypes. It is no wonder that analogues of 9 of the 11 climate types existing on our planet are found in the relatively small territory of Azerbaijan. The dry subtropical climate of central and eastern Azerbaijan is characterized by a mild winter and a long (four to five months) and very hot summer, with temperatures averaging about +27°C and maximum temperatures reaching +43°C. Southeast Azerbaijan is characterized by a humid subtropical climate with the highest precipitation in the country, some 1,200-1,400 mm a year, most of it falling during the cold months. A dry continental climate, with a cold winter and a dry, hot summer, prevails in AR Nakhchyvan from -5 to +25°C. Moderately warm, dry, or humid climate types are to be found in other parts of Azerbaijan. The mountain forest zone has a moderately cold climate, while an upland tundra climate characterizes high elevations with minus 10°C and more. Frosts and heavy snowfalls make the passes at such altitudes inaccessible for three or four months of the year.

2.3 Flora and fauna

The Republic of Azerbaijan has a very abundant *flora*. There are more than 4.500 species of higher plants there. Sixty-six per cent of the species growing in the whole of Caucasus can be found in Azerbaijan, including: Sultanbud forests (pistachio), Geygel Eldar pine trees (related to the "natural monuments"), Narband (Nakhchyvan); elm (Absheron peninsula); chestnut trees (Kutkashen area); zubovniki (Zakatala, Khachmaz regions); and endemic and relict flora in Talysh (iron trees, chestnut-leaf oak; zelcova etc.) and others (Table 1).

The *fauna* of Azerbaijan is characterized by an exclusive variety and is represented by 99 species of mammals, 123 species and subspecies of fish, 360 species of birds, 54 species of reptiles, and 14 thousand species of insects (Figure 1). The subalpine forests support a number of mammal species, including bear, deer, lynx, and wild boar. Leopards, though rare, also inhabit the forests. Reptiles such as lizards and poisonous snakes, gazelles, jackals, and hyenas populate the Kura-Araz depression. In the Caspian Sea, sturgeon, providing meat and caviar, is highly valuable. The water basins of Azerbaijan contain such valuable fish species as bream, sazan, rutilus kutum and others. Fish species such as herring are fished for in the Caspian Sea.

FIGURE 1: Flora and fauna of Azerbaijan (GIA, 2006)

The Red Book of the Azerbaijan Republic includes 108 species of animals, with 14 species of mammals, 36 species of birds, 13 species of reptiles and amphibians, 5 species of birds and 40 species of insects.

TABLE 1: The number of protected areas established in Azerbaijan

Type of reserve	Number of reserves
National parks (Gircan, Gusar etc.)	3
State natural reserves (Shirvan, Goy-Gol, Gyzylagach etc.)	16
State restricted areas (Shuvalan, Jannat etc.)	22
Protected trees (over 100 years: Pisttachio grove, Eldar pine, Plane etc.)	2038
Protected geological and paleontological sites (Barda, Astara; Zangilan etc.)	37
Coastal national park (Baku)	1
Historical natural state reserve (Gobustan)	1

3. HYDROGEOLOGY: ZONING AND USAGE

Azerbaijan is rich in fresh, mineral, thermal and industrial groundwater with a wide range of gas composition, physio-chemical and medicinal features. The patterns of their origin and distribution, predicted and productive reserves (fresh and mineral waters up to 350-700 m, geothermal and industrial waters up to 2000-3000 m altitude) have been studied in detail. Considering the geological-structural features of the region, three large areas can be distinguished. Grouping the general characteristics of origin and distribution, groundwater can be divided into a number of characteristic regions (Figure 2) (Israfilov, 2002), or:

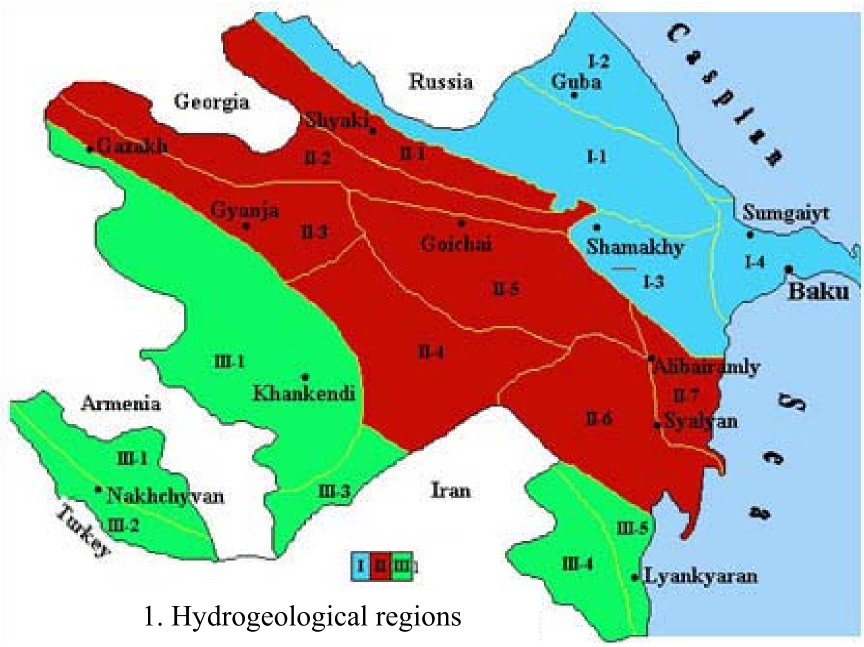


FIGURE 2: Azerbaijan hydrogeological zoning (GIA, 2006)

I. Greater Caucasus basin. It is characterized by the development of joint-veined stratal-porous fresh groundwater. Sulphide minerals, geothermal waters with a high content of *I, Br, B,* and highly mineralized deposits of a Meso-Cenozoic complex are widely developed. They are used for medicinal purposes. This region has developed mud volcanism.

II. Absheron region. Groundwaters of variable types, fresh drinking to highly mineralized industrial, including oily waters, occur widely. Fresh groundwater is found in the Upper Pliocene and Quaternary rocks and is widely used for the local water supply. Fresh ground and surface waters are transported from other regions of the Republic to eliminate a deficit of potable water. Mineralized - high-temperature waters with a high content of H_2S, CH_4, *I, Br, B* have been revealed in deeper horizons. They are of medicinal and industrial importance.

III. Kura-Araz depression basin. A wide distribution of groundwater can be noted here. Fresh soil and confined groundwater are mainly found in deposits of cones of river sediments and are widely used for the water supply of inhabited localities and for ground irrigation. Thermal waters with temperatures higher than 90°C and a high content of H_2S, *I, Br, B,* along with minor constituents, have been discovered in the Meso-Cenozoic deposits. Thermal and mineral waters containing H_2S, CH_4, *I, Br, B* and minor constituents have been discovered in deeper horizons of the Meso-Cenozoic complex. These waters are already used for medical purposes by local people.

IV. Lesser Caucasus basin. Mineral and geothermal waters of carbon dioxide, hydrogen sulphide and methane composition are widely distributed. Carbon dioxide mineral sources, unique in their chemical composition and medical features, are widely developed. Medical centres and plants are based on their occurrence. Fresh ground and confined waters are found in river valleys only, and are confined to gravel and sandy formations of Quaternary age (Figure 2, III.2). The waters of deeper horizons differ by being highly mineralized.

V. Talysh mountain region. In this region there are huge resources of high-temperature mineral waters with *I, B, Br,* H_2S, CH_4 and minor constituents content. Waters from mineral sources are widely used for medical purposes. Soil waters are widely distributed (Figure 2, III.5). Fresh confined waters, mainly connected with gravel-shingle and sandy deposits, have been found as well.

4. GEOGRAPHIC INFORMATION SYSTEM (GIS)

The multitude of environmental problems in a world of dynamic and unpredictable natural systems calls for new methods that make use of recent developments in the digital integration of human reasoning, data and dynamic models. A Geographic Information System or GIS is a set of computerized tools (including both hardware and software) for collecting, storing, retrieving, transforming, and displaying spatial data. GIS is essentially a marriage between computerized mapping and data base management systems. GIS technology can be used for scientific investigations, resource management, and community education. GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information to their locations. The ability of GIS to integrate maps and data bases, using geography as the common factor, has been extremely effective in the context of planning development (Noorollahi, 2005).

4.1 Using GIS for different thermal waters

GIS is useful for specifying different types of models. In Figures 3-10 we can see the range of temperatures and chemical composition of the mineral and thermal springs in the study region. Hydrogeological conditions of formation and underground waters are quite diverse. Each area is characterized by specific natural geographical factors. GIS considers independent natural objects or object groups with parameters close to the natural environment.

Greater Caucasus. In accordance with the stratigraphic geological section of a given strip (in Quaternary and Pliocene deposits), water-bearing layers with local distribution are distinguished. Mineral waters in these complexes are of the fresh, hydro-carbonate-calcium and hydro-carbonate-sodium type with mineralization 0.3-1.0 g/l, in some cases up to 2.5-3.5 g/l (sulfate calcium-sodium waters), with H_2S gas 10-20 mg/l. Well discharges vary within wide ranges: up to 104 l/s (Appendix I), (Ibrahimova et al., 2001). Examples of springs and spas are:

"Chagan" spring (Analogue of "Mendji" (Georgia))
Main characteristics:

$$M_{1,7}\frac{SO_4 74Cl14}{Na75Ca22}T33°C, pH7{,}4$$

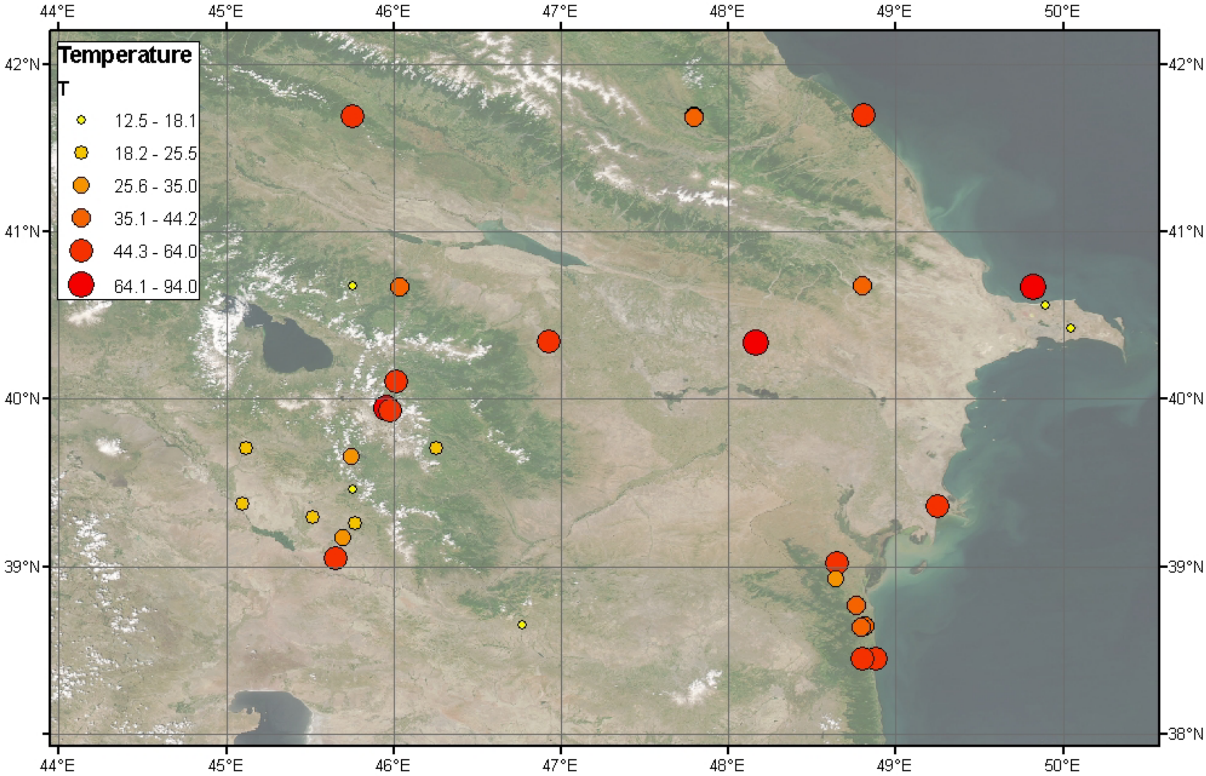


FIGURE 3: Range of temperatures (T, °C) for the mineral and thermal springs in the study region

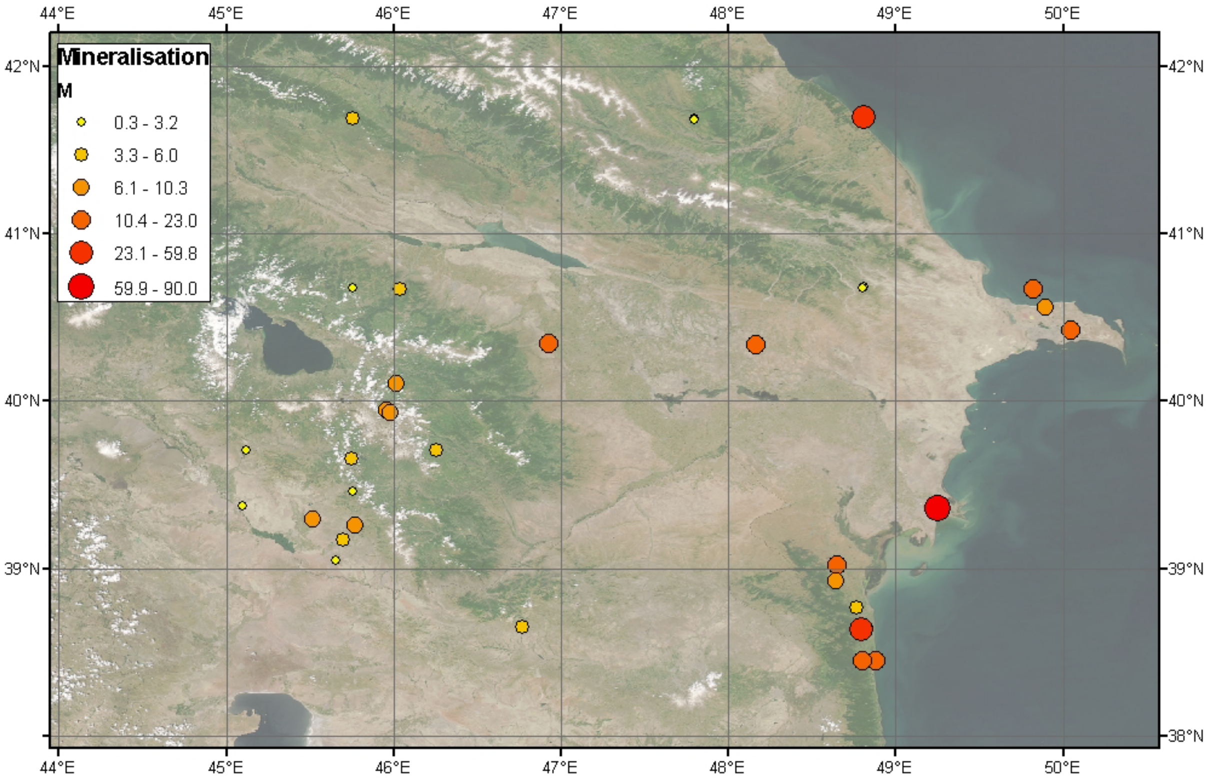


FIGURE 4: Range of mineralization (M, g/l) for the mineral and thermal springs in the study region

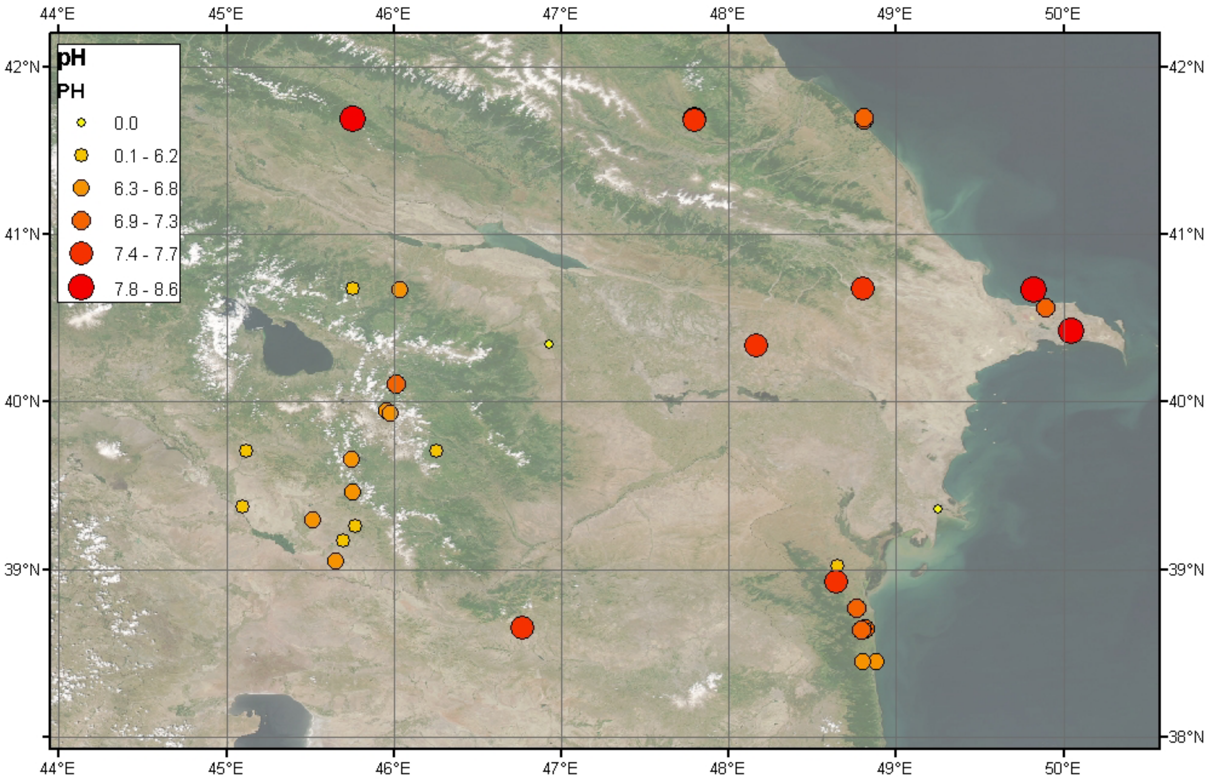


FIGURE 5: Range of pH for the mineral and thermal springs in the study region

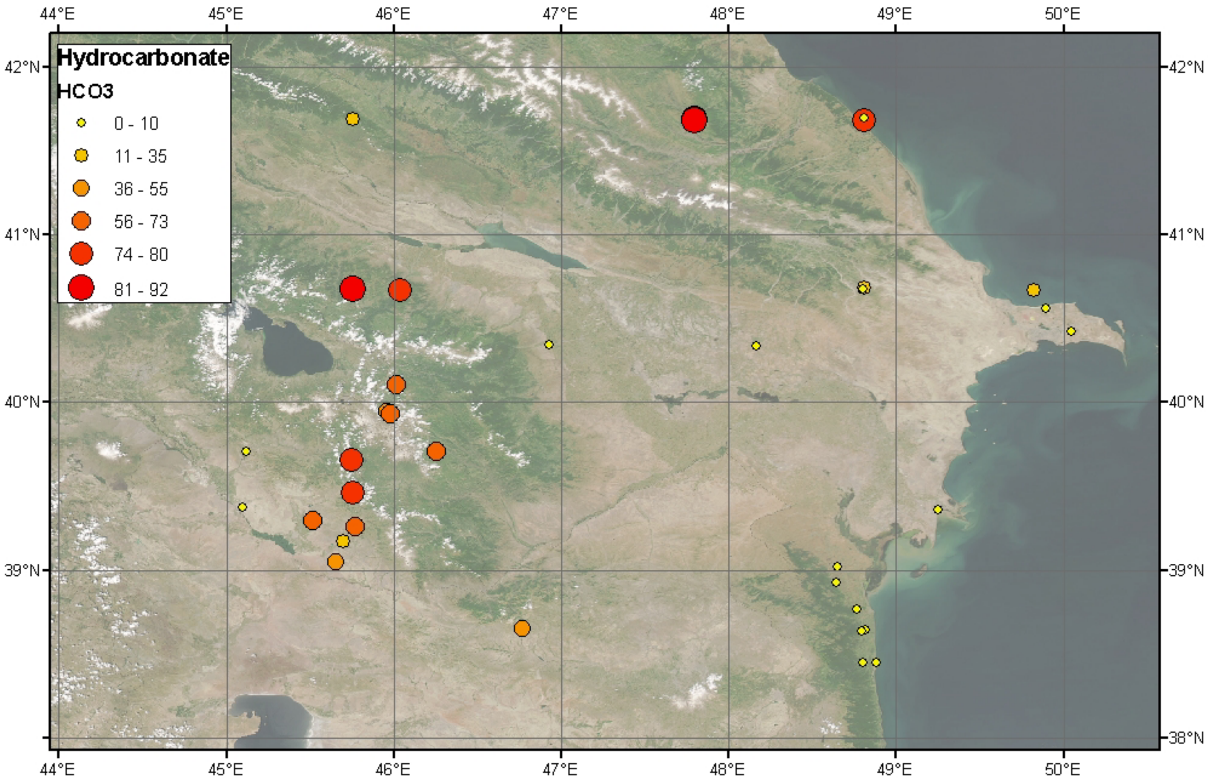


FIGURE 6: Range of hydrogen-carbonate (HCO_3, % equ.) in the mineral and thermal springs in the study region

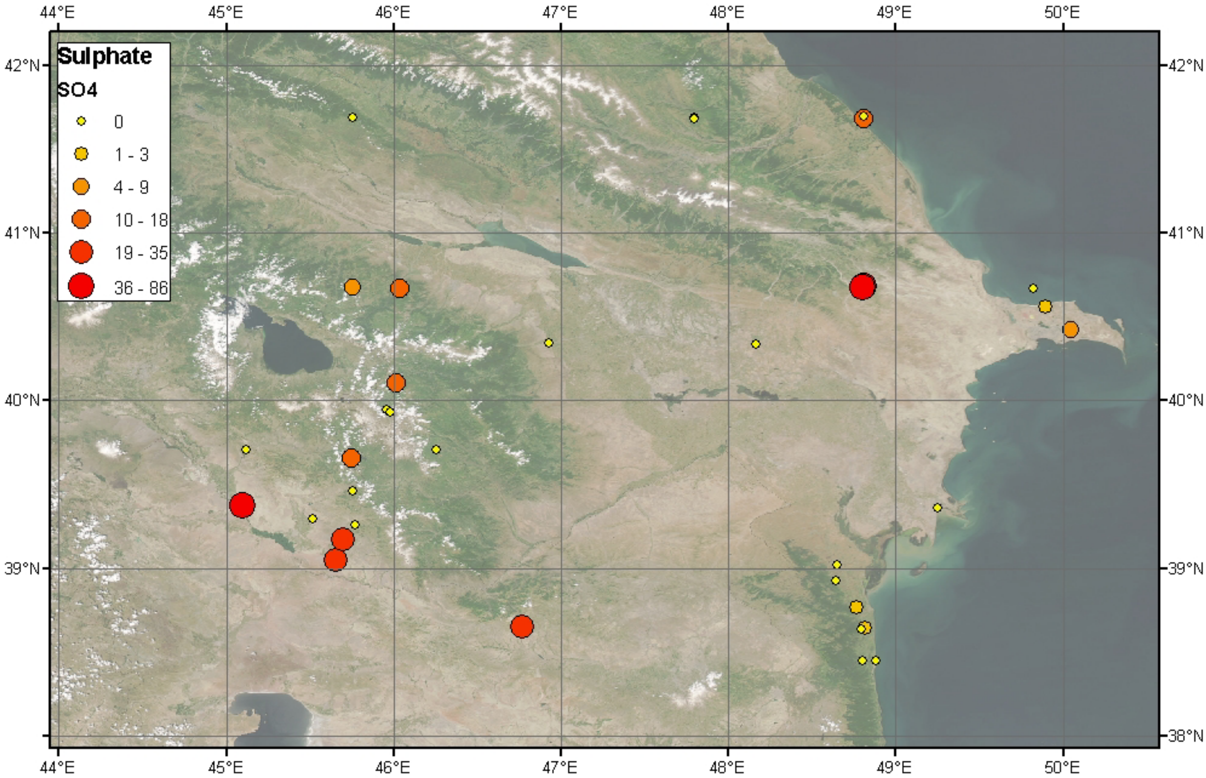


FIGURE 7: Range of sulphate concentration(SO_4, % equ.) in the mineral and thermal springs in the study region

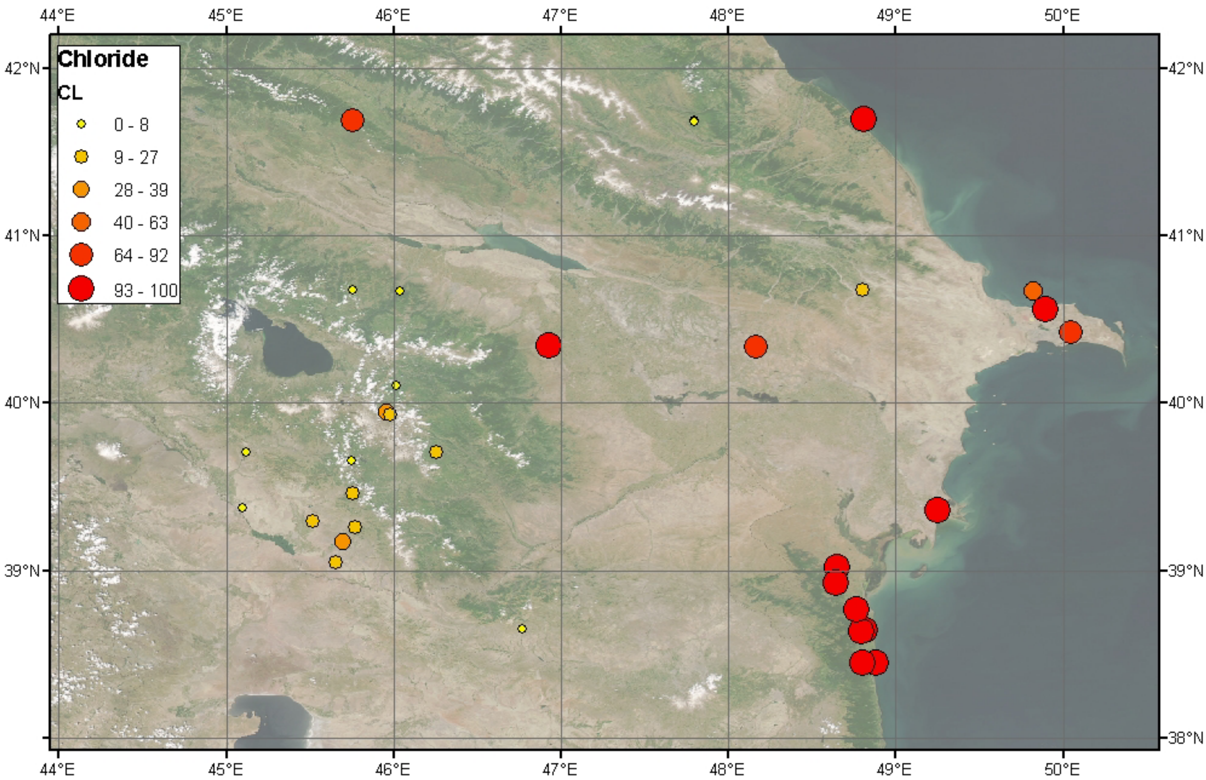


FIGURE 8: Range of chloride concentration (Cl, % equ.) in the mineral and thermal springs in the study region

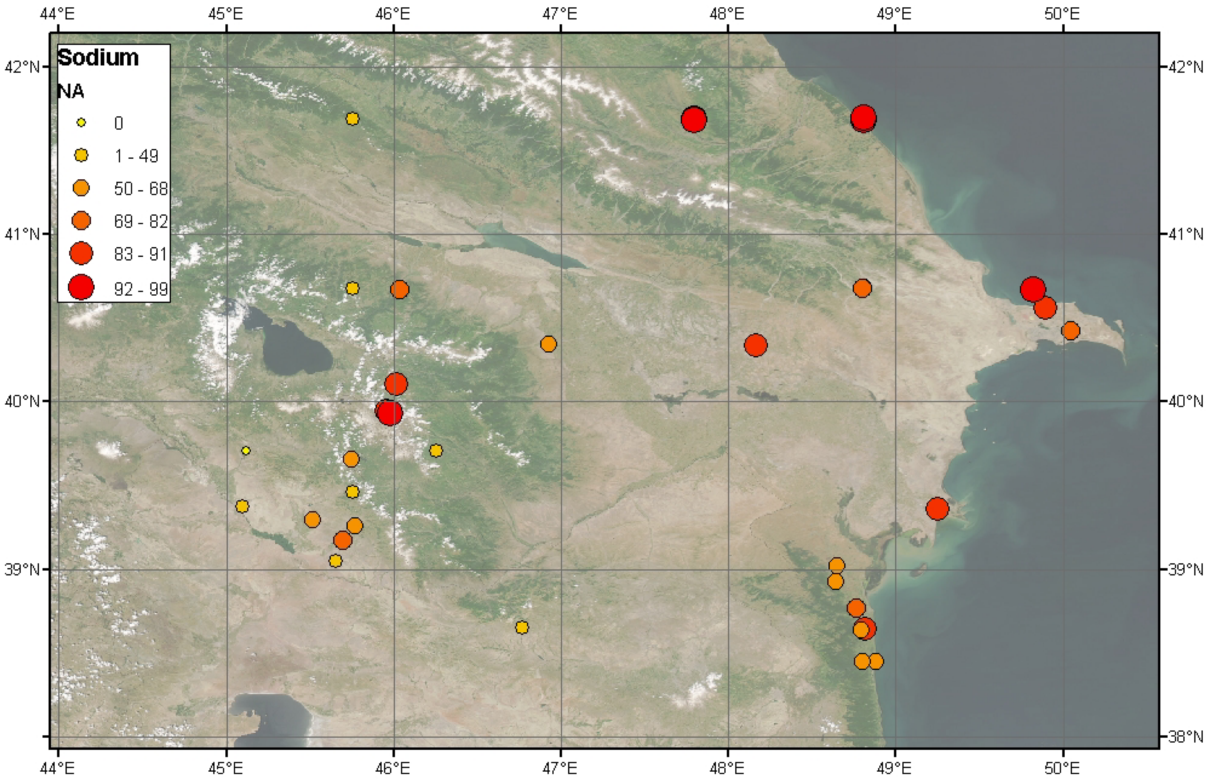


FIGURE 9: Range of sodium concentration (Na, % equ.) in the mineral and thermal springs in the study region

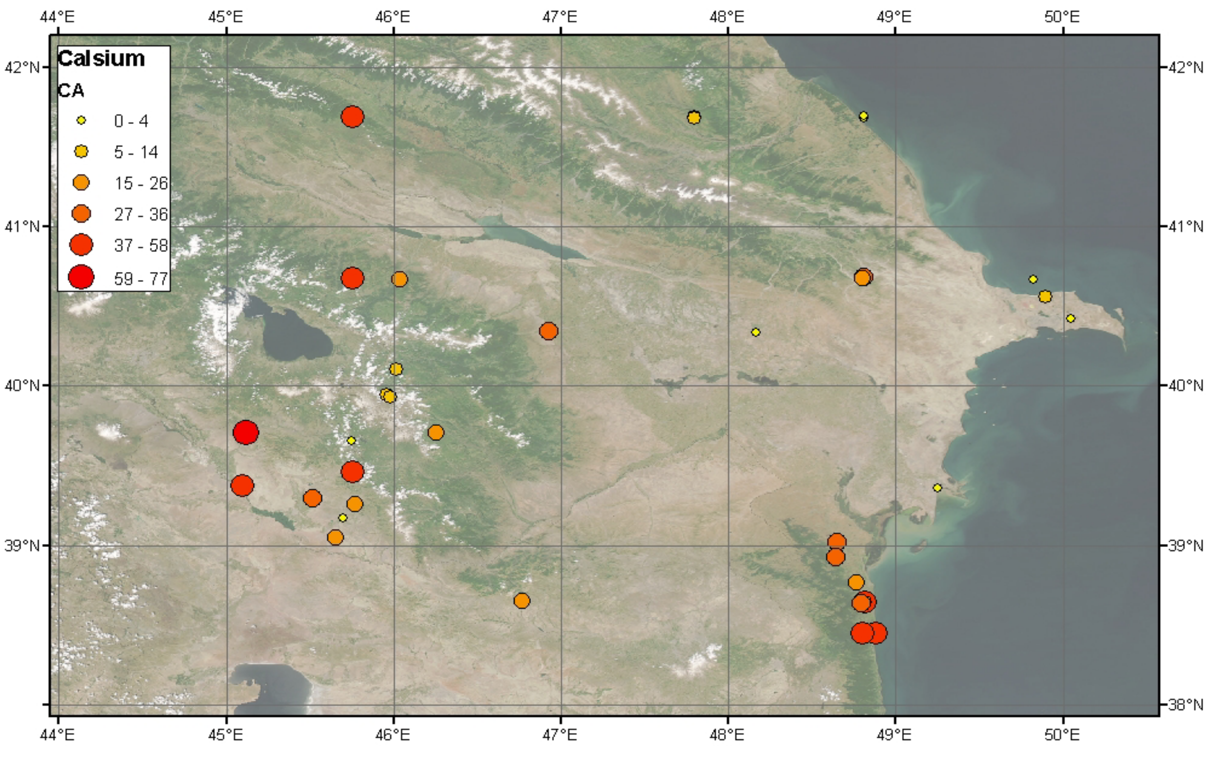


FIGURE 10: Range of calcium concentration (Ca, % equ.) in the mineral and thermal springs in the study region

Within the region, Cretaceous, Paleogene and Neogene complexes of deposits that are outcropping on the surface in the mountain zone have subsided in the direction of the sea, and others are overlain by Quaternary formations of coastal plains and the *Absheron peninsula*. Principally different conditions for the formation and distribution of underground water are created. Groundwater in Paleogene-Neogene deposits differs within a sporadic distribution and is mainly confined to zones of jointing and small synclinal structures. Descending springs discharge up to 1.0, rarely to 3.5 l/sec. The depth to water range is from 0 to 60 m, with mineralization from 0.5 to 145.7 g/l. The chemistry of the water is hydro-carbonate-chloride, sulphate-chloride sodium-calcium-magnesium and sodium (Babayev and Ibrahimova, 2004b).

In Quaternary deposits, groundwater is contained in aquifer horizons of Pleistocene as well as recent, eluvial-talus-proluvial and beach deposits at depths from 0.2 to 26 m and more, with the discharge of descending springs from 0.4-1.0 l/s, specific discharge of wells 0,01-2 l/s m, and mineralization from 0.7 to 90 g/l. The chemistry of the water is mainly hydrogen-carbonate-sulphate, hydrogen-carbonate-chloride, sulphate-chloride and chloride-sulphate-hydrogen-carbonate sodium-calcium, sodium-magnesium.

"Shikhovo" balneotherapeutic health resort

Main characteristics:

$$M_{17}\frac{Cl63HCO_3 32}{Na97}T68°C, pH8,2$$

The geological and morphological structures of the *Kura-Araz depression* characterize the region as a reservoir of underground waters. Within the region, these waters are confined to Quaternary and Paleocene deposits. They are saline everywhere, and mineralization varies from 5 to 129 g/l. The chemistry of the water is chloride, chloride - sulphate and sodium, sodium- calcium.

"Neftchala" spring

Main characteristics:

$$M_{90}\frac{Cl99}{Na90}T60°C$$

Mineral and geothermal sources are widely developed in Miocene rocks, linked with dislocated tectonic disturbances and are concentrated on the border of the *Talysh Mountains* (Masally area and the Lyankaran lowland).

Masally area – Arkevan, Donguz-Oten, Gotursu (Yanarsu), Misharsu (Muradsu, Misharchay), located along the right bank of Vilyashchay river, belongs to the Masally group of sources. Water temperature is 48-68°C, total discharge approximately 70 l/s. The mineralization of the water is 12-17 g/l, and it is chloride-sodium-calcium. One can observe spontaneous gas emanations of which 80-85% are hydrocarbons, mostly methane, and the rest nitrogen.

"Donguz-Oten" spring

Main characteristics:

$$M_{17}\frac{Cl99}{Na64Ca34}T64°C, pH7,9$$

Lyankaran lowland – (Anjyn), (upper Lyankaran (Ibadisu), Haftoni and Gavzavua are related to the Lynkaran group of sources. The temperature of the springs is 37-50°C and of the wells 34-47°C, but temperature increases with depth. The total discharge of all natural and artificial outlets (wells) reaches approximately 50 l/s, the water is saline, and of chloride-sodium-calcium type. Dry residue from springs amounts to 3.6-4.5 g/l. The hydrogen sulphide concentration is 2.9-6.0 mg/l, that of iodine is 15-37 mg/l and bromine 20-30 mg/l, and SiO_2 ranges from 26.2 to 40.5 mg/l. Gas emanations of nitrogen may sometimes be observed. In wells the gas composition is dominated by hydrocarbons of the methane order in quantities, reaching 77.5% below a depth of 500 m.

"Ibadisu" balneotherapeutic health resort
Main characteristics:

$$M_{3,7}\frac{Cl96SO_4 3}{Na78Ca22}T47°C, pH6,7$$

In Azerbaijan *Lesser Caucasus* lies between the rivers Kura and Araz. Here there is wide a range of igneous rocks of intrusive and effusive magmatism (interstratified with carbonate, sandstone and clay rocks). In A.R. Nakhchyvan, the major source of chemicals in the water is Devonian, Jura and Palaeogene carbonate rocks. Mineralization of the water is in the range 1.5-18.2 g/l. The waters include a wide variety of carbonate water: mainly hydrogen-carbonate calcium, hydrogen-carbonate sodium-calcium, hydrogen-carbonate magnesium, hydrogen-carbonate-sulphate sodium-calcium, sulphate-chloride etc. Examples of spas are:

"IstiSu" SPA (analogue "Karlovy-Vary" in Czech Republic)
Main characteristics:

$$M_{4,4}\frac{HCO_3 50Cl39}{Na90Ca8}T71°C, pH6,7$$

"Darydag" SPA in Nakhchyvan (analogue "Lya-BurBul" in France)
Main characteristics:

$$M_{21,1}\frac{HCO_3 42SO_4 35Cl23}{Na45Mg29Ca25}T52°C, pH6,5$$

5. GEOTHERMAL UTILIZATION

Direct use is one of the oldest, most versatile and also most common form of utilization of geothermal energy (Dickson and Fanelli, 2003). By 2005, geothermal resources had been identified in some 90 countries and there are quantified records of geothermal utilization in 72 countries. The direct use increased by 43% from 1999 to 2004.

Geothermal utilization is commonly divided into two categories, i.e. electricity generation and direct use. The range of production temperatures in a geothermal field that is generally required for different types of utilization was summarised by Líndal (1973). Conventional electrical power production is limited to fluid temperatures above 150°C, but considerably lower temperatures can be used for power generation using binary cycles (outlet temperatures of the geothermal fluid are usually above 110°C) (Fridleifsson and Freeston, 1994).

The main types of direct use of geothermal energy are space heating 52% (thereof 32% with the use of heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4%, and fish farming 4% (Lund et al., 2005).

FIGURA 11: Ancient uses of thermal waters (Register, 2006)

5.1 History of the utilization of thermal waters

Thermal waters have been used for centuries as an integral part of general health and well being. Throughout the ages, the Greeks, Romans, Japanese, and people of many other cultures have realized its many benefits to the spirit, mind and body (Ratoti, 2003). The healing power of warm water therapy was first used by members of the military, who used it to treat sore muscles and injuries, but this knowledge quickly spread to the general population (Figure 11).

Thermal spas were frequently built near natural volcanic vents, where water from the hot springs was conducted and contained in large public baths. Hot springs were not always available, so spas were built with furnace rooms that were used to heat the water, but only the wealthiest could afford to build and maintain their own private spas.

Romans, Chinese, Ottomans, Japanese and central Europeans have bathed in geothermal waters for centuries. Today, more than 2,200 hot spring resorts in Japan draw 100 million guests every year, and the "return-to-nature" movement in the US has revitalized many hot spring resorts. The geothermal water at Xiaotangshan sanatorium, northwest of Beijing, China, has been used for medical purposes for over 500 years. Today, the 50°C water is used to treat high blood pressure, rheumatism, and skin diseases, diseases of the nervous system, ulcers and it is generally used for recuperation after surgery. In Rotorua, New Zealand at the centre of the Taupo volcanic zone of North Island, the Queen Elizabeth Hospital was built during World War II for US servicemen and later became the national hospital for the treatment of rheumatic disease. The hospital has 200 beds, an outpatient service, and a cerebral palsy unit. Both acidic and basic heated mud baths are used to treat rheumatic diseases (Lund, 1996).

In Beppu on the southern island of Kyushu, Japan, the hot water and steam meet many needs: heating, bathing, cooking, industrial operations, agricultural research, physical therapy, recreational bathing, and even a small zoo (Taguchi et al., 1996). The waters are promoted for "digestive system troubles, nervous troubles, and skin troubles." Many sick and crippled people come to Beppu for rehabilitation and physical therapy. There are also eight Jigokus ("burning hells") in town showing vicious geothermal phenomena, used as tourist attractions.

In the Czech and Slovakia Republics, the use of thermal waters has been traced back to before the occupation of the Romans and has a recorded use for almost 1000 years. Today, there are 60 spa resorts, located mainly in Slovakia, visited by 460,000 patients, usually for an average of three weeks each. These spas have old and well-established therapeutic traditions. Depending on the chemical composition of the mineral waters and spring gas, availability of peat and sulphurous mud, and climatic conditions, each sanatorium is designated for the treatment of specific diseases. The therapeutic successes of these spas are based on centuries of healing tradition (balneology), systematically supplemented by the latest discoveries of modern medical science (Lund, 1990).

Bathing and therapeutic sites in the USA include: Saratoga Springs, New York; Warm Springs, Georgia; Hot Springs, Virginia; White Sulphur Springs, West Virginia; Hot Spring, Arkansas; Ternopol's, Wyoming and Calistoga, California. The original use of these sites was by Indians, where they bathed and recuperated. There are over 115 major geothermal spas in the USA with an annual energy use of 1531 TJ (Lund et al., 2005).

5. 2 Geothermal waters in Azerbaijan

Natural outlets of geothermal and geothermal mineral water are confined to zones of tectonic dislocations and faults. These waters issue from wells within the Kura-Araz depression at 305-1600 m depth, Guba - Pre-Caspian (800-3385 m) and Lyankyaran (48-1000 m) lowlands and Absheron peninsula (Shikhovo, not more than 300 m).

The production capacity of the Lyankaran, Massaly, and Astara regions (*Talysh Mountains*) is estimated to be about 25,000 m^3/day. Wells have produced waters with wellhead temperatures of 50°C and rates of 40 l/s (Babayev and Ibrahimova, 2004a).

In the *Kura-Araz depression*, thermal waters in the 30-70°C range are found at 200-4500 m depth. In the Jarly region, wellhead temperatures are 70-100°C, and the total mineral content is 40 g/l. Geothermal waters with a similar mineral content are found in Muradkhanly, with surface temperatures of 62°C.

On the *Caspian side of Greater Caucasus* of the Kuba zone, at a depth of 1400 m, fresh bicarbonate-calcium-sodium hot waters were found with temperatures of up to 55°C and flowrates in the range 1-45 l/s. The Khudat region is characterized by 82°C surface temperatures and flowrates of 50 l/s with salt concentrations up to 60 g/l (Ramazanov, 1994). The characteristics and forecast reserves of the thermal waters in Azerbaijan are shown in Table 2.

TABLE 2: The characteristics and forecast reserves of the thermal waters

Hydrogeology region	**Temperature of water (°C)**	**Reserves forecast (m^3)**
Greater Caucaus mountain zone:	30-50	2000
Gusar plain	30-67	21,654
Absheron peninsula	20-90	20,000
Lesser Caucasus mountain zone:	30-74	4171
Nakhchivan AR	40-53	3000
Talysh Mountain zone:	31-43	14,405
Lyankaran plain	44-64	7908
Kura-Araz depression	22-71, 94	172,466
Total		245,604

As we can see in Figures 12-15 and Table 3, the temperature range for thermal waters in Azerbaijan is: in the Greater Caucasus (northeast part of country) – between 10°C (natural springs) and 68°C (well); in the Absheron peninsula (oil-and-gas bearing area, eastern part of the region) in the well waters, up to 70°C (Figure 12); in the Lesser Caucasus (northwest) – 6-75°C (well); in Nakhchyvan (west) up to 56°C (Figure 13).

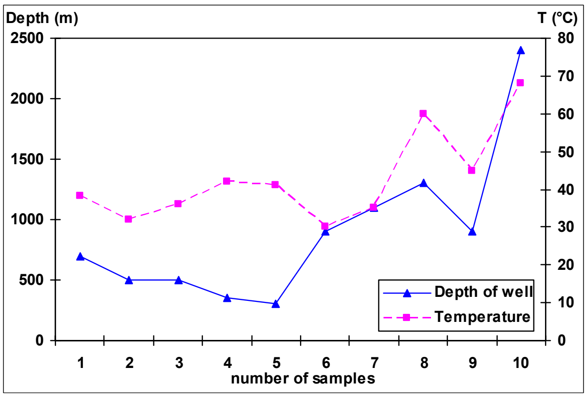


FIGURE 12: Temperature and depth range of waters in the region of Greater Caucasus

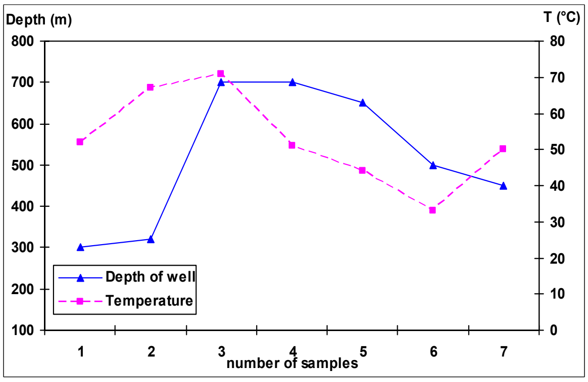
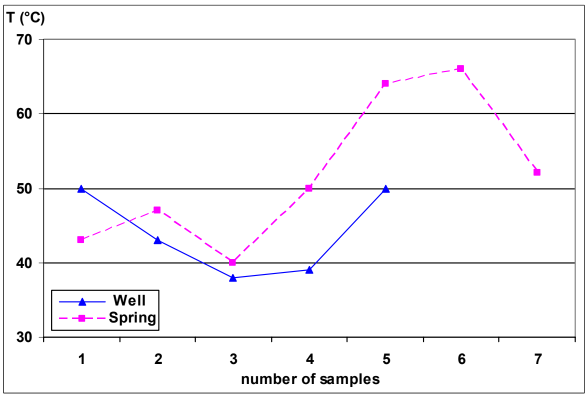


FIGURE 13: Temperature and depth range of waters in the region of Lesser Caucasus



FUGURE 14: Temperature and depth range of waters in the region of Talysh mounatins

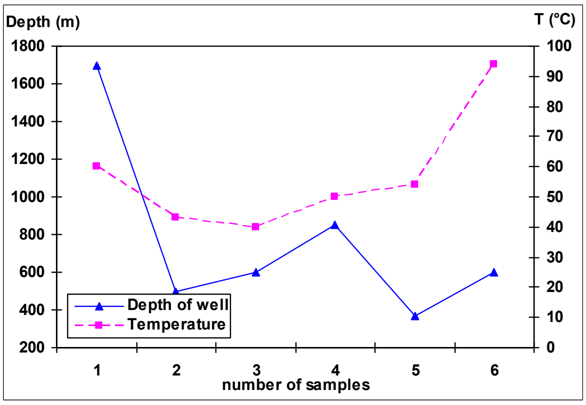


FIGURE 15: Temperature and depth range of waters in the region of Kura-Araz depression

In Talysh Mountains (south), temperatures up to 65°C are found innatural springs, and in wells in the Lyankaran lowland up to 50°C. The high temperature water is in magmatic rocks (Figure 14).

In the Kura-Araz depression (between Greater and Lesser Caucasus, and Talysh Mountain), temperatures in a well reaches up to 94°C (Figure 15). There are large resources of thermal stratal water. In the Palaeogene-Neogene, water temperatures can reach 200°C (theoretically) (Ramazanov, 1994).

Chloride-sodium and chloride-bicarbonate-sodium 70-90°C thermal waters with 2-15 g/l mineral content and a total flowrate of 8000 m^3/day are found in the Absheron zone. There are wells in the Baku region producing 70°C H_2S waters at 400-500 m^3/day flowrates. The IstiSu (Lesser Caucasus) health resort is famous for its mineral springs which are used for medical purposes. Carbonic acid-bicarbonate-sulphur-sodium waters at 28-75°C are characteristic of this region.

The "Jaarly" area in the Kura-Araz depression and the Talysh Mountain region is promising for future geothermal utilization. A 600 m well in "Jaarly" yields 11.6 l/s. The main characteristics are:

$$M_{17,2}\frac{Cl91(HCO_3 2)}{Na89Ca9}T94°C, pH7,7$$

TABLE 3: General characteristics of hot springs in the Azerbaijan

Area	Type (depth of well, m)	T (°C)	pH	Mass flow (l/s)
	Greater Caucasus			
Gax	Well (700)	38	8.4	11.6
	Well (500)	39	8.4	8.1
Gebele	Spring	39	7.4	0.9
	Spring	38	7.5	1.9
Oguz	Well (500)	32	7.5	1.0
Shamaxa	Well (700)	36	7.5	2.0
Guba	Well (350)	42	7.2	1.4
Devechy	Well (1300)	60	6.9	5.8
	Well (900)	45	7.3	0.4
	Well (700)	40	7.7	0.2
Absheron	Well (2400)	68	8.2	5.8
	Well (2300)	40	7.8	0.7
	Well (1400)	23	7.4	0.5
Total				**40.3**
	Lesser Caucasus			
AR Nakhchyvan	Spring	25	6.1	0.3
	Well (1080)	28	6.9	1.7
	Well (500)	30	6.5	3.2
	Well (700)	42	6.4	3.2
	Well (300)	52	6.5	9.7
	Spring	29	6.1	0.4
Kelbadjar	Spring	55	6.6	0.3
	Well (250)	64	6.5	23.1
	Spring	54	6.7	2.3
	Well (700)	71	6.7	34.7
	Spring	39	6.8	9.3
	Well (320)	67	7.1	0.2
	Well (700)	51	7.1	0.6
	Well (700)	44	6.7	9.3
Gazahk	Well (450)	50	8.1	0.2
Total				**98.5**
	Talish Mountain			
Astara	Spring	46	7.4	11.6
	Well (500)	50	6.7	11.6
Lerik	Spring	42	7.1	3.5
	Well (1000)	43	7.7	11.6
	Spring	47	6.7	11.6
	Spring	38	7.1	0.6
	Well (900)	37	7.3	3.5
Masally	Spring	50	6.2	11.6
	Spring	64	7.9	17.4
	Spring	66	8.2	4.7
	Spring	44	7.3	2.3
	Spring	52	7.5	5.2
Total				**95.2**
	Kura-Araz depression			
Neftchala	Well (1700)	60		12.7
	Well (43)	43	6.9	13.9
	Well (600)	40	7.3	3.5
Ter-Ter	Well (850)	50	7.2	7.0
	Well (370)	54	7.6	0.9
Jaarly	Well (600)	94	7.7	11.6
Total				**49.6**

5.3 Balneological utilization of thermal waters in Azerbaijan

Azerbaijan possesses rich natural thermal and mineral water resources, which can potentially be used for:

- Bottled water production;
- Medicinal purposes, for spas and health clinics that utilize the waters to treat arthritis, dysfunction of the nervous system and skin diseases;
- Thermal heat, for warming soil, hotbeds and hothouses with the aim of early and rapid growth of vegetables and fruits (40-50°C). This could provide three harvests a season. Taking tomato and cucumbers as an example, based on the current prices for these products, the return period for an investment in a covered greenhouse using thermal water would be 1.5 to 2 years;
- For the generation of electricity (80-100°C and higher).

In Azerbaijan, about 200 groups of mineral and geothermal waters discharge more than 100 million l/day (Table 3). Analogues of all the world's famous carbonic, arsenious, iodine-bromine deposits and hydromineral resources such as at Vishy and Lya-BurBul (France), Ems (Germany), Borjomi (Georgia), Marianske Lazne (Czech Republic) etc. have been discovered and explored (Figure 16) (Ibrahimova, 2002).

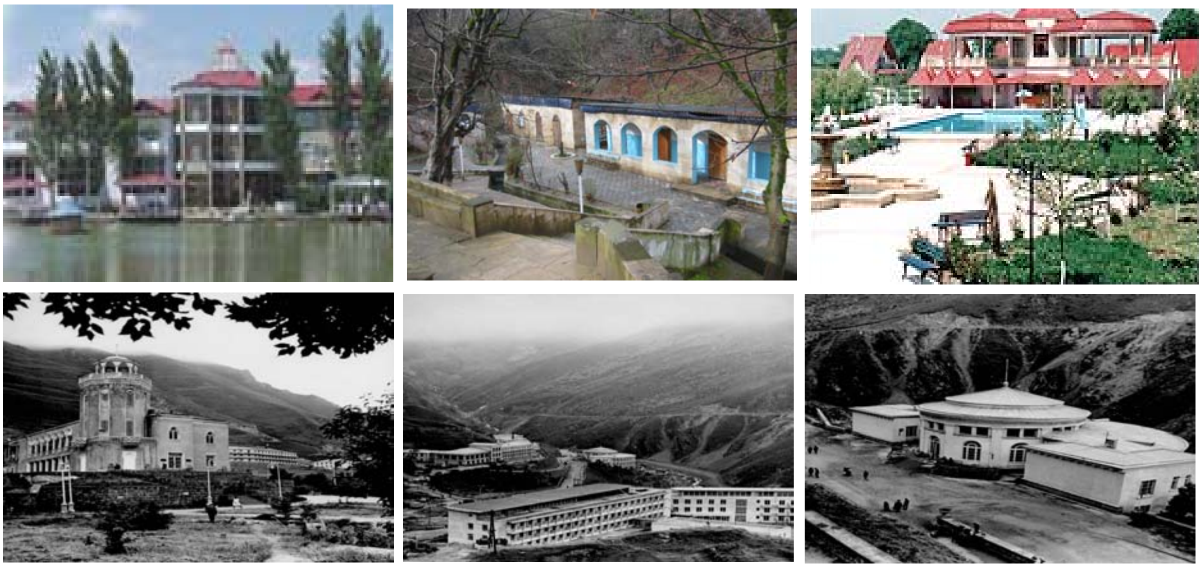


FIGURE 16: Health kurorts and spas in Azerbaijan

The most famous spas and health sanatoria in Azerbaijan are:

"Naphtalan" – in the Kura-Araz depression: This balneological health resort is situated 337 km to the west of Baku. The main natural curing factor is a unique Naphthalan oil (Naphthalan) which is extracted from boreholes. It is used for curing diseases and the after effects of injuries to the motor and supporting organs, diseases of the peripheral nervous system, skin, peripheral vessels and gynaecological disorders. Naphthalan positively affects the activity of endocrine glands and metabolism, and possesses local anti-inflammatory and anesthetic properties.

"Kala-Alty" – in the Greater Caucasus: Hydrogen-carbonate calcium-sodium-magnesium waters, containing organic substances of oil origin are the main natural curing factors. The waters are imbibed (the local mineral water is of the "Naphtusi"- type of water of the health resort "Truskavetz" in the Ukraine). The main conditions treated are: diseases of the stomach, the liver and biliary ducts, the kidneys and the urethra canal, urology and metabolic disorders.

"Lyankaran" – in the Talysh Mountain: Thermal sulfide, chloride, sodium-calcium waters (up to 43°C) of Andjin (Upper and Lower) mineral springs, situated 12 km to the west of the town, are the main natural curing factors, together with a mild climate, a warm sea and a fine sandy beach (bathing season from May to October). The waters are used for balneotherapy to treat diseases of the motor and supporting organs, the peripheral nervous system and skin, and gynaecological ailments (Table 4).

TABLE 4: Mineral water reserves and balneological features of the fields

Water suitability for balneological purposes	Mineral water reserves (m^3/d)		Names of mineral water fields
	Approved	Forecast	
Cardio-vascular diseases	1069	8700	Astara, Arkivan, Bagyrsag, etc.
Neuralgic diseases	6309	2050	Buzovni, Surakhany, Chagan
Gastric-intestinal diseases	4648	14	Badamly, Vaikhyr, Sirab, Slavyanka, etc.
Skin diseases	252	3100	Bilgin, Mardakyan, Surakhany etc.
Gynaecological diseases	1802	4000	Bagyrsag, Nabran, Surakhany etc.
Diseases of kidney / urinary tracts	15.7 / 365	-	Galaalty, Badamly etc.
Musculo skeletal diseases	1948	1670	Bilgyakh, IstiSu, Meshasu, Nabran, Surakhany, etc.
Mineral table waters	3951	-	Goturlu, Garasu, Mozchay, etc.

Due to the differences in chemical composition and temperature (6-100°C) of the mineral and thermal waters, and natural-climatic conditions, the resort business in Azerbaijan has become one of the major branches of the national public health services.

Large reservoir carbon dioxide mineral waters are mainly found in the Lesser Caucasus and are confined to joints of volcanogenic deposits. Hydrogen sulphide waters are found on the south and southeast slope of the Greater Caucasus, in the eastern piedmont of Talysh and are confined to sedimentary deposits. In some places these waters are confined to joints of rocks where sulphide mineral waters prevail. Nitrogen and nitrogen-methane waters are widely developed in the oil and gas bearing regions of the Republic (Ibrahimova, 2001).

6. ENVIRONMENTAL IMPACT ASSESSMENT

Since the first Environmental Impact Assessment (EIA) system was established in the USA in 1970, EIA systems have been set up worldwide and become a powerful environmental safeguard in the project planning process. Many countries have adopted their own EIA procedures. Some national and international organizations or legislatives refer to the World Commission on Environment and Development that espoused the principle of sustainable development in its 1987 report, and to the 1992 United Nations Conference on Environment and Development, established to adapt human activities to nature's carrying capacity (Morris and Therivel, 1995), in order to influence the relationship between development and the environment. An Environmental Impact Assessment is the tool most widely used in environmental management.

The environmental issues considered in this assessment include: geology, landscape, land use, climate, flora, fauna, water quality, air quality, occupational and public safety and socio-economic conditions. Initial screening of potential impacts due to development indicated that impacts on the land use, climate, flora, fauna and air quality were too low to entail noticeable environmental disturbances. The small portion of land required for development will not alter the existing land use. The estimated air emissions of greenhouse gases from the atmosphere discharge systems are considered significant due to the rarity of wild life and vegetation.

Only potential impacts on the geology, landscape, water quality, occupational and public safety and socio-economic conditions are further addressed in more detail.

Before an EIA study is undertaken it has to be made clear what developments are planned and what they will entail, e.g. what is the planned development, an exploratory well or a full scale plant?

Alternatives: One of the aims of the EIA study is to compare the economic and environmental consequences of a project with other projects based on other energy sources, as well as a "no project" alternative."

Previous work: An account of all previous work in the area will have to be prepared.

Physical disturbances: Road construction, number of wells drilled, number of drill pads needed, the number and nature of buildings and other installations required must be listed. Is it likely that surface geothermal activity will change, and in what way, i.e. are hot springs likely to disappear or is reduced pressure likely to induce boiling and cause increased surface activity? Is there a substantial tourist industry in the area which might be affected by such changes? Are increased noise and unpleasant smells likely to disturb the local community and/or tourists? Weather conditions and their effects will be studied. Are there any monuments, either natural or constructed, that may need protection?

Chemical changes: Is the chemical composition of the effluent likely to affect the present environment by contaminating groundwater or surface water, either water for human consumption or streams or rivers where there is fishing? Water that is discharged into the environment needs to comply with international safety standards, and must not cause damage to installations either by deposition or corrosion. In addition to water analysis, thermodynamic calculations and possibly laboratory experiments may be needed to ascertain its safety. The chemical composition should be monitored regularly during production.

Quantity of water: Flow and temperature of discharged water must be monitored and decisions on appropriate use and treatment made. Where two or more wells have been drilled, pressure data should be employed to estimate the reservoir capacity. Pressure, temperature and flow should be monitored regularly during production.

Analysis of data: Appropriate computer programs should be used to study the interaction between the various parameters determined during exploration and production.

6.1 Environmental conditions in Azerbaijan

Environmental problems refer to undesirable changes which occur in the environment as a result of human activity and which have a negative influence on human health, the state of the ecosystem and the ability of the environment to function (Roberts, 1991). Analysis of the environment in Azerbaijan revealed that the most acute problems are in the area of environmental preservation.

From a geographical point of view, the parameters affecting the distribution of the negative influence of anthropogenic processes on the environment are quite variable and are found, to a certain extent, all over the Republic. Almost 30% of the coastal area is exposed to contamination. More than half the rivers (50.6%), totalling more than 100 km in length, are considered to be contaminated. All the lakes of the low-lying parts of Republic have been exposed to changes in their thermal, biological and chemical regimes. The lakes of the Absheron Peninsula and the Kura-Araz depression, with a total area of more than 200 square km, are in a critical state (Figure 17).

The most important towns of the Azerbaijan republic – Baku, Sumgait and Ganja are on the top of the list of the cities with a high level of environmental contamination. In these cities, the contamination level, with reference to the amount of different contaminants, is several times higher than the average level in the Republic. More than 60% of the Republic's territory is already exposed to erosion processes of varying intensity, including 16% being strongly-eroded, 14.8% suffering average erosion and 31.2% being slightly eroded. Up to 80% of the mountainous area and more than 45% of the agricultural lands are exposed to erosion. The area of salinized lands all over the Republic is almost 1.5 million hectares or 50% of all agricultural lands. The area damaged through technology along with the contaminated regions constitutes almost 25 thousand hectares.

FIGURE 17: Result of anthropogenic pollution by oil and gas exploration in Absheron region (SCENRA, 1995-1999)

Among the most acute and common problems relating to the protection of flora are: an extremely high (83.8%) share of forests, pollution of forests by industrial waste (12,000 hectares), cattle pasture (15,500 hectares) and recreational activities (about 2,000 hectares).

The strongest anthropogenic impact on forests is the felling of timber for fuel, which has become especially acute during the last few years due to a rapid decrease in the natural gas supply and the lack of other types of fuel (bituminous coal, kerosene and others). About 65% of the Republic's population suffer from a lack of fuel, and due to this, the use of wood for space heating has increased 3-4 times, mainly using local resources. There has been a depletion in the forest berry fields, mushroom areas and medicinal flora. Due to military hostilities and a demographic redistribution caused by the presence of more than 1 million refugees, there has been a sharp increase in population pressure on the central regions. Growth in the amount of livestock displaced from the territories under occupation is an areal threat, which may cause over-grazing, and a depletion of the main plain pastures. The situation with the fauna is in close correlation. With the reduction of habitat areas and an increase in anthropogenic pressure, the abundance and variety of fauna has declined. The list of rare and endangered species of fauna and flora to be included in the "Red Book" of Azerbaijan has been considerably extended.

The reduced water volume and the change in the character of flow distribution, temperature, transparency, etc, have resulted in a rapid decrease in the volume of commercial fish catches.

6.2 Water pollution

Four kinds of pollutants in a surface water body are considered: inorganic non-toxic, inorganic toxic, organic non-toxic, and organic toxic. The indices which describe pollution in a water body are: oxygen demand, i.e. BOD (Biochemical oxygen demand), COD (Chemical oxygen demand), TOD (Total oxygen demand), TOC (Total organic carbon), vegetative nutrients, i.e. water body eutrophication, oil pollutants, phenolic pollutants and heavy metal pollutants (Thors and Thóroddson, 2006).

The pollution level of the water basin in Azerbaijan is extremely high. About 12 billion m^3 of effluents are released into the natural water reservoir – the Caspian Sea – and 80% of the effluents come from the Volga River (SCENRA, 1995-1999). While most of the coastal zone of Azerbaijan is, in general, moderately polluted, the Baku bay and the water basins in the vicinity of Sumgayit have been exposed to severe pollution.

Estimates show that, on average, 581 million m^3 of wastewater (copper, zinc, phenol, oil residues and toxins) substances are discharged into the Kura River. In addition, an annual discharge of 50,000 tons of untreated organic waste from industrial and municipal effluent sources leads to eutrophication (Appendix II). In general, the main cause of pollution in natural water reservoirs is a shortage of sewage systems and treatment facilities, and those that are in use have become obsolete.

Pollution of groundwater is different from pollution of surface water. Its main characteristics are concealment and irreversibility, revealed by water quality assessment, water quantity assessment, and a relevant geological environmental quality assessment. The assessment parameters chosen are general physical properties resulting from the chemical properties and reaction characteristics of groundwater, common heavy metals and poisonous materials, organic pollutants and bacteria.

6.3 Air pollution

Due to the recent reduction in production, the amount of emissions from stack sources has been in considerable decline. However, due to the recent increase in the number of vehicles, the share of emissions from mobile sources of the total amount of emissions released into the atmosphere has increased up to 40%; in 1996, it constituted 26%.

It should be noted that the main sources of gas emissions to the atmosphere are oil exploration, oil refineries, oil chemistry and energy producing plants and vehicles. The emissions from stack and mobile sources are mainly solid dust particles, carbon oxides, nitric oxides, sulphur oxides, hydrocarbons and other gaseous substances. Of these, 96% are released from the five large cities of Azerbaijan – Baku, Sumgayit, Ali-Bayramli, Mingachevir and Ganja. The main causes are outdated technologies and obsolete facilities as well as the use of mud fuel in lieu of natural gas and a lack or inefficiency of gas and dust scrubbers; these emissions are supplemented by an increase in the number of vehicles.

6.4 Soil degradation

The soil environmental quality assessment is divided into three categories: original soil environmental quality assessment, soil environmental pollution assessment and soil quality assessment. These entail:

- A status survey of soil environmental quality, including chosen sampling spots, a sample collection, preparation for monitoring and analysis, and a vegetation survey including a sample collection.
- Chemicals considered include heavy metals and poisonous materials, i.e. *Hg, Cd, Zn, Pb, Cu, Cr, Ni, Fe* etc; organic poisonous materials, such as phenol, oil, DDT etc.; acidity, total P, and so on.
- The standards chosen for the accumulation assessment include regional background values, and concentrations of reference chemicals in soil and vegetation (based on Environmental quality standard for soils, GB 1561-95), etc.

The soil cover in the country varies and suffers from environmental problems due to manmade impacts. Only 4.2 million hectares of a total of 8.6 million hectares of land in the country are suitable for agricultural purposes. This land has tended to degrade due to the effects of erosion, salination, bogging, chemical pollution and other processes.

One of the factors playing a particularly important role in this process is erosion (wind, washout, ravine and irrigation erosion) to which 3.7 million hectares have been exposed and of those 0.7 million hectares or 43% are agricultural land, the nominal value of which is about one billion US dollars. Exposure of this land to adverse effects, besides climatic conditions, is linked to their remaining idle for a long time in terms of cultivation, as well as to the low level of agrarian culture, unregulated grazing, destruction of forests and vegetation and other manmade factors.

Some areas are vulnerable to biannual water torrents which can cause enormous damage, washing away about one million cubic metres of soil. The zone in danger partly encompasses the Great Caucasus mountain range.

6.5 Surface disturbances

The main environmental effects of geothermal development are related to surface disturbances, the physical effects of fluid withdrawal, heat effects and the discharge of chemicals. All these factors will affect the biological environment as well. As with all industrial activities, there are also some social and economic effects (Ármannsson and Kristmannsdóttir, 1992).

Among the causes of desertification are natural factors such as climate change, wind, water torrents etc., but human impacts play a significant role as well. Unprofessional agricultural management in some parts of the rural area, constituting 0.18 hectares per person, is subjected to degradation resulting from natural and human impacts. As a result, general productivity has dropped, on average, 10-20 % in areas with low salinization, 20-40 % in areas with moderate salinization and 65-75 % in areas with high salinization. About 30,000 hectares have become wasteland as a result of mining activities. The extraction of oil and gas, ferrous and non-ferrous metals, raw construction materials from the subsoil, irrigation facilities, and underground construction have all brought on the contamination of the topsoil and the emergence of bogs. As a result, 60.5 thousand hectares of land have become wasteland. In the Absheron peninsula alone, contaminated and destroyed land covers 13.5 thousand hectares.

About 20-25% of the land in the Absheron peninsula is used by the large cities of Baku and Sumgayit, comprising numerous settlements, industrial sites, roads, various communication facilities etc. In recent years, an increased loss of topsoil has been witnessed from privately constructed houses in connection with land privatization.

As a result of the disposal of industrial and municipal wastes from these cities, 1000 hectares have been turned into dumping sites and become wasteland. Serious damage has been caused to the land resources of the Absheron peninsula. Drilling and oil processing activities have caused 7400 hectares of land to become wasteland, natural lakes have been polluted and many artificial lakes have emerged. Oil and oil residues have sunk to a depth of 3 m and more, thereby causing contamination of groundwaters.

6.6 Waste management

Significant opportunities exist for the application of more environmentally sound and cost effective technologies and practices in industry throughout the developing world. Cleaner production (CP) practices frequently allow inefficient industries to increase productivity, reduce costs, enhance competitiveness in domestic and export markets, improve their public images, as well as public health, and the environment.

Until recently about 3 million tons of waste had been dumped in temporarily designated sites due to the absence of toxic waste landfills. Over 8 million tons of DDT, which is forbidden and unfit for use, and other persistent organic pesticides are stored in a landfill located in Gobustan. Their detoxification remains a problem due to a shortage of funds and a lack of modern technology.

One global challenge is to alleviate the pollution levels of persistent organic pollutants and heavy metals. This is an actual issue for Azerbaijan and an important challenge. The main sources of such pollution are oil refineries, oil chemicals, chemicals, energy production, construction materials, industry and transport. The pollution is also caused by the use of pesticides in agriculture and the burning of waste. Dioxins, furans, biphenyls, and heavy metals are discharged to the environment from these sources. The aforementioned compounds are chemicals that have a durable negative effect on the environment as well as on human health.

The disposal of industrial and municipal wastes over a long period of time has, in its turn, been the cause of the emergence of dangerous environmental situations. Several tons of mercury dumped at a Detergent Plant in Sumgayit has made this area an environmental disaster area. The gradual permeation of this substance into the soil as well as its evaporation has posed a serious threat to human health.

There is also a particular concern about the disposal of municipal wastes in large human settlements, especially in large industrial centres. A great number of unauthorized landfills have been created around such cities as Baku, Sumgayit, and Ganja. This, along with environmental pollution, has also become a source of disease, posing a threat to human health.

It is necessary to completely change Baku's current disposal system, which does not meet contemporary standards, from collection and transportation to detoxification of the solid municipal wastes generated. The recycling of wastes is another approach to the reduction of wastes. Findings showed that small businesses operating in Baku produce plastic containers for non-food products, watering pipes and accessories, shoe soles and other goods by recycling industrial and municipal wastes. These wastes, containing polymer and plastic substances, are collected from the public. However, since the production capacity of these enterprises is limited, only a small part of the waste can be recycled. By today's standards, their technological processes are carried out using substandard equipment.

7. NATURAL DISASTERS IN AZERBAIJAN

Earthquakes and seismic effects can be considered the most investigated type of hazard within Azerbaijan territory. When marking possible dangers in the mudvolcanic areas, it is necessary to pay attention to the regional and local hazards connected with mudvolcanic gas bursts. Often the most dangerous fiery eruptions occur within the eastern part of Azerbaijan. There are three levels of gas burst intensity of mud volcanoes to be considered: great, average or little risk. Local risks connected with mud volcanic manifestations can be subdivided into three categories (Figure 18).

FIGURE 18: Mud volcanoes of Azerbaijan (GIA, 2006)

The first risk category concerns fiery eruptions in the area of the mud volcano and its vicinity, at up to 1-2 km distance, becoming a zone of increased temperatures considered dangerous. The second risk category concerns secondary gas bursts around the volcano itself, on its slopes and beyond the breccia. The third risk category concerns the accumulation of mudvolcanic gas in the top part of the structure to a depth of 500-1000 m. The gases emanating via volcanic conduits fill the sandy pockets in Quaternary upper Pliocene deposits and emerge with great intensity upon drilling and vibro-impact. This type of risk may exist at significant distances from the mud volcano, up to 5 km and more depending on the geological structure (Guliyev, 2006).

The possible natural disasters in Azerbaijan may cause secondary hazards connected with technological activity. The greatest hazards are the following: destruction and collapse of buildings, bridges and other structures, floods caused by the breakage of dams and water pipes, fires caused by damage to oil storage units and the breakage of oil and gas pipe-lines, the collapse and overturning of objects inside and outside buildings, the damage of transport, communication, energy and water supply systems, and radioactive outflows from nuclear reactors.

8. CONCLUSIONS AND RECOMMENDATIONS

In Azerbaijan there is a large number of underground geothermal, mineral, and spring water resources. Twenty-eight significant mineral water springs could be further developed at existing spas (health resorts), sanatoria and curative centres. The mineral geothermal water from the IstiSu (near Kelbajar, a region under occupation by Armenians) can be compared to the famous therapeutic warm sulphur springs of the Karlovy Vary resort in the Czech Republic.

The natural outlet of geothermal and geothermal mineral water is confined to zones of tectonic dislocations and faults.

The natural mineral spring water resources supply a great number of towns and villages in the Republic and there is a great demand for bottled water in the country. All in all, Azerbaijan is blessed with many rich and varied mineral deposits, already discovered but waiting for development.

Caspian petroleum and petrochemical industries have contributed to present air and water pollution problems in Azerbaijan. In the areas of health and the environment, three fields require immediate attention. These can be identified as the need for improved access to medical services, increased quality of services and attention to the social aspects of diseases.

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APPENDIX I: Water for human consumption (mg/l)

Chemical	Characteristics	Max. desirable quantities	Max permitted quantities	
			WHO, 1984	EES, 1998
pH	taste, corrosion	6.5 – 7.5	6.5 – 9.0	6.5 – 9.5
Dissolve	taste	500	1000	1500
Silica (SiO_2)		-	-	-
Sodium (Na)	taste, toxic	20	200	150
Potassium (K)			1000-2000	12
Calcium (Ca)	deposition	<100	75-200	75 – 200
Magnesium (Mg)	taste, deposition	30	50	50
Chloride (Cl)	taste, deposition	50 – 250	300	300
Fluoride (F)	toxic	0.7 – 1.0	1.5	1.5
Sulphate (SO_4)	toxic	50 – 150	400	200
Hydrogen sulphide (H_2S)	taste, bad smell	0.05 – 0.1	0.2	0.2
Carbon dioxide (CO_2(t))		-	-	-

Chemical	Characteristics	Max. desirable quantities	Max permitted quantities	
			WHO, 1984	EES, 1998
Hydrogen carbonate (HCO_3^-)	harmful	-	700	700
Carbonate (CO_3^{--})	harmful	-	350	350
Nitrate (NO_3-N)	toxic	6	11	25
Nitrite (NO_2-N)	toxic	0	0.3	0.1
Ammonia (NH_4-N)		0.05	0.5	0.5
Aluminium (Al)	taste	0.05	0.3	0.2
Silver (Ag)		0	0.01	0.01
Arsenic (As)	toxic	0.01	0.05	0.01
Barium (Ba)	toxic	0.01		0.7
Boron (B)		1.0		0.3
Iron (Fe)	taste, bacteria	0.05 – 0.2	0.3	0.2
Manganese (Mn)	taste, deposition	0.02 – 0.05	0.1	0.05
Copper (Cu)		0.02 – 0.05	1.0	1.0
Phosphorus (P_2O_5)		0.04		
Zinc (Zn)	taste, deposition	0.5	5.0	3.0
Mercury (Hg)	toxic	0	0.001	0.001
Antimony (Sb)			0.01	0.005
Lead (Pb)	toxic	0	0.05	0.01
Cadmium (Cd)	toxic	0	0.005	0.003
Chromium (Cr)	toxic	0	0.05	0.05
Selenium (Se)	toxic		0.01	0.01
Cyanide (CN^-)	toxic	0.05	0.1	0.1
Nickel (Ni)				0.02

APPENDIX II: Environmental limits (mg/l) for biological protection (The Ministry of the Environment, 1999)

Limit	I	II	III	IV	V
Cu	≤ 0.0005	0.0005-0.003	0.003-0.009	0.009-0.045	>0.045
Zn	≤ 0.005	0.005-0.02	0.02-0.06	0.06-0.3	>0.3
Cd	≤ 0.00001	0.00001-0.0001	0.0001-0.0003	0.0003-0.0015	>0.0015
Pb	≤ 0.0002	0.0002-0.001	0.001-0.0003	0.003-0.015	>0.015
Cr	≤ 0.0003	0.0003-0.005	0.005-0.015	0.015-0.075	>0.075
Ni	≤ 0.0007	0.0007-0.0015	0.0015-0.0045	0.0045-0.0225	>0.0225
As	≤ 0.0004	0.0004-0.005	0.005-0.015	0.015-0.075	>0.075
P	≤ 0.02	0.02-0.04	0.04-0.09	0.09-0.15	>0.15

I: Metals: very little or no risk of impact. Nutrients (P): Nutrient dearth
II: Metals: Risk of impact small. Nutrients (P): Low nutrient value
III: Metals: Impact on vulnerable biological systems. Nutrients (P): Nutrient-rich
IV: Metals. Impact expected. Nutrients (P): Very rich in nutrients
V: Metals: Always unsatisfactory for biological systems/dilution area. Nutrients (P): Eutrophic