Hydrogeological and geotechnical assessments of the Kadifekale landslide area, İzmir, Turkey

G. Tarcan · M.Y. Koca

Abstract The study area is located in the south of İzmir city centre in an area built without planning permission or any overall city plan. In this area, a number of mass movements occurred in the past and the region is still an active landslide field at present. The real sliding factor is geological structure, which is made up of hard volcanic rocks overlying soft Neogene clayey soils, and forms a typical structure prone to sliding. Unplanned human activities change the hydrogeological and geotechnical stabilities of the geological formations in a negative way. Rain and water leaking either directly from the mains or septic holes infiltrate into the ground and act as one of the factors in causing landslides. It is clearly shown that the irregular urbanization in and around Kadifekale is one of the factors contributing to the landslides in the area. To prevent the occurrence of landslides in the study area an effective surface and under ground drainage should be established. Rain and wastewater should be removed from the area by separate systems. Slopes should be reduced, water-loving trees should be planted and construction of high rise buildings should be avoided.

Keywords Groundwater contamination · Irregular urbanization · Kadifekale–İzmir–Turkey · Landslide · Water leakage

Introduction

İzmir is the third largest city in Turkey and a famous historic city known in the past as Symirna. Kadifekale is also located in the south of the İzmir bay (Fig. 1). In Kadifekale, Mt. Pagos, stands in the impressive ruins of a castle and its walls were built by Lysimachus during the reign of Alexander the Great, which still dominates İzmir today. Agora, or marketplace, is the another ancient settlement area of İzmir and is also located in the study area. It was originally constructed during the rule of Alexander the Great. What remains today, however, dates from the rebuilding under Marcus Aurelius after a devastating earthquake in 178 AD. At the present time, unplanned urbanization, a high rate of population increase and emigration from village to city have played an important role in disturbing the balance of hydrogeological and geotechnical processes, and have caused the occurrence of landslides in the Kadifekale area (Fig. 2).

This paper describes a study conducted on the hydrogeological and geotechnical processes in and around the Kadifekale landslide area. A number of mass movements have occurred in the study area over the past four decades. The geology of the Kadifekale landslide fields has been extensively studied (Lahn 1950; Taşdemiroğlu 1962; Gez and Özküçük 1977; Tarkan and others 1981; Ergün and Akçığ 1981). These earlier studies mainly discuss site and lithological descriptions, the distributions of the landslide fields, and general geological structure and main properties. However, detailed geotechnical and hydrogeological studies, including monthly sampling for chemical analyses, are incomplete. Therefore, hydrogeological and geotechnical studies were carried out to define the mechanisms that result in landslides, the factors that cause rock mass movements and major sliding factors and to determine the contaminated water sources. Data taken from DEU (1992) were generally used for these purposes.

The chemical and bacteriological analyses of water samples were conducted at Dokuz Eylül University's Geochemical Laboratory and Environmental Engineering Laboratory. All the analyses were made by using methods described in APHA-AWWA-WPCF (1975). The pH of water was determined with a mod 300 WTW pH meter and the electrical conductivity (EC) with a 700 Chemtrix portable conductivity meter. In groundwater tracing tests Merck uranine dye (Na-fluorescein) and 1.5-mm diameter Merck activated carbon grains were used. Mean annual rainfall for İzmir and its surroundings, for the years 1938–1991, was 691 mm. Calculated real evapotranspiration (Etr) was done using the Thornthwaite method and was ~345 mm.

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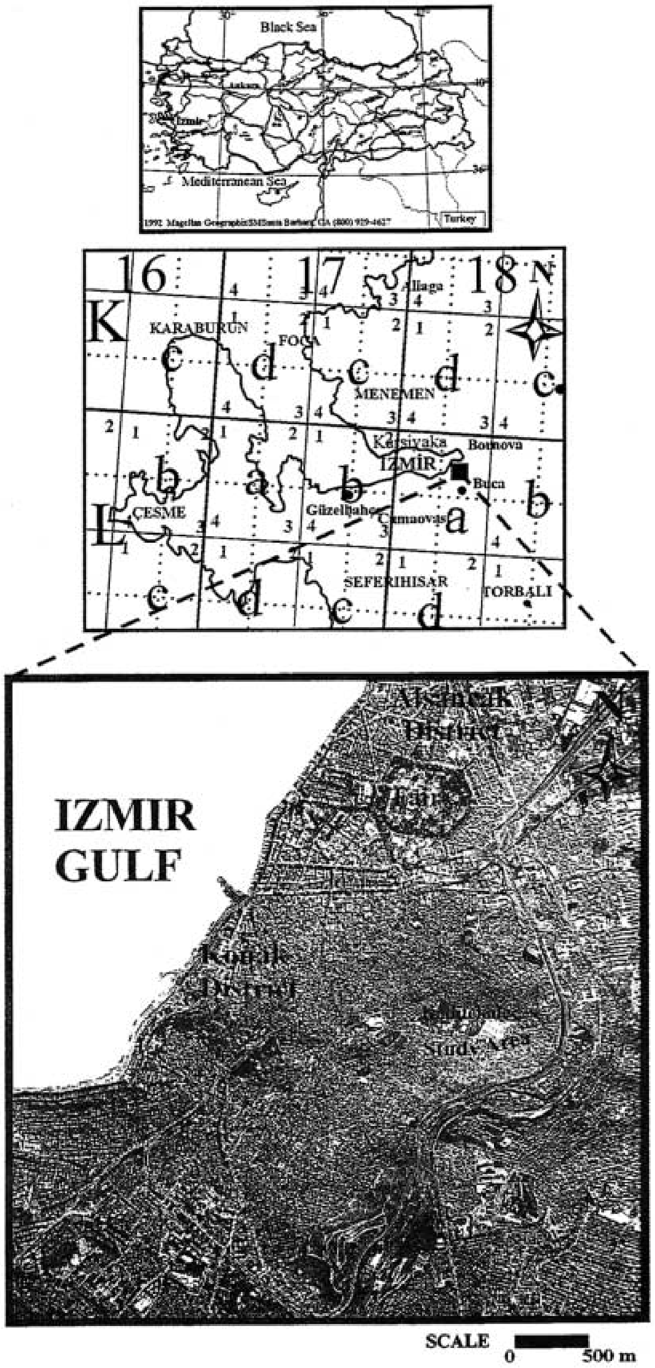

Fig. 1
Location map

Geology

Many investigators have carried out several geological studies for different purposes in and around İzmir. All of them have been summarized in later studies (Şahinci and Önal 1987; Tarcan 1989; Erdoğan 1990; DEU 1992; Filiz and Tarcan 1994; Filiz and Tarcan 1995; Koca 1995; Koca and Türk 1997). Upper Cretaceous-Palaeocene melange rocks, which consist of sandstone-shale intercalation, conglomerate, limestone, mafic volcanics, radiolarite, olistholite limestones and serpentinites and their complex, are found in the basement in and around İzmir. Weakly cemented Neogene sedimentary rocks that have variable thickness and consist of conglomerate, sandstone, claystone, marls and lacustrine limestone intercalation lie unconformable on top of the basement. Volcanic rocks have formed as a result of several volcanic episodes and these discordantly overlie the Neogene sedimentary rocks. Quaternary alluvium covers all the units in and around İzmir metropolitan area (Fig. 3).

The clayey and marly levels of these Neogene sediments mentioned above are found in the bottom of the Kadifekale area, south of İzmir bay. Neogene andesitic volcanics, known as Kadifekale volcanics, overlie the clayey and marly levels of sedimentary rocks. These volcanics generally have tuffs at the base and are continuous with agglomerates and andesitic lavas, in that order. When preparing the geological map of the study area the geological structure was simplified and some units, e.g. alluviums, colluvium, etc., were neglected (Fig. 4).

Field characteristics and mechanisms that cause landslides

The geological structure of Kadifekale is made up of heterogeneous and anisotropic materials, and clayey and marly layers lie at the base of the volcanics. As Kadifekale volcanics are highly fractured, they form a fractured rock aquifer. The fractures and voids are connected with each other, and their permeabilities are increased by fractures. The Neogene clays and marls form a relatively impermeable base below the Kadifekale volcanics. The major landslides in the field have occurred in the years 1978, 1979, 1980, 1981, 1984, 1995, 1996, 1998 and 1999. The mean precipitation data from 1971 to 1997, obtained from İzmir Meteorology Station for this study, are shown in Fig. 5. It appears that there is a relationship between previous landslides and the amount of precipitation in the area. Additionally, rainfall in and around İzmir is not regular. Thus, it is noted that landslide occurrence probability increases with the increasing amount and intensity of rain.

Spring discharge rate measurements made 1 day after a period of rainfall showed that springs 9 and 10 discharges had doubled after the rain (DEU 1992). For example, whereas the discharge rate from spring no 9 was 154 1/min before rain, it measured 277 1/min at 1 day after rain. There has not been a significant increase in discharge rate after periods of sudden and heavy rain from springs outside the landslide area. These results show that there is fast groundwater movement in the landslide area and that rainwater infiltrates into the ground quickly, and flows out of the ground after a short period. The variations in the spring discharge are caused by (1) rain-

Fig. 2
A view of the Kadifekale Hill and its high density housing

fall, (2) water leakage from the water mains of the city and (3) leakages from the septic holes. Variations in the discharge of some springs cannot be explained only by rain infiltration into the ground (Fig. 6). Sudden spring quantity variations have also been observed in some springs because of leakages from water mains and excessive water usage.

The rainfall and wastewater that infiltrate through the fractured rock aquifer change the properties of the clayey and marly layers at the base, and generate high pore water pressure. This causes landslides or the formation of springs. Weathering of the Kadifekale volcanics, which causes instability of the slopes, forms clays. It is noted that there are two kinds of rock mass movement in the area. The first is associated with the clay materials formed as a result of the weathering of andesites of the Kadifekale volcanics, the second is associated with the Neogene clayey layers at the base of the Kadifekale volcanics. It was determined that the rock mass was prone to sliding along the cooling joints, even at very low angles of incidence, at higher elevations of Kadifekale Hill. However, for tectonic joints, the movement of the rock blocks are controlled by the dip angle and the cohesion and internal friction angle of the weathering products: andesites and clay fills. These types of slope failure occur as moderately and highly weathered andesite blocks move along the topographic slopes (α>17°). They occur suddenly and the topographic slope angles where these types of failures take place varies between 17 and 22°. These sorts of failures are very frequently observed in the higher elevations of the Kadifekale landslide area (Figs. 7 and 8). Building columns are bent and buildings are separated from one another because of the indirect effect of the sliding movements in addition to large-scale damage and failure. Andesites are weathered to clay minerals and have thickness of 5–10 m in the stepped structure forming areas. The degree of weathering changes with depth and in most parts water moves along fractures and mixes with groundwater. Andesite blocks laying on the surface are seen to move by rotation. Thus, the overlaying buildings are observed to have failed by back tilting. As a result, rotational movements occur at the base of the rock blocks and swelling occurs at the front of the blocks. These sort of sliding movements are time dependent and take place slowly. Initially, cracks are developed in the buildings and then the buildings fail.

The second type of movement in the Kadifekale landslide area is very important because of the large-scale damages it causes. A large landslide occurred in the Vezirağa district, which was caused by agglomerates sliding over the marl and tuff. Agglomerates are highly fractured, and fractures are open and consist of cemented andesite blocks with tuffs. They are found lying concordant with tuffs and unconformably with marls. Landslides in agglomerates are formed when agglomerates slide on marls and clays, which are formed by weathering of the tuffs. Both rock units are highly weathered. The residual saturated shear strength parameters are in the range of $C_r = 0.4\ \mathrm{kg/cm^2}$ and ϕ_r varies between 10 and 15°. Sliding of agglomerates on marl and tuff layers is made easy by the surface and groundwater running along the open joints that exist in the agglomerates. As the groundwater runs along the discontinuities it increases the pore water pressure and also weathers the rock mass. The sliding mechanism is more clearly shown in Fig. 7.

Kadifekale and its surroundings are divided into three zones by taking into account the rock mass movements, morphology and geological structure of the area. There is an active zone, a partially active zone, and a stable zone (Figs. 7 and 8). In the active zone, there are more slopes and landslides are actively observed. Buildings are cracked and the ground is fractured in the area. The partially active zone encircles ~60–150 m wide area around

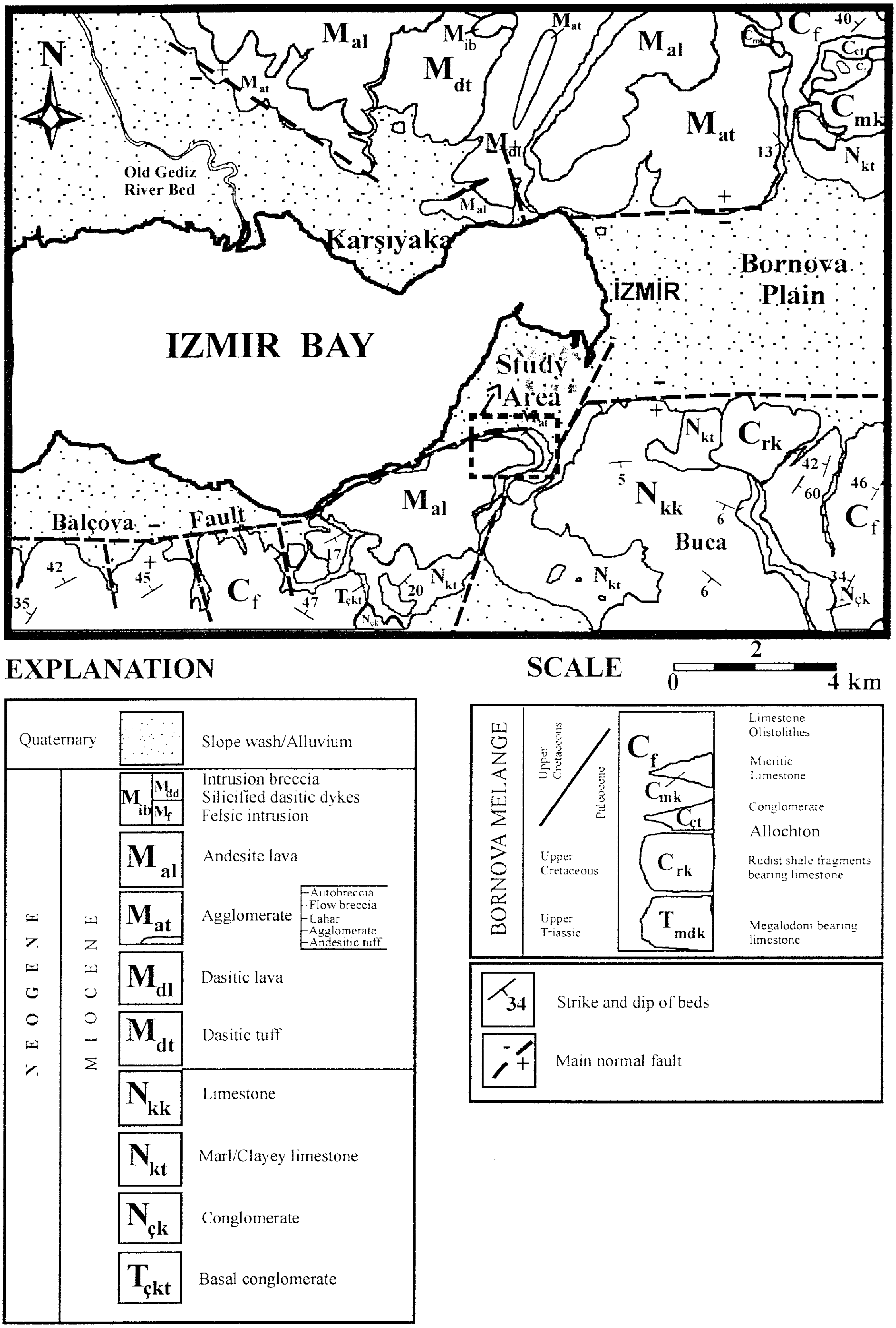

Fig. 3 Simplified geological map of the İzmir metropolitan area (modified from Koca, 1995)

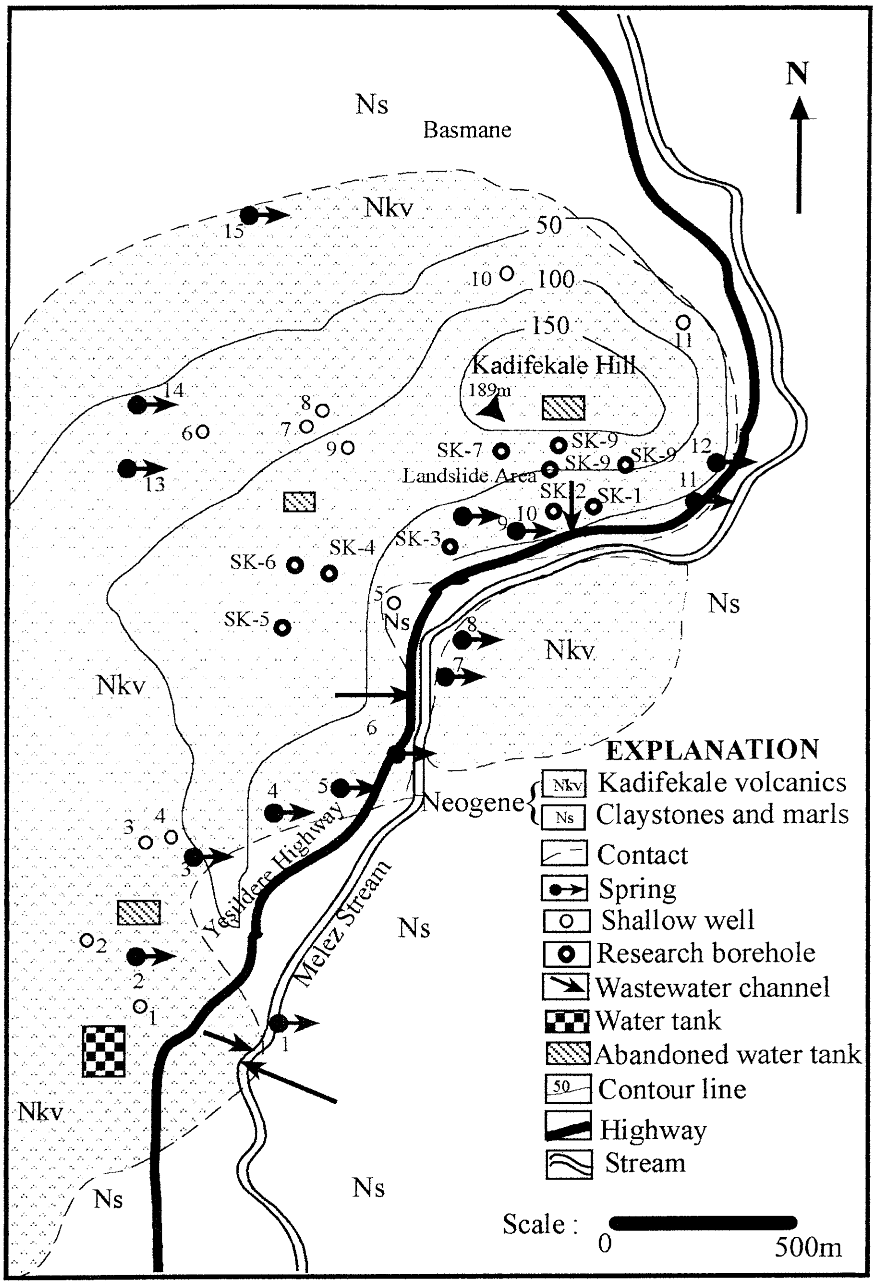

Fig. 4
Geological map of the study area and locations of the water points

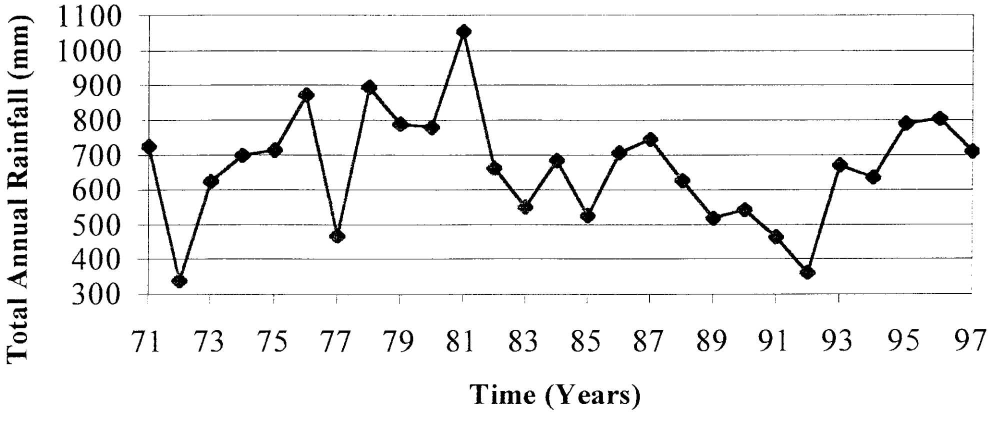

Fig. 5
Total annual rainfall amount between the years 1971 and 1997

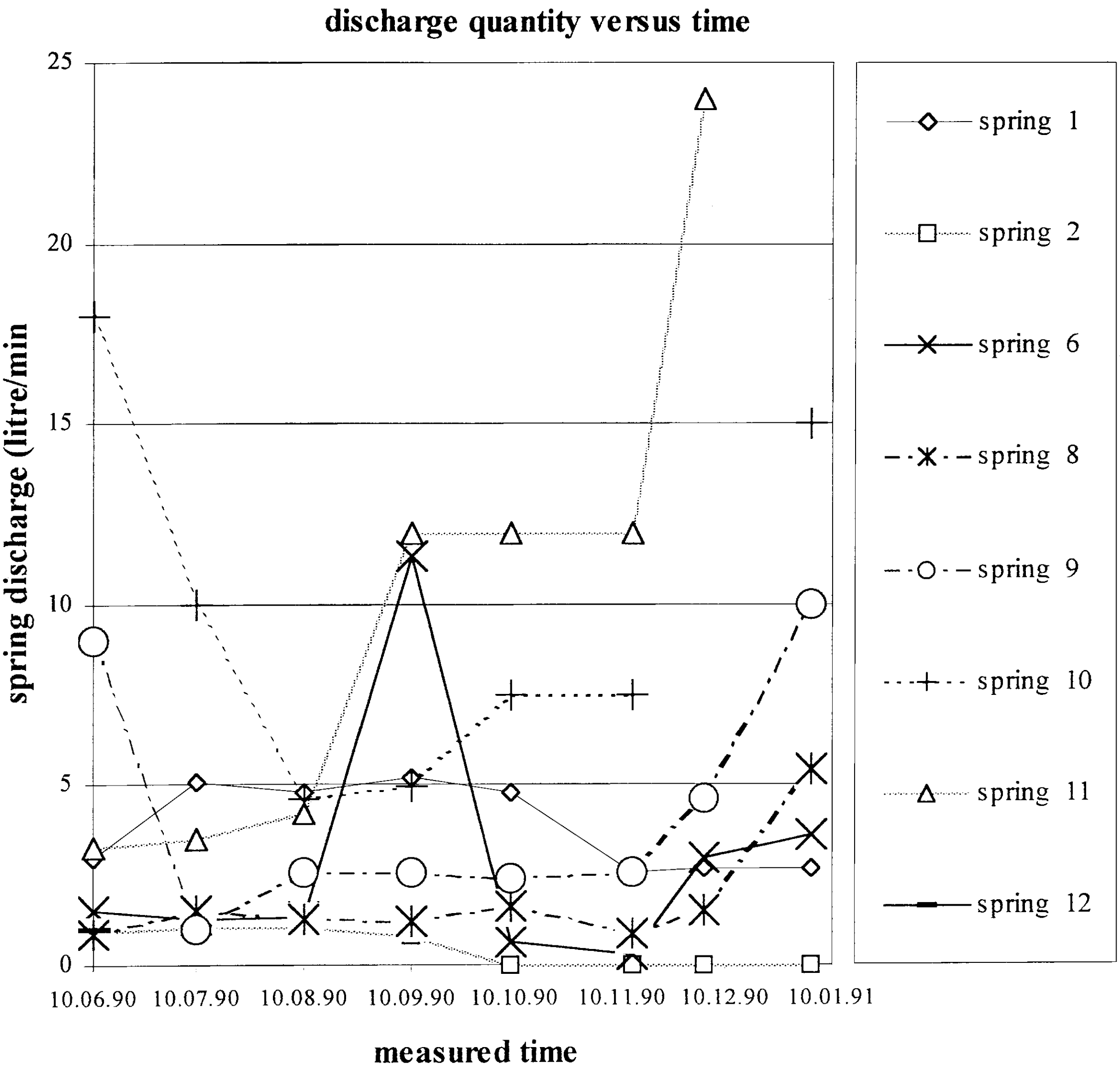

Fig. 6
Monthly variations of some spring discharge quantities in the field

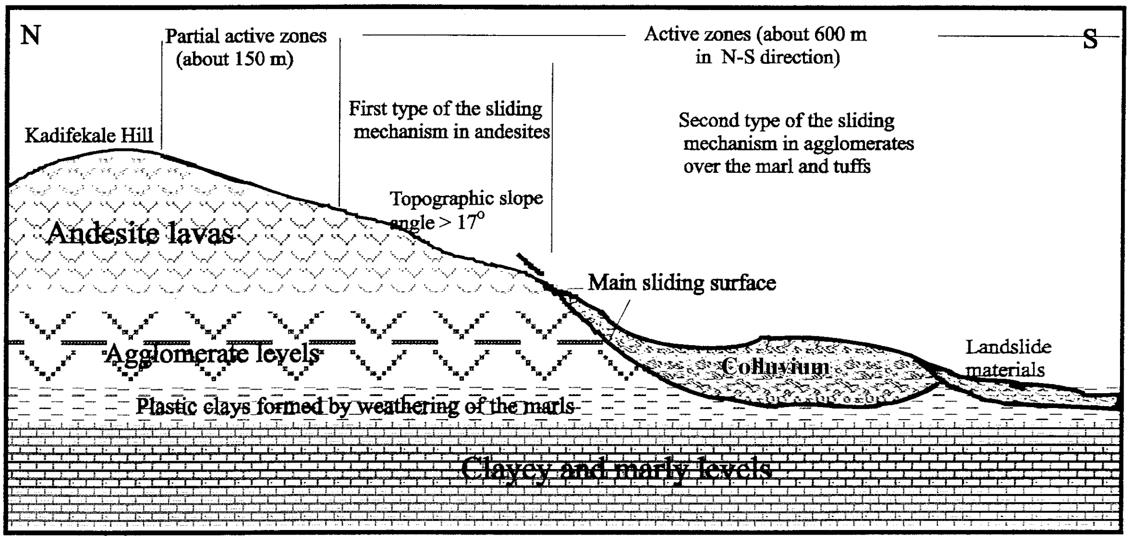

Fig. 7
Schematic geological sketch showing the landslide mechanism in the study area

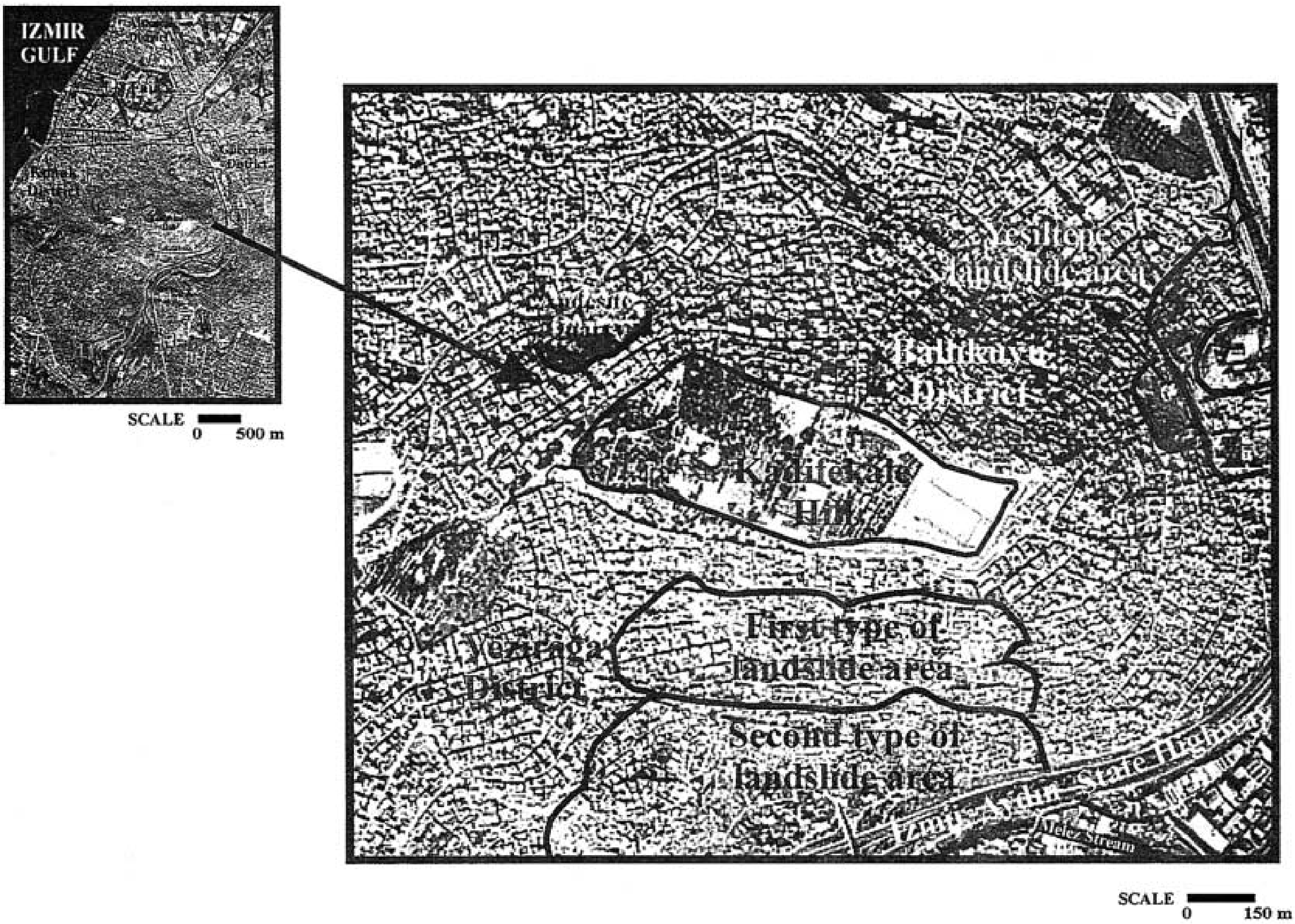

Fig. 8
A view of the study area from air photographs and the first and second type of landslide fields south of Kadifekale Hill in İzmir

the active zone. Although, there has not been any slope activity observed in this zone, probable medium-high intensity earthquakes and a rapid rise of groundwater could result in the stability of slopes reaching a critical state. The following results were obtained from geotechnical tests carried out on rock and soil samples taken from the Kadifekale area.

As the ground is highly permeable depending on the discontinuities of andesites, sudden heavy rains could change the natural environmental balance and cause landslides. Large water overflows take place when there is heavy rain because of a lack of sufficient surface drainage. It was also observed that some of the buildings were invaded by water after this sudden heavy rain. Such sudden heavy rainfall can easily lead to landslides. Additionally, in this area, groundwater is highly vulnerable to contamination because of the high permeability of the rocks and the rapid hydrological cycle.

There is no regular sewage system in the study area. Thus, water (rain, leaking from water mains and septic holes) infiltrates the ground and adds to the factors that cause landslides. Because of the paucity of a sewage system in the area, water leaking either directly from the mains or sewage septic holes, gives the same results. Prevention of this water leakage from water mains in İzmir is important not only for economical benefits but also to inhibit the landslide mechanism. If water is not discharged by regular sewage pipelines, it changes groundwater level and causes landslides.

Although the use of groundwater is banned by the health authorities around Kadifekale, people still use the groundwater in the area for their daily needs. Additionally, the banned water springs are connected to the sewage system, where it exists, and this is directed to dry wells or holes, or they are left running by themselves below the houses. Local people have said that the colour of the spring water has sometimes changed and the regularity of this has increased over the years. This indicates that there is a direct influence of human activity in disturbing the hydrogeological balance. This view has gained importance during the hydrogeological studies carried out in the area. It is clearly understood that the hydrogeological balance is negatively affected because of irregular housing in and around Kadifekale and that this is one of the factors that has caused or is causing landslides in the area. Groundwater tracers were used in highly permeable Kadifekale volcanics in the landslide area in order to investigate the relationships between two or more points in the ground. Dye, microorganisms and ion solutions were used as tracers in this study. Artificial dyes are the principal and most successful tracers at the present time. Uranine [Na-fluorescein ($C_{20}H_{12}O_5$)] was used for this study. This green fluorescein has a peak excitation and a peak emission of 485 and 515 mm respectively. They can be detected even at 0.01 mg/m^3 with the use of a digital fluorometer. A uranine injection was made in a borehole (SK$_9$) located in the upper elevation of the landslide area (Fig. 4) and in the recharge area of the springs and water channels, on 26 November 1990 at 10.00 a.m. An aliquot of 100 cm^3 of uranine was mixed in 50 l of water and injected into the borehole (SK$_9$) using 2 m^3 of water. Activated carbon was placed at a wastewater drainage channel borehole located at a lower elevation (SK$_3$) and at springs 9 and 10, which were located at a lower level where the uranine carrying water was expected to exit. Activated carbon was changed at 4-, 6-, 12- and 24-h intervals for 2 weeks. The reason for using activated carbon to trace the uranine was as follows; (1) it has the ability to detect very low concentrations of uranine in water (minimum delectability is 0.01 mg/m^3); (2) to keep the water under control continuously; and (3) to carry out a systematic investigation using a minimum number of personnel.

The uranine was extracted from the activated carbon by leaving the dried carbon in a potassium hydroxide mixture dissolved in 96% ethyl alcohol and 15% water for 24 h. The uranine that had a sensitivity of 0.01 mg/m^3 was investigated by this new solution. There was not a significant amount of uranine measured in borehole (SK$_3$), or from springs 9 and 10. However, there was a noticeable trace of uranine in the water channel 4 days after the injection. The maximum concentration recorded on the 4th day was 72 mg/m^3, and the minimum concentration was 3 mg/m^3. The distance between the uranine injected borehole (SK$_9$) and the wastewater channel where the activated carbon was sampled was ~500 m. Maximum sudden velocity of the dye injected water is Vs = 125 m/day. The maximum mean horizontal velocity was as follows.

$tm = t_1 + t_2/2 = 1 + 4/2 = 3$ day, and $Vm = 500/3 = 166$ metres per day = 7 metres per hour = 0.002 metres per second where, t = time (day), v = velocity. This proves that the ground is highly permeable and fractures are connected with each other.

Bacteriological examination of waters can be undertaken to establish the hygienic quality of the water and, if contaminated, to help trace possible sources of pollution. Highly permeable and connected fractured aquifers are bad water filters and thus transmission of microorganisms is to be expected. They can be considered as living tracers. Bacteriological analyses were carried out for 13 springs in July 1990 in order to find the relationship between the polluted and unpolluted points and between the different regions. The majority of the analysis results, except for springs 1, 11 and 12, and well 11, show the presence of faecal coliform contamination indicating leakage from the sewage system and septic holes, and this also influences the chemistry of the groundwater in a negative way (Table 2). It is well known that there should not be any faecal coliform bacteria in drinking water, but excessive counts of faecal coliform bacteria were found in most of the water analysed from the area (Table 2). This indicates that most of the natural springs are highly polluted and are connected with the leaking sewage system and/or septic holes.

Ions in solutions and variations in their concentrations can be used as a natural tracer to determine the relationship between water seepage points, flow rate and routes, and to determine the contaminated water sites and contaminants. Thirteen water points (12 springs and one shallow well) were systematically sampled in order to establish the hydrogeochemical properties of geological formations at Kadifekale. The chemical analyses of Kadifekale waters and, for comparison, unpolluted limestone and andesite waters are listed in Table 3 and plotted on a Durov diagram (Fig. 9). The locations of the water samples are shown in Fig. 4. The values of springs 1–15 listed in Table 2 were obtained by calculating the mean annual values during the period from June 1990 to January 1991. These water springs were considered to carry chemical signals about the hydrogeological structure and from their analyses it was hoped to gain an idea about the groundwater contamination and landslide occurrence. The values of springs 16 and 17 were also reported by calculating the mean annual values during the period June 1987 to April 1988 (Tarcan 1989). The plots of springs 16, 17 and 1 can be easily differentiated from the

Table 1
Some geotechnical properties of the rocks and soils in the study area

	Slightly weathered andesites	Highly weathered andesites	Highly weathered tuff	Highly weathered marl
Dry unit weight (g/cm^3)	2.4	2.27	1.72 ± 0.04	1.63 ± 0.06
Saturated unit weight (g/cm^3)	2.5	2.4	2.01 ± 0.03	1.96 ± 0.04
Porosity (%)	1.0–1.5	10–13		0.36 ± 0.08
Surface sliding friction angle	56° ± 3°	41° ± 5°		13°–16°
Dry uni-axial comprehensive strength (kg/cm^2)	655 ± 80	482 ± 63		
Saturated uni-axial comprehensive strength (kg/cm^2)	456 ± 52	272 ± 30		
Point load strength index (kg/cm^2)	48 ± 4.2	30 ± 83		

Table 2
Microbiological quality of some water points from the Kadifekale area in July 1990. Resource nos. (spring and well numbers) are the same as the locality numbers shown in Fig. 4

Resource no	Parameter	Measured concentration (no./100 ml)
1. Spring	Faecal coliform	nil
2. Spring	Faecal coliform	36
5. Spring	Faecal coliform	74
6. Spring	Faecal coliform	49
8. Spring	Faecal coliform	142
9. Spring	Faecal coliform	39
10. Spring	Faecal coliform	24
11. Spring	Faecal coliform	nil
12. Spring	Faecal coliform	nil
13. Spring	Faecal coliform	53
14. Spring	Faecal coliform	13
15. Spring	Faecal coliform	8
11. Well	Faecal coliform	nil

others in Fig. 9 because spring 1 discharges from Neogene sediments, and springs 16 and 17 are located in different area. All the other waters discharge from Kadifekale volcanics and reflect the changes caused by pollution.

Monthly periodic analytical results show no significant changes in major constituent concentrations with time for waters in the Kadifekale fields and so are not shown on a graph. Small monthly fluctuations are not regular and cannot be explained by natural hydrogeological conditions or seasonal factors. However, the mean annual compositions of waters from Kadifekale fractured rock aquifers have shown significant discrepancies in ion concentrations (Table 3, Fig. 9). Ion concentrations (particularly Ca and Mg) and hardness of waters discharged from Kadifekale volcanics are quite high with respect to the natural andesite waters. This is because of the water leakage from the water-mains of the city, and leakages from the sewage system and/or septic holes.

All the springs, except spring 1, originate from Kadifekale volcanics. Although these springs found in and around Kadifekale had high quality spring water in the past, nowadays they are chemically and bacteriologically polluted. Waters from spring 1 discharge from Neogene sediments, and springs 16 and 17 originate from andesite and limestones located in a different area. All the springs from the study area except spring 1 are plotted in the similar locations in the Durov diagram. However, springs 1, 16 and 17 can be easily distinguishable from the others. Interpretation and correlation of the analyses of 13 of the springs has shown that the groundwater was polluted with sewage and wastewater and was mixed with the İzmir mains water. As there is no sewage system in the area, water leaking either directly from the mains or septic holes contaminates the natural spring water with both chemicals and microorganisms from both systems. For instance, calcium and bicarbonate enrichment that corresponds to the chemistry of İzmir water-mains, which originates from Mesozoic karstic limestones, has been found in these spring waters. İzmir mains water reflects calcium and bicarbonate water type. The dominant ions of the spring waters originating from Kadifekale volcanics are calcium, magnesium and bicarbonate. This is a contradictory result, but is evidence of leakage from the İzmir water-mains and septic holes. While chloride increased with increasing rainfall, sulphates and sodium decreased, and EC values were variable. This shows that infiltration was not equally affective at the 13 springs and they have a different response system.

Table 3
Mean annual chemical analysis of water springs sampled for this study. Spring numbers (1–15) are the same as Table 1 corresponding to the locality numbers shown in Fig. 4. Spring numbers 16 and 17 refer to unpolluted (natural) groundwaters originating from andesite and limestone respectively (Tarcan 1989). The values of springs 16 and 17 were also obtained by calculating mean annual values from June 1987 to April 1988

Spring no.	Na (mg/l)	K (mg/l)	Ca	Mg (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	EC (mg/l)	pH (µS/cm)	Hard (Fr)	Q spring (l/min)	Water type (cation or anion) (>20% meq/l)
Spring 1	41	3	117	20	70	411	74	889	6.5	27.4	2.64	Ca-HCO_3–Cl
Spring 2	38	5	58	24	92	147	77	745	6.1	18.5	3.42	Ca–Mg–Na–Cl–HCO_3–SO_4
Spring 5	29	7	53	24	60	228	24	663	6.56	26.3	16.2	Ca–Mg–Na–HCO_3–Cl
Spring 6	29	5	38	17	60	126	69	526	6.2	24.4	6.36	Ca–Mg–Na–HCO_3–Cl–SO_4
Spring 8	25	5	46	17	45	175	66	534	6.3	23.8	42	Ca–Mg–Na–HCO_3–SO_4–Cl
Spring 9	42	8	87	42	114	309	80	834	7.03	23.1	27.8	Ca–Mg–HCO_3–Cl
Spring 10	40	8	78	34	110	285	74	866	6.04	16.5	2.34	Ca–Mg–HCO_3–Cl
Spring 11	39	5	61	27	73	207	69	664	6.24	23.4	25.7	Ca–Mg–Na–HCO_3–Cl–SO_4
Spring 12	37	4	54	24	80	155	78	680	6	38.4	–	Ca–Mg–Na–HCO_3–Cl–SO_4
Spring 13	53	6	91	38	135	208	82	973	6.5	39	4.14	Ca–Mg–Na–Cl–HCO_3
Spring 14	35	20	61	21	41	328	64	700	7.08	33.5	8.94	Ca–Mg–Na–HCO_3
Spring 15	51	28	79	21	62	367	102	818	6.74	28.4	240	Ca–Na–HCO_3–SO_4
Spring 16	18	5	15	4	24	94	50	219	7.38	5.5	48	Na–Ca–HCO_3–SO_4–Cl
Spring 17	16	5	103	5	38	308	39	709	7.33	28	150	Ca–HCO_3

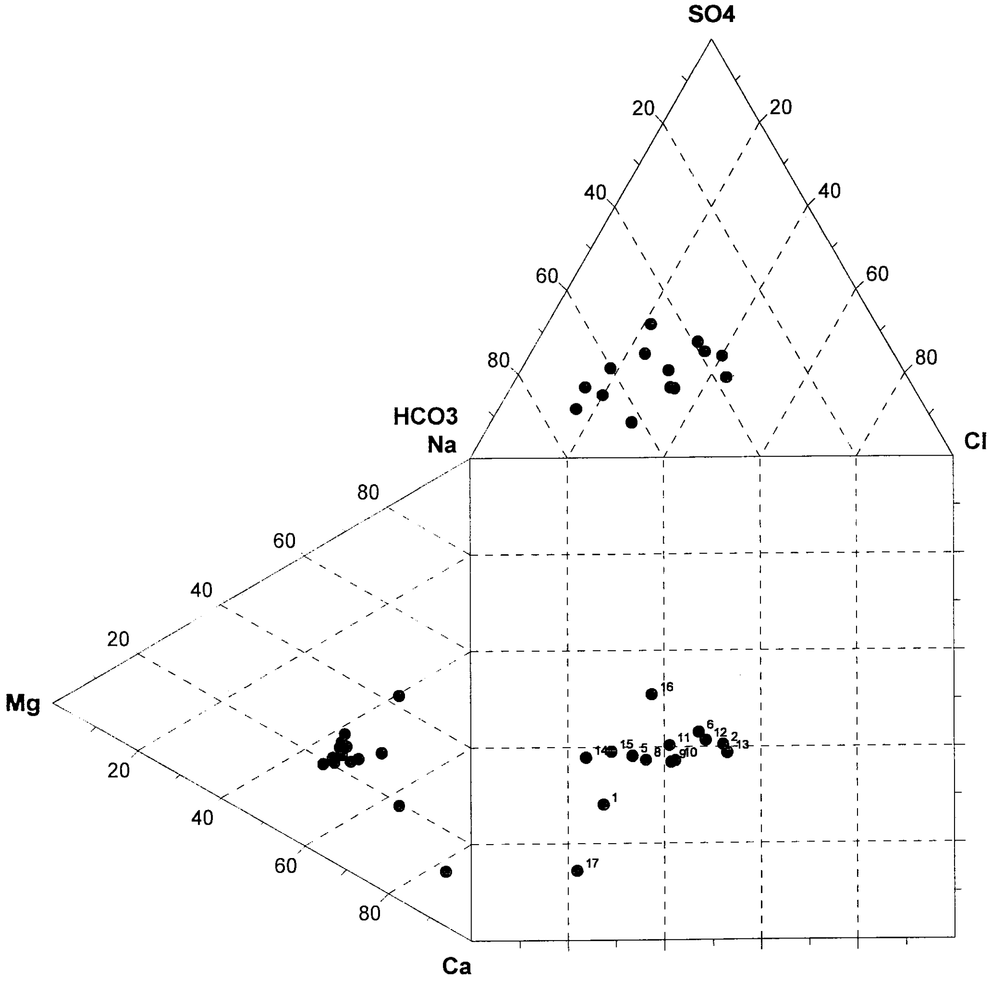

Fig. 9
Durov diagram of waters from the study area. Spring numbers (1–15) are the same as Fig. 3, springs 16 and 17 correspond to unpolluted andesite and limestone respectively

It is noted that the insufficiency of the infrastructure, a sudden increase in pore water pressure, formation of slippery ground, deficiency of plants and trees and presence of concrete structures upsets the rain surface flow and infiltration patterns. The groundwater regime is, in parts, under pressure and in other parts is characterized by turbulence flow. This is a typical behaviour shown by springs that do not show an equal response to the same amount of rain. Kadifekale volcanics are anisotropic, heterogeneous media that have a rapid groundwater circulation together with artificial water infiltration and hydrogeological media ready to any time.

Summary and conclusions

The hydrogeological structure of Kadifekale is made up of heterogeneous and anisotropic materials, and the clayey and marly layers lie at base of the volcanics. The maximum mean groundwater velocity was estimated to be 7 m/h (0.002 m/s) from the uranine dye tracer test carried out in the borehole in the Kadifekale volcanics. As Kadifekale volcanics are highly fractured and fractures and voids are connected with each other, they form a fractured rock aquifer. Their permeabilities are increased by fractures. These types of aquifers are highly vulnerable to contamination because of the high permeability. Landslides that have occurred around Kadifekale are closely related with the quantity of precipitation falling in the area in the past. As the rain intensity and quantity increase, the landslide occurrence risk increases. As there is not a sufficient surface and subsurface drainage system to remove sudden and heavy rainwater, surface overflows cause erosion and weathering as well as landslides. It has been established that the Kadifekale volcanics lying on the top of the succession are highly permeable and are affected by natural and artificial water influxes. Because there is no proper sewage system in the area, the artificial water recharge changes the natural drainage and causes landslides. Water leaking either directly from the mains or sewage septic holes gives the same results.

All springs in the study area except spring 1 originate from andesitic volcanics. But they have different chemical compositions from normal water springs originating from andesitic volcanics. Although springs found in and around Kadifekale had high quality spring water in the past, nowadays they are bacteriologically as well as chemically polluted. Calcium and bicarbonate enrichment corresponding to the chemistry of İzmir water mains, which originates from Mesozoic limestones, has been found in these spring waters originating from Kadifekale volcanics. As there is no sewage system in the area, water leaking either directly from the mains or septic holes contaminates the natural spring water with both chemicals and microorganisms from both systems. To prevent the occurrence of landslides in the study area an effective surface and underground drainage system should be established. Rain and wastewater should be removed from the area by separate systems. Slopes should be reduced, water-loving trees should be planted and the construction of high-rise buildings should be avoided.

Acknowledgements This is part of a report on the minimization of damage induced by landslides in and around the Kadifekale area of İzmir city centre, within the framework of the contact signed between the Natural Disaster Affairs General Directorate of the Ministry of Construction and the Dean of the Engineering Faculty of the Dokuz Eylül University. Some parts of this manuscript were presented by the first author in the Integrated Water Resources Management of Med. Campus Project Course at the University of Malta between 1 and 15 October 1995. The authors would like to thank Cem Kıncal for his help with art work, and Drs Şevki Filiz, Necdet Türk and Faruk Çalapkulu for their advice, guidance and encouragement, and for giving us the opportunity to carry out this study. Critical reviews by Jan Vicko and an anonymous reviewer in an earlier version of this manuscript are gratefully acknowledged.

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