LANDSLIDE RISK REPORT OF ISTANBUL

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TOMORROW'S CITIES TECHNICAL REPORT

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Tomorrow's Cities is the UKRI GCRF Urban Disaster Risk Hub

About Tomorrow's Cities

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Tomorrow's Cities is the UK Research and Innovation (UKRI) Global Challenges Research Fund (GCRF) Urban Disaster Risk Hub – a five-year global interdisciplinary research hub.

Our aim is to catalyse a transition from crisis management to multi-hazard risk-informed and inclusive planning and decision-making, for cities in low-and-middle income countries.

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1. Introduction

Landslides are the falling or flowing of rocks, soil, or debris masses down the slope. The biggest triggers of landslides, which cause extensive damage each year with its direct and indirect effects, are heavy rains, earthquakes, underground water levels, storms, and riverbed erosions [1]. Besides, with the increase of urbanization, the destruction of forests and the excavation of slopes for road or building construction are some of the important factors that cause landslides.

Concerning economic damage in many developing countries, natural disasters account for 1–2% of the national gross product [2]. Landslides cause numerous lives, property, and economic losses, especially in high areas. In the United States, landslides lead to $1-2 billion economic losses and a loss of 25-50 lives in a year [3]. In China, an average of 125 people lost their lives annually due to landslides between 1951 and 1989 [4]. Between 1971 and 1974 almost 600 people were killed worldwide each year as a result of slope failures [5]. In 1979, the Landslides Committee of the International Association of Engineering Geology reported that landslides could be linked to about 14 percent of the lives lost in natural disasters. In Italy, landslides account for almost 37 percent of the lives lost due to all-natural hazards owing to their unique geographical and geomorphological environments [6].

Many external factors can cause ground slides, including heavy flooding, earthquake shaking, and a rise in water levels, flood waves, or rapid erosion of flows that can result in rapidly increased shear stress or reduced shear strength in materials that form a slope. Moreover, as development extends into vulnerable hillslope areas under the pressures of rising population and urbanization, human activities such as deforestation or slope mining for road cuts and construction sites, etc., have become significant triggers for the occurrence of landslides [7].

In Istanbul, landslides are the first largest disaster in terms of the number of incidents and the second-largest natural disaster after earthquakes in terms of affected houses. There were 1,153 landslides reported in Istanbul, 908 earth sliding, and 245 rockfalls [8]. The social and economic losses of landslides can be reduced by effective planning and management. These approaches can be summarized as follows [7].

a) Limiting residential areas in places at high risk of landslides
b) Compliance with regulations on excavation, filling, landscaping, and building construction
c) Monitoring of groundwater level, slope surfaces, and structures in risky areas with measuring devices to prevent or control landslides.
d) Development of early warning systems.

This report summarizes the research escapades and investigates the characteristics of past landslides, especially in Istanbul. For this purpose, in the second part of the report, landslide prediction methods and the factor of safety are explained. In the third section, landslide risk assessment methods are discussed. In the fourth chapter, multi-hazard risks are highlighted and the importance of landslides in multi-hazard risks is discussed. The fifth chapter includes past research on disaster risk management. In the sixth section, the landslide hazard of Istanbul is reviewed separately for 14 regions. The results obtained in this report are summarized and discussed in the conclusion section.

2. Methodology

2.1. Assessment of Probability of Landsliding

It is very important to discover the reasons that make the ground unstable and the events that trigger the ground movement in order to calculate the probability of landslides in a given period. The factors affecting the probability of landslides can be grouped into two main groups which are factors preparatory and triggering (Table 1). The first factor is of triggering factors are earthquakes and heavy rainfalls [7]. The probability of landslides is difficult to estimate as these parameters can change quickly over time. If we neglect the triggering factors, the "susceptibility" describes the probability of landslides. It is more applicable to use the landslide susceptibility as the probability of landslide if we smooth the triggering factors within the long-term landslide records.

Table 1. The factors affecting the probability of landslides.

Prepatory Factors	Geology
	Slope gradient and aspect
	Elevation
	Geotecnical properties
	Vegetation cover
	Drainage paterns
	Weathering
Triggering Factors	Heavy rainfall
	Earthquakes

Likelihood and probability are two similar terms, but probability is used for quantitative description of probability whereas likelihood is used for qualitative description of probability. Probability has a value between zero and one. It is an indicator of the level of certainty. Probability can be explained under the four main headings described below [9]:

• **Spatial probability:** The probability that a given area is hit by a landslide
• **Temporal probability:** The probability that a given triggering event will cause landslides
• **Size/volume probability:** The probability that the slide has a given size/volume
• **Runout probability**: The probability that the slide will reach a certain distance downslope

Factors that decide the probability of landslides on a particular slope or region may be divided into two categories [10]:

1. **Preparatory variables**: Make the slope vulnerable to failure without actually initiating it and thus tend to position the slope in a slightly stable state, such as geology, slope gradient and shape, elevation, soil geotechnical properties, vegetation cover, and long-term patterns of drainage and weathering.

2. **Triggering variables**: Shift the slope from a slightly stable to an unstable state and thus induce failure in a region of given susceptibility, such as heavy rainfall and earthquakes

If triggering variables are not considered, the term ‘‘susceptibility’’ can be assigned to identify the likelihood of occurrence of a landslide. Landslide susceptibility can be defined as quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides that exist or potentially may occur in an area. Susceptibility may also contain an explanation of the velocity and intensity of the existing or potential Landsliding [9]. At present, when evaluating the probability of Landsliding on local scales, it could be possible to take into account landslide susceptibility as the probability of Landsliding based on the assumption that long-term historic landslide records tend to smooth-out the temporal effect of triggering factors on landslide occurrence [7].

The approaches for landslide susceptibility assessment are generally based on two assumptions [9]:

• The regions which have been exposed to landslides in the past are likely to experience landslides in the future.

•

The fields with environmental properties (as characterized by topography, geology, soil, geomorphology, and land use) as the areas which have experienced landslides in the past are also likely to experience landslides in the future.

Landslide frequency is a measure of probability expressed as the number of incident occurrences in a given time. As the landslide scale (magnitude) determines the run-out distance, the area covered by the deposit, and the intensity of impact, the frequency for each landslide magnitude class needs to be measured. Small landslides are considered to occur more often than large landslides. Landsliding frequency can be expressed as [11]:

- The number of landslides that can occur in the area of study during a given period. (i.e. per year).
- The possibility of a particular slope experiencing landslides in a given timeframe
- Driving forces beyond the resistant forces in terms of likelihood or reliability, with event frequency determined by considering the yearly likelihood of reaching critical pore water pressures (or critical ground peak acceleration) in the analysis.

Numerous approaches have been developed to determine the probability of landslides. These methods are divided into inventory, heuristic, statistical, and deterministic approaches [12], [13].

2.1.1 Inventory Method

The landslide inventory method can be defined as the selection of landslide features in a given region over a time period, ideally in digital form with spatial data location (as points or polygons) together with characteristic details. Ideally, these characteristics should provide information on the type of landslide, date of an event or relative age, size and/or volume, current activity, and trigger of occurrence. Landslide inventories are either constant over time or have so-called event-based landslide inventories, which are inventories of landslides that have occurred as a result of a specific trigger event (extreme weather, earthquake).

Landslide inventory maps form the basis for several other methods of determining landslide susceptibility. However, they can also be used as a basic form of a susceptibility map since they show where a particular type of slope movement has occurred in the region. The density of landslides (of different types) per administrative unit can be taken as an appropriate map of susceptibility at national and regional scales. Density contour maps (isopleths maps) can be an appropriate solution upon these small scales. Transient details may play a major role in inventory maps of landslides. They should include information on landslide occurrences over a longer period (e.g. over decades), as well as on landslide activity in the event of slow-moving or irregular landslides [9].

2.1.2 Heuristic Method

In heuristic methods, expert insights are used to predict landslide potential from data on preparatory variables. It is assumed that the relationship between the susceptibility to landslides and the preparatory variables is identified and determined in the models.

It is assumed that the correlations between landslide susceptibility and the preparatory variables are known and are specified in the models. Then a set of variables is included in the model to calculate the susceptibility of landslides. [14]. This approach is qualitative and is based mainly on the expert's knowledge and experience. Nevertheless, such susceptibility maps can provide extremely reliable results when performed by professional geomorphologists, as the susceptibility can be evaluated separately for each locality without the need to add a certain extent of simplification of causal relationships that are needed for most other approaches.

2.1.3 Statistical Method

Statistical models contain a statistical estimation of variables that contributed to the occurrence of landslides in the past. Statistical forecasts are made for regions generally free from landslides, but where comparable conditions exist [7]. Existing multivariate statistical approaches, such as multiple regression analysis and discriminant analysis, have been used to evaluate the susceptibility of landslides. [15], [16]. With the development of continuous data measuring devices, larger data can be statistically analyzed now.

Conditional Analysis holds a special position among statistical techniques, a simplified technique that is very compatible with GIS operating features and provides results that non-specialists can easily evaluate [17].

One of the most used methods among statistical methods is the multi-variate statistical model. The relationship between a dependent variable (landslide occurrence) and a set of independent variables (landslide control factors) is assessed by multivariate statistical models. All related variables are sampled either on a grid basis or in (morphometric) units in this method [9].

In recent years, with the development of artificial learning techniques, the uses of the Artificial Neural Network (ANN) technique have expanded. ANN is described as a non-linear approximator algorithm of functions used widely for pattern recognition and classification. Neurons are the fundamental units of a neural network, structured to measure a non-linear function of the inputs. A neuron receives input(s) with a given weight(s) which affects the neuron's overall impact [9].

2.1.4 Deterministic Method

Deterministic methods are based on analyzes of slope stability which extend only where the ground conditions are reasonably consistent around the sample region and the forms of landslides are defined and sufficiently easy to evaluate. The benefit of the deterministic models is that they allow quantitative safety factors to be measured with proper consideration as to the variation of soil properties when needed, while the biggest issue is the high degree of generalization that is typically required for the use of such models. Another disadvantage of the applicability of deterministic models is that data requirements for deterministic models can be unfeasible, and it is always difficult to obtain the input data needed to properly use the models [7].

2.2. Factor of Safety

Research on uncertainties contributed to the advancement of analytical approaches in a probabilistic sense while retaining the fundamental geotechnical models. For site-specific slopes, the probability of failure is generally defined as simply the possibility that the safety factor is less than unity. The Factor of Safety F(X) is defined as [18]:

$$F(X) = G(X) + 1$$

The performance function of slopes, indicated by G(X) where X is a set of random input variables, is a function that identifies the failure or safety status of the slope. The function is formulated in such a way that failure is indicated when $G(X) < 0$, and safety is defined by $G(X) > 0$. The limit defined by $G(X) = 0$ separating the safety and failure regions is called the boundary state.

3. Landslide Risk Assessment

The risk estimation can be defined as the probability of loss estimation of a disaster by risk analysis methods. Landslide risk analysis methods can be collected under two headings. The first one is qualitative risk analysis which an analysis that involves word form, descriptive or mathematical assessment measures to define the severity of possible effects. The second method is the qualitative risk analysis that an approach focused on numerical probability, vulnerability, resulting in a risk mathematical formula of the risk [9]. Whether qualitative or quantitative assessments are more effective depends on both the required precision of the result and the nature of the problem and should be consistent with the quality and quantity of the available data [7]. The methods used for the quantification of vulnerability can be categorized as:

- **Heuristic**: The vulnerability values are evaluated by expert opinion.
- **Empirical:** The vulnerability is evaluated based on the damage from past disaster information, generally by statistical back-analysis. The outcomes calculated via empirical approaches are more realistic than in the previous case as they fit real disaster data.
- **Analytical:** The vulnerability values are evaluated by direct analytical models, using as an input the intensity of the event and the features of the exposed elements. The analysis methods vary according to the sort of exposed elements. The outcomes provide more detail than in previous cases.

Landslide risk depends on “Landslide Hazard”, “Vulnerability” and “Elements at Risk” as shown below:

Risk = Hazard x Vulnerability x Elements at Risk

Landslide hazard can be defined as the probability of the occurrence of a landslide at a specific site or region. Vulnerability represents the conditions determined by physical, social, economic, and environmental elements or operations, which increase the susceptibility of society to the effect of hazards. Elements-at-risk is the population, assets, financial activities, including government services, or all the other defined values exposed to hazards in each region [19].

3.1. Assessment of Vulnerability

The vulnerability can be defined as the amount of loss of a given element or group that is subjected to a landslide of a given magnitude/intensity. It is expressed on a 0 (no loss) to 1 (total loss) level. The evaluation of vulnerability is subjective and mostly relying on past information. For instance, the vulnerability of a house at the foot of a steep slope down which a debris flow may occur is higher than for a house at the boundary of the deposition region (since the velocity of flow is less) [20].
Generally, the vulnerability to Landsliding may depend on:

(a) Runout distance of landslide
(b) The volume and velocity of sliding
(c) The elements at risk (buildings and other structures), their nature, and their proximity to the slide
(d) The elements at risk (persons), their proximity to the slide, the nature of the building/road that they are in, and where they are in the building, on the road, etc. [21].

Types of vulnerability can be examined in five categories as shown below:

- **Physical vulnerability**: Physical vulnerability represents the damage of properties (Buildings) and infrastructures (transport, pipelines, telecommunications, and energy supply lines, etc.).

- **Human vulnerability:** Human vulnerability refers to the likelihood of a landslide that causes injury or death.

- **Socio-economic vulnerability**: Socio-economic vulnerability is related to the socio-economic consequences of landslides.

- **Environmental vulnerability**: Environmental vulnerability referring to the effect on environments, vegetation, agriculture, animals, contamination due to leakages, etc.

- **Cultural heritage:** Cultural heritage is about the danger of historical and cultural structures being damaged or destroyed in landslides.

3.2. Elements at Risk

Elements-at-risk inventories can be performed at different levels, based on the requirement of the work. Elements-at-risk data should be gathered for specific essential spatial units, which may be grid cells, governmental units (countries, provinces, municipalities, neighborhoods), or uniform units with similar features concerning the type and density of elements-at-risk. Risk can also be evaluated for linear items (e.g. transportation lines) and some areas (e.g. a dam site). The risk estimation will be done for these spatial units of the elements-at-risk, rather than for the ones used in the hazard assessment. Elements at risk maps are used to develop the consequence scenarios map and, as well as the landslide susceptibility zoning map, may be used as information and advisory for legislators and governmental units [9].

3.3. Runout Behaviour of Landslide Debris

In general, runout behavior is a group of quantitative or qualitative spatially distributed parameters that describe the damaging potential of a landslide. Landslide risk assessment mainly includes [22], [23]:

- **Runout distance:** The distance from the landslide source area to the distal toe of the deposition field.
- **Damage corridor width:** The width of the site exposed to landslide damage in the distal part of the landslide path where the effect on buildings and other facilities occurs.
- **Velocity:** The travel time of deposit within the damage corridor which identifies the potential damage to facilities and the design parameters.
- **Depth of the moving mass:** The influences of the impact force of the landslide within the damage corridor.
- **Depth of deposits:** Landslide deposits may increase to a sufficient depth behind a building that can lead to collapse.

There are many methods used for the prediction of runout distance. These methods can be classified as follows:

1. **Analytical Methods:** The analytical methods contain various formulations based on lumped mass methods that the debris mass is assumed as a single point.

2. **Empirical Methods:** The common empirical approaches generally contain the mass-change method and the angle of reach. The mass-change method is based on the phenomenon that as the landslide debris moves downslope, the initial volume/mass of the landslide is being changed through loss or deposition of materials and that the landslide debris halts when the volume of the actively traveling debris becomes negligible [24].

3. **Numerical methods**: Numerical methods for modeling the runout behavior of landslide debris generally include fluid mechanics approaches and distinct element method.

3.4. Landslide risk Assessment Methods

3.4.1. Distributed landslide Risk Assessment

Distributed landslide risk assessment focuses on providing a risk map that shows the degree of risk in terms of fatality or economic loss at certain areas of a given region quantitatively or qualitatively. Landslide risk maps are the subdivision of the region in zones that are classified by different probabilities of losses (physical, human, economic, environmental) that might occur as a result of landslides. The risk may be identified as either qualitatively (as high, moderate, low, and no risk) or quantitatively (in numbers or economic values).

3.4.2. Global landslide Risk Assessment

The purpose of the “Global Risk Assessment” is to identify the relative contribution to the overall risk (e.g. the number of deaths each year), and will provide a guide for assessing landslide hazards and evaluating the distribution of capital and policy-making. It can be determined by summing up the site-specific risk of all slopes in the studied area.

3.4.3. Site-specific landslide Risk Assessment

Site-specific risk assessment provides a comprehensive hazard and risk assessment in terms of fatality (or economic loss) at a particular site or possible landslide. The method consists of the steps below. [10]:

- Consider possible triggers, such as earthquakes or/and rainstorms.
- Identify potential modes of failure.
- Evaluate the probability of failure for each mode of failure.
- For each failure mode, determine the run-out behavior of landslide debris.
- For each failure mode, determine the risk.
- For all possible failure modes, sum up the risk.

4. Landslide Risk Management

Some significant strategies can be implemented to reduce the risk in an area that has a high landslide risk. These strategies are planning (to reduce elements at risk), engineering solutions (to calculate the spatial impact of landslide), acceptance (to determine the risk is acceptable or unavoidable), monitoring and warning (to reduce elements at risk), and decision making (to choose the best strategy).

4.1. Planning

Planning is the most effective and economic strategy to reduce landslide risk. It is the strategy that decision-makers should first consider where there is a high landslide risk. This strategy can be implemented by two methods[7]:

a) Removing or converting current residential areas: These areas can be closed to people's access or converted to parks or forestland according to the level of landslide hazard. Excavations should also be prohibited to protect the landslide area.
b) Deterrent practices to reduce the resettlement of people in current residential areas: This method is more economic to apply for governments. For instance, the attractiveness of these regions can be reduced by imposing additional obligations (additional taxes, restrictions, and prohibitions) to people living in these areas.

4.2. Engineering Solutions

Engineering solutions are the strategies that directly reduce the landslide risk; however, it is quite expensive. It is generally applied in areas where residential areas are concentrated. This strategy can be examined under two topics[7]:

a) Correction unstable landslide areas: The most common correction methods are the modification of slope of the hillside, drainage of underground water, construction of retaining walls, and anchor structures to support the internal of slopes.
b) Controlling landslide debris: Control the flow of debris that is likely to occur as a result of a landslide. The most used method is to direct the landslide debris to predetermined areas with levees and distracting structures. The volume and debris of the landslide debris must be well defined for this method to be applied. These controlling structures are not suitable for deep landslide areas. This method should be well evaluated in the decision-making process because it is a high cost and low-efficiency method.

4.3. Acceptance

Landslide risk can be acceptable in cases where the risk of landslides is fully understood, and the risk is below the acceptable threshold. This strategy can be applied in areas where the landslide area is low in the human population or in conditions where the risk is tolerable. However, for the landslide risk to be acceptable, the landslide area should be fully researched and analyzed. The tolerable risk threshold may vary depending on the economic, social, and political structure of countries [7].

4.4. Monitoring and Warning

Slope movement can be monitored in areas where the risk of landslides is high with the help of advanced sensors, and people in the area can be evacuated with warning systems in case of danger. These systems are appropriate for landslide areas that are likely to be triggered by earthquakes because when ground acceleration crosses the predetermined threshold, landslide warnings can be sent to people in the area. These systems are used for the following purposes [7]:

- To determine if the landslide site is active.
- Assessing the hazard of a landslide.
- Getting a real-time warning about landslide activity.
- Assess the correlation between the probability of landslides and the amount of precipitation.

4.5. Decision Making

As a result of assessing the danger and risk of landslides, it is very important to decide which strategy is best suited. Cost and effectiveness are the most important factors during decision making. Decision-makers must produce the optimal solution by considering all landslide scenarios. The optimum solution is usually "planning", which is the least costly and effective solution.

5. Landslide Risk Assessment of Istanbul

The number of landslides/rockfalls in Istanbul is relatively small compared to other cities in Turkey [25](Figure 1). The main reason for this is the geography of the city, which is less rugged than in other cities. However, there are important landslide zones within the provincial borders, and in recent years, due to climate change, the probability of spot landslides due to sudden and heavy rains is in an increasing trend. These events should be expected to affect areas in the high slope, exposed to dense and poor-quality construction, and fortified points with incorrect or poorly constructed retaining walls in Istanbul.

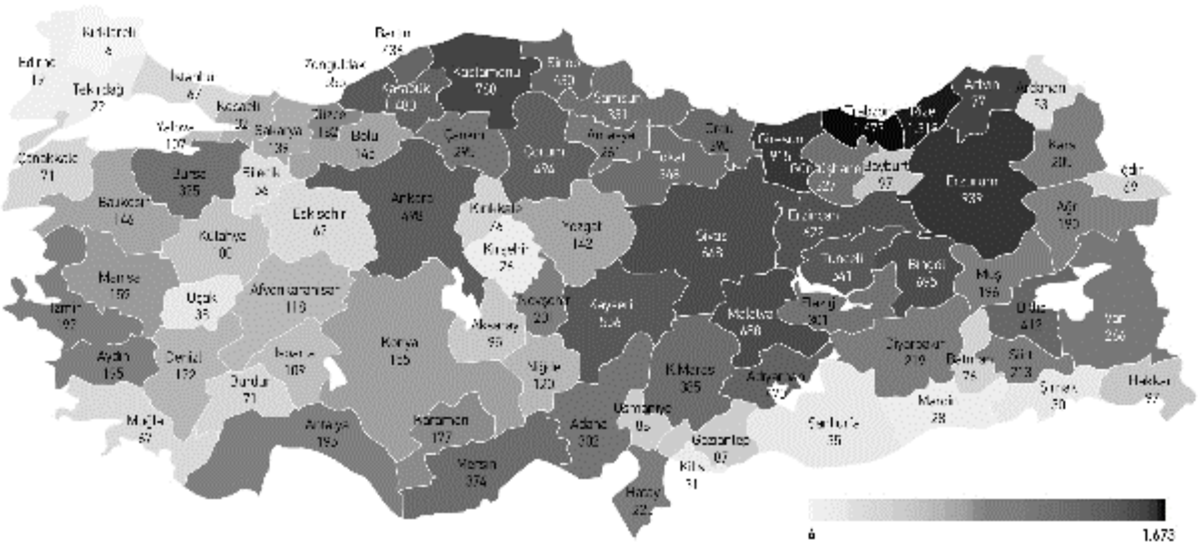

Figure 1. The number of landslides in Turkey between 1950 and 2019 [25].

Although the loss of life and property caused by landslides is less than other disasters all over the World (Figure 2), landslides are increasingly observed due to the increasing trend in floods and storms caused by extreme weather events due to climate change (Figure 3). For example, in 2017, 8 out of 50 disasters that caused the greatest economic loss in the world were caused by landslides triggered by extreme weather events [26].

Figure 2. The number of deaths from natural disasters between 1970 and 2018 [26].

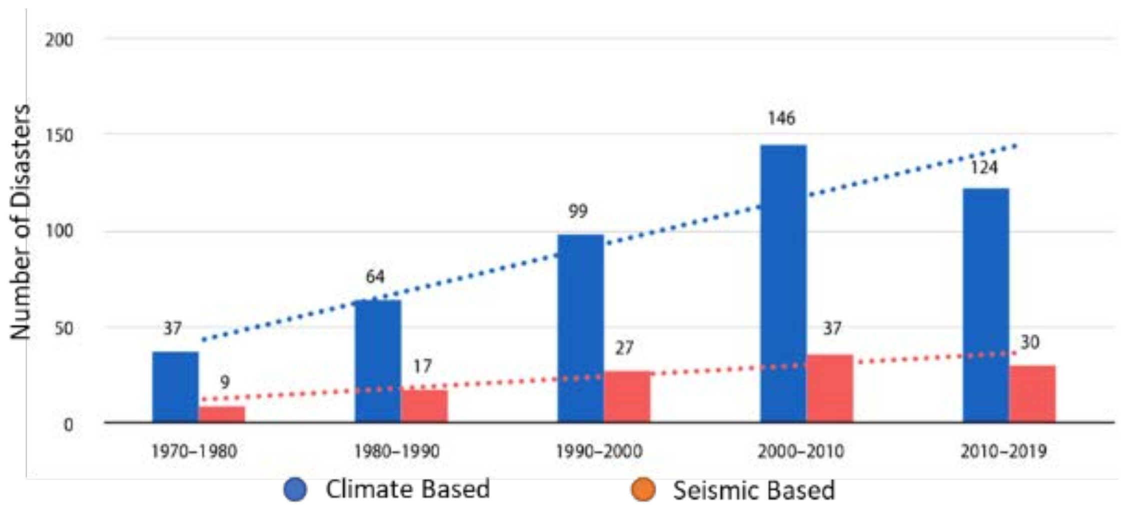

Figure 3. The number of disasters in the Asia-Pacific region [26].

Istanbul includes areas suitable for landslides from a geological and geomorphological perspective. High and sloping hillsides, soft-filled or clayey grounds, water-impermeable lands formed by the increase of construction are among the most important reasons that increase the danger of landslides. Heavy rains caused by climate change, which increase in effectiveness every day, also lead to an increase in the number of landslide events. In the studies carried out by the Istanbul Metropolitan Municipality, 850 landslides, and 237 rockfall areas were identified throughout Istanbul [8]. Among the landslide areas, 73 areas have been identified as high danger areas. In rockfall areas, activity continues in 59 areas (Figure 4).

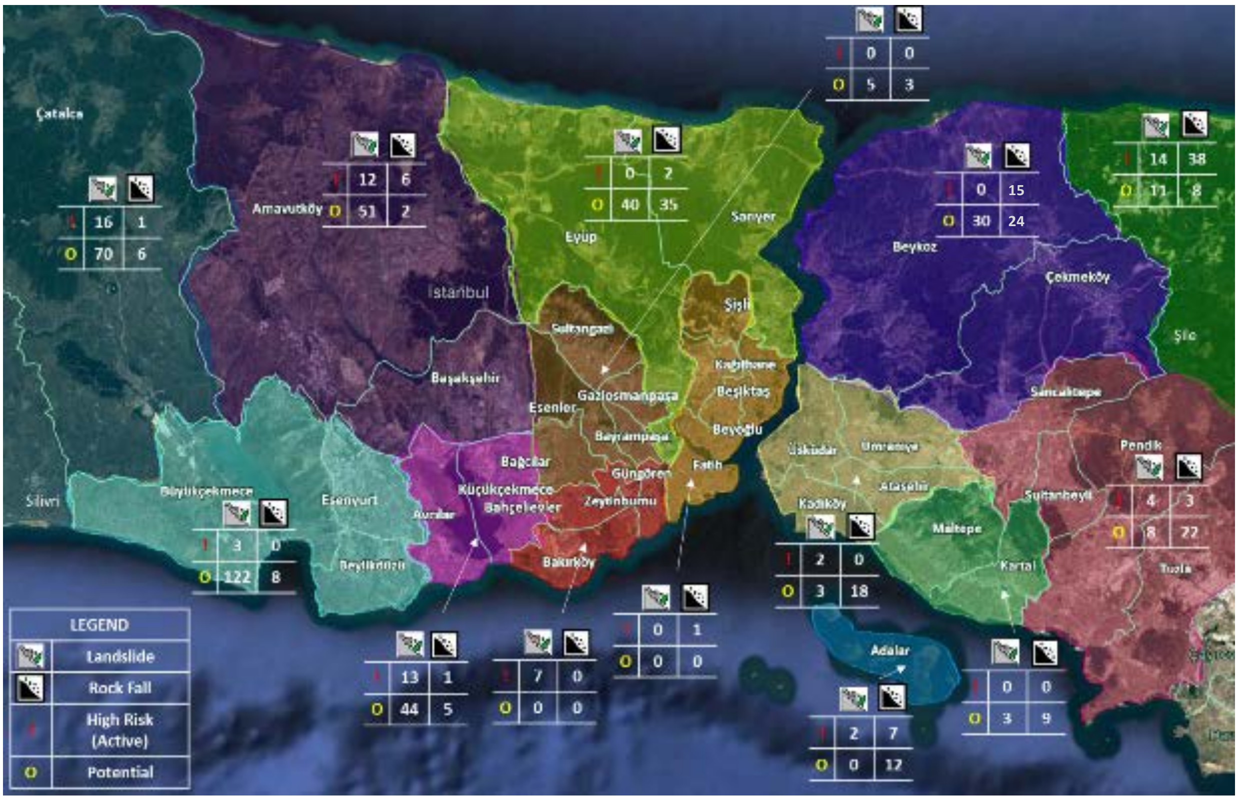

Figure 4. Distribution of high-risk and potential landslide and rockfall areas in Istanbul by region, according to Istanbul Metropolitan Municipality data [8].

In 2007, ground micro-zoning study was carried out by earthquake and ground investigation department (DEZIM) of IMM in order to determine in detail the regional hazards of natural disasters such as earthquakes, landslides and floods [27]. The study covers the southern half of the Anatolian side and the southern part of the area between Fatih and Beylikdüzü districts of the European side. In this study, the landslide safety factor (Fs) was calculated considering the earthquake case. According to the results of the stability analysis, based on the safety factor, slopes are divided into landslide hazard levels A_{SL}, B_{SL} and C_{SL}. Definitions of these hazard levels are as follows:

A_{SL} = Landslide safety factor (Fs) lower than 1 (Fs<1)

B_{SL} = Landslide safety factor (Fs) between 1.0 and 1.5 (1<Fs<1.5)

C_{SL} = Landslide safety factor (Fs) more than 1.5(Fs>1.5)

The results of the report revealed that the landslide hazard is high in the coastal part of Küçükçekmece, Avcılar and Beylikdüzü districts. On the other hand, the areas with high landslide hazard on the Anatolian side are less than the European side and concentrated in the center of Pendik, Sancaktepe and Sultanbeyli districts. The number and hazard level of landslide areas on the Anatolian and European sides are given in Table 2. Figure 5 and 6 shows the distribution of landslide safety factor in Anatolian and European side of Istanbul.

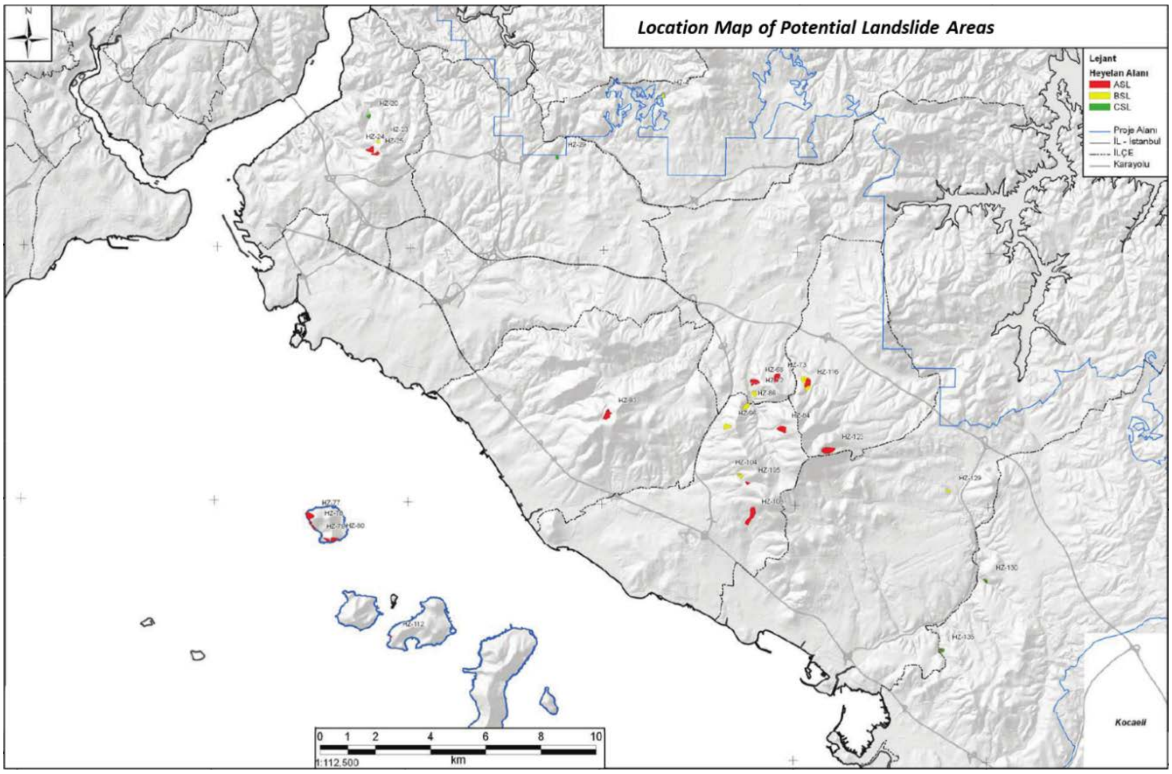

Figure 5. The map of Landslide Safety Factor in Anatolian Side of Istanbul [27].

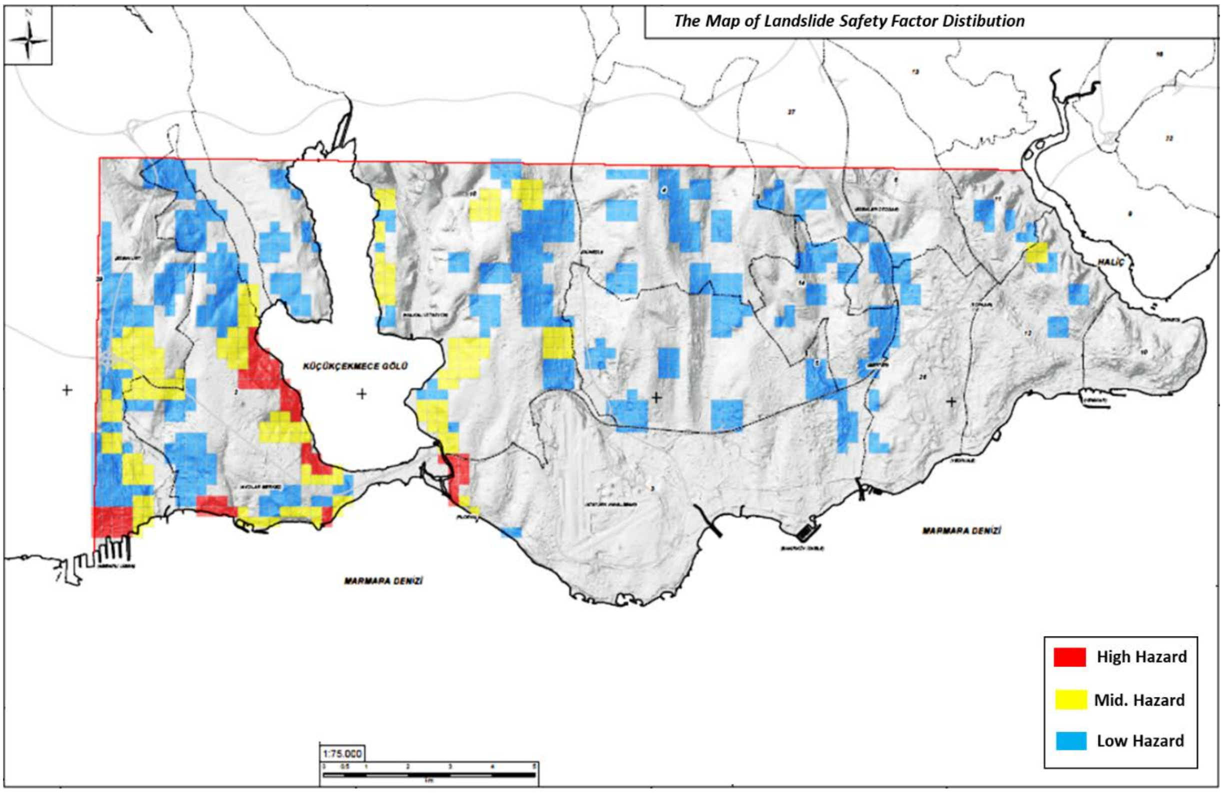

Figure 6. The map of Landslide Safety Factor in European Side of Istanbul [27].

Table 2. The number and hazard level of landslide areas on the Anatolian and European sides.

Hazard Level	European Side	Anatolian Side
A_{SL}	27	19
B_{SL}	69	10
C_{SL}	125	4

Another study conducted to determine the landslide areas in Istanbul was carried out by General Directorate of Mineral Research and Exploration (MTA) in 2009. In this study, shallow, old, and active landslide areas were mapped within the scope of the "Turkey landslide inventory" project. Figure 7 shows the distribution map of landslide areas in Istanbul [28].

In 2011, a study named "Geology of Istanbul Provincial Area" published by DEZIM. In this study, units prone to landslide were determined, and all mass movements observed in the field were mapped. Figure 8. shows areas where mass movements are intense in Istanbul [29].

In 2017, landslide hazard maps produced by DEZIM (2011), MTA (2009) and Tubitak - MAM (2016) were combined and "the integrated landslide area maps" were obtained (Figure 9)[30]. The integrated landslide areas map is considered as an important criterion in land use Assessment by IMM. Then, 12 regions in Istanbul were declared "Disaster-Exposed Zones" in terms of landslides and rockfall disasters with the Council of Ministers Decisions of different dates. The list of these locations and the map in which the digitized borders are marked are given in Figure 10 [31]. The names of these zones are as follows:

1. Ambarlı Neighborhood-Balabaan Heyelanı (Avcılar)
2. Şenlikköy (Bakırköy)
3. Yakuplu-Reşitpaşa Kızılburun (Beylikdüzü)
4. Binkılıç-Fatih Neighborhood (Çatalca)
5. Karaburun (Arnavutköy)
6. Kısırkaya-Tahlisiye Road (Sarıyer)
7. Değirmenköy (Silivri)
8. Çantaköy (Silivri)
9. Karacaköy (Şile)
10. Domalı (Sahilköy)
11. Doğancalı-Alacalı (Şile)
12. Cennet Neighborhood (Küçükçekmece)

The west and north sides of Küçükçekmece Lake in Istanbul contain a large number of landslide zones compared to other regions. Çatalca, Silivri, Büyükcekmece, Beylikdüzü, Esenyurt, Avcılar, Küçükçekmece, Arnavutköy, and Başakşehir districts are the districts where landslides have occurred the most in the past and are now sensitive to landslides. The most dangerous areas in terms of rockfall are Şile, Beykoz, Çekmeköy, Eyupsultan, and Sarıyer districts in the north of Istanbul. The rockfall events occur more than in other regions because the natural environment is relatively preserved in these regions.

Landslides are more predictable than other natural hazards, and the risk posed is more control controllable. It is possible to reduce the risk of landslides if analyses, risk maps, planning, and applications are done correctly. The continued construction in active landslide areas in Istanbul is the most important factor that increases the risk of landslides.

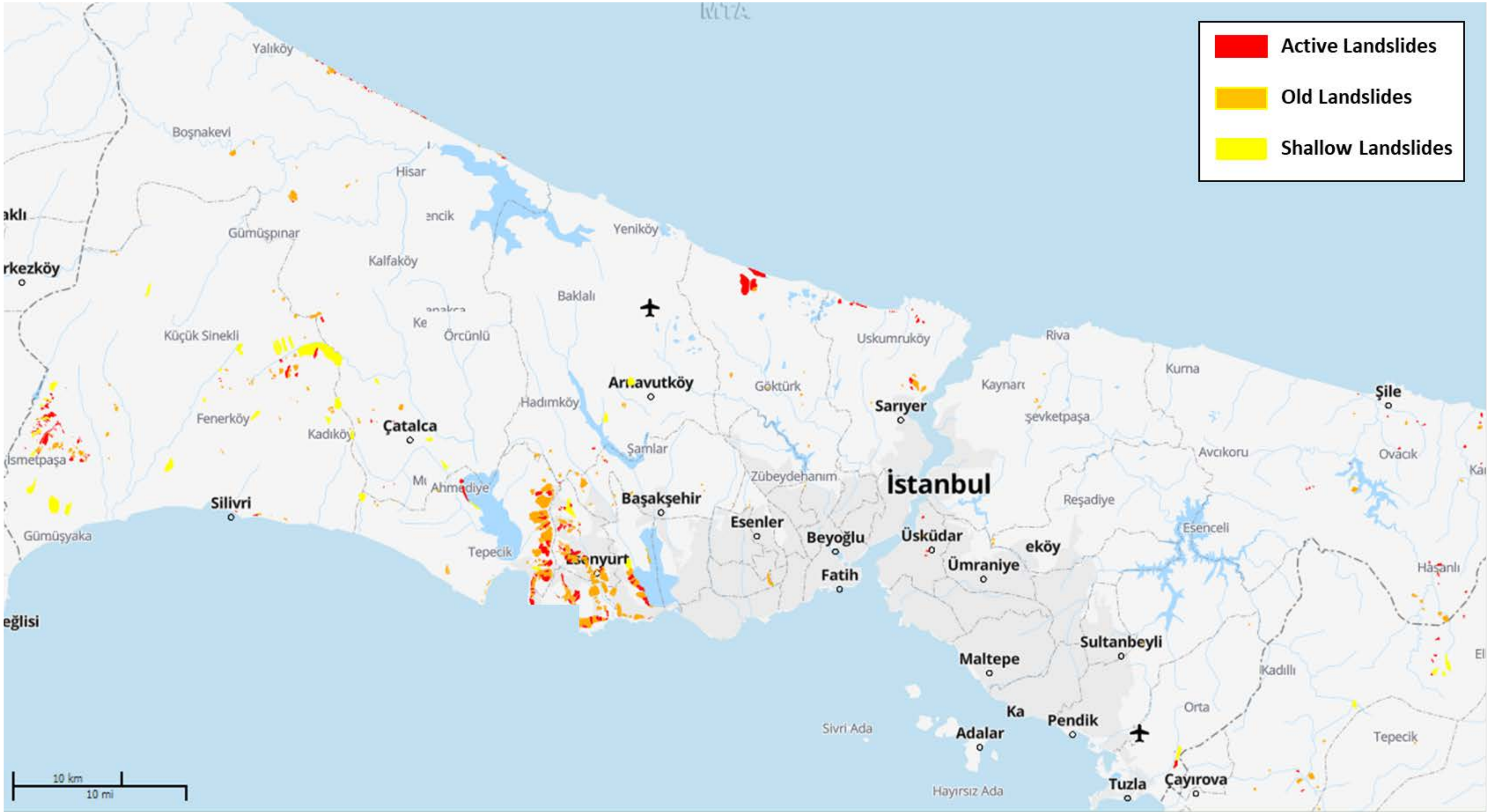

Figure 7. The distribution map of landslide areas in Istanbul (MTA, 2009).

Figure 8. The map showing the areas where mass movements are intense in Istanbul (DEZIM, 2011).

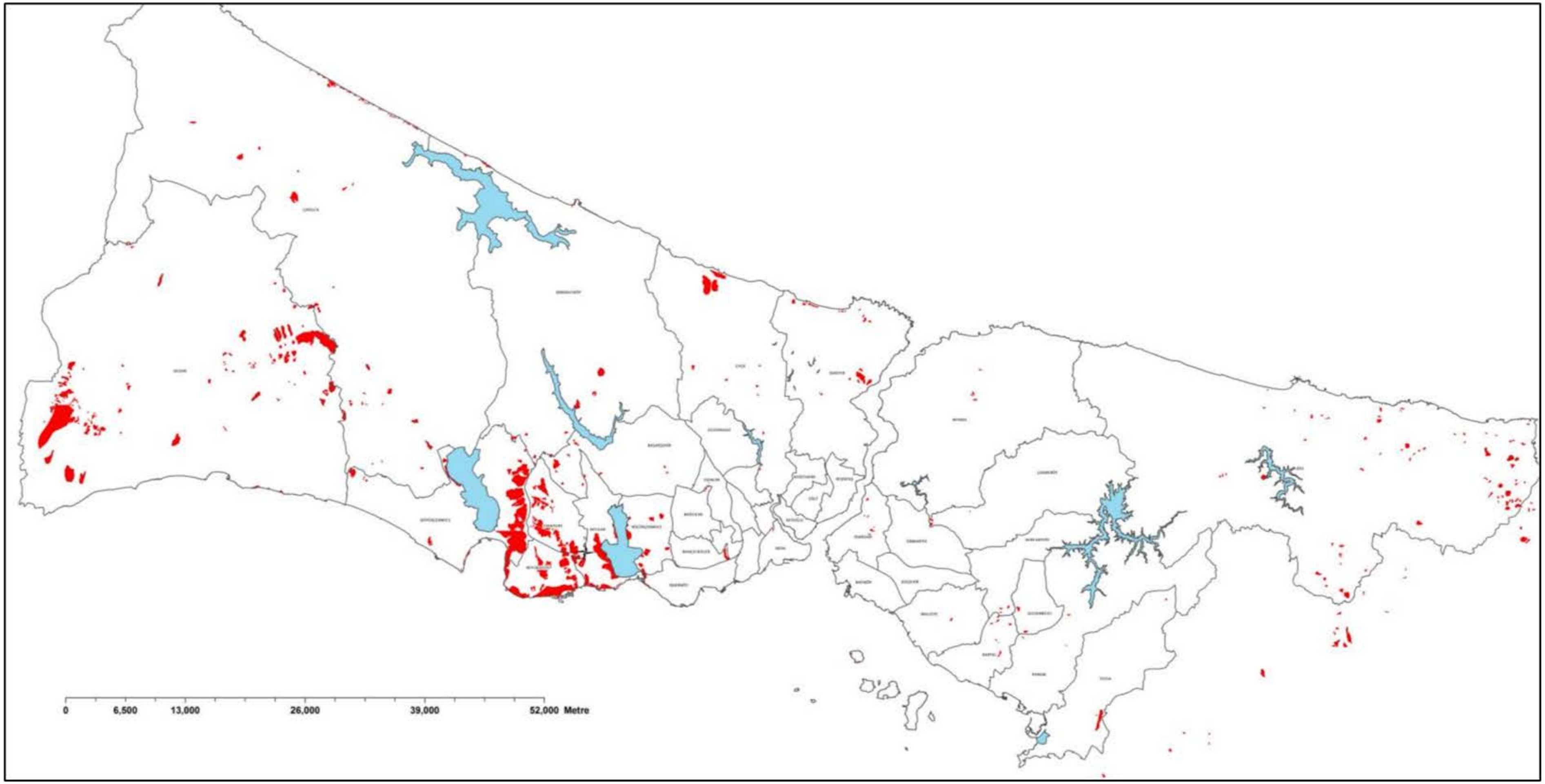

Figure 9. The integrated landslide areas map (IMM, 2017).

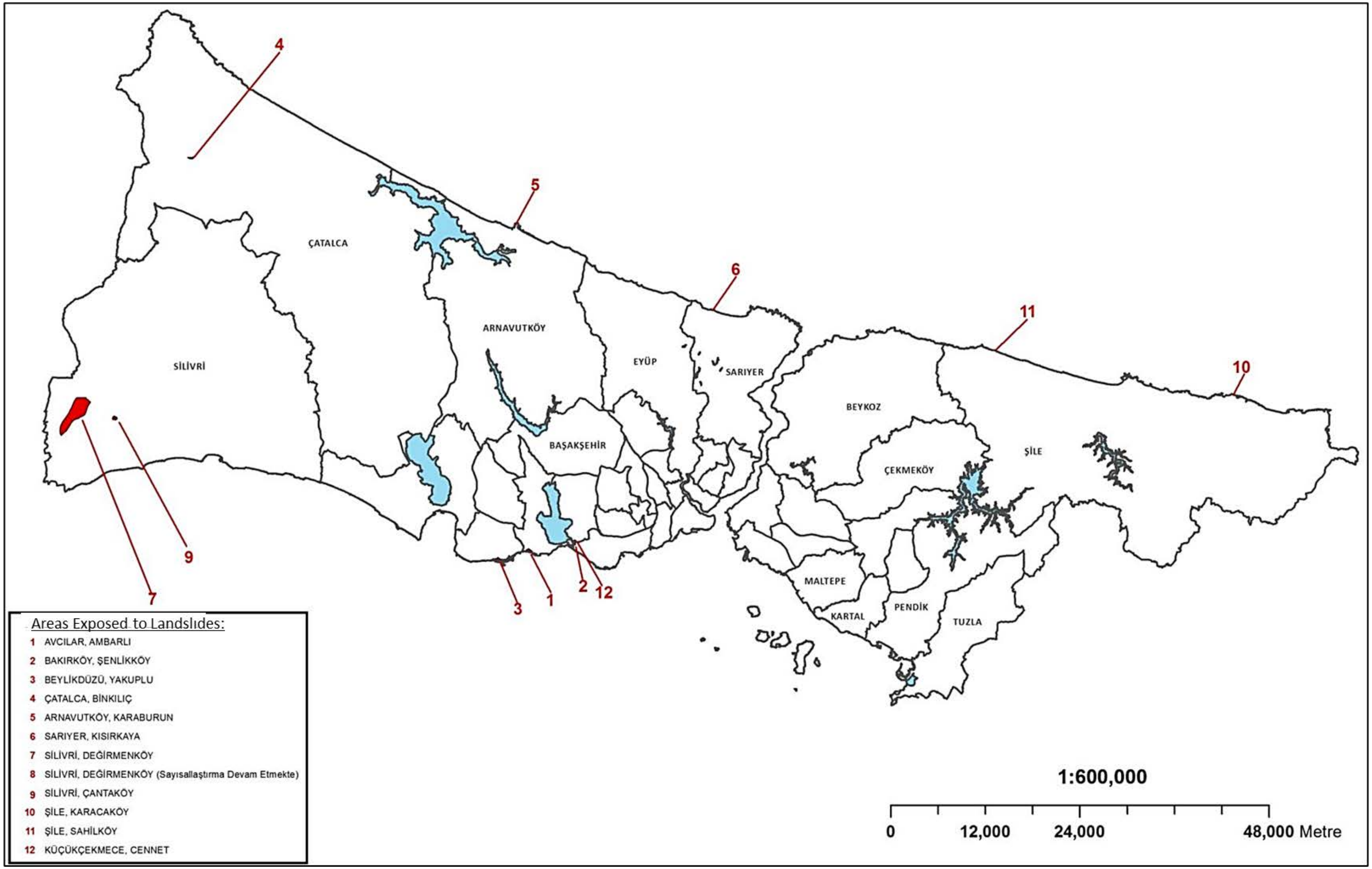

Figure 10. Areas exposed to landslides announced by Istanbul Provincial Disaster and Emergency Directorate in 2017.

5.1 Slope Stability Assesment in Scenario Earthquakes

In 2002, the project named "Istanbul Province Disaster Prevention / Mitigation Basic Plan Including Seismic Micro-Zoning " completed by the partnership of Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality (IMM) [32]. In the final report of this project, the stability assessment of the slopes in Istanbul was made for the scenario earthquakes. In this study, slope ratio, scenario earthquakes and ground shear force capacity are considered as calculation parameters. As the scenario earthquake, two possible scenarios named "Model A" and Model C "were selected.

Model A: This fault, which is about 120 km long, is the line extending from the west of the 1999 Izmit earthquake fault to Silivri (Fig. 11). This model is the most likely to occur in the four scenarios earthquakes as seismic activity is moving westward. The moment magnitude (Mw) is estimated to be 7.5.

Model C: This model assumes that the 170 km North Anatolian fault in the Sea of Marmara will break at the same time (Fig. 11). The moment magnitude (Mw) is estimated to be 7.7. This magnitude is the highest value that has ever occurred in the region, because the magnitude of the largest historical earthquake that occurred around the Marmara Sea is 7.6. There is no evidence that the whole line was broken at the same time. However, if we evaluate in terms of the maximum length of the fault, in the May 1766 earthquake, 1/3 of the line was broken and the rest of the line were broken in August 1766. In other words, this model represents the worst case within reasonable limits.

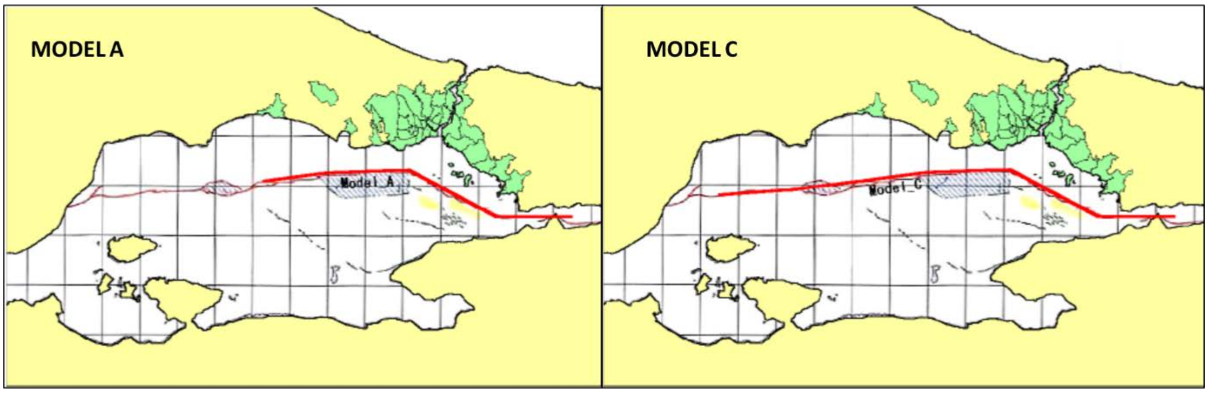

Figure 11. The fault lines that are expected to be broken in the selected scenario earthquakes.

In the case of Model A, "Very High Risk" grids are located in Adalar and Silivri. These areas correspond to steep cliffs and areas without residential areas. "Low Risk" grids are located in Avcılar, Küçükçekmece and Büyükçekmece. These areas are residential areas (Figure 12).

In the case of Model C, "Very High Risk" grids are dominant in Avcılar and "High Risk" grids are dominant in Büyükçekmece. "Low Risk" grids extend to Bahçelievler, Bakirköy and Güngören. All these areas are residential areas (Figure 13)[32].

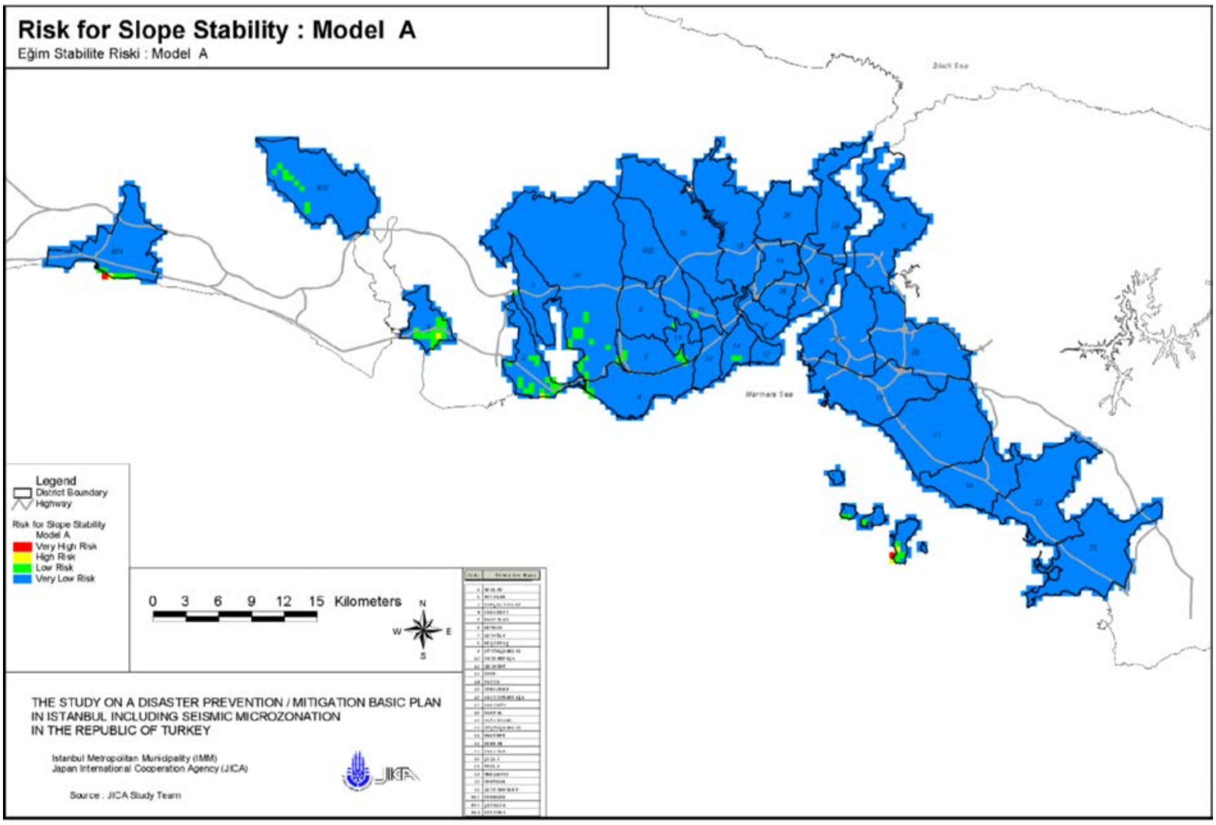

Figure 12. Slope stability assesment in Model A scenario earthquake (JICA and IBB, 2002).

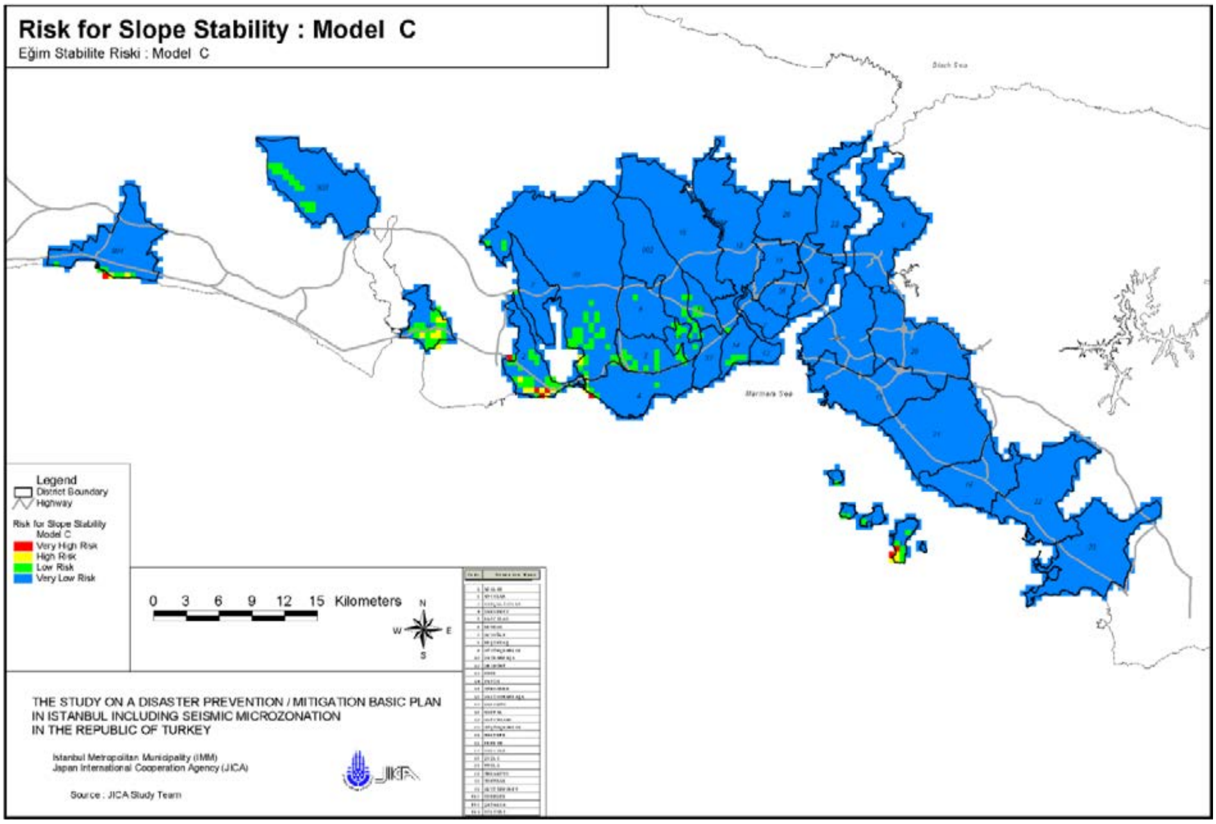

Figure 13. Slope stability assesment in Model C scenario earthquake (JICA and IBB, 2002).

5.1 Adalar Region

The majority of mass movements in the Adalar region, which were found to be active, are seen on the slopes in Kınalıada and neighboring the coast (Fig. 14). There are 2 high-risk landslide areas in this district. The number of rockfall areas is 19 in total and 7 of them are high risk [8]. The slopes with potential mass movements are located on the slopes of Büyükada, Heybeliada, and Sedef Island.

Figure 14. Mass Movement Locations of Adalar region according to activity status on the geology map (IMM, 2020).

5.2 Arnavutköy- Başakşehir Region

The active unstable slopes in the region are mostly located in the north and east of the Arnavutköy. In Başakşehir district, the active unstable slopes are concentrated on the stream slopes between Sazlıdere Dam Lake and Kücükçekmece Lake.

There are 52 potential and 12 high-risk landslide areas in these districts (Fig. 15). The number of rockfall areas is 8 in total and 6 of them are high risk [8]. Landslide areas are concentrated in the north of Çatalca (Yeniköy) and around the Sazlıdere pond. Besides, there are high-risk landslide areas around the small lakes in the Bolluca neighborhood on the east side of Arnavutköy. On the positive side, the human population is very low in regions with high landslide risk.

On the slopes in the region, there are undetectable unstable slopes due to dense vegetation and construction in some places. Therefore, excavation applications should not be carried out without detailed research and analysis of the stability analyses, especially in the dense decomposition units and the sloping rubble covering them.

It is necessary to investigate in more detail the slopes with geological and morphological characteristics similar to the areas where the unstable slopes are found in the region and to conduct the necessary technical examinations in the parts that are structural. Besides, it is important for the safety of life and property not to decide on new constructions without detailed research and analysis of slope stability for earthquake-free and earthquake situations.

Mass movements are spread throughout the region and are concentrated on the slopes facing the Black Sea coast to the north, the high-slope area to the east, and mostly on the slopes overlooking The Sazlidere Dam Lake in the south. In these areas, it is recommended to carefully prepare and implement preventive projects against slope migration in urban areas.

In 2012, a scientific and technical cooperation protocol was signed between IBB-DEZIM and the institute of earth and marine sciences of TUBITAK [33]. Arnavutköy. This cooperation covers the development of landslide detection and monitoring methods by investigating possible active faults in the Istanbul land area and conducting multidisciplinary research in priority landslide areas. In this context, Yeniköy neighborhood in Arnavutköy and Çatalca county town regions were selected as priority landslide areas. Yeniköy neighborhood is located in the north of the newly built Istanbul Airport and on the black seacoast (Fig. 16). As a result of this study, landslide formation models were obtained for these regions.

The first stage of the model given in Figure 17-A has been entered in the rising phase of the sea level. The coast begins to be eroded by the waves and currents of the sea. Collapses started in the coastline, the lower part of which was carved, and thus the coast regressed. Figure 17- A and B show the processes of scour, collapse, overturn, slip and shore regression. The crumbled materials accumulated on the shore due to the erosion and transportation effect of the sea were carried to the deep-sea environments by the sea and thus the stability balance of the coastal area was disturbed. These periods are shown in Figure 17- C and D. In the Yeniköy landslides, this cycle continues slowly today. It is thought that the transitions from D to A process given in Figure 17 are likely to develop only with sea level rise and vertical tectonic movements.

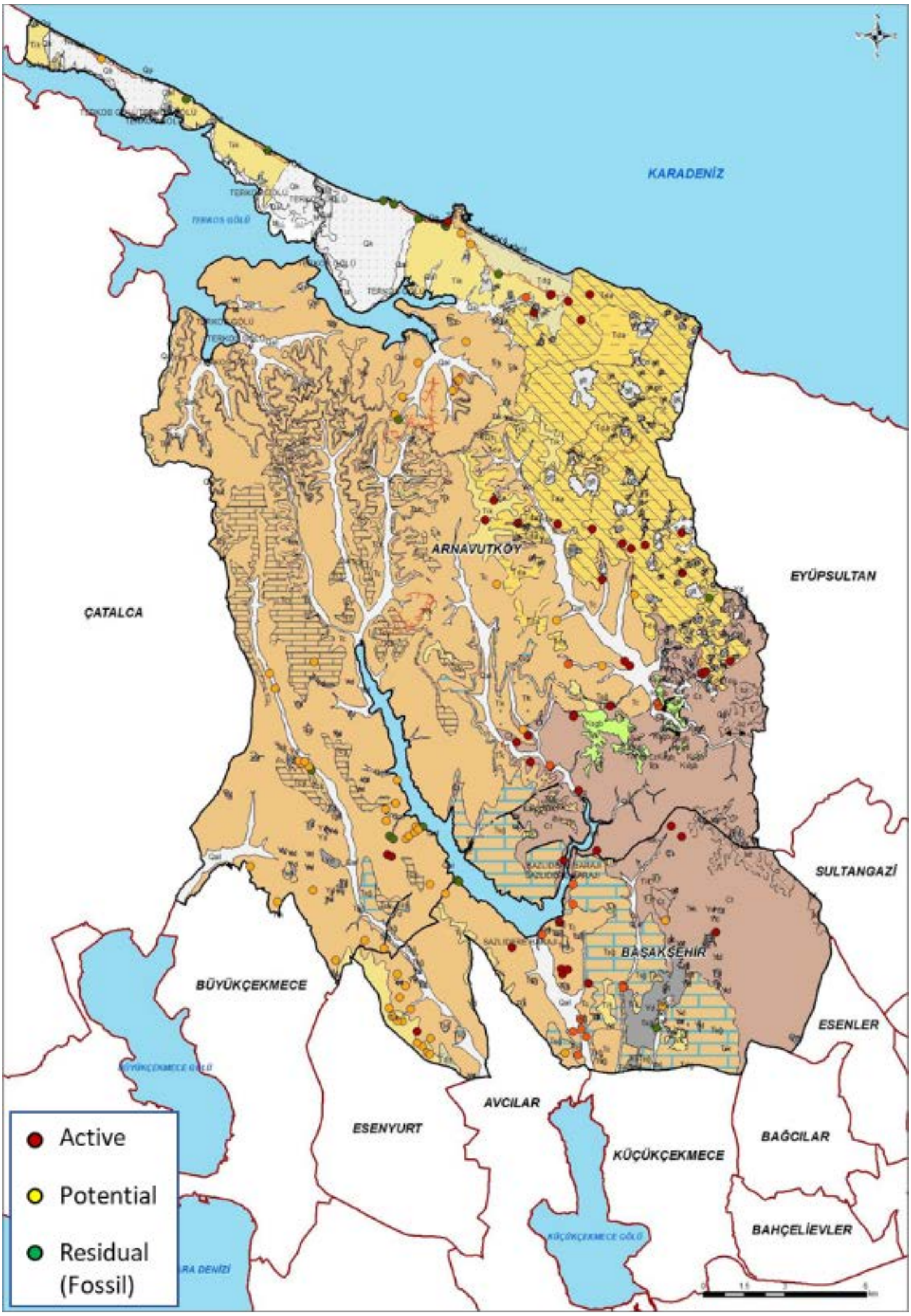

Figure 15. Mass Movement Locations of Arnavutköy-Başakşehir region according to activity status on the geology map (IMM, 2020).

Figure 16. The location of Yeniköy Neighborhood in Istanbul map.

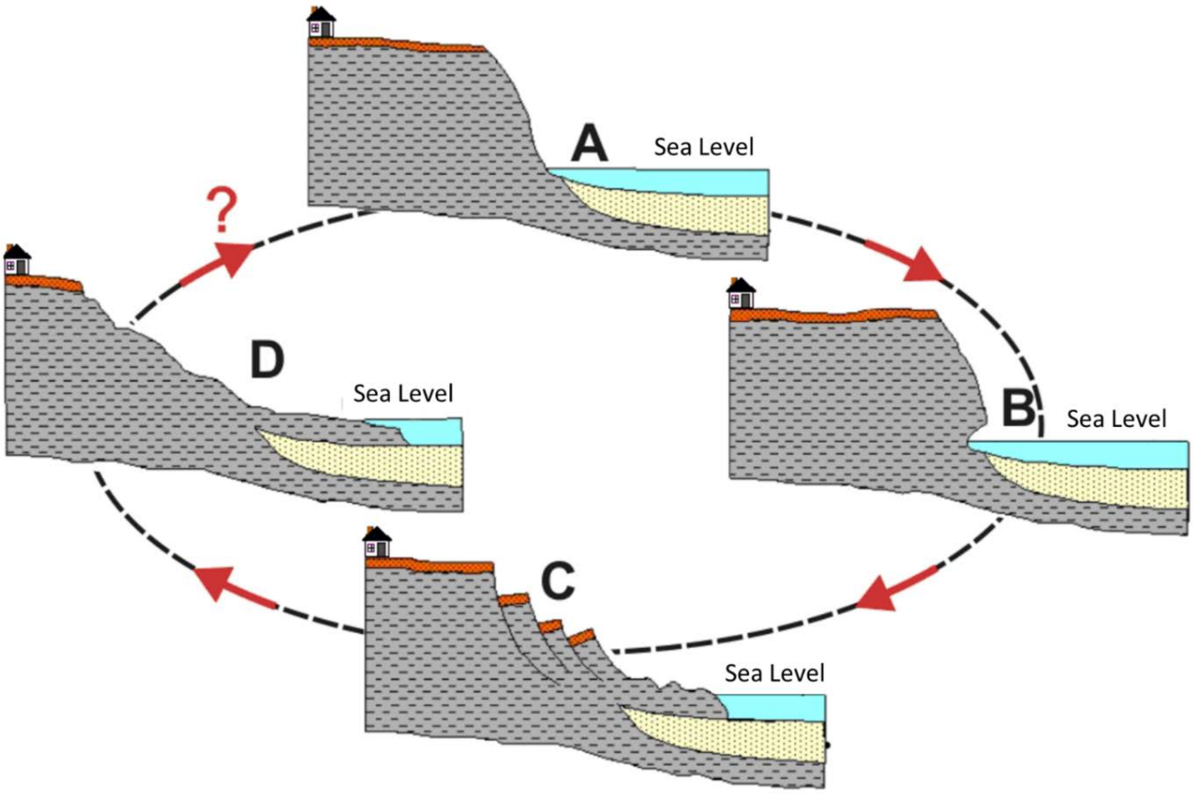

Figure 17. The model showing the landslide processes in the Yeniköy research area.

5.3 Ataşehir- Kadıköy- Ümraniye- Üsküdar Region

There are many sloping areas in Ataşehir- Kadıköy- Ümraniye- Üsküdar Region; however, landslide areas are few. Among the slopes with potential mass movements, 7 are located in Ümraniye, 13 in Üsküdar, and 1 in Ataşehir. There are 3 potential and 2 high-risk landslide areas in these districts. The number of potential rockfall areas is 18 in total (Fig. 18). More detailed investigation of such active geological and morphological slopes is important for life and property safety. Almost all ground shifts in the area have developed on hillside rubble and artificial fillings [8].

Considering that one of the triggering reasons for landslides is earthquakes, it is more important to take precautions against landslides for the coastal districts in the region, and ground subsidence and sliding should be investigated in areas where the population is high. However, no mass movement has been detected in the coastal parts of Kadıköy and Üsküdar districts to the Sea of Marmara.

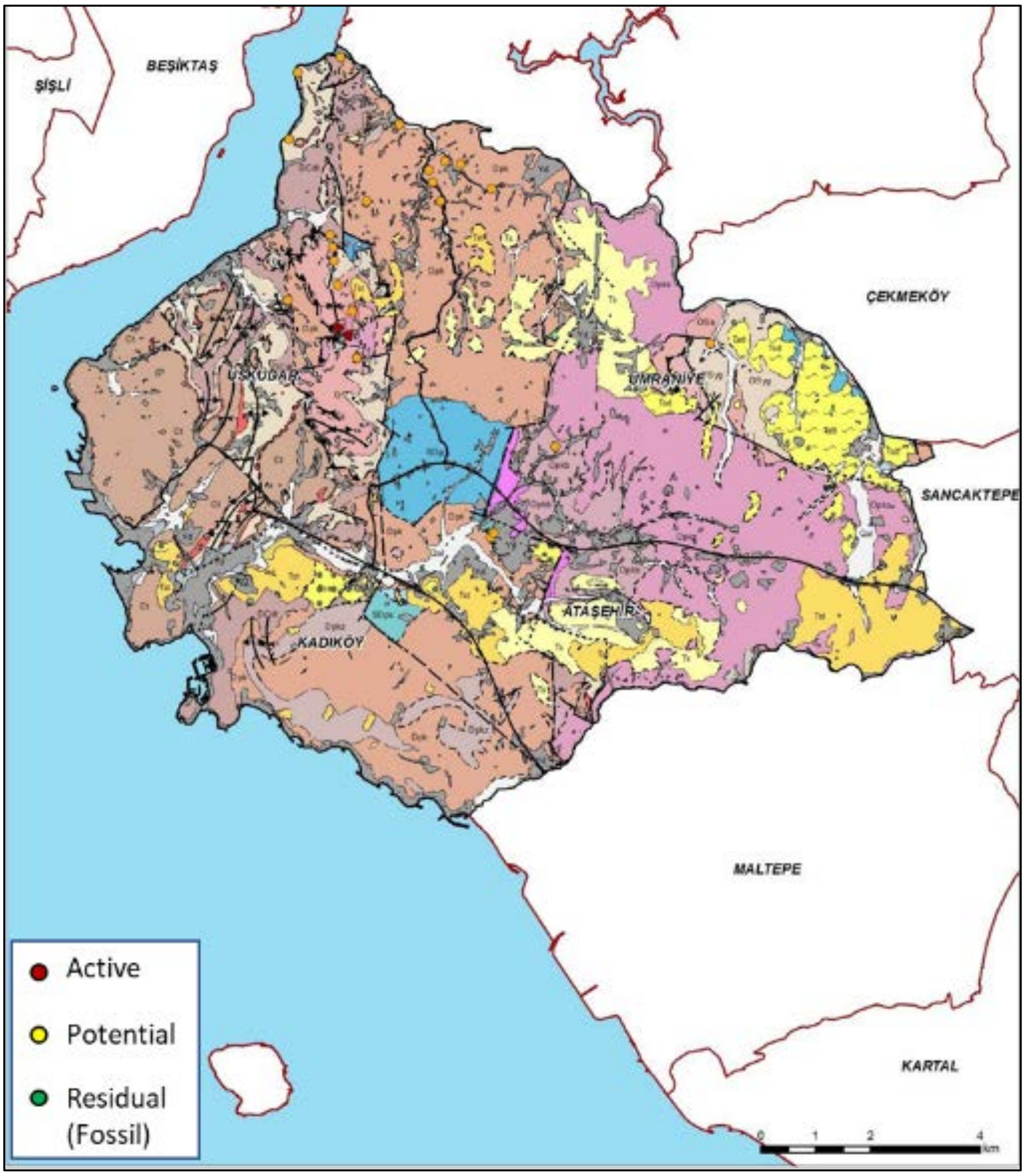

Figure 18. Mass Movement Locations of Ataşehir-Ümraniye-Kadıköy-Üsküdar region according to activity status on the geology map (IMM, 2020).

5.4 Avcılar- Küçükçekmece Region

Landslide areas in the region, which were found to be active and developed in ground environments, were mostly developed on the slopes covered with clay units belonging to Çekmece and Danişment Formation. Therefore, a more detailed investigation of such active geological and morphological slopes is important for life and property safety. There are 44 potential and 15 high-risk landslide areas in these districts (Fig. 19). The number of rockfall areas is 6 in total and 1 of them is high risk [8].

The most important of the active landslides in the region are the Firuzköy Landslides, which have been declared disaster-exposed zones and developed on the hillside overlooking the Marmara Sea and on the wide slopes west of Lake Küçükçekmece. 19.2% of the study area is covered by landslides which are typically located in the lithologies including the permeable sandstone layers and impermeable layers (Fig. 20). It can be said that lithology is one of the major conditions for landslides in the study area. The sandstone bedding planes and their orientations are secondary factors governing the landslides [34].

Altitude, slope, aspect, lithology, distance to faults, distance to drainage, distance to roads, geomorphological units, and relative permeability map are assumed as the preparatory factors of the landslides. The results show that the classes of 5–10 of slopes, the class of 180–225 of aspect, the class of 25–50 of altitude, Danisment formation – Acmalar member (Toda) of the lithological units, the slope units of geomorphology, the class of 800–1000 m of distance to faults, the class of 75–100 m of distance to drainage pattern, the class of 0–10 m of distance to roads and the class of low or impermeable unit of relative permeability map have the higher probability values than the other classes [34].

In 2005, a stability study was conducted on the seaside of the Ambarlı neighborhood of Avcılar district. According to the results of this study, it was concluded that a significant part of the land in the region is unstable and not suitable for settlement (Figure 21). In the remaining areas of the region, measures and restrictions on construction have been proposed [35]. As a result of this report, buildings in the area that were not suitable for settlement were demolished by municipal teams in 2016.

Studies have shown that unstable slopes are concentrated in high places in the region. In the region, especially the slopes overlooking the lake and the seashore, and the areas where these slopes are associated with the sea and the lake, are places where mass movements are intense. These scarps are more sensitive in terms of slope and the unstable slopes in the region are concentrated in these sections.

All of the active landslides in the region have developed on the slopes facing the shores, and it is recommended that the detailed analyzes of the slopes are meticulously carried out in the parts of these regions that are built or will be opened to new construction. In the seismic studies conducted in the region, fault extensions in the land direction, the high-slope layers are associated with areas with high landslide risk and faults known to exist on land, considering both the locations of these areas and the structural elements of the faults. Accordingly, medium and higher earthquake activities that may occur in the region may trigger these landslides.

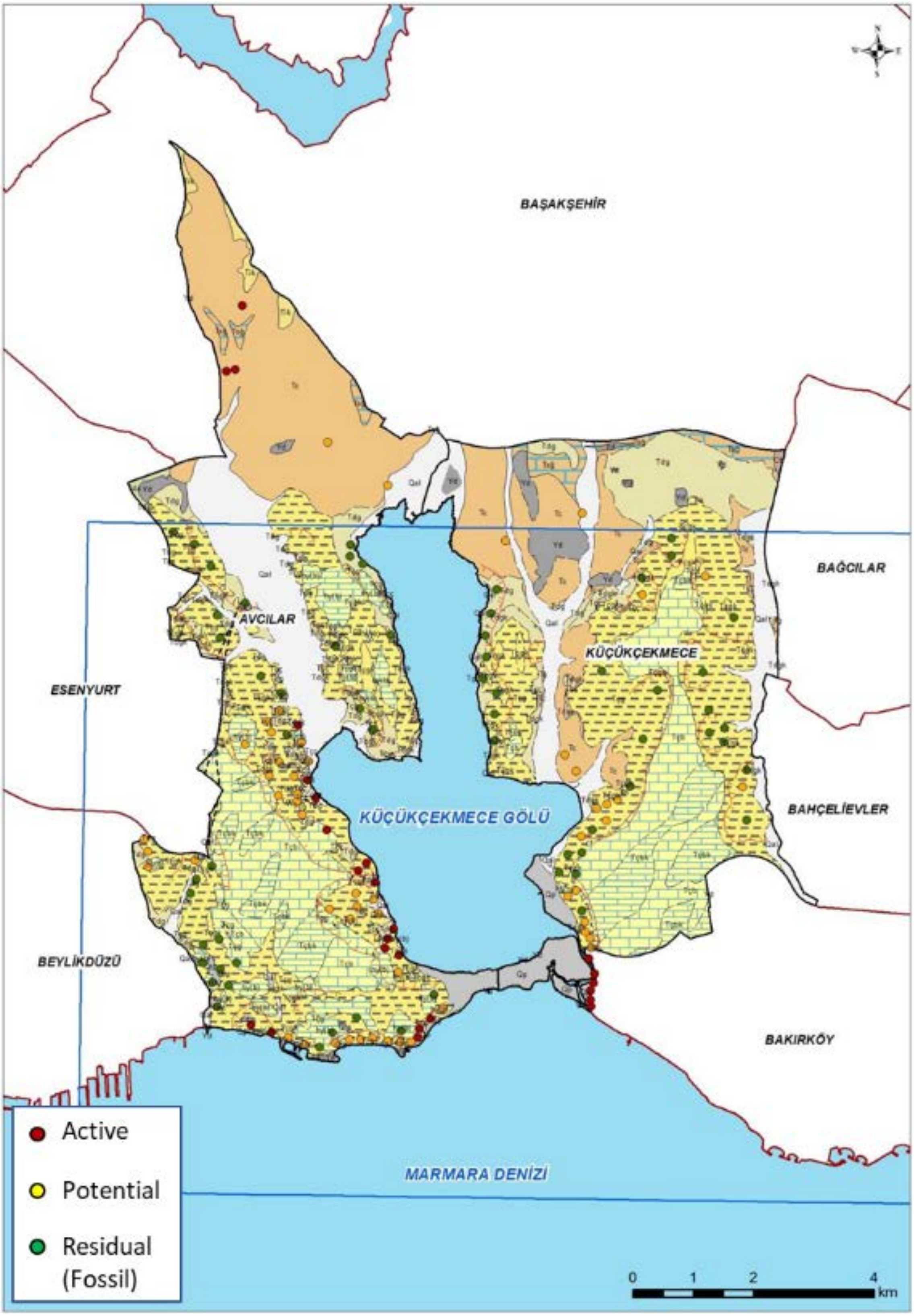

Figure 19. Mass Movement Locations of <u>Avcılar - Küçükçekmece</u> region according to activity status on the geology map (IMM, 2020).

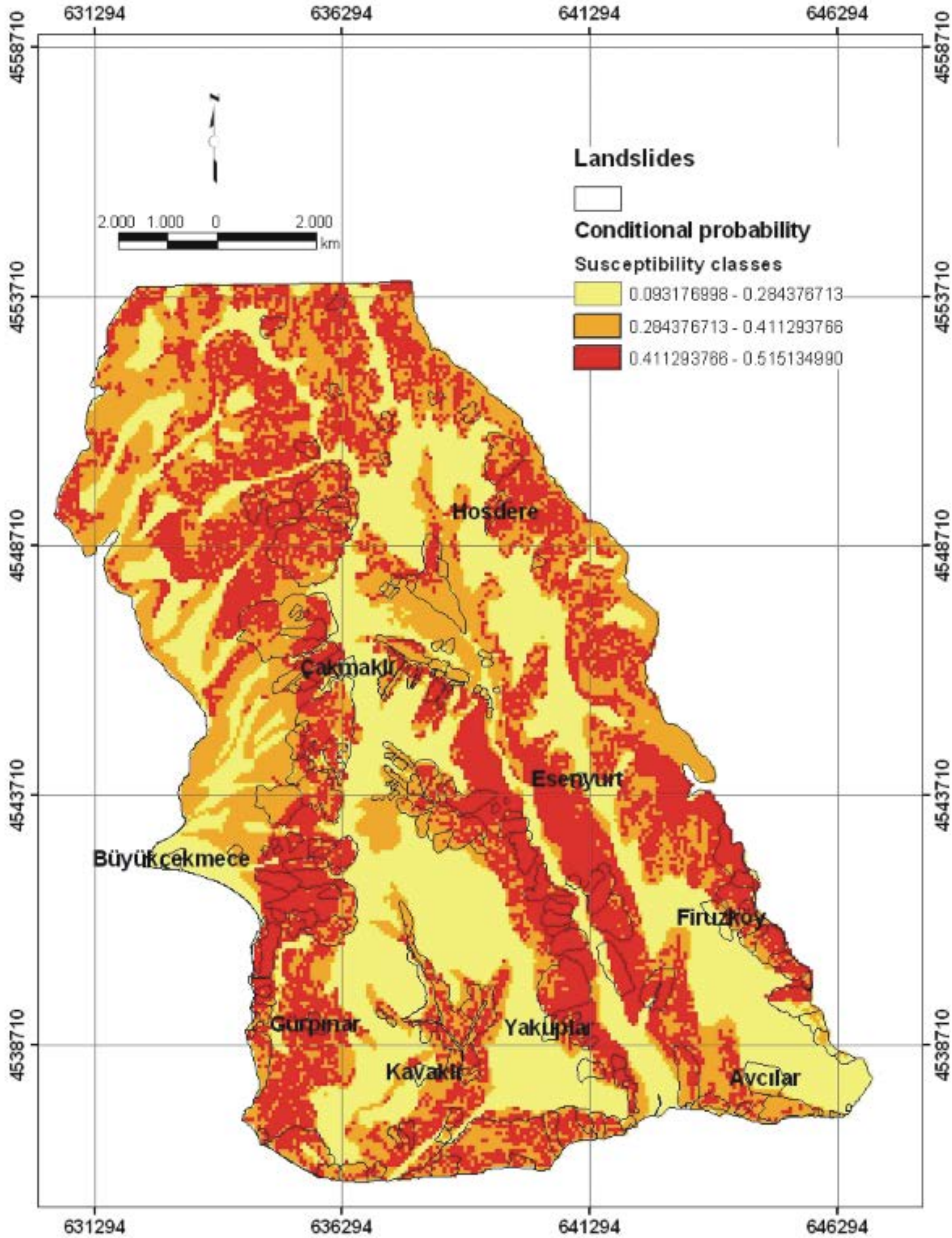

Figure 20. Landslide susceptibility map of the Avcılar- Büyükçekmece region (Duman et al., 2005).

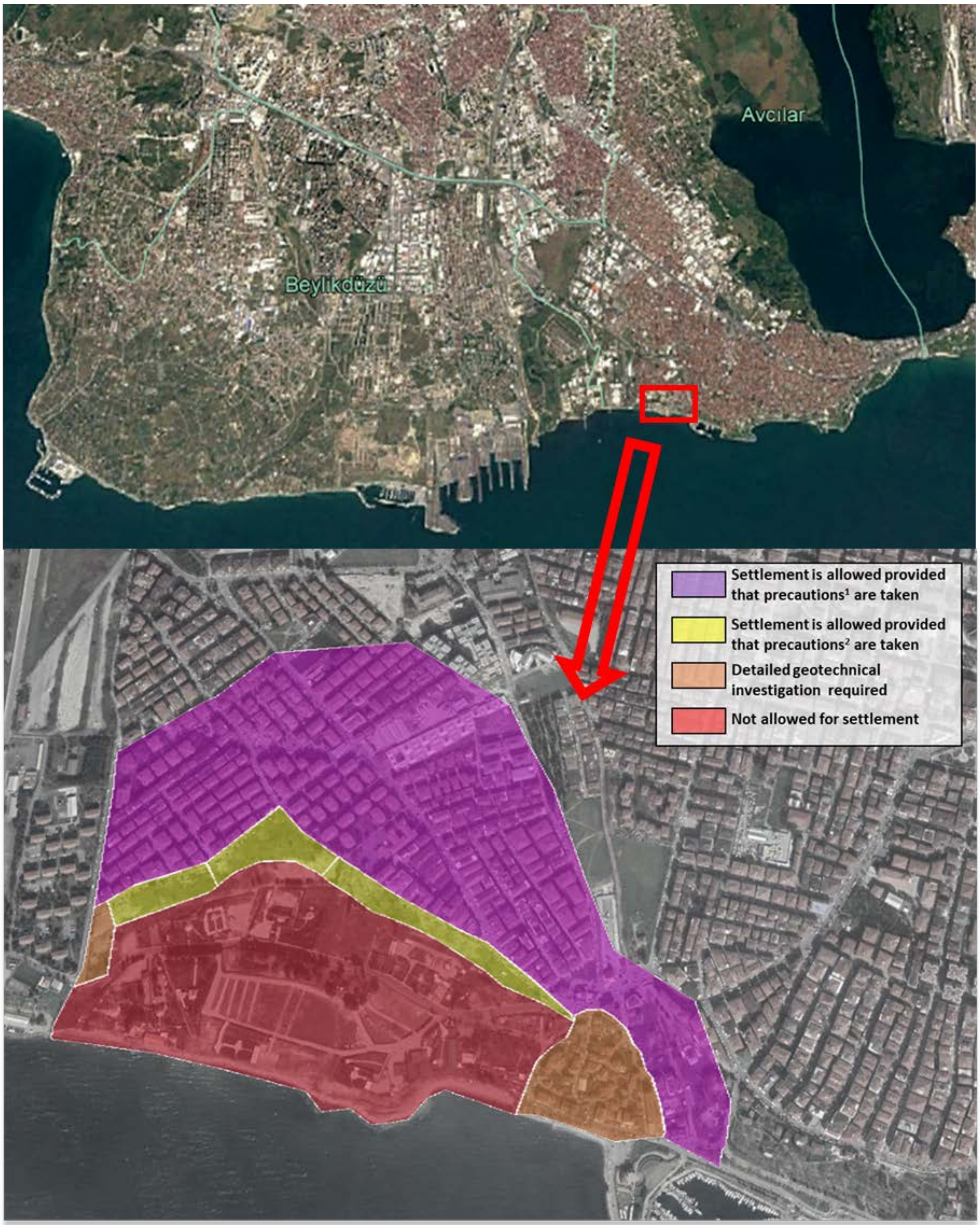

Figure 21. Settlement suitability map of Avcılar- Ambarlı neighborhood. [1] Measures and restrictions recommended in the 2001 report prepared by Belirti Company. [2] New measures and restrictions are recommended (ELC Group, 2005).

5.5 Bağcılar- Bayrampaşa- Esenler- Gaziosmanpaşa- Sultangazi Region

The only landslide area found to be active in the region is located in Gaziosmanpasa district and developed on the hillside covered with artificial fillings. Residual (fossil) landslides, which are the most common in the region and located in the southern part, are old landslide areas that have lost their effectiveness, although they have moved in the long past. They are not expected to be effective today under current geological, morphological, and physical conditions, and they have often lost their apparent landslide morphology. There are 5 potential landslide areas and 3 potential rockfall areas in these districts (Fig. 22). There is no high-risk landslide area in this region [8].

The sliding strength angles of the slopes, which are located in landslide blocks identified as fossil landslides, were calculated as approximately 200^0. Therefore, if the slopes have an angle of approximately 200^0 as a result of human-caused interventions such as uncontrolled construction excavations, digging the slope or heel, overloading the hillside or hillside; these areas should be expected to become active again [8].

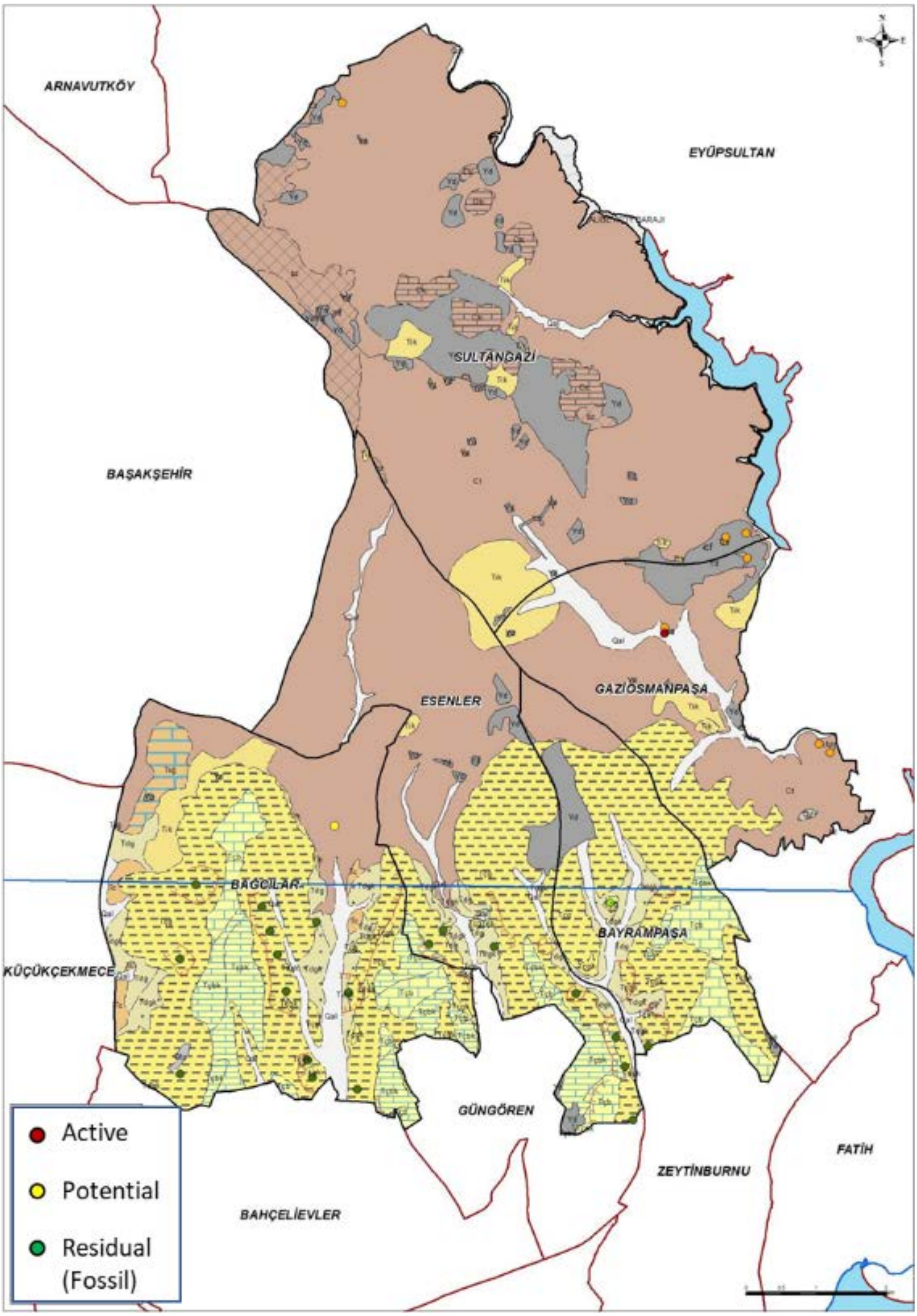

Figure 22. Mass Movement Locations of Bağcılar - Bayrampaşa- Esenler- Gaziosmanpaşa region according to activity status on the geology map (IMM, 2020).

5.6 Bahçelievler- Bakırköy- Göngören- Zeytinburnu Region

Active landslide areas in the region have mostly developed on slopes covered with clayey units belonging to Güngören Member of Çekmece Formation. There are 7 high-risk landslide areas in these districts and no rockfall area (Fig. 23). All high-risk areas are located near Küçükçekmece Lake to the west of Bakırköy [8].

Seismic studies conducted in the region in the past years show that fault extensions in the direction of land in high-sloping layers are associated with areas at high risk of landslides. Therefore, moderate and large earthquakes can trigger these landslides in the region.

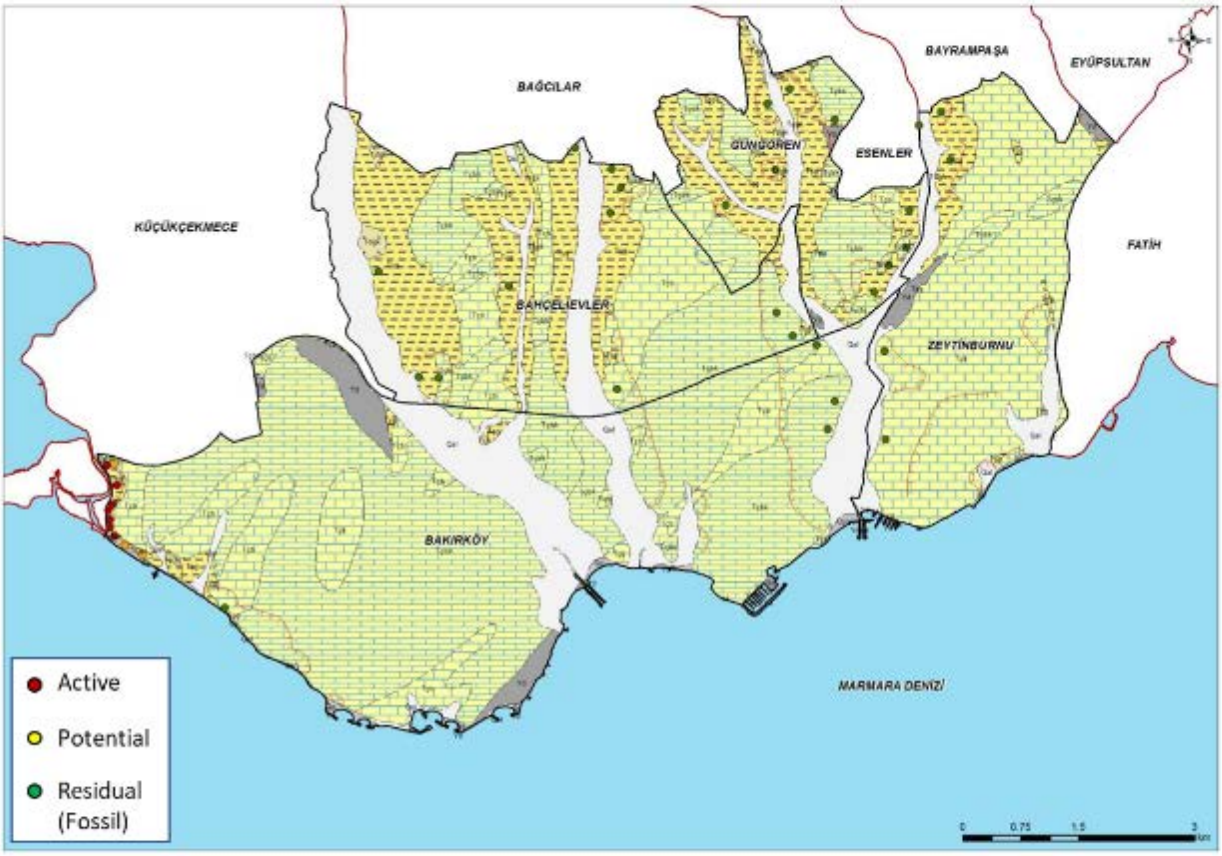

Figure 23. Mass Movement Locations of Bahçelievler- Bakırköy- Göngören- Zeytinburnu region according to activity status on the geology map (IMM, 2020).

5.7 Beşiktas-Beyoglu-Fatih-Kagithane-Şişli Region

The only landslide area active in the region is located in the Kağıthane district and developed on the hillside covered with units belonging to the Thrace Formation (Fig. 24). The most common residual (fossil) landslides in the Fatih district are the old landslide areas that have lost their effectiveness. They are not expected to be effective today and have often lost their apparent landslide morphology [8].

The sliding strength angles of the slopes, which are located in landslide blocks identified as fossil landslides, were calculated as approximately 200^0. Therefore, it should be expected that these areas will be able to become active again if the sliding has an angle of approximately 200^0 as a result of human-caused interventions such as uncontrolled construction of construction foundation excavations, digging the slope or heel, and overloading the hillside.

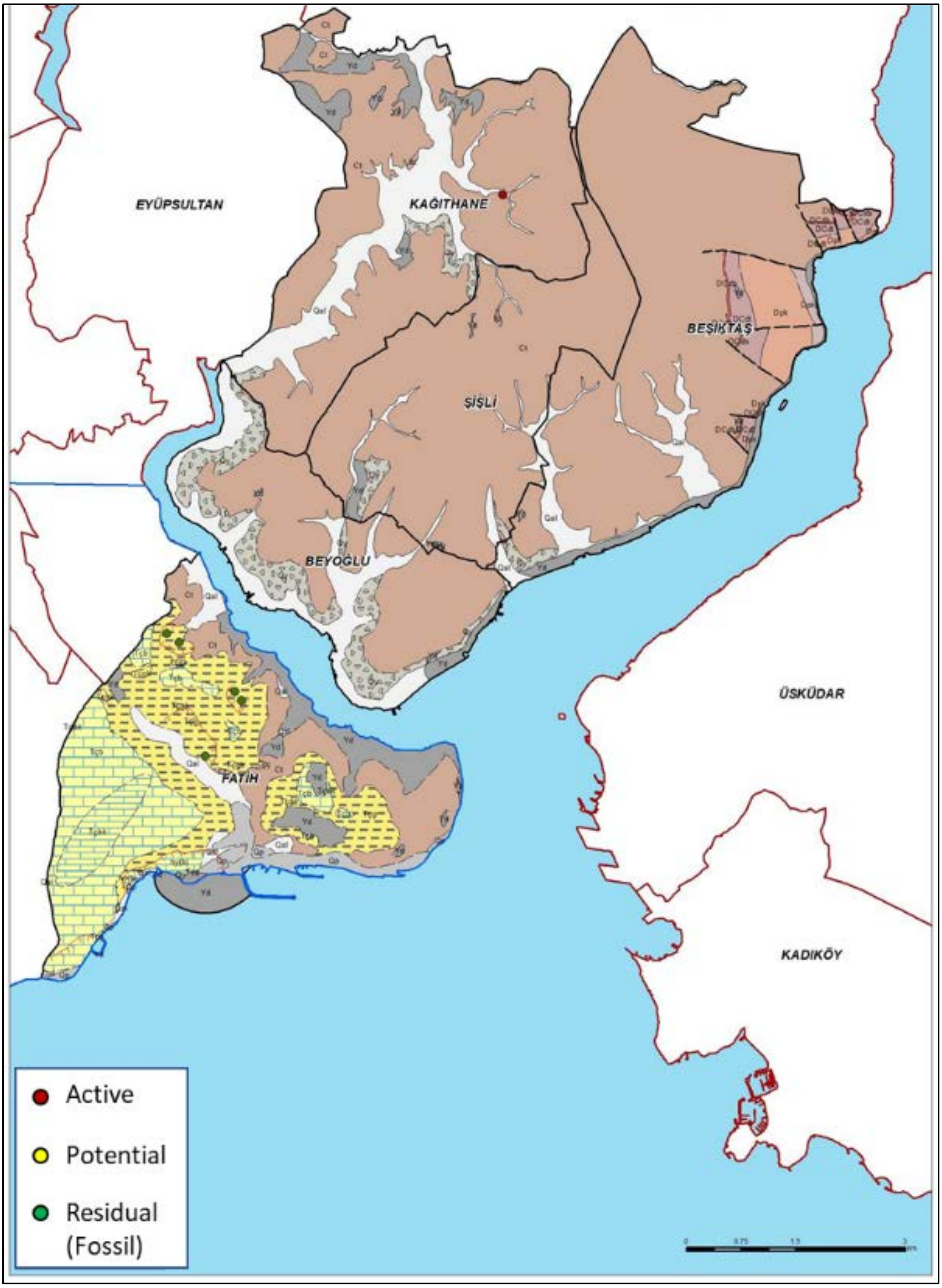

Figure 24. Mass Movement Locations of Beşiktas-Beyoglu-Fatih-Kagithane-Şişli region according to activity status on the geology map (IMM, 2020).

5.8 Beykoz- Çekmeköy Region

The majority of mass movements in the region are located within the borders of the Beykoz district. There are 30 potential and 38 active landslide areas in these districts (Fig. 25). However, there is no high risk among these landslide areas. The number of rockfall areas is 43 in total and 15 of them are active [8]. Landslide areas in this region are concentrated in. The active landslide areas are mostly concentrated on steep slopes in the central part of Beykoz such as örnekköy, elmalı, and polenezköy. Besides, slopes overlooking the Bosphorus and the Black Sea such as Küçüksu and Riva are prone to landslides.

One of the most important landslide areas in the region is the Elmalı dam watershed. Regarding the possible erosion risk in the watershed dam, the actual erosion risk increased in 1992 compared to the year 1984 when the defensive vegetation was removed from the steep slopes and reduced in 2003 when those slopes have been covered (Fig. 26). The major explanation for the high risk of real erosion in 1992 relative to 1984 is the irregular and unplanned forest destruction associated with urbanization. The campaign against illegal constructions made it beneficial to reduce the real risk of erosion in 2003 by separating it from 1994. Besides, reforestation also has major effects on soil conservation and the prevention of accumulation of water reservoirs; however, it offers a long-term solution. [36].

Due to extensive vegetation and construction, undetectable landslide areas can be found on the slopes of the region. Therefore, excavation applications should not be carried out without detailed investigations and analyses of the stability analyses, especially in the dense decomposition units and the sloping rubble covering them.

It is important to investigate the slopes with similar specialty to the landslide areas identified in the area and to make the necessary technical examinations in the parts that are being built. Furthermore, new constructions should not be decided without detailed slope stability analysis.

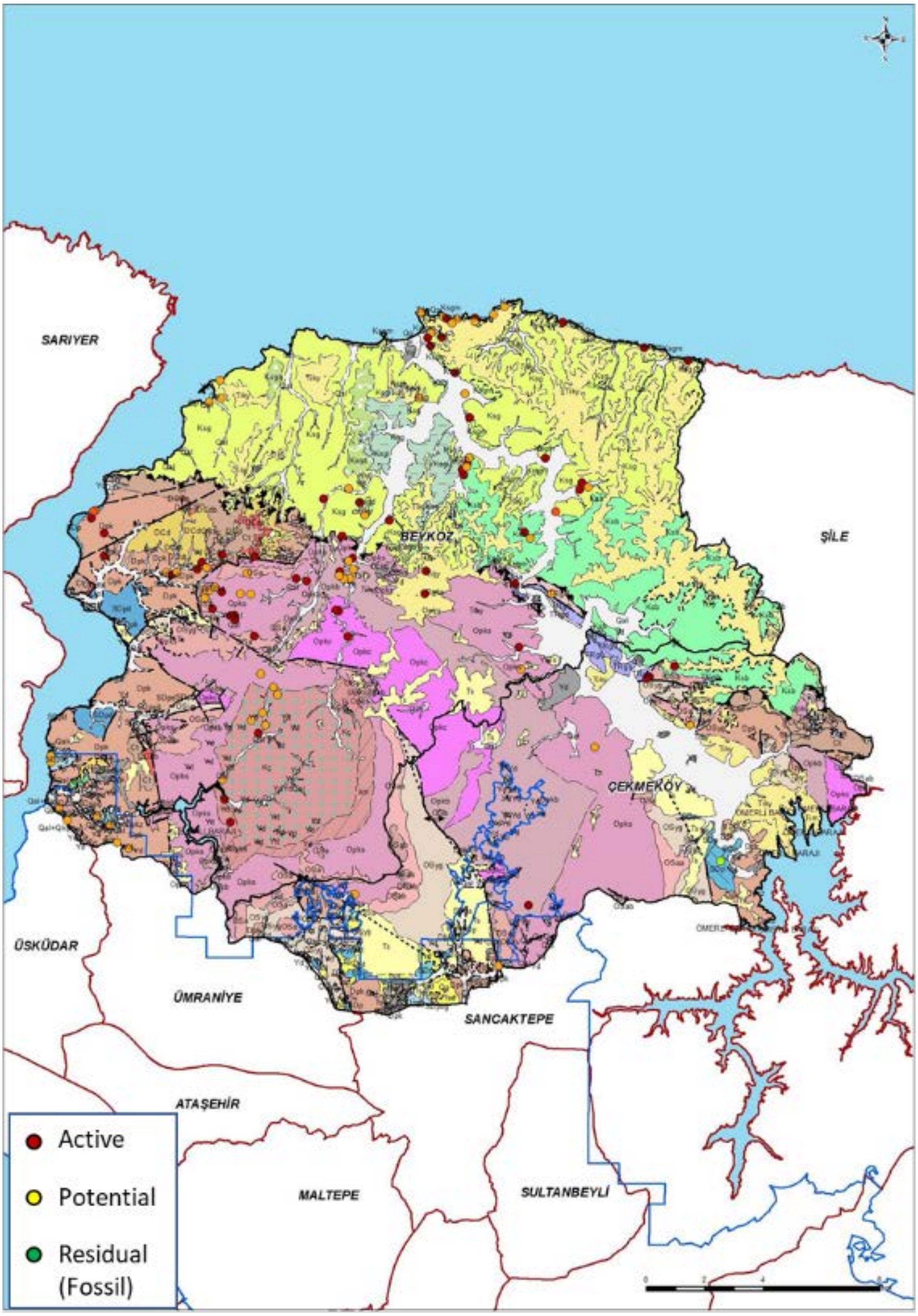

Figure 25. Mass Movement Locations of Beykoz- Çekmeköy region according to activity status on the geology map (IMM, 2020).

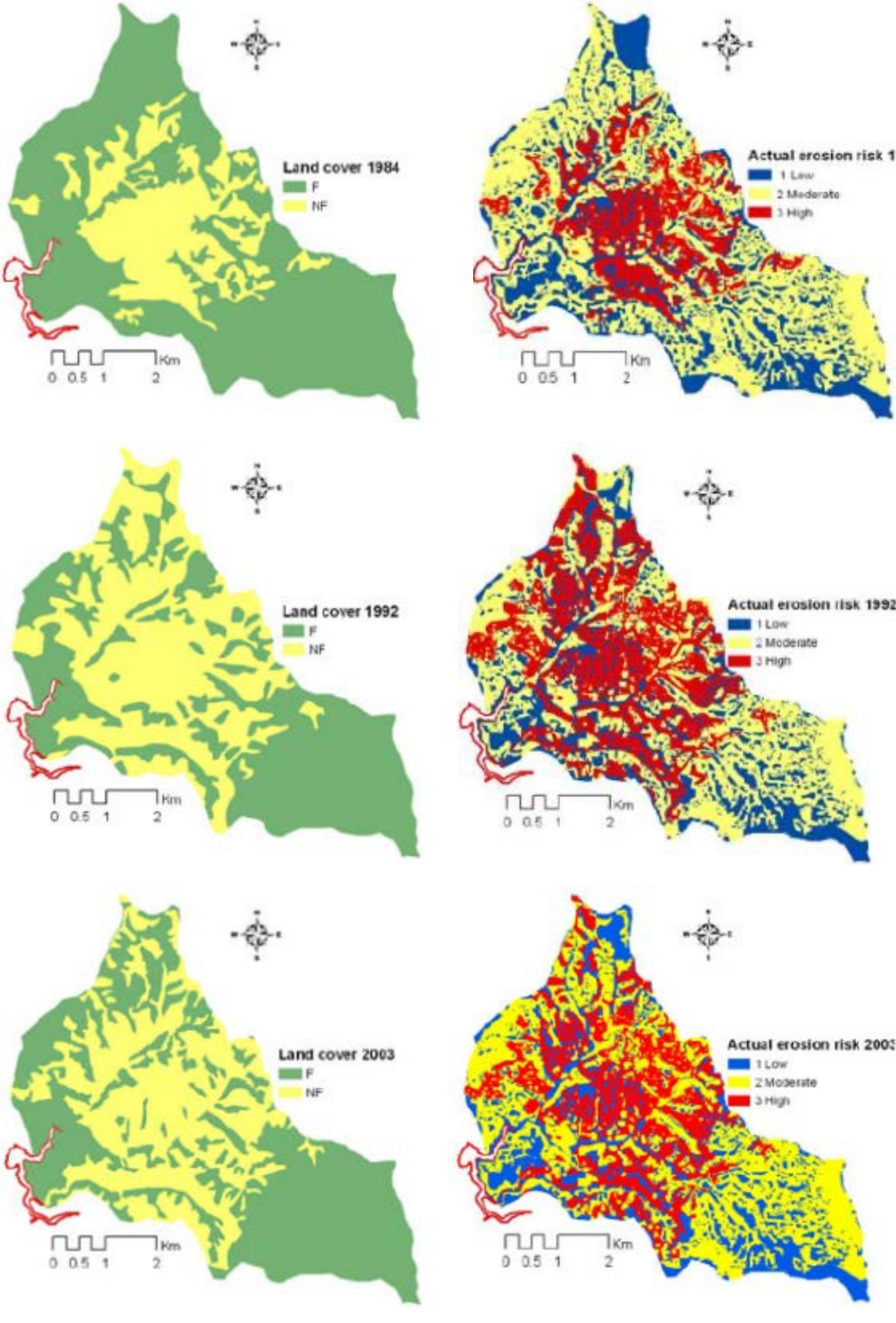

Figure 26. Land cover distribution and real erosion risk maps of Elmalı Dam in the years 1984, 1992, 2003 (Aydın and Tecimen, 2010).

5.9 Beylikdüzü- Büyükçekmece- Esenyurt Region

Active landslides in the region are concentrated on the slopes overlooking the Marmara Sea and the eastern slopes of Büyükçemece Lake, and potential landslides are spreading throughout the region. Fossil (residual) landslides are seen extensively on the western and eastern slopes of Haramidere. There are 122 potential and 3 high-risk landslide areas in these districts (Fig. 27). The number of potential rockfall areas is 8; however, none of them active [8].

Gürpınar Member clays, which are widely observed in the field, were found to have characteristics suitable for landslide formation and that this clay hoard contains pebbled and sandy lenses that can carry water. For this reason, it has been said that permeable silt units are suitable for the formation of high pore pressure. Therefore, it is important to perform detailed studies in the areas where these permeable units are located.

Landslide hazard maps of Beylikdüzü and Büyükçekmece districts were obtained in detail within the scope of the landslide areas research project developed in cooperation with Tubitak-MAM and IBB in 2016 and carried out by Prof. Dr. Volkan Ediger [30]. The study shows that the majority of landslides in the region are seen in the highly consolidated clays of the Gürpinar Member (Fig. 28). Mechanical experiments on clay in the environment show that the residual internal friction values are about 10°, meaning that stacks of these clays may not stop even on the middle slopes. Therefore, detailed studies are required in areas where such units are located.

Considering that earthquakes are one of the causes of landslides, especially in coastal districts, it should be considered that precautionary measures have become even more important and ground motions and shifts should be investigated in the residential areas.

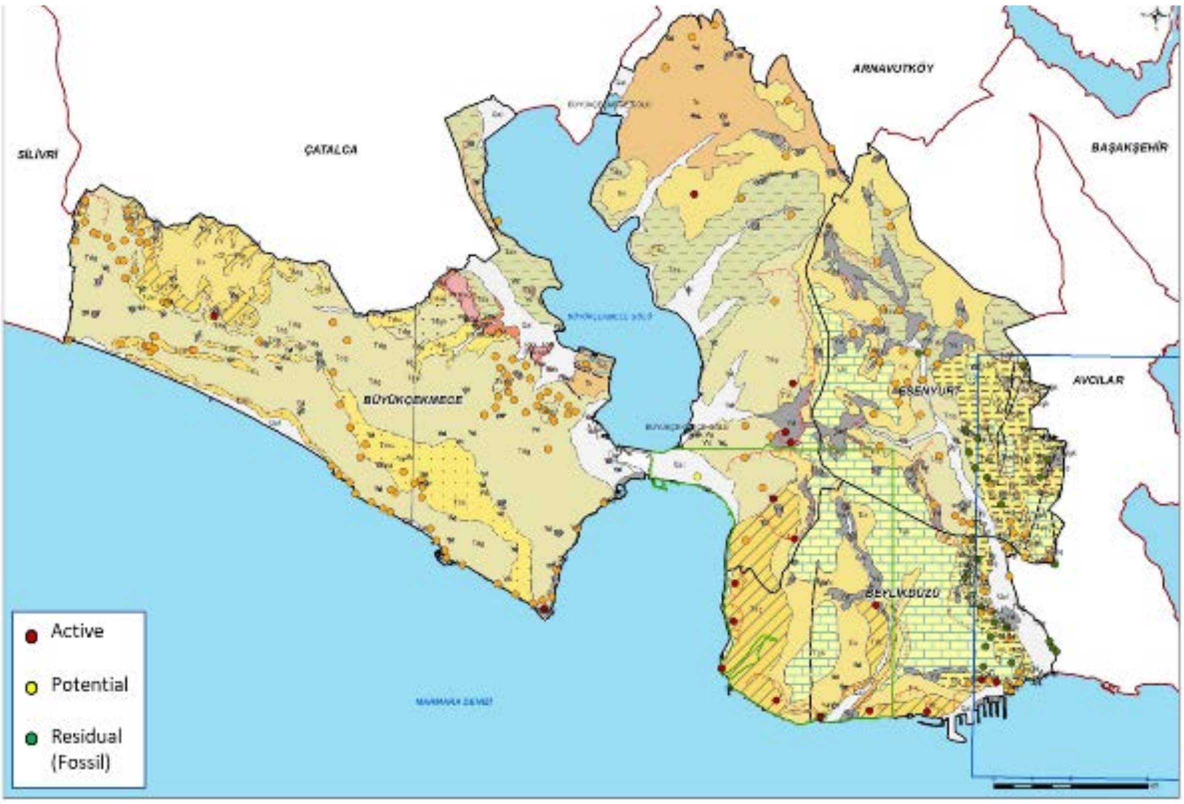

Figure 27. Mass Movement Locations of Beylikdüzü- Büyükçekmece- Esenyurt region according to activity status on the geology map (IMM, 2020).

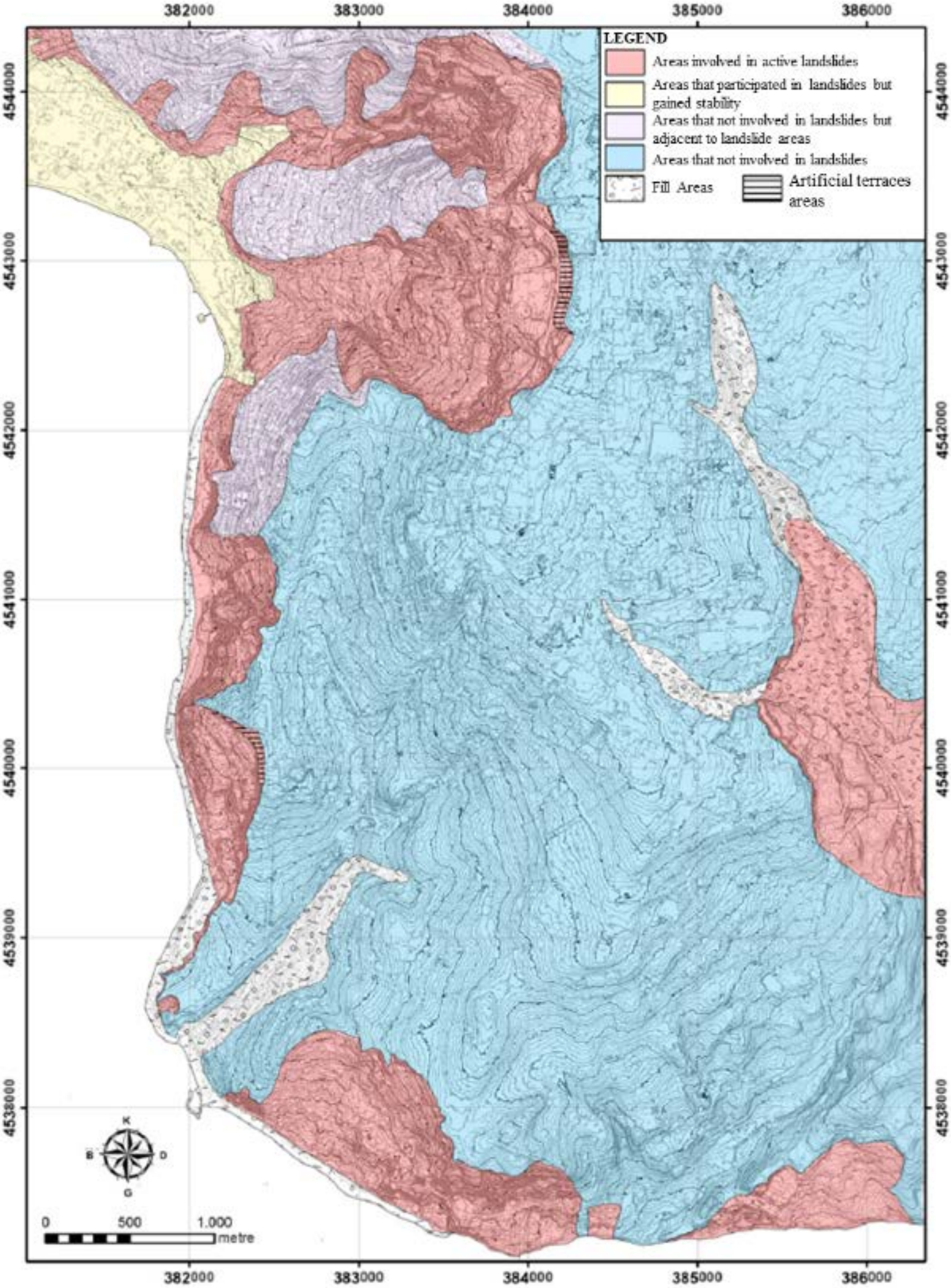

Figure 28. Landslide map of Gürpınar region (Ediger et al. 2016)

5.10 Çatalca- Silivri- Region

Çatalca and silivri districts have the most area in Istanbul in terms of the landslide area. In this region, mass movements were observed on a total of 181 areas: including 173 landslide areas, and 8 rockfalls areas (Fig. 29). Among landslides and rockfalls, 72 are active, 16 are asleep, 5 have gained stability, 11 are residuals (fossils), 1 is under control and 76 have potential instabilities. 16 of the landslide areas and 1 of the rockfall areas are high risks [8].

Approximately 84.70% of active landslides in the region were developed on the slopes of Silivri and 15.30% in the Çatalca district. Most of the landslide areas in Silivri are concentrated in the districts of Çantaköy, Akören, and Kabakça. In Çatalca, the Elbasan district is the site with the highest landslide areas. The slopes in the region may contain undetected unstable slopes due to dense vegetation and construction in some places. Therefore, excavation applications should not be carried out without detailed investigations into slope stability analyses.

In terms of geohydradic environments (groundwater permeability capacity), the western and northern parts of the region are mostly dominated by the permeable grainy environment and the southern and eastern parts are mostly semi-permeable. It is important to investigate the landslide areas in the region in more detail, to do the necessary technical examinations in the parts of the construction, and not to decide on new constructions without detailed analysis.

Çatalca district center is the second priority landslide area investigated within the scope of TUBITAK and IBB-DEZIM cooperation mentioned in 5.2 [33]. Çatalca district center is located in the northwest of Büyükçekmece lake and Çamaşır stream passes through it (Fig. 30). As a result of this study, landslide formation models were obtained for these regions.

In Figure 31 A and B, the processes of scour, collapse, overturn, slip and regression of the valley wall are represented. The weak materials accumulated on the valley floor due to the erosion and transport effect of the stream were transported to the marine environment by occasional floods. Thus, the stability balance of the valley slopes is disturbed. This period is shown in C and D in Figure 31. Today, in the landslides in the Çatalca area, the cycles given in Figure 31 C and D continue to slow down gradually. It is thought that the transitions from D to A process given in Figure 31 are likely to develop only with sea level rise and vertical tectonic movements.

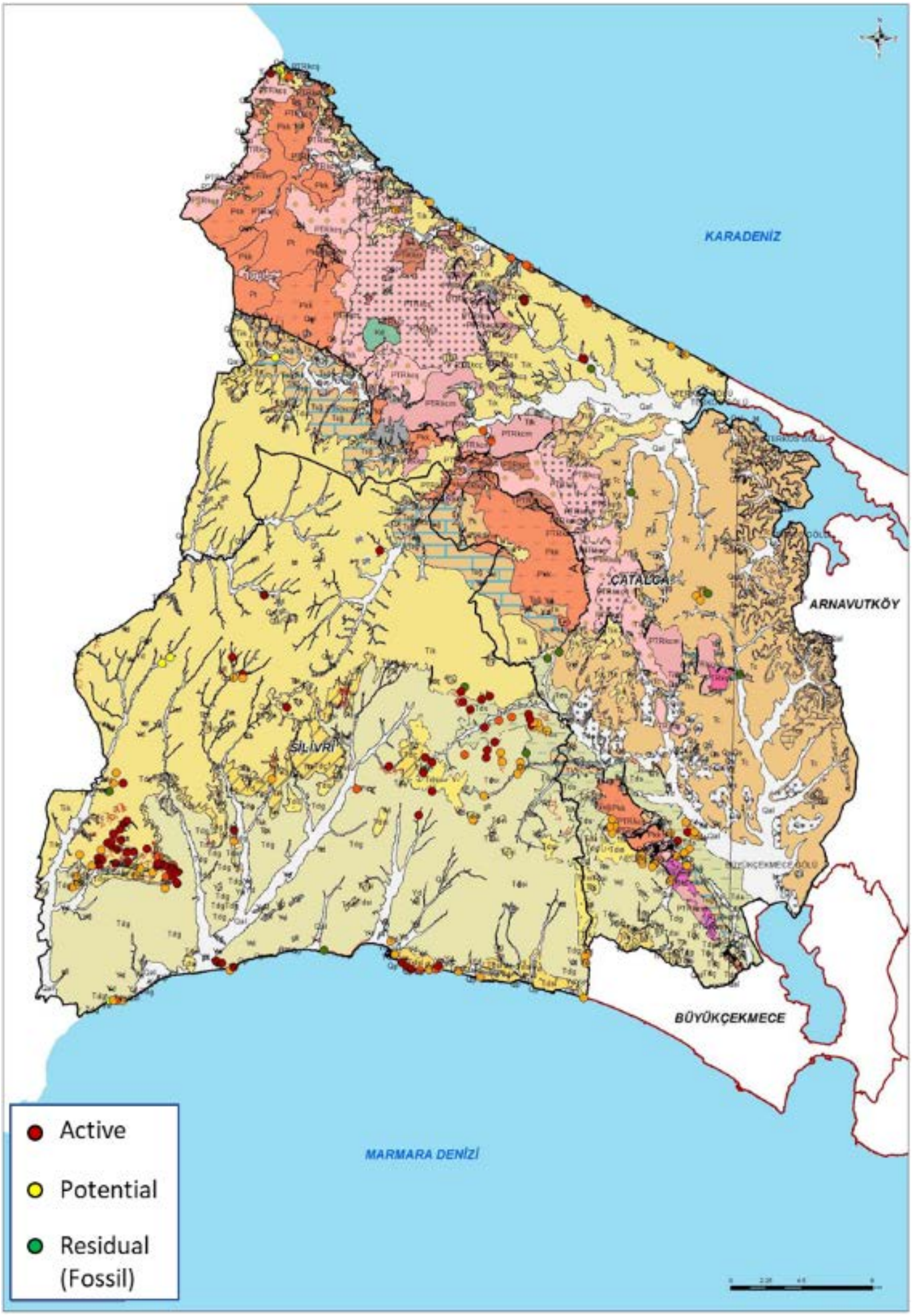

Figure 29. Mass Movement Locations of Çatalca- Silivri region according to activity status on the geology map (IMM, 2020).

Figure 30. The location of Çatalca district center in Istanbul map.

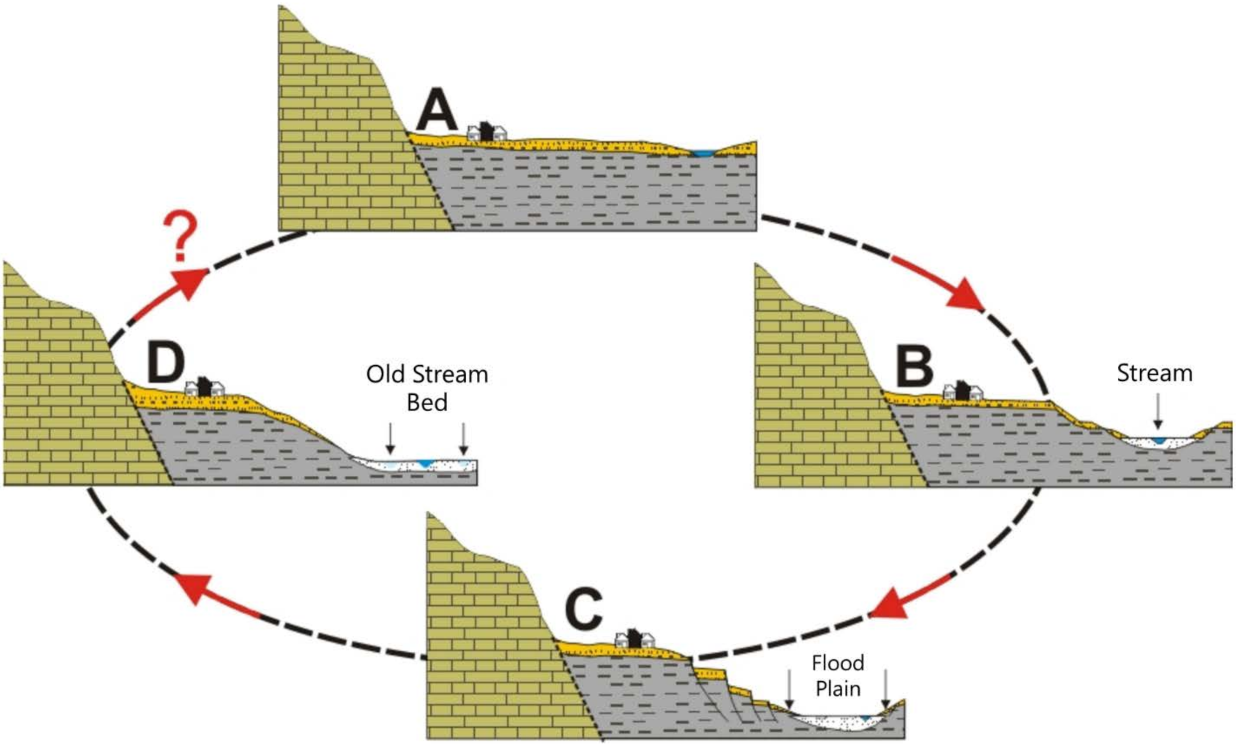

Figure 31. The model showing the landslide processes in the Çatalca research area.

5.11 Eyüpsultan- Sarıyer Region

Landslides active in the region are mostly concentrated on the slopes in the west and northwest of the Eyupsultan district. It is observed that the slope ratio of Eyüpsultan is less than Sarıyer. The slope of the Black Sea coast is 0–5% and the slope values increase considerably on the Bosphorus shore. In the northern, northeastern, and western parts of the estuary (Haliç), there are areas with slope ratios of 20% and over 30%. In the south, the slope rates are generally below 20% [8].

Mass movements occurred in the region totally on 130 slopes, 92 of them are ground landslides and 38 of them are rock landslides. 33 of the ground and rock landslides are active, 16 are asleep, 2 are under control, 4 are fossils (remains) and 75 are potentially unstable slopes. Among potentially unstable slopes, 40 of them are potential landslide areas and 35 of them are rockfall areas (Fig. 32). However, while none of the landslide areas is a high risk, 2 of the rockfall areas are high risk. The number of rockfall areas is 8 in total and 6 of them are high risk [8]. This region has the most rockfall areas after Şile. This is because there are more natural areas and forests in this region than in other regions. It is recommended to prepare and implement precautionary projects by conducting the necessary analysis against landslides in areas built in these regions.

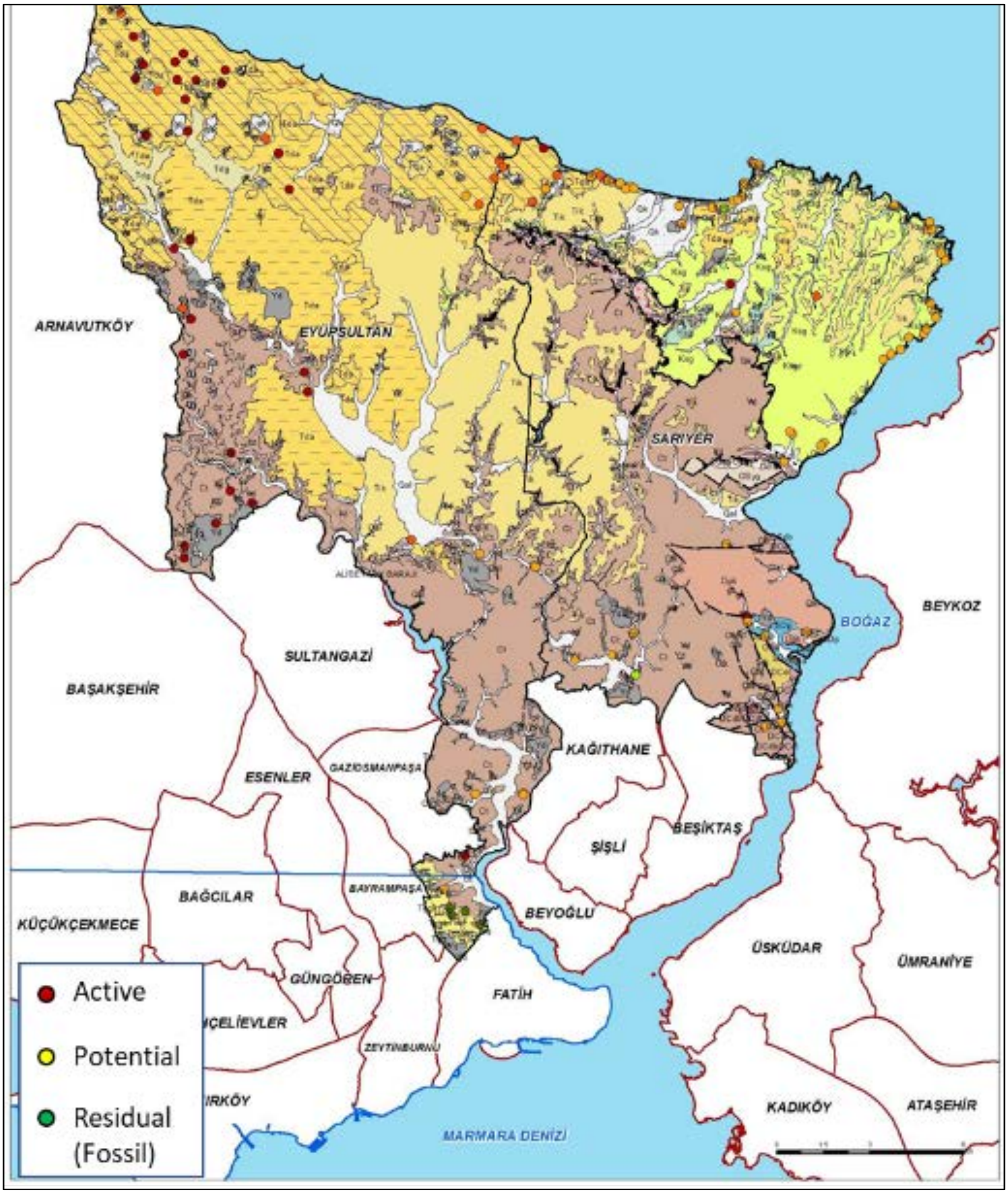

Figure 32. Mass Movement Locations of Eyüpsultan- Sarıyer region according to activity status on the geology map (IMM, 2020).

5.12 Kartal- Maltepe Region

Kartal - Maltepe region is one of the regions with the lowest risk of landslides and rockfalls in Istanbul. Mass movements are observed on 16 slopes in total, with ground landslides in 7 locations and rock landslides in 9 locations. 3 of the landslide areas are potential while 4 of them are active. As to rock falls, all of 9 areas are potential rockfall areas (Figure 33). Studies have shown that unstable slopes are concentrated in the high places in the Kartal- Maltepe region [8].

The vast majority of the region has slope values between 0-20% and these areas are areas close to the shore where settlement is located. As we go to the north-northeast of the region, slope values of 50% and above are observed. The central and northern parts of Maltepe district and the northeastern part of Kartal district are higher than other places and have a rugged morphology. The hillsides are more sensitive in terms of slope, and unstable slopes in the region are concentrated in these parts. Landslide areas in the area, which were found to be active, have mostly developed on slopes covered with rubble. Therefore, such rubble slopes need to be analyzed in more detail. Some studies should be performed to predict the behavior of these slopes during earthquakes. Necessary interventions should be done quickly and carefully to prevent these landslides[8].

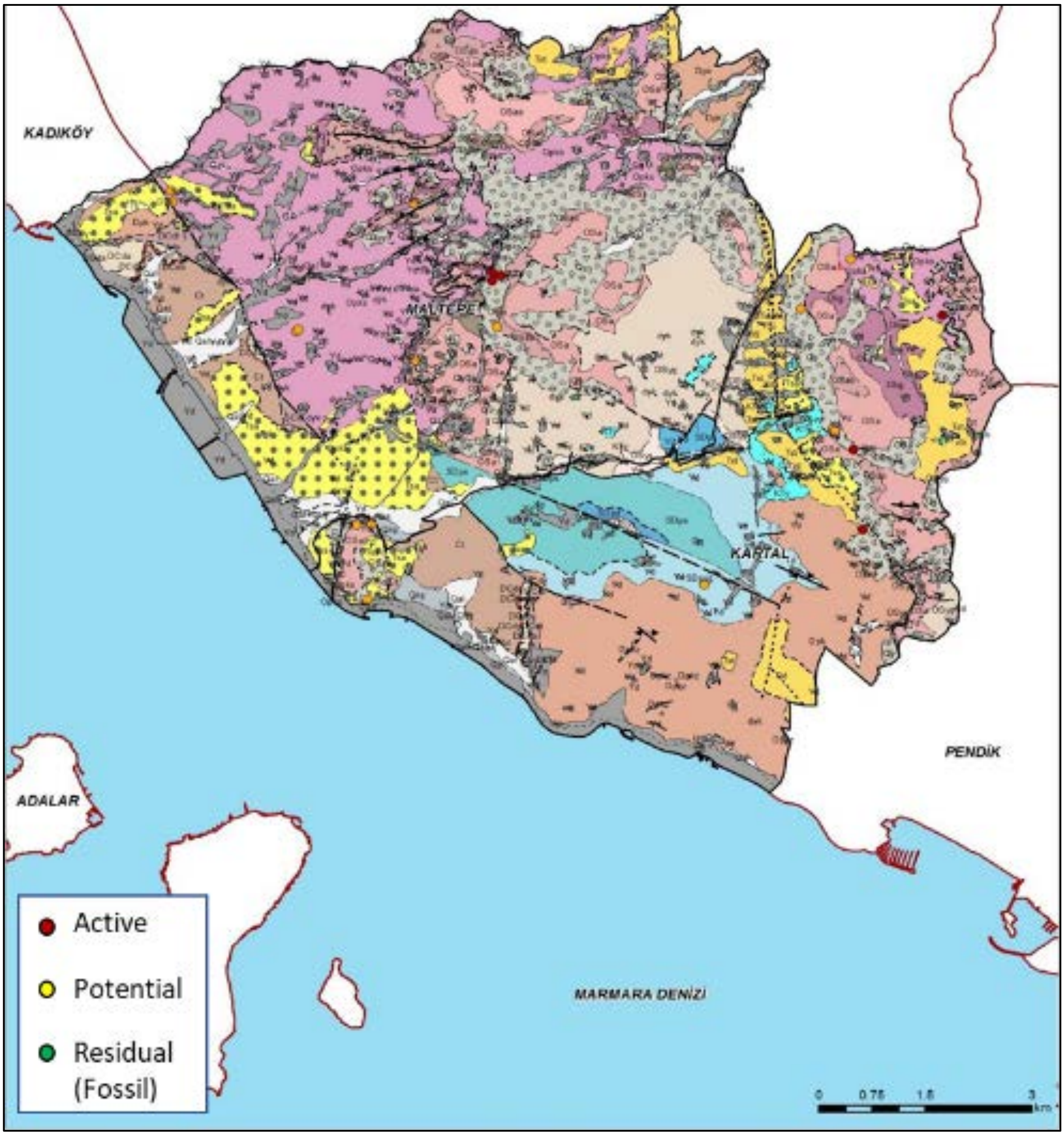

Figure 33. Mass Movement Locations of Kartal- Maltepe region according to activity status on the geology map (IMM, 2020).

5.13 Pendik- Sancaktepe-Sultanbeyli- Tuzla Region

The active landslide areas in the Pendik- Sancaktepe- Sultanbeyli- Tuzla region, have concentrated on slopes covered with rubble. Also, active landslides are seen on the slopes covered with Sultanbeyli Formation, Istanbul Formation, and artificial fillings. For this reason, regions with such formations should be investigated in more detail [8].

Mass movements occurred in the region totally on 41 slopes, 16 of them are ground landslides and 25 of them are rock landslides. 8 of the ground landslides are active and 8 are potentially unstable slopes. As to rock landslides, 3 are active and 22 are potential landslides [8](Fig. 34).

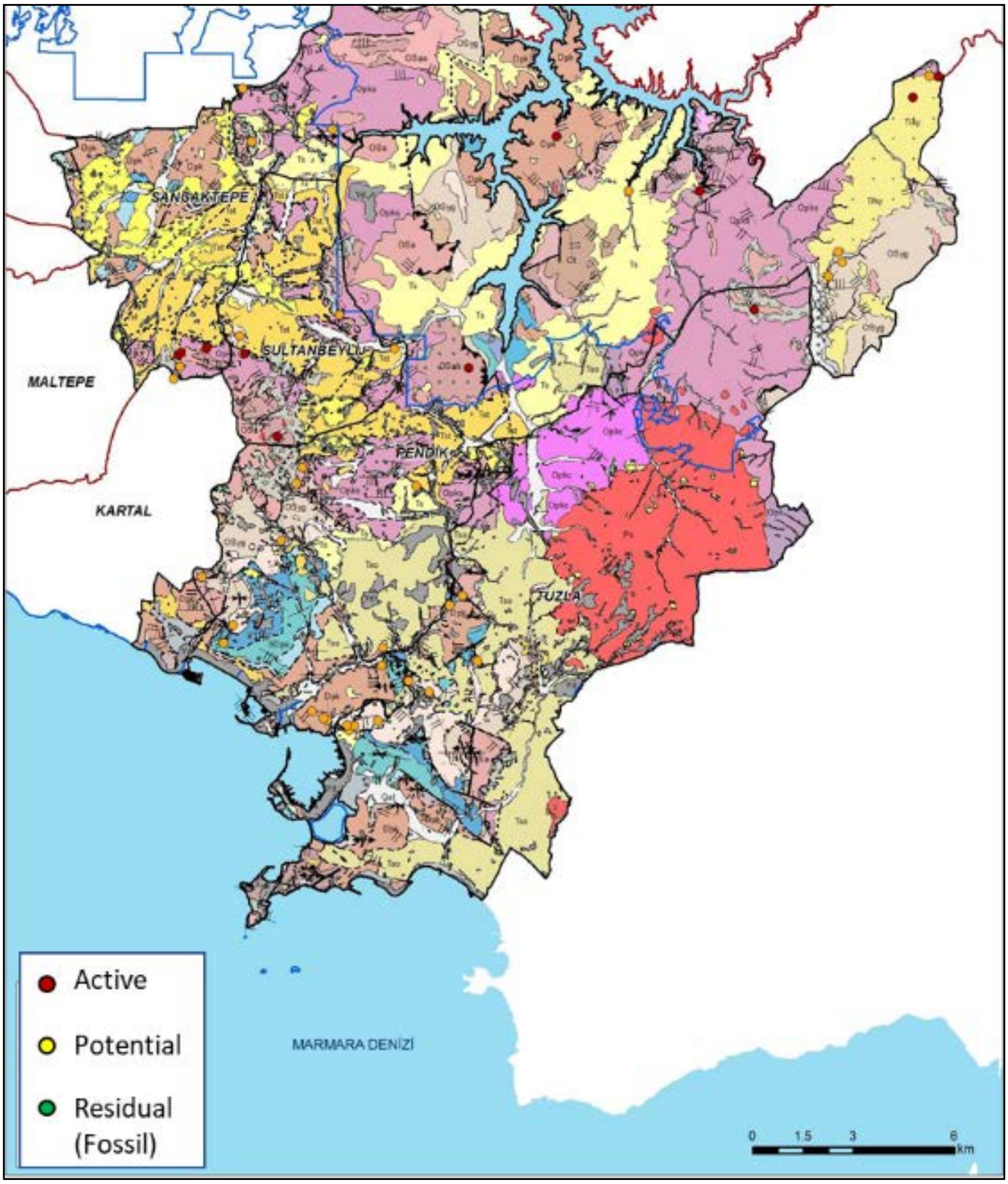

Figure 34. Mass Movement Locations of Pendik- Sancaktepe- Sultanbeyli- Tuzla region according to activity status on the geology map (IMM, 2020).

5.14 Şile Region

Şile is the district with the most rockfall areas due to the fact that there are more woodlands and natural areas. In this district, unstable slopes are concentrated in the high places in the region. It is observed that instability is common especially on slopes where the slope exceeds 30% and it also develops on the slopes facing the sea [8]. There was a total of 96 mass motions in the region, including 48 ground landslides and 48 rock landslides. 36 of the ground landslides are active, 1 are asleep, 11 are potentially unstable slopes. As to rock landslides, 38 of them are active, 2 are asleep, 8 are potentially unstable slopes (Figure 35).

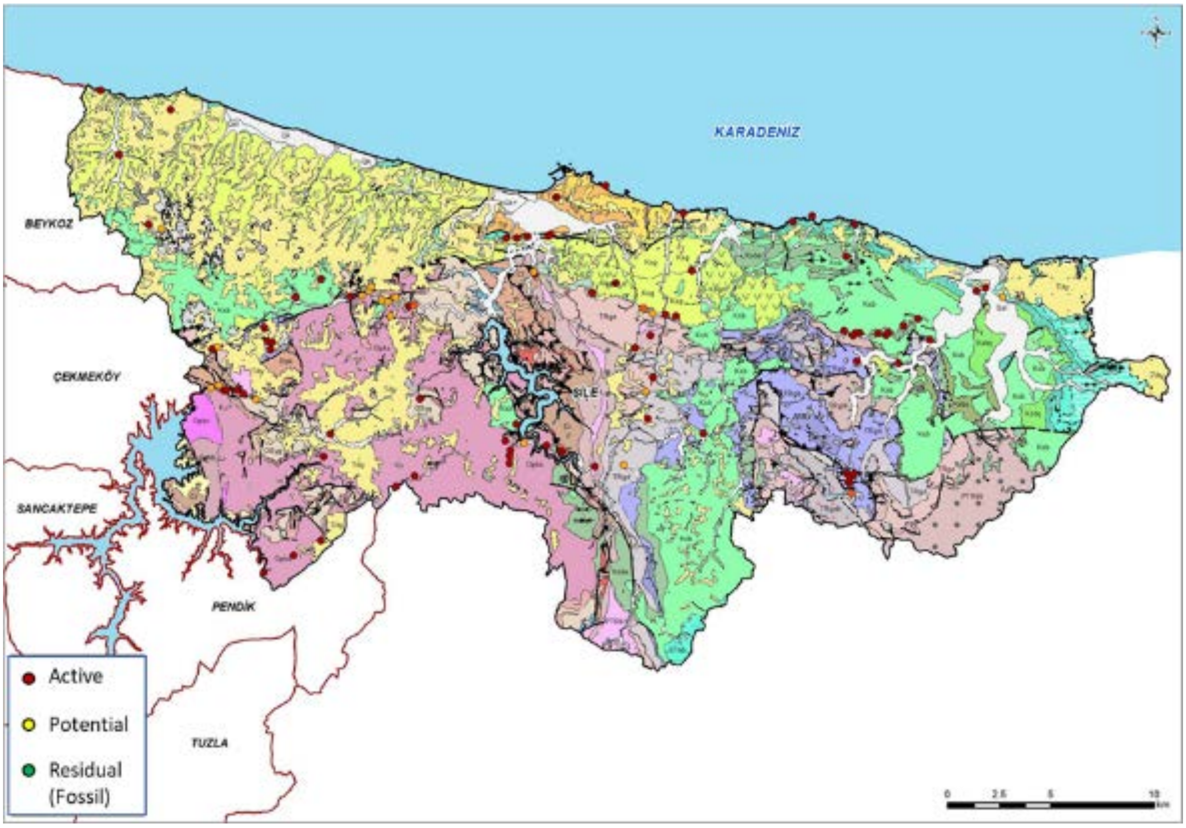

Figure 35. Mass Movement Locations of Şile region according to activity status on the geology map (IMM, 2020).

6 Conclusion

The risk of landslides in Istanbul is not critical except in some districts, but sudden and heavy rains caused by global climate change and unplanned urbanization increase the risk of landslides every day. In particular, increasing sudden and heavy rains are the most prominent atmospheric factors that trigger landslides. Also, earthquakes can trigger unstable grounds and cause landslides. Unauthorized excavations, deforestation, and soil deposits are among the other causes that pave the way for landslide formation.

If we look specifically at Istanbul, it can be said that the landslide hazard is less than in other cities. The western side of Küçükçekmece Lake is the region where the landslide risk is highest. The number of landslide areas in Büyükçekmece, Beylikdüzü, Esenyurt, and Silivri districts in this region is more than other districts of Istanbul. The reasons for the higher risk of landslides in these districts are that the ground formations are predisposing to landslides, and the streams and sloping lands are more than other districts. In the districts of Sile, Arnavutköy, and Adalar, there are more rockfall areas due to the conservation of natural life.

Landslides are not as indeterminate as earthquakes, and when sufficient data is collected and analyzed correctly, the danger and risk of landslides can be predicted with high accuracy. "Risk management" is very important in reducing the risk of landslides and the cheapest and most effective method in risk management is "planning". In most landslide areas, risk can be minimized only with proper planning. Besides, engineering studies such as retaining walls and ground improvements can reduce danger and risk based on the characteristics of landslide areas. Also, with the help of developing computer and sensor technologies, the movement of landslide areas can be monitored with sensors and the system can send warnings to the local people and state authorities in case of emergency.

Considering all these things, it can be said that the risk of landslides in Istanbul is increasing day by day with climate change and irregular settlements. Especially the western side of Istanbul is the area that should be focused on due to a large number of landslide areas. In order to reduce the landslide risk in this region, field studies, data collection, hazard analysis, and risk management are critical.

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