# DETERMINATION OF SEISMIC VULNERABILITIES AND RISKS FOR URBAN MITIGATION PLANNING IN TURKEY

Tuğçe SÖNMEZ[1]

**Abstract**

As the number of events and the losses from disasters are increasing worldwide, disaster reduction has become an increasingly important issue on the international agenda and the reduction of risks that are particularly concentrated in cities become the major objective and challenge of international disasters policy. As a result of this policy United Nations has established the International Strategy for Disaster Reduction in 2000, organized World Conferences on "Risk Reduction" in Yokohoma-1994, Toronto-2004, Kobe-2005 and announced 2010-2011 as the campaign years for 'Resilient Cities'. These conferences have extended and sharpened awareness about natural hazard risks and efforts of risk reduction on global agenda.

Chronic seismic hazards and resulting secondary impacts are due to the geological conditions of Turkey and the nature of current response mechanisms. Local know-how of building and settlement that evolved over centuries eroded with the growth in population, and the introduction of reinforced concrete building economics. This makes cities the most vulnerable geographical and social entities in Turkey. On the contrary, Turkish disaster policy has mainly focused on the post-disaster period and remains limited due to development of regulations that can not be fully implemented. No incentives or legislation existed to encourage risk analysis, risk mitigation or risk spreading approaches.

With this point of view, the aim of this research is to examine the factors that determine seismic vulnerabilities and risks of settlements and establish if analysis of seismic risks in cities and living environments could be determined on the basis of a set of attributes of the building stock. The scope is to exhibit and analytically compare such factors in settlements of Turkey. Quantitative information about a set of attributes of settlements is investigated statistically to determine which of the factors contribute most to risk levels described locally. Correlation and Regression analyses are employed to determine what combinations of the independent variables might best denote city-level risks. The seismic hazard maps of the Kandilli Observatory and Earthquake Research Institute and statistics published by the Turkish Statistical Institute, like census and housing data have a leading contribution to make. These secondary sources of information help to compose the database for a series of comparisons in the seismic vulnerabilities and risk levels of cities.

[1] Middle East Technical University, Ankara, Turkey - tugcesonmez@gmail.com

This study is expected to provide information about the critically vulnerable assets in cities, whether this could be considered as a function of hazard-proneness. Otherwise, interpretations of the most effective attributes that could describe vulnerabilities best and be related to risk information in cities could be explored. Findings of such analysis could provide guiding criteria for mitigation policies in Turkey and the research may thus generate information for a more effective disaster policy.

## 1. Introduction

Over the past decade, countries across the world have witnessed thousands of major natural disasters that threaten the sustainability of cities, disrupting their resources and affecting millions of people through losses of life, serious injury and loss of assets and livelihoods. The number of reported natural disasters and their impact on human and economic development worldwide has been increasing yearly and shows a relentless upward movement. Considering that half of the world's population is expected to live in urban areas by 2020 and over three-quarters of the 100 largest cities are exposed to serious natural hazards, it is time to adopt a new approach and invest in pro-active disaster reduction strategies.

In recent years, there has been a major shift in peoples' attitudes and behaviors towards coping with natural disasters. In the past more emphasis was placed on humanitarian response and relief activities, with little attention being paid to disaster reduction that have the potential to save thousands of lives. Today, there is increasing recognition that while humanitarian efforts are important and need continued attention, risk and vulnerability are crucial elements in reducing the negative impacts of hazards and thus essential to the achievement of sustainable development.

The idea for conducting a global review of disaster reduction initiatives was born in the millennium, following the United Nations International Decade for Natural Disaster Reduction (IDNDR) 1990-1999. In 1999, UN decided to continue the activities on disaster prevention and vulnerability reduction carried out during the IDNDR. It thus established the International Strategy for Disaster Reduction (ISDR), which is supported by the scientific and technical expertise and knowledge accumulated during the IDNDR.

Following this idea, a series of declarations of interest and determination to reduce risks have taken place at the international context (Balamir, 2005). These are; World Conferences on "Risk Reduction" in Yokohoma-1994, Toronto-2004 and Kobe-2005 have extended and sharpened this awareness about natural hazard risks and efforts of risk reduction on global agenda.

The reduction of growing rates of risks that are particularly concentrated in cities today is the major objective and challenge of the national and international disasters policy. As recent international policy emphasis has focused on risks and mitigation, the issue of seismic vulnerabilities and risk assessment are the primary objectives of the study.

On the other hand, Report on Disaster Reduction prepared by the Republic of Turkey for the World Conference on Disaster Reduction in Kobe reveals that the approach in Turkey to risk assessment, risk reduction and risk mapping are deficient and remains limited due to development of regulations that can not be fully implemented.

With this point of view, the examination and prioritization of the risk and seismic risk concepts in Turkey with an overview of current understanding and the evolution of the subject from its academic and scientific beginnings to its political implications in the realm of sustainable development of today constitutes the starting point of the study.

### 1.1. The Aim, Objectives and Scope of the Study

The World Conference on Disaster Reduction in Kobe provided a unique opportunity to promote a strategic and systematic approach to determination and reducing seismic vulnerabilities and risks of settlements. It is a guiding framework on disaster reduction for the twenty-first century.

The Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters determined five priorities for action:

1. Ensure that disaster risk reduction is a national and a local priority,
2. Identify, assess and monitor disaster risks and enhance early warning,
3. Reduce the underlying risk factors,
4. Use knowledge, innovation and education to build a culture of safety and resilience,
5. Strengthen disaster preparedness for effective response at all levels.

The overall objective of this research is to evaluate how these priorities are served in Turkey especially; in the identification, assessment and monitoring of disaster risks, the reduction of the risk factors and the use of knowledge to build a culture of safety and resilience.

The major purpose of this research is to develop a method for the identification of vulnerabilities and prioritization of most vulnerable settlements in anticipation of earthquake related hazards.

With this purpose, the aim of this research is to examine the factors that determine seismic vulnerabilities and risks of settlements and establish if analysis of seismic risks in cities and living environments could be determined on the basis of a set of attributes of the building stock. The scope is to exhibit and analytically compare such factors in settlements of Turkey.

## 1.2. The Approach and Method of the Study

Quantitative information about a set of attributes of settlements is investigated statistically to determine which of the factors contribute most to risk levels described locally.

The seismic hazard maps of the Kandilli Observatory and Earthquake Research Institute (KOERI) and statistics published by the Turkish Statistical Institute (TurkStat), like census and housing data have a leading contribution to make. These secondary sources of information help to compose the database for a series of comparisons in the seismic vulnerabilities and risk levels of cities.

In the determination of seismic vulnerabilities and risks of settlements, “loss levels” in the building stock in each settlement will evaluate based on seismic hazard intensity via seismic hazard maps produced by KOERI and building stock vulnerability curves derived by Demircioglu (2010). Settlement level loss in the building stock is the basic indicator of assumed risk and provides the dependent variables of the research.

The independent variables of the research are composed of building inventory data and related attributes of building stock on each settlement obtained from TurkStat. ‘Building Construction Statistics’ and ‘Building Census’ prepared by Turkish Statistical Institute is used within this research. Independent variables of the research are; Settlement Population, Population Growth Rate, Rates of Agglomeration, Population/Total Number of Buildings and Development Index.

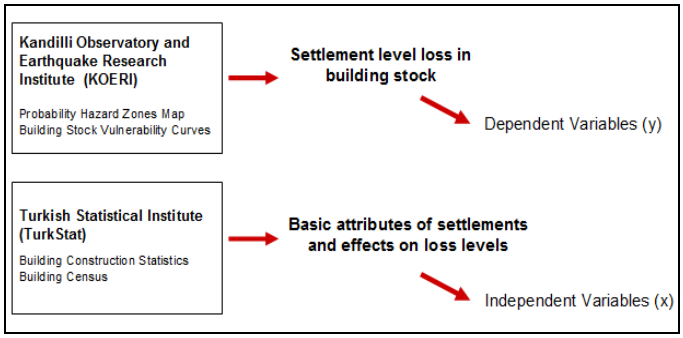



Figure 1. Dependent and Independent Variables of the Research

The study is expected to provide information about the critically vulnerable assets in cities, whether this could be considered as a function of hazard-proneness. Otherwise, interpretations of the most effective attributes that could describe vulnerabilities best and be related to risk information in cities could be explored.

Findings of such analysis could provide guiding criteria for mitigation policies in Turkey.

## 2. Loss Estimations and Determinants of Vulnerabilities in Settlements of Turkey

In order to determine and compare seismic vulnerabilities and risks in settlements of Turkey, statistical surveys and statistical analyses are used. Quantitative information about a set of attributes of settlements is investigated statistically to determine which of the factors contribute most to risk levels described locally.

Settlement level loss in the building stock is the basic indicator of assumed risk and provides the dependent variables of the research. The independent variables of the research are composed of building inventory data and related attributes of building stock on each settlement obtained from TurkStat.

The basic question of the research is: "How do loss levels in building stock correlate to independent variables?" and regression analyses are used to examine this question.

### 2.1. Loss Levels in Building Stock as Dependent Variables of the Research

Risk in settlement units is defined as a function of material loss in the building stock with respect to the expected seismic event. It is assumed that loss in the building stock in each settlement can be used as a proxy to express the comparative loss of human life, economic loss, damages in infrastructural systems, as well as secondary and indirect levels of losses in the settlement.

Therefore, settlement level loss in the building stock is the basic indicator of assumed risk and provides the dependent variables of the research.

**Y1 =** Loss Levels in Building Stock

Determination of Settlement level loss in the building stock has been realized by the following steps:

1. Assessment of the probabilistic seismic hazard, and production of Settlements in Hazard Zones Map (72-years; 50% probability),
2. Determination of Settlement Categories According to Size,
3. Identification of Categories of Building Types in Each Settlement,
4. Determination of Loss Levels of Each Building Category with Reference to Vulnerability Curves,
5. Identification of Loss Levels (Risks) Aggregated at Settlement Level

Following above described procedure, identification of most vulnerable settlements in each size-category and 'provinces with high-risk' are accomplished.

1. Assessment of the probabilistic seismic hazard and production of Settlements in Hazard Zones Map

The intensity distribution for 72 years period and %50 probability map produced by Erdik (2002) used in the assessment of the probability seismic hazard and production of Settlements in Hazard Zones Map.

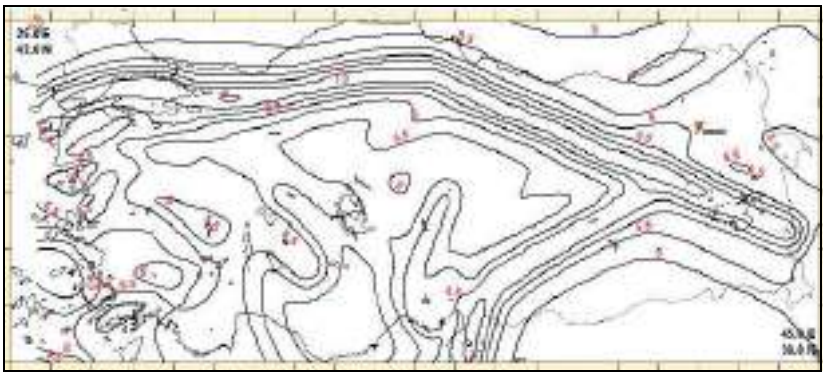


Figure 2. Intensity distribution for 72 years and %50 probability (Erdik, 2002)

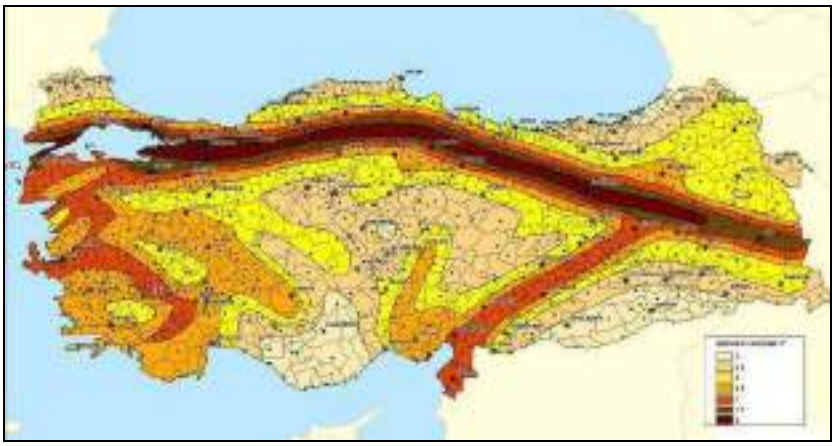


Figure 3. Spatial distribution of 72-year return period intensity and 50% probability

When we examine the distribution of settlements with reference to all seismic intensity levels, we saw that 45% of settlements are subject to intensities lower than 6.0 and 55% of settlements in the country is subject to intensities 6.5 and upper.

Table 1. The distribution of province and sub-province centers with reference to all seismic intensity levels according to number of settlements

| Settlement Size Categories | Settlements Subject to Intensity of **5.0** | Settlements Subject to Intensity of **5.5** | Settlements Subject to Intensity of **6** | Settlements Subject to Intensity of **6.5** | Settlements Subject to Intensity of **7** | Settlements Subject to Intensity of **7.5** | Settlements Subject to Intensity of **8** |
|---|---|---|---|---|---|---|---|
| 0- 50.000 | 43 | 142 | 160 | 154 | 108 | 32 | 38 |
| 50.000-490.000 | 13 | 21 | 24 | 35 | 22 | 4 | 5 |
| Metropolitan p. | 0 | 2 | 5 | 22 | 19 | 43 | 16 |
| Total | 56 | 165 | 189 | 211 | 149 | 79 | 59 |
| Total % | 6 | 18 | 21 | 23 | 17 | 9 | 6 |

All settlements with an expected hazard intensity level of 6.0 and less are excluded from the analyses assuming that insignificant damage is likely to take place in these settlements.

2. Determination of Settlement Categories According to Size

If absolute vulnerabilities are measured in terms of likely loss levels, a bias for larger settlements and developed regions is inevitable. In order to avoid bias in favour of larger settlements and developed regions, a method of sub-grouping is to be employed. Therefore, it may be appropriate to categorize the hazard-exposed settlements in terms of population size and a categorization of settlements with reference to population is considered as an initial step of the research.

Three groups of settlements are considered according to categorization of settlements with reference to population.

i- Metropolitan cities are identified as a separate category at the upper end. Irrespective of size and location, such province and sub-province centers are considered as a single settlement unit.

The remaining smaller cities are distinguished in two parts, almost identical in terms of total population. This marks the threshold size of 50.000.

ii- Sub-provincial and provincial centers of 50’000-500’000 are identified as a second category of settlements. These are often well-established settlements with higher rates of growth and expanding economies.

iii- Smaller sub-provincial and provincial centers with a population less than 50’000 make the third group of urban centers. These are relatively stagnant settlements.

The frequency distributions of province and sub-province centers subject to seismic disturbance of 6.5+ within 72 years with a probability of 50% are given below in terms of total population. The break-point of 50’000 is indicated in red.

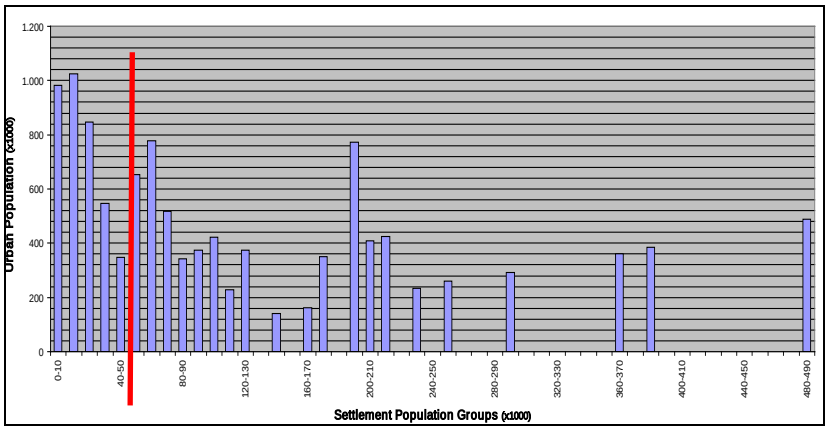



Figure 4. The frequency distributions according to population

The distributions of settlements within each size-category are given below.

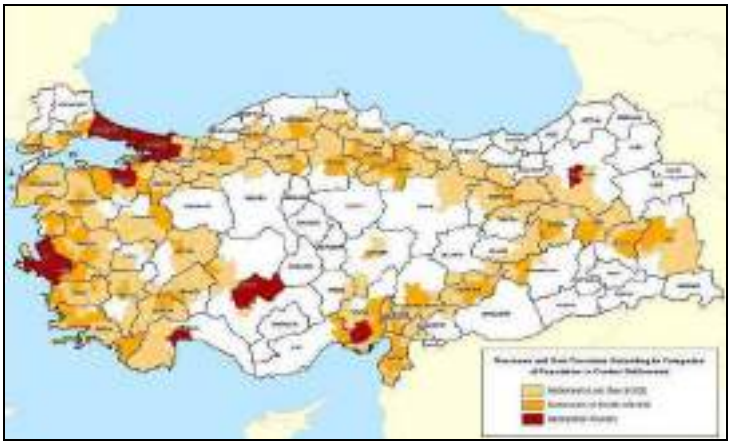


Figure 5. Spatial Distribution of Settlement Categories

When we examine the population distribution of settlements with reference to all seismic intensity levels, we saw that 35 % of all urban population live in settlements subject to intensities lower than 6.0. 65% of urban population lives in settlements subject to intensities 6.5 and upper. As 6.5+ intensities can be classified as the high hazard impact zone, we can easily say that approximately two third of all population lives under serious threat.

Table 2. The distribution of province and sub-province centers with reference to all seismic intensity levels according to total population

| Settlement Size Categories | Settlements Subject to Intensity of **5.0** | Settlements Subject to Intensity of **5.5** | Settlements Subject to Intensity of **6** | Settlements Subject to Intensity of **6.5** | Settlements Subject to Intensity of **7** | Settlements Subject to Intensity of **7.5** | Settlements Subject to Intensity of **8** |
|---|---|---|---|---|---|---|---|
| 0- 50.000 | 578.088 | 1.256.877 | 1.520.341 | 1.780.609 | 1.213.371 | 302.697 | 451.537 |
| 50.000-490.000 | 1.671.998 | 2.360.181 | 2.818.789 | 4.339.446 | 2.538.841 | 678.810 | 415.451 |
| Metropolitan p. | 0 | 5.140.959 | 4.067.916 | 4.216.666 | 3.137.913 | 14.466.195 | 1.841.525 |
| Total | 2.250.086 | 8.758.017 | 8.406.916 | 10.336.721 | 6.890.125 | 15.447.702 | 2.708.513 |
| Total % | 4 | 16 | 15 | 19 | 13 | 28 | 5 |

Distribution of settlement categories indicates significant variation with reference to intensity of seismic hazard. Almost half of the smaller settlements prove take place at the lowest end of the seismic scale under consideration. This is reversed in the case of metropolitan centers. This trend is observed to repeat itself with even greater shares in terms of population.

## 3. Identification of Categories of Building Types in Each Settlement

Information concerning building stock properties in each settlement is obtained from Building Census-2000 produced by TurkStat. The publication however of this source of information was not aggregated at the settlement level. A special disaggregated version of the building census 2000 at the level of settlements was accessed for this research.

Following the categorization of the building stock provided in Demircioğlu (2010), four distinct groups of buildings have been identified. Load-bearing buildings, reinforced concrete structures of low-rise, medium-rise, and high-rise building categories are available in terms of number of buildings in each settlement. Apart from 'construction type', the Census of year 2000 contains information on 'number of storeys', 'construction date', and 'use' for every settlement.

Table 3. Building stock categories of settlements according to construction type and number of storeys

| **Settlement Size Categories** | **Wall Bearing Construction (1-3 storeys)** | **Frame Construction Low- Rise (1-3)** | **Frame Construction Mid–Rise (4-9)** | **Frame Construction High–Rise (10+)** |
|---|---|---|---|---|
| 0-50.000 | 440.905 | 341.875 | 54.309 | 80 |
| 50.000 – 500.000 | 482.844 | 357.630 | 128.564 | 619 |
| Metropolitan provinces | 655.200 | 899.892 | 541.888 | 10.862 |
| Total | 1.578.949 | 1.599.397 | 724.761 | 11.561 |

## 4. Determination of Loss Levels of Each Building Category with Reference to Vulnerability Curves

Fragility (vulnerability) curves for each category of the building stock in Turkey, as empirically derived in Demircioğlu (2010) are employed here to determine the likely loss levels/risks in settlements. According to this procedure, each of the four categories of the building stock in every settlement is separately evaluated in their likely response to the estimated intensity of shake. As a statistical distribution, specific levels of loss from each category of the building stock can be determined by means of the fragility curves.

These curves are devoted for low-rise reinforced concrete buildings, as well as mid-rise and high-rise reinforced concrete buildings. The vulnerability curve of the 'load-bearing' category is assumed to approximate with the low-rise RC type of buildings.

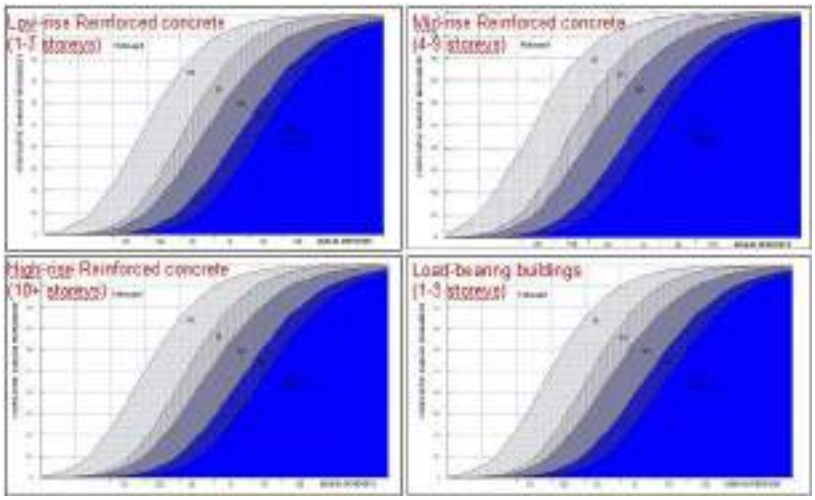



Figure 6. Intensity based vulnerability curves (Demircioğlu, 2010)

Using definitions from MSK-81 Scale, Coburn and Spence (1992) associates damage grades as D1-Slight, D2-Moderate, D3-Heavy, D4-Partial Destruction and D5-Collapse. Damage levels encompassing damages D3, D4 and D5 is an important descriptor of the earthquake damage since D3 represents an approximate borderline between repair and replacement of the building stock exposed to an earthquake.

With reference to the seismic hazard intensity that any settlement is likely to experience, total loss in building stock with its various types and categories are estimated in each group of settlements relying on the vulnerability curves of each building type. The approximate ratios of loss according to seismic intensity and level of damage in each category are observed as given in Table 4 below.

Table 4. Coefficients of likely forms of loss in the building stock of settlements subject to varying levels of seismic intensity

| Seismic Intensity | D1 Slight Damage | D2 Medium Damage | D3 Heavy Damage | D4 Partial Collapse | 5 Collapse |
|---|---|---|---|---|---|
| Low – Rise & Load-Bearing: | | | | | |
| 6.5 | 0.12 | 0.02 | 0.01 | 0 | 0 |
| 7 | 0.22 | 0.04 | 0.03 | 0 | 0 |
| 7.5 | 0.37 | 0.10 | 0.05 | 0.01 | 0 |
| 8 | 0.50 | 0.18 | 0.11 | 0.0.3 | 0.01 |
| Mid – Rise: | | | | | |
| 6.5 | 0.26 | 0.05 | 0.03 | 0 | 0 |
| 7 | 0.40 | 0.12 | 0.05 | 0.01 | 0 |
| 7.5 | 0.52 | 0.20 | 0.11 | 0.03 | 0.01 |
| 8 | 0.65 | 0.32 | 0.19 | 0.05 | 0.03 |
| High – Rise: | | | | | |
| 6.5 | 0.12 | 0.01 | 0 | 0 | 0 |
| 7 | 0.22 | 0.03 | 0.02 | 0 | 0 |
| 7.5 | 0.36 | 0.09 | 0.05 | 0.01 | 0 |
| 8 | 0.50 | 0.18 | 0.11 | 0.02 | 0.01 |

Number of buildings lost is determined by the combined levels of loss, which means adding up the three categories of the most severe forms of damage in buildings. These are “heavy damage” (D3), “partial collapse” (D4), and “total collapse” (D5) as identified in the building vulnerability curves for each ‘type’ of building.

This level of loss can be expressed in absolute terms (total number of buildings lost), or in relative terms as a ratio of loss from the total building stock. It is then possible to have priority lists in each category of settlement-size in absolute and relative terms.

## 5. Identification of Loss Levels/Risks Aggregated at Settlement Level

Following above described procedure, identification of most vulnerable settlements in each size-category and ‘provinces with high-risk’ are accomplished. A list of the provinces from the one with the highest risk to the one with the lowest is completed.

The top-10 settlements of the complete list in each size category according to absolute loss levels (Table 5, Table 6, Table 7) and the spatial distribution figures of settlements according to absolute loss and rates of loss is given below (Figure 7, Figure 8).

Table 5. The Top-10 Settlements for Category I According to Absolute Loss Levels

| CATEGORY I 0-50.000 | Sub-Province | Intensity | Absolute Loss | Total Building | Loss Rate | Sub-Province Population (2009) |
|---|---|---|---|---|---|---|
| TOKAT | NIKSAR | 8 | 1400 | 8343 | 0,17 | 64.930 |
| KASTAMONU | TOSYA | 8 | 1364 | 8575 | 0,16 | 40.894 |
| SAKARYA | HENDEK | 8 | 869 | 4969 | 0,17 | 74.084 |
| CORUM | OSMANCIK | 8 | 786 | 5037 | 0,16 | 45.080 |
| SAMSUN | HAVZA | 8 | 735 | 4620 | 0,16 | 45.933 |
| TEKIRDAG | SARKOY | 8 | 712 | 4059 | 0,18 | 30.248 |
| SAKARYA | AKYAZI | 8 | 681 | 3668 | 0,19 | 83.220 |
| AMASYA | SULUOVA | 7,5 | 633 | 9653 | 0,07 | 47.448 |
| ERZINCAN | UZUMLU | 8 | 631 | 4187 | 0,15 | 15.960 |
| BOLU | GEREDE | 8 | 583 | 3439 | 0,17 | 34.665 |
| **Group Average** | | | **96** | **2540** | **0.04** | **27.276** |

In the small-sized group of settlements, greatest loss is observed as in the table above, exhibiting the number of building loss. The top 10 of the settlements listed here are significantly above the category averages in terms of total loss, total number of buildings, rates of loss and settlement population.

Table 6. The top-10 Settlements for Category II According to Absolute Loss Levels

| CATEGORY II 50.000-490.000 | Sub-Province | Intensity | Absolute Loss | Total Building | Loss Rate | Sub-Province Population (2009) |
|---|---|---|---|---|---|---|
| VAN | CENTRAL | 7,5 | 2285 | 36235 | 0,06 | 360.810 |
| ERZINCAN | CENTRAL | 8 | 2025 | 12678 | 0,16 | 90.100 |
| BOLU | CENTRAL | 8 | 1841 | 10516 | 0,18 | 120.021 |
| YALOVA | CENTRAL | 8 | 1507 | 8302 | 0,18 | 92.166 |
| TEKIRDAG | CENTRAL | 7,5 | 1347 | 15683 | 0,09 | 140.535 |
| TOKAT | ERBAA | 8 | 1251 | 7895 | 0,16 | 58.845 |
| BURSA | ORHANGAZİ | 8 | 945 | 5313 | 0,18 | 54.319 |
| MANISA | CENTRAL | 7 | 919 | 24785 | 0,04 | 291.374 |
| OSMANIYE | CENTRAL | 7 | 905 | 29408 | 0,03 | 194.339 |
| HATAY | ANTAKYA | 7 | 768 | 23471 | 0,03 | 202.216 |
| **Group Average** | | | **454** | **14743** | **0,03** | **120796** |

In contrast to the previous category of settlements, many cases here prove high levels of absolute loss determined less dependently on strength of seismic shake.

There are variations in seismic intensity levels and rates of loss. Apart from a very few of the cases here, rates of loss seem to be lower than observed in the previous category.

Ordering seems to follow seismic intensities rather than absolute size of the building stock in metropolitan provinces.

Table 7. Metropolitan Provinces According to Absolute Loss Levels

| CATEGORY III Metropolitan Provinces | Sub-Province | Intensity | Absolute Loss | Total Building | Loss Rate | Sub-Province Population (2009) |
|---|---|---|---|---|---|---|
| ISTANBUL | ISTANBUL (M) | 7,5 | 83824 | 864540 | 0,10 | 10.149.637 |
| KOCAELI | KOCAELI (M) | 8 | 24077 | 139423 | 0,17 | 970.642 |
| BURSA | BURSA (M) | 7,5 | 16506 | 204907 | 0,08 | 1.515.911 |
| IZMIR | IZMIR (M) | 7 | 14531 | 421397 | 0,03 | 2.885.314 |
| SAKARYA | SAKARYA (M) | 8 | 8070 | 49609 | 0,16 | 490.560 |
| ADANA | ADANA (M) | 6,5 | 1913 | 175697 | 0,01 | 1.303.082 |
| ANTALYA | ANTALYA (M) | 6,5 | 1402 | 114998 | 0,01 | 603.190 |
| KONYA | KONYA (M) | 6,5 | 1355 | 113267 | 0,01 | 742.690 |
| ERZURUM | ERZURUM (M) | 6,5 | 439 | 32458 | 0,01 | 114.508 |

Figure 7. Absolute Loss Distributions

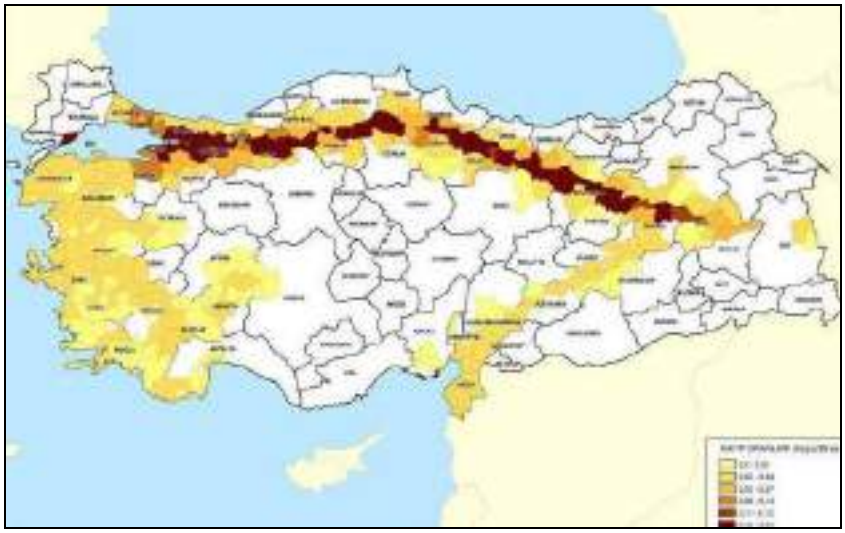


Figure 8. Loss Rate Distributions

## 2.2 Population-Building Stock Attributes as Independent Variables of the Research

The independent variables of the research are composed of building inventory data and related attributes of building stock on each settlement obtained from Turkish Statistical Institute. 'Building Construction Statistics' and 'Building Census' prepared by TurkStat is used within this research.

Independent variables of the research are;

**X1** = Settlement Population
**X2** = Population Growth Rate (‰)
**X3** = Rates of Agglomeration
**X4** = Population/Total Number of Buildings
**X5** = Development Index

X1=Settlement Population

We can consider that as the settlement population increases, building densities will increase also and this will increase the potential loss. Besides larger settlements in general have higher index of development implying greater likelihood of direct and indirect economic loss. So, we can say that larger the settlement population, greater is the risk.

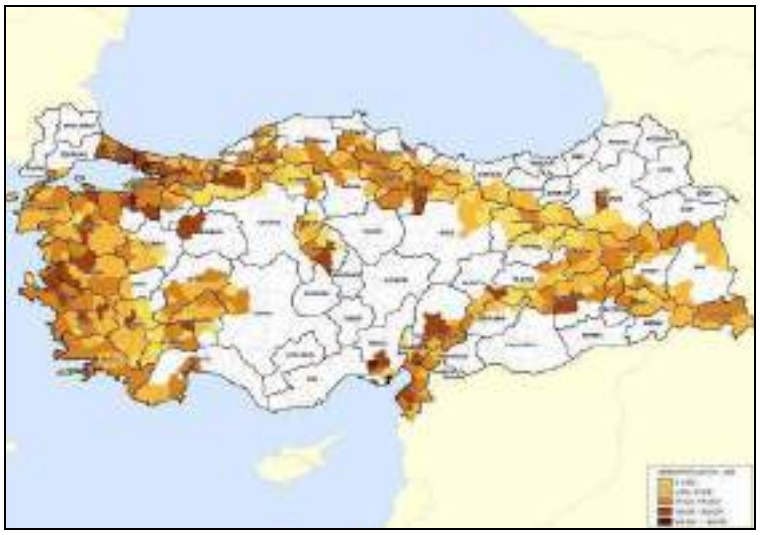


Figure 9. Urban Population Distributions

X2=Population Growth Rate

We can consider that as the rate of growth increases, control deficiencies will increase and this will increase the potential loss.

According to the Table 8; The smaller settlements in the average are either losing population or are stagnant. On the contrary larger cities and metropolitan cities are significantly growing and at the same pace.

Table 8.Average Values of Population Growth Rates in Settlements Categories

| AVERAGE VALUES | Total Number of Buildings | Settlement Population (2000) | Total Population (2000) | Settlement Population (2009) | Total Population (2009) | Population Growth Rate (Log-%) |
|---|---|---|---|---|---|---|
| 0-50.000 | 2540 | 12.292 | 32.033 | 11.290 | 27.276 | -0,945 |
| 50.000-490.000 | 14.743 | 96.999 | 152.395 | 120.796 | 169.592 | 2,438 |
| Metropolitan P. | 235.144 | 2.086.170 | 187.9779 | 2.629.144 | 2.697.045 | 2,570 |

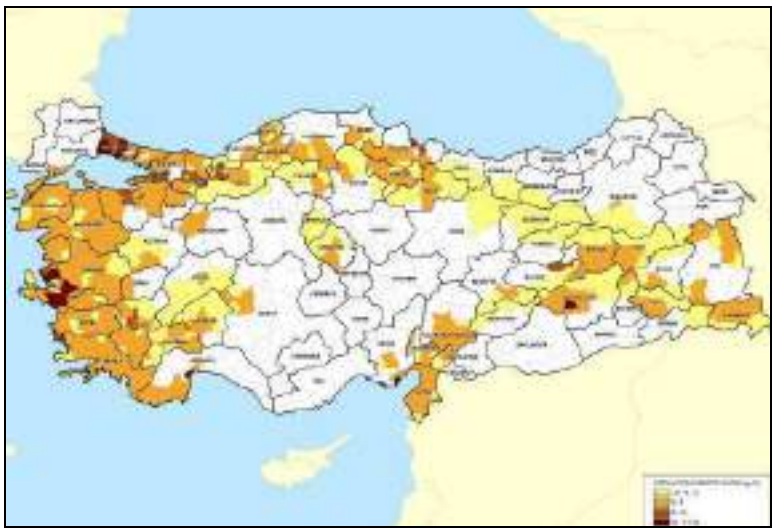


Figure 10. Population Growth Rates

X3=Rates of Agglomeration

Distinct rates of agglomeration are also a good indicator of how rural/urban natures of the sub-province or province differ. We can consider that as the rate of agglomeration increases, required urban services will increase and this will increase the potential loss.

According to the Table 9; Metropolitan settlements seem to have absorbed almost all of the population. However in provinces with smaller central settlements, greater parts of population live in the rural area.

Table 9. Average Values of Agglomeration Rates in Settlements Categories

| AVERAGE VALUES | Total Number of Buildings | Settlement Population (2000) | Total Population (2000) | Settlement Population (2009) | Total Population (2009) | Rate of Agglomeration |
|---|---|---|---|---|---|---|
| 0-50.000 | 2540 | 12.292 | 32.033 | 11.290 | 27.276 | 0,41 |
| 50.000-490.000 | 14.743 | 96.999 | 152.395 | 120.796 | 169.592 | 0,71 |
| Metropolitan P. | 235.144 | 2.086.170 | 187.9779 | 2.629.144 | 2.697.045 | 0,97 |

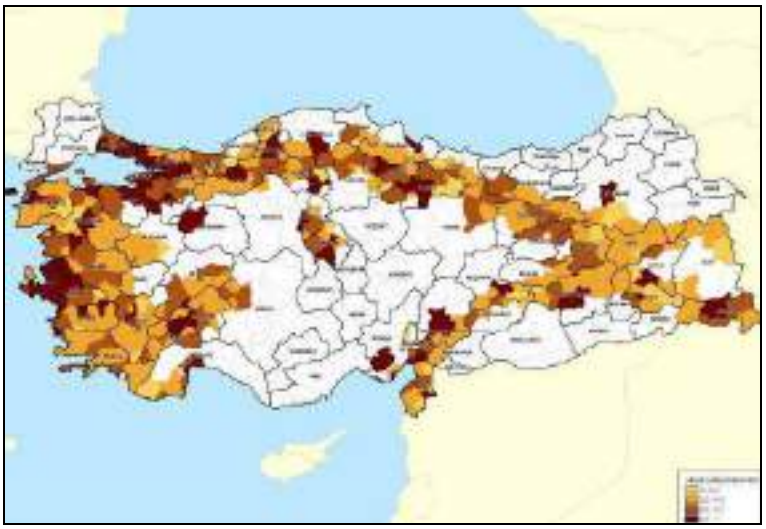


Figure 11. Urban Agglomeration

X4=Population/Total Number of Buildings

Average population density per building is significantly different in the categories identified. This is also a measure or indication of the increasing rate of human life losses in larger cities, another factor to reinforce the probable bias favoring larger settlements.

Table 10. Population Density in Settlement Categories

| Settlement Size Categories | Population (2000) | Total Number of Buildings | Population / Building |
|---|---|---|---|
| 0-50.000 | 4.080.822 | 843.188 | 4,84 |
| 50.000-490.000 | 6.401.962 | 973.014 | 6,58 |
| Metropolitan provinces | 18.775.534 | 2.116.296 | 8,87 |
| Total | 29.258.318 | 3.932.498 | 7.44 |

X5=Development Index

Socio-economic Development Index prepared by State Planning Organization covers demography, employment, education, infrastructure, construction and other welfare indicators.

The group of settlements with lower levels of population than 50.000 has a negative average development index of (-0.171). The average development index of category of 50.000-490.000 is 1.096. The average development index available for the third group representing metropolitan settlements is distinctly higher 5.73946 (Adana, Bursa and Konya only). This index is obviously higher for Istanbul, Ankara, and Izmir to increase the average further.

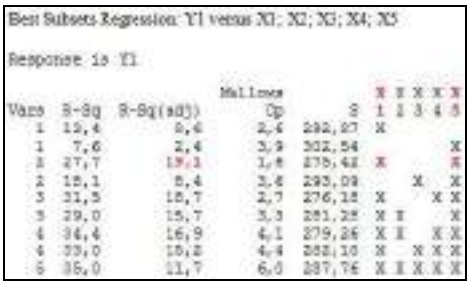
## 3. Evaluation of Risk Prioritization Variables of the Research

Dependent and independent variables of the research are determined as shown above. Best subsets regression analyses are employed to determine what combinations of the independent variables might best denote city-level risks. The results of the best subsets analyses should give us the "most appropriate combination" for the regression analyses.

### 3.1. Best Subsets Regression Analyses

**Best Subsets Regression Analyses – Category I (0-50.000)**

The first best subsets regression analyses is employed between the first dependent variable Y1 (absolute loss) and independent variables (X1, X2, X3, X4, X5) in order to see which independent variable is more related with Y1. In best subsets regression analyses the more related variable is the one that have the biggest number of R-Sq (adj.). According to the Figure 12 the biggest R-Sq (adj.) is 19, 1% in the third line and this means that the most related variables with Y1 is X1 and X5.

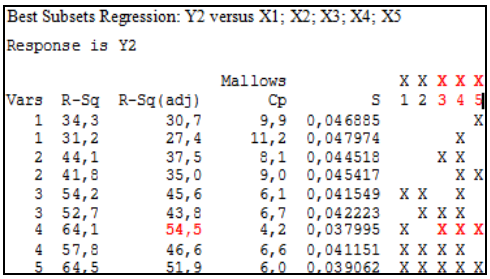

Best Subsets Regression: Y1 versus X1; X2; X3; X4; X5

Response is Y1

| Vars | R-Sq | R-Sq(adj) | Mallows Cp | S | X1 | X2 | X3 | X4 | X5 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 15,4 | 8,6 | 2,6 | 282,87 | X | | | | |
| 1 | 7,6 | 2,4 | 5,9 | 302,54 | | | | | X |
| 2 | 27,7 | 19,1 | 1,8 | 275,42 | X | | | | X |
| 2 | 15,1 | 8,4 | 3,6 | 293,09 | | | X | | X |
| 3 | 31,5 | 18,7 | 2,7 | 276,18 | X | | | X | X |
| 3 | 29,0 | 15,7 | 3,3 | 281,29 | X | X | | | X |
| 4 | 34,4 | 16,9 | 4,1 | 279,26 | X | X | | X | X |
| 4 | 33,0 | 15,2 | 4,4 | 282,10 | X | | X | X | X |
| 5 | 35,0 | 11,7 | 6,0 | 287,76 | X | X | X | X | X |

Figure 12. Best Subsets Regression: Y1 versus x1; x2; x3; x4; x5

The second best subsets regression analysis is employed between the second dependent variable Y2 (rate of loss) and independent variables, Figure 13 shows us that the biggest R-Sq (adj.) is 54,5% and this means that the most related variables with Y2 is X3, X4 and X5.


Best Subsets Regression: Y2 versus X1; X2; X3; X4; X5

Response is Y2

| Vars | R-Sq | R-Sq(adj) | Mallows Cp | S | X1 | X2 | X3 | X4 | X5 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 34,3 | 30,7 | 9,9 | 0,046885 | | | | | X |
| 1 | 31,2 | 27,4 | 11,2 | 0,047974 | | | X | | |
| 2 | 44,1 | 37,5 | 8,1 | 0,044518 | | | X | X | |
| 2 | 41,8 | 35,0 | 9,0 | 0,045417 | | | | X | X |
| 3 | 54,2 | 45,6 | 6,1 | 0,041549 | X | X | | X | |
| 3 | 52,7 | 43,8 | 6,7 | 0,042223 | | X | X | X | |
| 4 | 64,1 | 54,5 | 4,2 | 0,037995 | X | | X | X | X |
| 4 | 57,8 | 46,6 | 6,6 | 0,041151 | X | X | X | X | |
| 5 | 64,5 | 51,9 | 6,0 | 0,039062 | X | X | X | X | X |

Figure 13. Best Subsets Regression: Y2 versus x1; x2; x3; x4; x5

Five regression analyses are performed according to the results of best subsets regression analyses for the Category I (0-50.000). These are;
Regression Analysis: Y1 versus X1, Y1 versus X5, Y2 versus X3, Y2 versus X4 and Y2 versus X5.

**Best Subsets Regression Analyses – Category II (50.000-490.000)**

Best subsets regression analyses is employed between the Y1 (absolute loss) and other independent variables. According to the Figure 14 the biggest R-Sq (adj.) is 19,3 % and this means that the most related variables with Y1 is X2 and X4.

**Best Subsets Regression: Y1 versus X1; X2; X3; X4; X5**

Response is Y1

| | | | Mallows | | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|---|
| Vars | R-Sq | R-Sq(adj) | Cp | S | 1 | 2 | 3 | 4 | 5 |
| 1 | 22,4 | 18,0 | 0,1 | 488,91 | | | | X | |
| 1 | 7,3 | 2,2 | 3,2 | 534,07 | | X | | | |
| 2 | 27,8 | 19,3 | 1,0 | 485,11 | | X | | X | |
| 2 | 27,6 | 19,1 | 1,0 | 485,88 | | | | X | X |
| 3 | 30,1 | 17,0 | 2,5 | 491,99 | | | X | X | X |
| 3 | 29,8 | 16,6 | 2,6 | 493,19 | | X | | X | X |
| 4 | 31,9 | 13,7 | 4,1 | 501,71 | | X | X | X | X |
| 4 | 31,2 | 12,9 | 4,3 | 504,14 | X | X | | X | X |
| 5 | 32,6 | 8,5 | 6,0 | 516,65 | X | X | X | X | X |

Figure 14. Best Subsets Regression: Y1 versus x1; x2; x3; x4; x5

The second best subsets a regression analysis is employed between Y2 (rate of loss) and other independent variables, Figure 15 shows us that the biggest R-Sq (adj.) is 45, 8 and this means that the most related variables with Y2 is $X_1$ and X4.

Best Subsets Regression: Y2 versus X1; X2; X3; X4; X5

Response is Y2

| | | | Mallows | | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|---|
| Vars | R-Sq | R-Sq(adj) | Cp | S | 1 | 2 | 3 | 4 | 5 |
| 1 | 25,6 | 21,5 | 6,7 | 0,053812 | X | | | | |
| 1 | 16,3 | 11,7 | 9,6 | 0,057075 | | | | X | |
| 2 | 51,5 | 45,8 | 0,8 | 0,044715 | X | | | X | |
| 2 | 30,1 | 21,8 | 7,4 | 0,053701 | X | | | | X |
| 3 | 53,1 | 44,3 | 2,4 | 0,045351 | X | | X | X | |
| 3 | 52,6 | 43,7 | 2,5 | 0,045585 | X | X | | X | |
| 4 | 54,2 | 42,0 | 4,0 | 0,046251 | X | X | X | X | |
| 4 | 53,2 | 40,7 | 4,3 | 0,046775 | X | | X | X | X |
| 5 | 54,2 | 37,9 | 6,0 | 0,047874 | X | X | X | X | X |

Figure 15. Best Subsets Regression: Y2 versus x1; x2; x3; x4; x5

Four regression analyses are performed according to the results of best subsets regression analyses for the Category II (50.000-490.000). These are;
Regression Analysis: Y1 versus X2, Y1 versus X4, Y2 versus X1 and Y2 versus X4.

**Best Subsets Regression Analyses – Category III (Metropolitan provinces)**

Best subsets regression analyses is employed between Y1 (absolute loss) and other independent variables. According to the Figure 16 the biggest R-Sq (adj.) is 95, 5% and this means that the most related variables with Y1 is X1, X3 and X4.

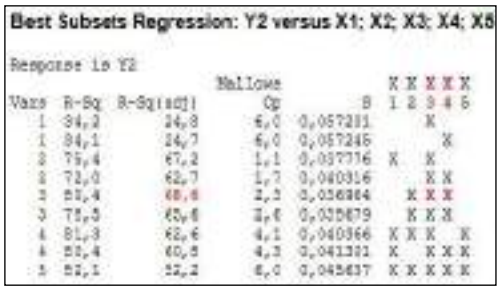
**Best Subsets Regression: Y1 versus X1; X2; X3; X4; X5**

Response is Y1

| | | | Mallows | | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|---|
| Vars | R-Sq | R-Sq(adj) | Cp | S | 1 | 2 | 3 | 4 | 5 |
| 1 | 92,2 | 91,1 | 5,7 | 7871,2 | X | | | | |
| 1 | 55,4 | 49,0 | 56,6 | 18873 | | | | X | |
| 2 | 96,1 | 94,8 | 2,4 | 6040,9 | X | | X | | |
| 2 | 93,2 | 90,9 | 6,4 | 7960,2 | X | | | X | |
| 3 | 96,5 | 94,4 | 3,9 | 6278,2 | X | X | X | | |
| 3 | 96,4 | 94,3 | 3,9 | 6327,2 | X | | X | | X |
| 4 | 97,8 | 95,5 | 4,1 | 5579,2 | X | | X | X | |
| 4 | 97,5 | 95,0 | 4,5 | 5917,6 | X | | X | X | X |
| 5 | 97,8 | 94,2 | 6,0 | 6364,5 | X | X | X | X | X |

Figure 16. Best Subsets Regression: Y1 versus x1; x2; x3; x4; x5

The second best subsets regression analysis is employed between Y2 (rate of loss) and other independent variables, Figure 17 shows us that the biggest R-Sq (adj.) is 68, 6% and this means that the most related variables with Y2 is X3 and X4.



**Best Subsets Regression: Y2 versus X1; X2; X3; X4; X5**

Response is Y2

| Vars | R-Sq | R-Sq(adj) | Mallows Cp | S | X1 | X2 | X3 | X4 | X5 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 34,2 | 24,8 | 6,0 | 0,057231 | | | X | | |
| 1 | 34,1 | 24,7 | 6,0 | 0,057245 | | | | X | |
| 2 | 75,4 | 67,2 | 1,1 | 0,037716 | X | | X | | |
| 2 | 72,0 | 62,7 | 1,7 | 0,040916 | | | X | X | |
| 3 | 81,4 | 68,6 | 2,1 | 0,036864 | | X | X | X | |
| 3 | 78,5 | 65,6 | 2,6 | 0,039879 | | | X | X | X |
| 4 | 81,3 | 62,6 | 4,1 | 0,040966 | X | X | X | | X |
| 4 | 81,4 | 60,5 | 4,3 | 0,041321 | X | | X | X | X |
| 5 | 81,1 | 52,2 | 6,0 | 0,045837 | X | X | X | X | X |

Figure 17. Best Subsets Regression: Y2 versus x1; x2; x3; x4; x5

Five regression analyses are performed according to the results of best subsets regression analyses for the Category III (Metropolitan Provinces). These are;
Regression Analysis: Y1 versus X1, Y1 versus X3, Y1 versus X4, Y2 versus X3 and Y2 versus X4.

### 3.2. Analyses by Means of Regression Methods

**Analyses by Means of Regression Methods – Category I (0-50.000)**

Five regression analyses are performed according to the results of best subsets regression analyses for the I. Category (0-50.000). These are;
Regression Analysis: Y1 versus X1, Y1 versus X5, Y2 versus X3, Y2 versus X4 and Y2 versus X5.

**Regression Analysis 1:**

Regression Analysis 1 is performed with Y1 (absolute loss) and X1(settlement population). In regression analyses in order to say that there is a relation between variables, the R-Sq (adj.) must be minimum 64%. As shown in the Figure 18, the R-Sq (adj.) is 8, 6%. This ratio is insufficient to verify the relationship between Y1 and X1, so we can say that there is a **no relation** between the regression equations of Y1 versus X1.

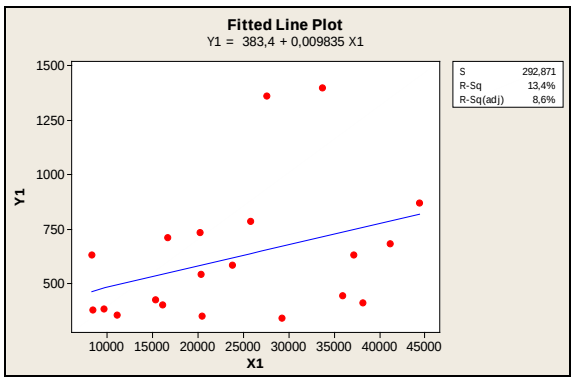



Figure 18. Regression Analysis 1: Y1 versus X1

**Regression Analysis 2:**

Regression Analysis 2 is performed with Y1 (absolute loss) and X5 (development index). As shown in the Figure 19, the R-Sq (adj.) is 2, 4%. This ratio is insufficient to verify the relationship between Y1 and X5, so we can say that there is a **no relation** between the regression equations of Y1 versus X5.

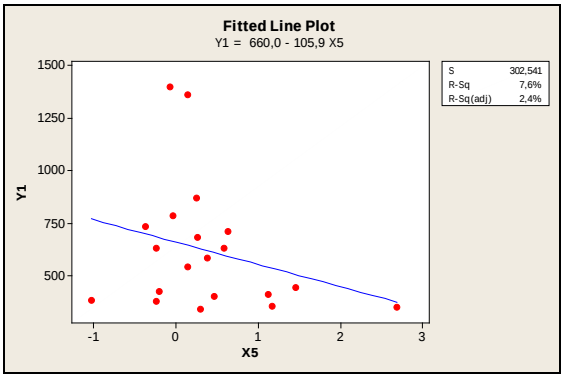



Figure 19. Regression Analysis 2: Y1 versus X5

**Regression Analysis 3:**

Regression Analysis 3 is performed with Y2 (rate of loss) and X3 (rates of agglomeration). As shown in the Figure 20, the R-Sq (adj.) is 21, 9%. Although this ratio isn't sufficient enough to verify the relationship between Y2 and X3, we can say that there is a **weak relation** between the rate of loss and the rate of agglomeration.

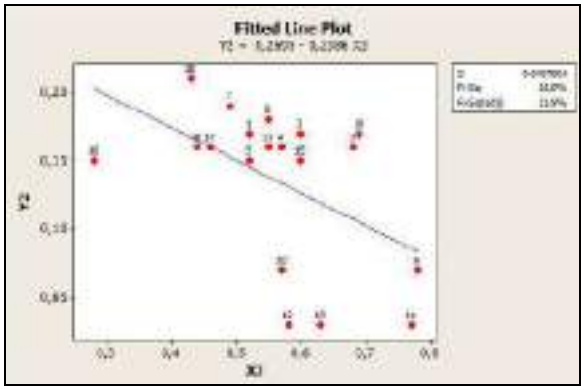



Figure 20. Regression Analysis 3: Y2 versus X3

**Regression Analysis 4:**

Regression Analysis 4 is performed with Y2 (rate of loss) and X4 (pop. /total number of buildings). As shown in the Figure 21, the R-Sq (adj.) is 27, 4%. Although this ratio isn't sufficient enough to verify the relationship between Y2 and X4, we can say that there is a **weak relation** between the rate of loss and the ratio of population to the number of buildings.

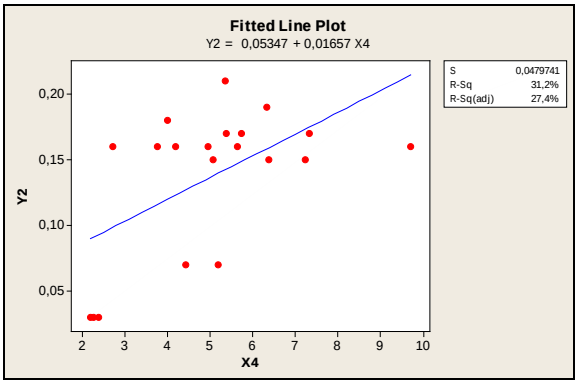



Figure 21. Regression Analysis 4: Y2 versus X4

**Regression Analysis 5:**

Regression Analysis 5 is performed with Y2 (rate of loss) and X5 (development index). As shown in the Figure 22, the R-Sq (adj.) is 30, 7%. Although this ratio isn't sufficient enough to verify the relationship between Y2 and X5, we can say that there is a **weak relation** between the rate of loss and the ratio of population to the number of buildings.

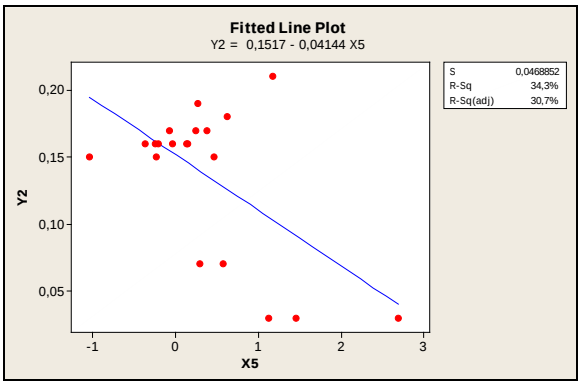



Figure 22. Regression Analysis 5: Y2 versus X5

Five regression analyses are performed for top-20 settlements in Category I. The Results of these analyses show that;

Y1 (absolute loss) has no relation with independent variables and,
Y2 (rate of loss) has weak relations with X3 (Rates of Agglomeration)
X4 (Pop. /Total Number of Buildings)
X5 (Development Index)

**Analyses by Means of Regression Methods – Category II (50.000-490.000)**

Four regression analyses are performed according to the results of best subsets regression analyses for the Category II (50.000-490.000). These are;
Regression Analysis: Y1 versus X2, Y1 versus X4, Y2 versus X1 and Y2 versus X4.

**Regression Analysis 6:**

Regression Analysis 6 is performed with Y1 (absolute loss) and X2 (population growth rate). As shown in the Figure 23, the R-Sq (adj.) is 2, 2%. This ratio is insufficient to verify the relationship between Y1 and X2, so we can say that there is a **no relation** between the regression equations of Y1 versus X2.

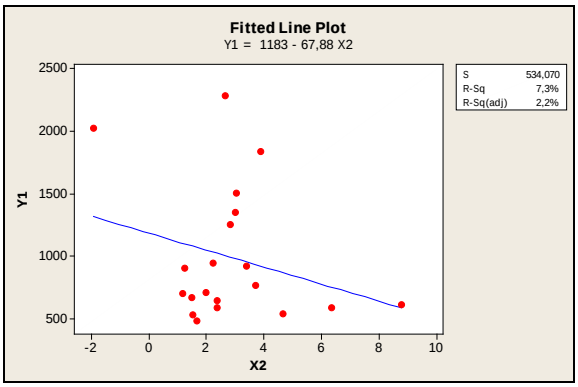



Figure 23. Regression Analysis 6: Y1 versus X2

**Regression Analysis 7:**

Regression Analysis 7 is performed with Y1 (absolute loss) and X4 (pop./total number of buildings). As shown in the Figure 24, the R-Sq (adj.) is 18, 0%. Although this ratio isn't sufficient enough to verify the relationship between Y1 and X4, we can say that there is a **weak relation** between absolute loss and the ratio of population to the number of buildings.

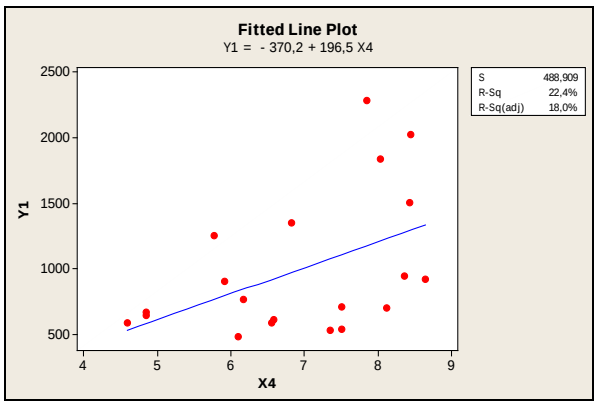



Figure 24. Regression Analysis 7: Y1 versus X4

**Regression Analysis 8:**

Regression Analysis 8 is performed with Y2 (rate of loss) and X1 (settlement population). As shown in the Figure 25, the R-Sq (adj.) is 21, 5%. Although this ratio isn't sufficient enough to verify the relationship between Y2 and X1, we can say that there is a **weak relation** between the rate of loss and settlement population.

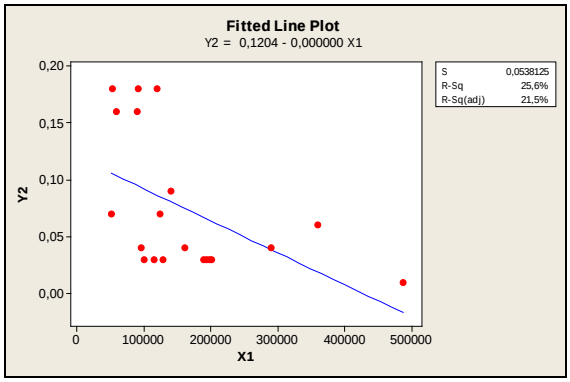



Figure 25. Regression Analysis 8: Y2 versus X1

**Regression Analysis 9:**

Regression Analysis 9 is performed with Y2 (rate of loss) and X4 (pop./total number of buildings). As shown in the Figure 26, the R-Sq (adj.) is 11, 7%. This ratio is insufficient to verify the relationship between Y2 and X4, so we can say that there is a **no relation** between the regression equations of Y2 versus X4.

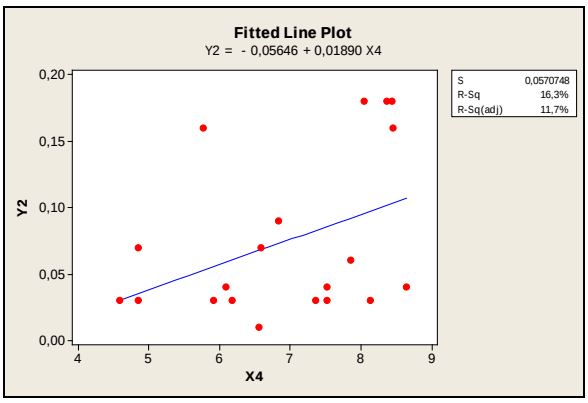



Figure 26. Regression Analysis 9: Y2 versus X4

Four regression analyses are performed for top-20 settlements in Category II. The Results of these analyses show that;

Y1 (absolute loss) has no relation with X2 (population growth rate) and weak relations with X4 (Pop./Total Number of Buildings).

Y2 (rate of loss) has weak relations with X1(settlement population) and no relation with X4 (Pop./Total Number of Buildings).

**Analyses by Means of Regression Methods – Category III (Metropolitan pro.)**

Five regression analyses are performed according to the results of best subsets regression analyses for the Category III (Metropolitan Provinces). These are;
Regression Analysis: Y1 versus X1, Y1 versus X3, Y1 versus X4, Y2 versus X3 and Y2 versus X4.

**Regression Analysis 10:**

Regression Analysis 10 is performed with Y1 (absolute loss) and X1(settlement population). As shown in the Figure 27, the R-Sq (adj.) is 91, 1%. This ratio is sufficient to verify the relationship between Y1 and X1, so we can say that there is a **strong relation** between the regression equations of Y1 versus X1.

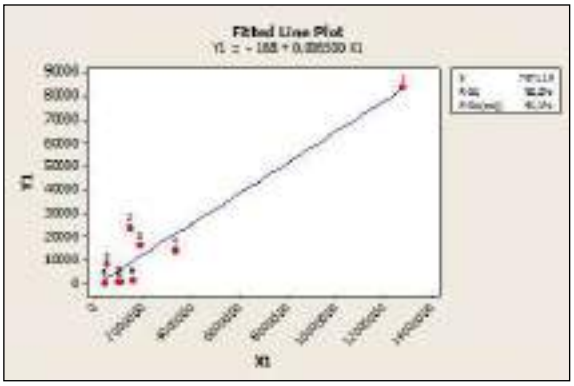



Figure 27. Regression Analysis 10: Y1 versus X1

**Regression Analysis 11:**

Regression Analysis 11 is performed with Y1 (absolute loss) and X3 (rates of agglomeration). As shown in the Figure 28, the R-Sq (adj.) is 5, 0%. This ratio is insufficient to verify the relationship between Y1 and X3, so we can say that there is a **no relation** between the regression equations of Y1 versus X3.

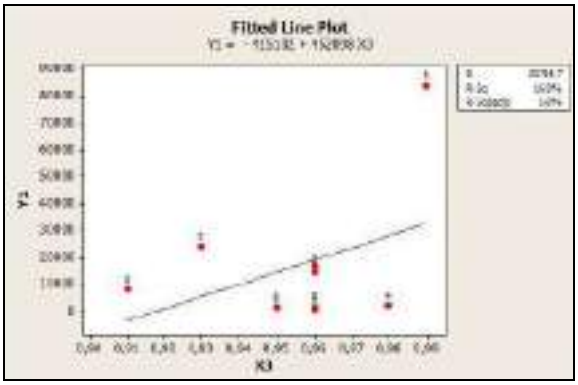



Figure 28. Regression Analysis 11: Y1 versus X3

**Regression Analysis 12:**

Regression Analysis 12 is performed with Y1 (absolute loss) and X4 (pop./total number of buildings). As shown in the Figure 29, the R-Sq (adj.) is 49, 0%. Although this ratio isn't sufficient enough to verify the relationship between Y1 and X4, we can say that there is a **weak relation** between the rate of loss and settlement population.

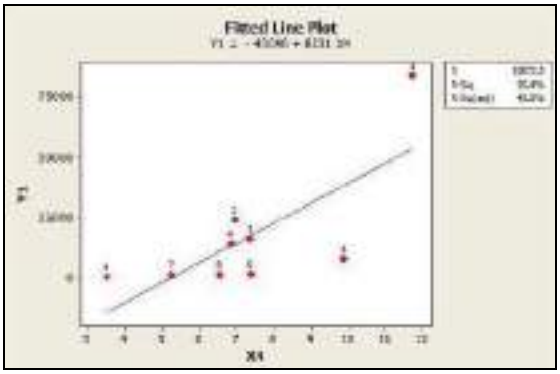



Figure 29. Regression Analysis 12: Y1 versus X4

**Regression Analysis 13:**

Regression Analysis 13 is performed with Y2 (rate of loss) and X3 (rates of agglomeration). As shown in the Figure 30, the R-Sq (adj.) is 24, 8%. Although this ratio isn't sufficient enough to verify the relationship between Y2 and X3, we can say that there is a **weak relation** between the rate of loss and settlement population.

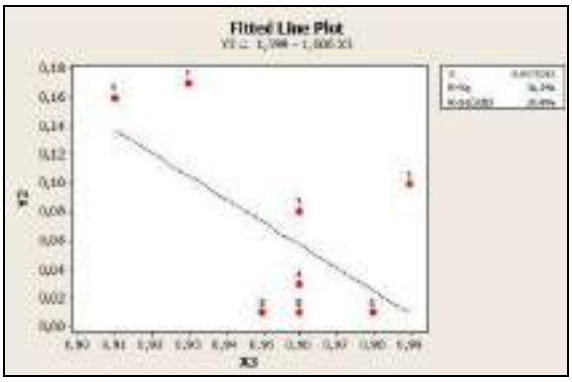



Figure 30. Regression Analysis 13: Y2 versus X3

**Regression Analysis 14:**

Regression Analysis 14 is performed with Y2 (rate of loss) and X4 (pop./total number of buildings). As shown in the Figure 31, the R-Sq (adj.) is 24, 7%. Although this ratio isn't sufficient enough to verify the relationship between Y2 and X4, we can say that there is a **weak relation** between the rate of loss and settlement population.

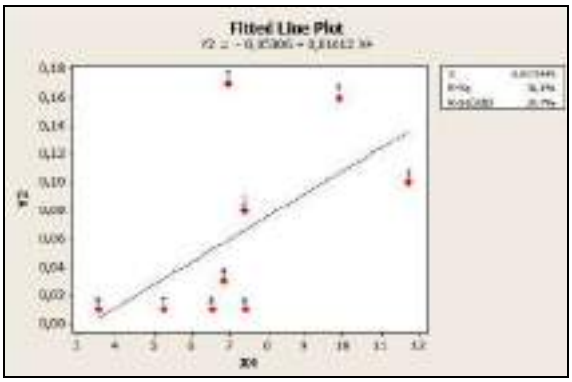



Figure 31. Regression Analysis 14: Y2 versus X4

Five regression analyses are performed for the top-20 settlements in Category III. The Results of these analyses show that;

Y1 (absolute loss) has strong relations with X1 (settlement population), no relation with X3 (Rates of Agglomeration) and weak relations with X4 (pop./ total number of buildings).

Y2 (rate of loss) has weak relations with X3 (rates of agglomeration) and X4 (pop./total number of buildings).

## 4. Conclusions

This study is set out with the aim to examine the factors that determine seismic vulnerabilities and risks of settlements and establish if analysis of seismic risks in cities and living environments could be determined on the basis of a set of attributes of the building stock. The scope is to exhibit and analytically compare such factors in settlements of Turkey. The basic question of the research is: “How do loss levels in building stock correlate to independent variables?” and regression analyses are used to examine this question.

Five regression analyses are performed for top-20 settlements in Category I. The results of these analyses show that; Y1 (absolute loss) has no relations with independent variables, Y2 (rate of loss) has weak relations with X3 (rates of agglomeration), X4 (pop. /total number of buildings) and X5 (development index).

Four regression analyses are performed for top-20 settlements in Category II. The results of these analyses show that; Y1 (absolute loss) has no relations with X2 (population growth rate) and weak relations with X4 (pop./total number of buildings). Y2 (rate of loss) has weak relations with X1(settlement population) and no relations with X4 (pop./total number of buildings).

Five regression analyses are performed for the top-20 settlements in Category III. The results of these analyses show that; Y1 (absolute loss) has strong relations with X1 (settlement population), no relation with X3 (rates of agglomeration) and weak relations with X4 (pop./ total number of buildings). Y2 (rate of loss) has weak relations with X3 (rates of agglomeration) and X4 (pop./total number of buildings).

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