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A Seismic Hazard Study through the Comparison of Ground Motion Prediction Equations Using the Weighting Factor of Logic Tree

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Toward the assistance on selection of ground motion prediction models for seismic assessment, this article presents a seismic hazard study (compared to the viewpoint of attenuation equations), using a recent tool based on engineering judgment, called “weighting factor,” through a procedure similar to logic tree. For this purpose, the weighting factors were incorporated with a Venn diagram of attenuation models regarding experimenter’s concern and expert’s knowledge. It is found that the attenuation equations of the newer and intersection ones could be considered to estimate plausible and reasonable accelerations. The results indicate that the weighting factors could beneficially assist for suitability of attenuation models. This work is a novel for the region (Gaziantep, Turkey), thus it could complement expert’s knowledge about the attenuation models for future studies.

Keywords Weighting Factor; Venn Diagram; Logic Tree; Seismic Hazard Assessment; Attenuation Equation

1. Introduction

One of the important issues through the seismic hazard assessment of a region is to employ the appropriate ground motion prediction equations (i.e., attenuation equations) for accurately predicting the expected distribution of strong ground motions and damage potential of the structures at a site due to possible earthquake scenarios. The selected attenuation equations must fully reflect the strong ground motion in the target region since their variability directly affects the computed hazard in the study area. The employment of attenuation equations is mostly subjective since there is usually no evident indication about which one of the candidate attenuation models is more suitable for the site of interest [Scherbaum et al., 2004; Cotton et al., 2006; Delavaud et al., 2009; Gülü, 2012]. Also, there could be no prediction equations developed particularly for the region which is to be investigated, or the equations could be very limited. Sometimes, it is likely necessary to use the equations imported from another country with similar seismotectonic environment. In both cases, there are usually difficulties when selecting the appropriate equation. This situation leads to a model uncertainty which is generally called epistemic uncertainty that could be defined as the uncertainty attributable to incomplete knowledge about a phenomenon that affects our ability to seismic hazard model [Cornell, 1968; Coppersmith and Youngs, 1986; Kramer, 1996; Cramer, 2001; Cotton et al., 2006]. In order to capture the
epistemic uncertainty in a seismic hazard analysis, more than one ground-motion prediction equation is recommended to use in general. Although the epistemic uncertainty arises mainly from the lack of incomplete or inadequate data as well as a lack of sufficient hazard models, they can be incorporated into attenuation equations based on engineering judgments, parameter conversions or suitable mechanisms [Coppersmith and Youngs, 1986; Douglas, 2003; Scherbaum et al., 2004; Cotton et al., 2006; Bommer and Scherbaum, 2008].

The procedures that discuss the comparison of attenuation equations through their selection and ranking points for seismic hazard assessment are always interested by researchers. Cotton et al. [2006] proposed some criteria (i.e., relevance to tectonic regime, published in an international peer-reviewed journal, sufficient dataset, superseded by more recent publications, frequency range, functional form, and the regression) about selection and paying rank to attenuation equations. However, these criteria are effective mostly for preselection, thus quantitative approaches are required for decision making on attenuation equation to be appropriate. There are various statistical methods (Pearson’s correlation coefficient, Chi-square, Kolmogorov-Smirnov, variance reduction, etc.) applied in the past works for testing the suitability of predictive models at a given region [Ghasemi et al., 2008; Gülü, 2012]. However, their robustness is mostly sensitive to the residual of accelerations, obtained from observed and estimated ground-motion data, which must follow a lognormal distribution. It is worth to note that since most of the traditional tests of statistical methods only checks for one hypothesis (i.e., normal distribution, zero mean, or unit standard deviation), they are not perfect tools for comparison of the considered attenuation models through a ranking manner for making decision. Also, it is the author’s experience [Gülü, 2012] that the statistical methods take long time requiring a considerable effort for final decision to the suitability of attenuation equation. Due to the limitations of statistical methods, an attention on appropriateness and ranking could be given to the procedures maximum likelihood method (LH) and its extension of the information-theoretic approach (LLH) proposed by Scherbaum et al. [2004, 2009]. These methods are interpreted as relatively stable in previous works [Hintsersberger et al., 2007] and found usable as a robust selection and ranking technique in various studies [Delavaud et al., 2009; Delavaud et al., 2012a] to identify appropriate attenuation equations for specific seismic prone regions. However, it is reported [Kale and Akkar, 2013] that both LH and LLH methods may suffer from a consistent handling of sigma associated with attenuation equations since they could favor the attenuation equation with higher sigma amongst two ground-motion predictive models of similar median estimations, which may result in considerably large seismic hazard at long return periods [Restrepo-Velez and Bommer, 2003].

Recently, a tool based on the engineering judgment with weighting factors, which represent a probability concern, has alternatively become popular to combine the multiple models of ground motion equations (primarily due to the procedure developed for logic tree approach). Actually, the use of weighting factors (through the logic tree approach) has been initiated by earlier works [Kulkarni et al., 1984], but it has been an increasing interest by the use of recent works that promise new insights for seismic assessment to help in decision making involving the uncertainties [Wahlström and Grünthal, 2000; Giner et al., 2002; Bommer et al., 2005; Sabetta et al., 2005; Scherbaum et al., 2005; Bommer and Scherbaum 2008; Molina et al., 2010; Delavaud et al., 2012a, 2012b]. Since various attenuation models could be allowed and their weights of probability could be assigned, the weighting factors could be relatively beneficial for capturing the epistemic uncertainty. The experimenter assigns the weights to the branches of models reflecting the relative confidence.
As the number of ground-motion models investigated for the seismic hazard assessment increases, the importance of the weights on the hazard estimations decreases [Bommer et al., 2005]. Mixing methodologies for seismic hazard assessment via logic tree using the weighting factors were applied, and the results were found sensitive to the attenuation models used in the seismic assessment [Giner et al., 2002]. The weight factors by logic tree were used for the sensitivity of PSHA (probabilistic seismic hazard analysis) results to attenuation equations, and it was concluded that the assigned weights do not significantly affect the hazard results when the attenuation equations compared for the region are four or more [Sabetta et al., 2005]. The final selection of attenuation models and assigned weighting factors for seismic hazard analysis were found seldom reproducible and often totally opaque [Hintsberger et al., 2007]. The factor weights and probabilities through the logic tree were studied, and a consistent weight assignment for the measures of attenuation equations to become their applicability in the seismic hazard study sustainable was proposed [Scherbaum and Kühn, 2011]. The weighting factors toward a ground-motion logic tree was applied for probabilistic seismic hazard assessment in Europe, and it was concluded that the procedure is reproducible and contributes to the seismic hazard study on the way that a logic tree should be built for ground motion prediction [Delavaud et al., 2012a]. Also, according to the experiences [Delavaud et al., 2012b], it is reported that the key element using the weighting factors for construction of a ground motion logic tree is the collection of data from independent sources and different methods as much information as possible. This information can come from experts due to their knowledge and experience. The weighting factors have also been used for a seismic risk and loss estimation in a recent study [Molina et al., 2010], with the computations of the degree of damage on specific building typologies, the associated economic losses and number of casualties. They were implemented with the scheme which accounts for the uncertainties of inputs (attenuation equations, soil models, scenario earthquakes) or inventory data (building typology, fragility functions, and capacity curves). The previous studies arised above relatively imply to extension of the weighting factor on the use of seismic hazard assessment, since they demonstrate that the definition of the weights could become considerably less important as compared with the effort given for the actual selection of attenuation models for the studied region [Sabetta et al., 2005; Scherbaum et al., 2005]. This relatively provides a wide flexibility of application for the weighting factors in different categorization of attenuation models due to experimenter’s concern in seismic hazard assessment.

This article performs a seismic hazard study specifically addressing to comparison of ground-motion prediction equations (i.e., attenuation equations), using the weighting factors via Venn diagram associated with experimenter’s concerns on attenuation equations and expert’s knowledge about the seismicity of region. Use of the Venn diagram in seismology could be encountered in the application to compare and contrast seismic waves and earthquake characteristics occurring along convergent and divergent plate boundaries [McConnell et al., 2010]. However, to the authors’ knowledge, there is a lack of research that uses the Venn diagram to study the influence of attenuation equations in seismic hazard assessment. In mathematics, it is mostly used to show relationships between sets of information, and helps an experimenter to examine similarities and differences. The seismic hazard study has been conducted for Gaziantep (Turkey) employing domestic Turkish attenuation equations. The present work with the application of weighting factor likely has been attempted first time for the region. It is believed that the findings from the comparisons could be beneficial for the expert’s judgment about the attenuation models for future seismic hazard studies in the study region.
2. Study Region

The seismic hazard assessment through the comparison of attenuation equations has been performed for Gaziantep city (Turkey), which is close to the seismically active East Anatolian Fault (EAF) of country. Documentation of seismic hazard for the region can be found somewhere else, in the sources of regional [Güllü et al., 2008], national [TSM, 1996], and international [Giardini, 1999; SHARE, 2015]. As well as concerning a high population of the city, since it is one of the major industrial zones of the country, a possible seismic hazard due to the fault activity around the city has become a significance consideration in the point of economy. The seismic sources for the active faults around Gaziantep have been represented in the active fault map of country given by Şaroğlu et al. [1992]. EAF, Bozova Fault, Tut Fault, and Elbistan Fault were considered as the potential seismic sources, which can contribute to the seismic hazard study in the region. These faults in this study have been modeled as linear seismic sources that were presented in Fig. 1. Maximum-magnitudes of the earthquakes generated by each fault have been obtained from Güllü et al. [2008]. The maximum magnitudes are 7.7, 6.5, 6.2, and 6.7 for EAF, Bozova Fault, Tut Fault, and Elbistan Fault, respectively. The accelerations from Turkish seismic map [TSM, 1996] particularly for Gaziantep region become reasonable in comparison with the ones estimated from the acceleration maps proposed by the recent works [Kayabali, 2002; Kayabali and Akin, 2003; Ulusay et al., 2004; Güllü et al., 2008] belonging to the country. Thus, this national seismic map [TSM, 1996] could be a good candidate for comparison of seismic hazard results obtained from the study.

![FIGURE 1 Linearly modeled active faults around Gaziantep city (map modified from Güllü et al., 2008).](image)
3. Attenuation Equations

Since the peak ground acceleration (PGA) is the most common parameter in seismic hazard assessments [Güllü and Erçelebi, 2007, 2008; Güllü, 2012], this characteristic has been selected as the ground motion parameter of seismic hazard study in this article for the comparison of attenuation equations. For the attenuation modeling that estimates the PGA, number of 11 Turkish domestic predictive equations [Aydan et al., 1996; Inan et al., 1996; Ansal, 1997; Aydan, 2001; Gülkan and Kalkan, 2002; Ulutaş and Özer, 2003; Öz bey et al., 2004; Kalkan and Gülkan, 2004; Ulusay et al., 2004; Akkar and Bommer, 2007; Güllü et al., 2008] derived from the Turkish strong ground motion catalogs have been included in the comparison (Table 1). The variables of the equations in terms of magnitude, source-to-site distance and site conditions have been described in this table. As shown from Table 1, the domestic Turkish ground motion equations are generally different in the scale of magnitude, type of distance measure, categorization of the site classifications, and the unit of PGA. Moreover, the prediction equations do not include exactly the same input parameters. For instance, while the site condition is employed by some of the prediction equations [Aydan, 2001; Gülkan and Kalkan, 2002; Öz bey et al., 2004; Kalkan and Gülkan 2004; Ulusay et al., 2004; Akkar and Bommer, 2007; Güllü et al., 2008], it is not included by the others [Aydan et al., 1996; Inan et al., 1996; Ansal, 1997; Ulutaş and Özer, 2003].

As a consequence of the concerns which differ in the attenuation equations, it is important for the engineers in practice to decide that the equations could be suitably used for the seismic hazard assessment. On the applicability of the approaches using weighting factors for this issue, it is reported [Bommer et al., 2005] that the epistemic uncertainty could not be correctly captured by the weighted assignments, if the ground motion prediction equations are based on different definitions of parameters. Hence, they propose the use of conversions between different parameter definitions (e.g., magnitude scale, source-to-site distance, site classification, etc.) to compensate the incompatibilities among the prediction relations. For instance, they recommended to use the empirical relationships given by Ambraseys and Free [1997] and Bungum et al. [2003] for conversion of the moment magnitude, $M_w$, to the surface wave magnitude, $M_s$. On the other hand, Bommer et al. [2005] noted that the conversions between different magnitude scales are usually empirical and there is no perfect correlation among them. Moreover, they state that those conversions carry their own uncertainty. Actually, the magnitude values for most earthquakes were reported by various institutions in different scales, and hence, there is usually confusion for using them in seismic hazard assessment studies.

As for the present study, due to the reasons above mentioned and also in order not to exclude the equation of Inan et al. [1996] in which the magnitude scale was not defined, the magnitude scales of the prediction equations have been assumed to be same. Due to the widespread usage in most of the prediction equations, the moment magnitude was selected as the reference magnitude scale. In regards to the source-to-site distance, since the major damaging earthquakes occur within a shallow region (about the uppermost 30 km) of the earth crust, hypocentral and epicentral distances become equal at intermediate and far distances [Douglas, 2003]. Furthermore, the hypocenter distance may not be correctly determined because the focal depth is usually not located accurately or not given in strong ground motion records. Similarly, the use of the closest horizontal distance is questionable since it is difficult to identify the exact location and position of the rupture planes in most earthquake events. Therefore, those measures of source-to-site distance given in the equations involved here have been replaced by the epicentral distance. For the site conditions, as well as considering the available site parameter definitions of the domestic prediction equations, on the basis of the previous studies [Boore et al., 1993; Ambraseys et al., 1996;
### Turkish attenuation equations employed in the study

<table>
<thead>
<tr>
<th>Reference</th>
<th>Ground motion prediction equation (attenuation equation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aydan <em>et al.</em> [1996]</td>
<td>( a_{\text{max}} = 2.8 (e^{-0.025} g e^{-0.50M} - 1) ) (1)</td>
</tr>
<tr>
<td>Inan <em>et al.</em> [1996]</td>
<td>( \log(PGA) = 0.65M - 0.9 \log I - 0.44 ) (2)</td>
</tr>
<tr>
<td>Ansal [1997]</td>
<td>( \log(A_p) = 0.329M - 0.00327R - 0.792 \log R + 1.177; R = (R_{\text{epc}}^2 + h^2)^{1/2} ) (3)</td>
</tr>
<tr>
<td>Aydan [2001]</td>
<td>( a_{\text{max}} = 2.8 e^{-0.025} (e^{-0.50M} - 1) ) (4)</td>
</tr>
<tr>
<td>GÜlkan and Kalkan [2002]</td>
<td>( \ln(Y) = -0.682 + 0.253(M - 6) + 0.039(M - 6)^2 - 0.642 \ln 0.297 \ln(V_s/1381); r = (r_{ij}^2 + 4.48^2)^{1/2} ) (5)</td>
</tr>
<tr>
<td>Özbey <em>et al.</em> [2004]</td>
<td>( \log(Y_g) = 3.287 + 0.503(M_w - 6) - 0.079(M_w - 6)^2 - 1.1177 \log \left( \sqrt{R_g^2 + 14.82^2} \right) + 0.141G_1 + 0.331G_2 ) (6)</td>
</tr>
<tr>
<td>Ulutas and Özer [2003]</td>
<td>( \log(A) = 0.505171 + 0.537579M - \log(R) + 0.008347 \times 10^{-5M} - 0.0024 R ) (7)</td>
</tr>
<tr>
<td>Kalkan and GÜlkan [2004]</td>
<td>( \ln(Y) = 0.393 + 0.576(M - 6) - 0.107(M - 6)^2 - 0.899 \ln I - 0.200 \ln(V_s/1112); r = (r_{ij}^2 + 6.91^2)^{1/2} ) (8)</td>
</tr>
<tr>
<td>Ulusay <em>et al.</em> [2004]</td>
<td>( PGA = 2.18 \exp(0.1783M_w - 0.8275 + 15.84 \log(V_s/330)) ) (9)</td>
</tr>
<tr>
<td>Akkar and Bommer [2007]</td>
<td>( \log(PGA) = 1.647 + 0.767M - 0.074M^2 - (-3.162 + 0.321 M) \log \left( \sqrt{R_{ij}^2 + 7.68^2} \right) + 0.105S_h + 0.020A - 0.045F_N + 0.085F_R ) (10)</td>
</tr>
<tr>
<td>Güllü <em>et al.</em> [2008]</td>
<td>( \ln(\text{PGA}) = 0.192 + 0.867M_w - 0.294 \ln(R_e) - 0.008S_e + 0.113S_i ) (11)</td>
</tr>
</tbody>
</table>

(1) \( a_{\text{max}} \): maximum ground acceleration in gals; \( M_s \): surface wave magnitude; \( R \): hypocentral distance in km; 3.5 \( \leq M_s \leq 7.6; 10 \text{ km} < R < 350 \text{ km}; \) Number of record = 27.

(2) \( PGA \): peak ground acceleration in cm/s\(^2\); \( M \): earthquake magnitude (magnitude type was not mentioned); \( R \): epicentral distance in km.

(3) \( A_p \): peak horizontal acceleration in gals; \( M \): moment magnitude; \( R \): hypocentral distance; \( R_{\text{epc}} \): epicentral distance; \( h \): focal depth in km.

(4) Notations are same as (1). The coefficient 2.8 becomes 0.56 for firm soils and rocky grounds.

(5) \( Y \): ground motion parameter (peak horizontal acceleration) in g; \( M \): moment magnitude; \( r_{ij} \): closest horizontal distance from the station to the site in km; \( V_s \): shear wave velocity for the station in m/s. The coefficients were determined for PGA; 4.5 \( \leq M \leq 7.4; 1.20 \text{ km} < r_{ij} < 150 \text{ km}; \) Number of record = 93, \( \sigma = 0.562 \).

(6) \( Y_g \): ground motion parameter (peak ground acceleration) in cm/s\(^2\) from the \( j^\text{th} \) recording of the \( i^\text{th} \) earthquake; \( M_{ij} \): moment magnitude of the \( i^\text{th} \) earthquake; \( R_{ij} \): closest horizontal distance from the vertical projection of the rupture from the \( i^\text{th} \) earthquake to the location of the \( j^\text{th} \) recording in km; \( G_1 = 0, G_2 = 0 \) for rock sites; \( G_1 = 1, G_2 = 2 \) for soil sites; \( G_1 = 0, G_2 = 1 \) for soft soil sites; 5 \( \leq M_{ij} \leq 7.4; 3 \text{ km} < R_{ij} < 300 \text{ km}; \) Number of record = 195, \( \sigma = 0.260 \).

(7) \( A \): peak ground acceleration in gals; \( M \): moment magnitude; \( R \): epicentral distance in km; 5 \( \leq M \leq 7.4; \) Number of record = 221.

(8) Notations are same as (5); 4 \( \leq M \leq 7.4; 1.20 \text{ km} < r_{ij} < 250 \text{ km}; \) Number of record = 112, \( \sigma = 0.612 \).

(9) \( PGA \): peak ground acceleration in gals; \( M_w \): moment magnitude; \( R_e \): epicentral distance in km; \( S_a = 0, S_b = 0 \) for rock sites; \( S_a = 1, S_b = 0 \) for soil sites; \( S_a = 0, S_b = 1 \) for soft soils sites; 4.1 \( \leq M_w \leq 7.5; 5.1 \text{ km} < R_e < 100 \text{ km}; \) Number of record = 211.

(10) \( PGA \): peak ground acceleration in gals; \( M_w \): moment magnitude; \( R_{pb} \): Joyner-Boore distance in km. \( S_a = 1, S_b = 0 \) for soft soil sites; \( S_a = 0, S_b = 1 \) for stiff soil sites; \( F_N = 1, F_R = 0 \) for normal faults; \( F_N = 0, F_R = 1 \) for reverse faults; otherwise those constants are zero; 5 \( \leq M_w \leq 7.6; 0 < R_{pb} < 100 \text{ km}; \) Number of record = 532, \( \sigma_1 = 0.557 - 0.049 \text{ M (intra-event)}; \sigma_2 = 0.189 - 0.017 \text{ M (inter-event)} \).

(11) \( PGA \): peak ground acceleration in gals; \( M_w \): moment magnitude; \( R_e \): epicentral distance in km. \( S = 0 \) for rock sites; \( S = 1 \) for soil sites; 3.2 \( \leq M_w \leq 7.4; 10 \text{ km} < R_e < 100 \text{ km}; \) Number of record = 210, \( \sigma = 0.903 \).
FIGURE 2 Comparison of Turkish attenuation equations for soil and rock sites with the observed data of $M = 7.4$ Kocaeli earthquake and $M = 7.2$ Duzce earthquake.

It has been decided to use two broad site soil categories as soil ($V_{s30} = 200$ m/s) and rock ($V_{s30} = 800$ m/s). However, it would not be possible to incorporate all the prediction equations because some of them do not contain any site soil parameter as emphasized before. Therefore, they remained unchanged for the soil and rock site conditions. The domestic prediction equations have been adopted in the seismic hazard estimations according to the adjustments described above. Further discussions of the issues about the predictive equations are out of the scope of this article, but can be found in detail somewhere else [Güllü and Erçelebi, 2007; Güllü et al., 2008].

For the validation of the Turkish prediction models introduced above, they have been compared with the actual case records of the accelerations from the strong ground motions occurred in Turkey. The adopted strong ground motions for the comparison belongs to the two significant earthquakes occurred in Turkey, 1999 Kocaeli earthquake ($M = 7.4$) and 1999 Düzece earthquake ($M = 7.2$), which are supplied from the database of PEER [2014]. Attenuation curves of the prediction equations by comparing actual records is given in Fig. 2. As shown from the acceleration curves in Fig. 2, the equations of Aydan et al. [1996], Inan et al. [1996], and Aydan [2001] generally produce high values for PGA, but the remaining ones relatively give consistent results with the strong ground motion data. The scatter of the recorded data along the curves implies that the prediction models are broadly fitted with the case records. Even though it has been obtained a broad fitting with the actual case records, it could be noted that since whole empirical approaches are always open to improvement, the existing attenuation relations can be improved by additional strong ground motion data and/or additional new input parameters. Also, some new equations can be investigated by using some new prediction tools. These kinds of improvements may be more meaningful for better predictions.
4. Methodology

The comparison of Turkish ground motion prediction equations (i.e., attenuation equations) through the seismic hazard study for Gaziantep has been performed, with the incorporation of a methodology using Venn diagram applying a weighting factor. Distinct Venn schemes that regard the effects of the attenuation equations with various weighting factors have been constructed on the basis of the experimenter’s concern in practice and expert recommendations about seismicity of region. Scherbaum et al. [2005] consider various methods (expert knowledge, equal weights, random weights, and model independency), which could be expressed as an appropriate base for the Venn diagram representation in this study. However, Scherbaum and Keuhn [2011] indicate some problems with standard approaches to the weighting factors through logic-tree construction. On the other hand, Runge et al. [2013] present an approach to rigorously elicit weights from experts. The assignment of weighting factors applied in this study resembles to the approach performed in logic tree [Wahlström and Grünthal, 2000; Giner et al., 2002; Bommer et al., 2005; Sabetta et al., 2005; Scherbaum et al., 2005; Delavaud et al., 2012a]. Thus, the epistemic uncertainties involved with the seismic hazard models could be taken into account. The weighting factor could be interpreted as the relative likelihood of the experimenter’s concern involving the model. The seismic hazard analysis through the weighting factors is carried out for the combination of models and/or parameters associated with each terminal branch (or concerned Venn schemes in this study). The relative likelihood of the combinations implied by each terminal branch is obtained by the product of the relative likelihood of the terminal branch and all prior branches leading to it. The result of each analysis is weighted by the relative likelihood of its combination of branches, with the final result taken as the sum of the weighted individual results. The sum of weightings factor for all the branches at each node should be equal to unity. Through each path on the corresponding branches, the seismic hazard is calculated separately. An overall weight is applied to the result according to the weights gained along the path by simply multiplying the weights. The results calculated from all the alternative paths are combined and then a single hazard value can be obtained as a final product [Kulkarni et al., 1984; Kramer, 1996; Giner et al., 2002]. However, it is important to note that the experimenters performing the seismic hazard assessment using weighting factor included by the corresponding methodology should be aware of its calculation effort that increases dramatically with the inclusion of more branches [Bommer et al., 2005; Sabetta et al., 2005]. To prevent this trouble, Bommer et al. [2005] suggested avoiding using branches with slight differences between the options that they carry, in cases when those options result in very similar nodes. Therefore, when selecting the weighting factors in the Venn schemes in this study, the cases contrasting (or different) with each other as much as possible have been taken into consideration. Consequently, the schemes were constructed by employing at least two different prediction equations. The weighting factors in the previous approaches (i.e., logic tree) are adequately found in an application manner to attenuation equations in seismic hazard assessment. For a thorough background and discussion, the readers are referred to previous publications [Wahlström and Grünthal, 2000; Giner et al., 2002; Bommer et al., 2005; Sabetta et al., 2005; Scherbaum et al., 2005; Delavaud et al., 2012a].

The Venn diagrams applied in this study including six distinct set of schemes in the point of ground motion prediction equations (i.e., attenuation equations) for seismic hazard assessment have been shown in Fig. 3. The weighting factors of the schemes for the attenuation equations are presented in Table 2, with the construction concerns of experimenter. Here, it should be noted that the reason for construction of six schemes could be attributed to both the experimenter’s concerns fairly being issues in practice for seismic
hazard assessment of Gaziantep city and the expert’s knowledge, which is fairly insufficient, about the application of the employed attenuation equations for the seismicity of region. As the experimenter’s concerns for the seismic hazard assessment change and the experiences on the seismicity of the region increase, an alternate number of Venn scheme categorizations could be attempted in future studies for reliability of seismic hazard assessment. For the construction of Scheme 1, it was simply assumed that all the prediction equations were equally likely to be true. Therefore, all of the equations were incorporated in the scheme. For the purpose of presenting the difference between the results of relatively older equations and those of the newer ones, the set of equations was divided into two groups. The older prediction equations were included in Scheme 2, and the newer equations in Scheme 3. As mentioned before, some of the equations involve site classification parameters, whereas others do not. In order to distinguish between the equations with and without the site soil parameters, Schemes 4 and 5 were employed, respectively. The last scheme (Scheme 6) was constructed according to the common selection of the authors which actually reflects the intersection set of their subjective decisions. The prediction equations included in each group have been assigned by equal weights because their accuracy degrees could not be defined clearly by the expert’s knowledge due to insufficient studies about the seismic hazard assessment of Gaziantep, as mentioned above. However, again it should be emphasized that as the expert’s knowledge about the seismicity of region increases, more reliable weight assignment could be performed for the weighting factors in future works. Scherbaum and Kühn [2011] recently showed the importance of weight treatments through the logic tree approach as probabilities instead of simply as generic quality measures of attenuation equations, which are subsequently normalized. In particular, they indicated to the danger of independently assigning of grades by different quality criteria, which could result in an apparent insensitivity to the weights. In order to provide the consistency with a probabilistic framework, they proposed assigning the weight factors in a sequential manner (such that if the first attenuation equation of three selected gets a 0.6 weight, then the remaining two models is 0.4 as sum). This approach proposed by Scherbaum and Kühn [2011] is not inconsistent with the weight assignment manner.
<table>
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<tr>
<th>Prediction equation</th>
<th>Weight factors</th>
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<td>Scheme 1</td>
</tr>
<tr>
<td>Aydan et al. [1996]</td>
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<td>Inan et al. [1996]</td>
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<td>Ansal [1997]</td>
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<td>Aydan [2001]</td>
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(Table 2) applied in this study. Taking the considerations of attenuation relations previously discussed (Table 1) into account, the Venn diagrams in this study were limited to the six schemes, but they could be extended to more than six depending upon the expert’s opinion and the experimenter’s concern, as noted earlier. Here, it is also important to note that the methodologies (i.e., logic tree approach) using the weighting factors in the previous applications is generally associated with probabilistic seismic hazard analysis (PSHA). To date, it is the author’s knowledge that the estimations have not been observed for deterministic seismic hazard analysis (DSHA). However, it is reported that [Bommer et al., 2005] they are relatively able to employ for the deterministic procedure in the same manner as well. Accordingly, the seismic hazard assessment via Venn schemes in this study has been carried out for the probabilistic and deterministic methods in both.

Here, it is worth remembering that, despite of their some issues (for instance, equally weight assignment in this study, due to the reasons explained above), the approach of weighting factor could provide some beneficial aspects in the seismic hazard study in the point of effort that is relatively less for the actual selection of attenuation models as compared to the conventional seismic hazard methodologies [Sabetta et al., 2005; Scherbaum
et al., 2005]. However, it appears from Sabetta et al. [2005] that the effect of the selection of the attenuation model is much more important than the weighting scheme adopted. They report that the selection of different logic-tree weighting schemes proved on the contrary to be quite low for all the return periods, response frequencies, and sites considered. As a general and conclusive remark of Sabetta et al. [2005], it is indicated that the selection of a specific attenuation model for the seismic hazard assessment of a region has a greater impact than the expert judgment applied in assigning weight factors to branches of the logic tree. Regarding the considerable findings of Sabetta et al. [2005], it is strongly recommended that the weighting factors should be considered as an assistant tool primarily, throughout the present study.

For the seismic hazard assessment via the probabilistic approach in this study, the seismic hazard curves have been produced by estimating the PGA values for a 10% probability of exceedance in 50 years (i.e., 475-year return period). In the characterization of the earthquake sources, uniform probability distribution has been assumed for the potential rupture locations within each source. Earthquake recurrences for the region (Gaziantep) have been determined using Gutenberg-Richter relation [Gutenberg and Richter, 1944]. The seismicity parameters of $a$ and $b$ of this relation for the region have been supplied from Güllü et al. [2008] as 5.14 and 1.16, respectively. The parameters $a$ and $b$ indicate that the Gaziantep region has an active seismicity with the low size earthquakes. The earthquakes that have magnitude greater than 4 within a 50 km radius of the source zones were used for the seismic hazard assessment. The seismic characteristics in detail can be found in Güllü et al. [2008]. The Poisson model has been used to describe the temporal occurrence of earthquakes, since it is still the most common probability model applied in probabilistic seismic hazard assessments. As for the deterministic method, earthquake scenarios have been considered for all the potential earthquake generating seismic sources. The worst-case acceleration values of the scenarios due to each of the seismic sources were estimated using the domestic prediction relationships. The seismic hazard assessments have been carried out for the soil and rock sites in both. The flow chart representing the algorithm of computations in Fig.4 was used for the seismic hazard assessment throughout the study.

For a thorough discussion of seismic hazard assessment, confirmation of the results from the Venn schemes has been performed with the conventional seismic hazard procedure of Cornell [1968] (i.e., derivation of a seismic hazard curve between a ground motion parameter and its frequency of exceedance through the probabilistic calculation utilizing the total probability theorem with the assumption of Poisson model) and Turkish seismic map [TSM, 1996]. The seismic hazard assessment using the conventional procedure suggested by Cornell [1968] has been carried out for both the probabilistic (also for 10% probability of exceedance within a period of 50 years) and deterministic methods, considering the peak ground accelerations of the individual predictive equations (Table 1). The estimated corresponding seismic hazard curves of the conventional procedure are shown in Fig. 5. Also, their PGA values for the probabilistic and deterministic methods with together have been given in Table 3. The seismic hazard curves (Fig. 5) and the probabilistic and deterministic PGA results presented in a single table (Table 3) could be beneficial for the convenience of comparison. As for the confirmation with the Turkish seismic map [TSM, 1996], it is known that the predicted PGA values for the city center of Gaziantep due to the seismic map are in the range from 0.2 g and 0.3 g. The PGA values due to the Venn schemes could be compared with the ones of seismic map in order to understand whether they are within the corresponding range of seismic map for confirmation. Even though the Turkish seismic map [TSM, 1996] is a possible way of confirmation of the results from the Venn schemes, it should be emphasized that the acceleration range given in this earthquake zoning map in any area could be sufficient for validation or controlling prediction.
FIGURE 4 Flow chart representing the algorithm employed in this study for seismic hazard assessment.

performed for the present time. However, the earthquake zoning map of Turkey is also open to modification (or improvement)—just as mentioned about the employed attenuation models earlier—based on some new additional seismological data to be obtained in future. Therefore, it is important to note that sustainability of validation with the Turkish seismic map needs to be controlled with new data in the future. Next, the results due to the Venn schemes for the probabilistic and deterministic methods have been presented and compared with the conventional procedure and seismic map.

5. Comparison of Results

5.1. Probabilistic Method

Through the combination of the Venn schemes (Fig. 3, Table 2) with the probabilistic approach, the assigned weight factors given in Table 2 have been applied for obtaining seismic hazard curves. The seismic hazard curves with respect to each scheme have been shown in Fig. 6. For the soil sites (Fig. 6a), it is clearly shown from the curves that while Scheme 2 gives the highest seismic hazard values in terms of the total hazard, Scheme 6 predicts the lowest ones. Actually, these two weighting schemes include different prediction equations from each other except one equation which is common in both schemes (PE3 in Fig. 3). Schemes 1 and 4 follow Scheme 2 in the point of production of high hazard results (Fig. 6a). The reason for the high results obtained here is that these three schemes are dominated mainly by the equations of Aydan [2001] and Gülkan and Kalkan [2002], which were represented by PE4 and PE5, respectively. As shown in the probabilistic assessment
due to the conventional procedure in Table 3, both of these equations give very high acceleration values for soil sites. Similarly, the high predictions are obtained by the equation of Aydan et al. [1996] (PE1), which was already included in Schemes 1 and 2 (Fig. 6a). On the other hand, the weighting Schemes 3 and 6 produce lower hazard values for the soil sites (Fig. 6a). Obviously, the hazard curves obtained for Schemes 3 and 6 are almost same, because both of them have been affected by the same prediction equations (PE6, PE8, PE9, PE10, and PE11) mostly. The effects of remaining equations (PE3 and PE7),
<table>
<thead>
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<th>Attenuation equation</th>
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<th>Deterministic PGA (g)</th>
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<tr>
<td></td>
<td>for %10 probability of exceedance in 50 years</td>
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<td>Soil Sites</td>
<td>Rock Sites</td>
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<td>0.22</td>
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<tr>
<td>Aydan [2001]</td>
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<tr>
<td>Gülüllü et al. [2008]</td>
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<td>0.28</td>
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*TABLE 3* Probabilistic and deterministic PGA values calculated from the attenuation equation using conventional procedure of Cornell [1968]
which are not shared together, are relatively little since they do not give very different results. Actually, the common equations in Schemes 3 and 6 are also involved in Scheme 4, as shown in Fig. 3. However, the result of Scheme 4 is completely different from the ones of Schemes 3 and 6 that yield to nearly identical results. The result obtained from Scheme 4 could be attributed to the inclusion of the prediction equations PE4 and PE5, which clearly generate very high hazard values, as mentioned earlier. There is another seismic hazard result obtained from Scheme 5 to be considered. As shown from Fig. 6a, the results of Scheme 5 follow those of Schemes 3 and 6, but its results are not quite similar to those of Schemes 3 and 6. As for the rock sites of seismic hazard curves of Venn schemes (Fig. 6b), Scheme 2 again seems to be the most hazardous source of estimations, since it still produces highest hazard results. This scheme is followed by Schemes 4 and 1, respectively, in the viewpoint of the seismic hazard effect. Similar to the case of the soil sites, Scheme 6 yields to the lowest hazard values, and also the identical results nearly have been obtained by Scheme 3. As generally expected, there is an apparent decrease in the seismic hazard results of rock sites when compared to the hazard curves of the soil sites. However, the only exception to this general trend is due to the estimation of Scheme 5, which has already been composed of the prediction equations that do not alter with different site conditions (i.e., not including site effects).

Figure 7 shows the PGA results of the probabilistic calculations of the Venn schemes by considering 10% probability of exceedance in 50 years. Schemes 1, 2, and 4 relatively produce high PGA values for both the soil and rock sites of Gaziantep city. With regard to Scheme 5, it is seen that a moderate acceleration value has been obtained for both of the site conditions soil and rock. As mentioned above, its results of soil and rock are identical due to the included prediction equations, which estimate the same result for all possible site conditions. As for Schemes 3 and 6 in Fig. 7, they generate more consistent PGA results with each other, since they include nearly the same models. However, their acceleration values are relatively lower than the ones of all remaining schemes.

As compared to the probabilistic results of Venn schemes (Figs. 6 and 7) with the conventional procedure Cornell [1968] (Fig. 5 and Table 3) and the seismic map of Turkey [TSM, 1996] for confirmation, it could be said that the PGA values of the seismic hazard curve (Fig. 6) due to the probabilistic Venn diagram are reasonably within the responses of the prediction equations (Fig. 5) treated for the region. Similar results can be found when the PGA results of 10% exceedance probability in 50-year due to the Venn scheme (Fig. 7) is compared with the results of probabilistic method (Table 3). However, these PGA results due to the Venn scheme (Fig. 7) are mostly obtained higher than the acceleration range (i.e., between 0.2–0.3 g) of Turkish seismic hazard map [TSM, 1996]. On the other hand, resulting as a main conclusion, it can be seen from Fig. 7 that the accelerations in Schemes 3 and 6 including the prediction equations PE 6-11 and PE 3, 6, 8-11, respectively, are in good agreement with the seismic hazard map [TSM, 1996]. This indicates that the expert opinion (Schemes 3 and 6) for the seismic hazard assessment of Gaziantep is accurate.

5.2. Deterministic Method

For the evaluation of deterministic seismic hazard analysis due to the Venn schemes, the worst-case approach could be adopted for the faults around the city. The possible earthquake scenarios with the maximum magnitude that can be generated and the shortest distance for the deterministic approach are presented in Table 3 (i.e., the conventional procedure). It is observed from Table 3 that the predictive equations of Inan et al. [1996] and Aydan et al. [1996] and Aydan [2001] mostly result in higher PGA values, whereas the equations of Ansal [1997], Özbev et al. [2004], Kalkan and Güldan [2004], and Akkar and
FIGURE 6 Seismic hazard curves incorporated with Venn schemes for the site conditions: (a) soil and (b) rock.

Bommer [2007] relatively estimate lower PGA values. As a consequence of the earthquake scenarios, the control earthquake occurred by the EAF with the magnitude 7.7, which is able to produce the strongest shaking for both the soil and rock sites in Gaziantep city, was adopted for the investigation using the Venn schemes. Similar to the probabilistic method, the weighting schemes have been equally applied for the Venn diagram through the deterministic method. However, in the deterministic method, the resultant PGAs of the Venn schemes have been calculated by simply multiplying the PGA value of each prediction equation with its own weight, and then summing the weighted PGAs.

The results of the deterministic method due to the Venn schemes are shown in Fig. 8. It is seen from Fig. 8 that highest PGA values are obtained from Scheme 2 for the soil sites,
FIGURE 7 The PSHA results of Venn schemes according to 10% probability of exceedance of the PGA within 50 years.

FIGURE 8 The DSHA results of Venn schemes according to the controlling earthquake ($M_w = 7.7$) on the EAF.

and from Scheme 5 for the rock sites. Lowest PGAs are estimated from Scheme 6 for both the soil and rock sites. Except Scheme 5, all of the schemes by the deterministic method generate lower PGA values than the ones from the probabilistic estimation due to Venn schemes (Fig. 7). The deterministic result of Scheme 5 is higher than the probabilistic one. However, similar to the probabilistic method, it normally gives the identical result for both the soil and rock sites, since the equations of Scheme 5 have been modeled without any site classification parameter.

As compared with the conventional procedure of deterministic method (Table 3) for confirmation, it can be said that the acceleration values of the Venn scheme (Fig. 8) are reasonably within the responses of prediction equations in the point of total accelerations of all faults (Table 3). In comparison with the seismic map of Turkey [TSM, 1996], while some of the accelerations (Schemes 2 and 5) from the deterministic Venn scheme (Fig. 8) are fairly higher than the ones of the seismic map of TSM [1996], the remaining ones seem to result in close to the accelerations of the seismic map. From this it can be revealed that
the prediction equations in Schemes 3, 4, and 6 among the constructed schemes through the deterministic method seem to provide the most consistent accelerations for Gaziantep city. As compared to the deterministic results with the probabilistic ones, the accelerations of the prediction equations in Schemes 3 and 6 of the deterministic Venn scheme are in a good agreement with the accelerations due to the probabilistic Venn scheme (Fig. 7) when concerned with the seismic map.

6. Discussion

This study is aimed to conduct a seismic hazard assessment towards to comparison of ground motion prediction equations (i.e., attenuation equations). A methodology of using a Venn diagram applying a weighting factor of logic tree was incorporated for this purpose. The seismic hazard study has been conducted for Gaziantep city (Turkey) (Fig. 1), and domestic Turkish attenuation equations (Table 1) have been employed for the comparison through the seismic hazard assessment. The attenuation equations have been compared with the case records of strong ground motion to find out their validity through the investigation with the weighting factors (Fig. 2). Six distinct Venn schemes that regard the effects of the attenuation equations with various weighting factors have been constructed on the basis of the experimenter’s concern in practice as well as expert’s recommendation (Fig. 3, Table 2). The PGA values (Fig. 5, Table 3) due to the conventional seismic hazard procedure of Cornell [1968] and Turkish seismic map [TSM, 1996], where the accelerations for the center of Gaziantep city are in the range 0.2–0.3 g, have been assisted for confirmation of the acceleration results due to the Venn schemes incorporated with weighting factors. The seismic hazard assessment through the comparison of attenuation models via the Venn schemes has been performed for both the probabilistic (Figs. 6 and 7) and the deterministic (Fig. 8) methods. Then, the results have been discussed concerning the influences of attenuation equations in seismic hazard assessment.

When the results of Venn schemes (Figs. 6–8) in the point of their concern of construction (Fig. 3, Table 2) are observed, it is seen that, for Scheme 1, which is included by all the prediction equations, while the probabilistic method yields high PGA values for both the soil and the rock sites, the deterministic method predicts relatively lower accelerations. The most extreme results have been obtained from Scheme 2, which was constructed by relatively older prediction equations. Scheme 2 generates the highest PGAs for both the soil and rock sites from the probabilistic method, and for the soil sites from the deterministic method. Also, it produces the second highest result for the rock sites from the deterministic approach. Scheme 3, where only the newer prediction equations were included, seems to offer the results reasonably with the ones of conventional procedure (Fig. 5, Table 3). Among all the schemes involved, the PGA results of Scheme 3 for the deterministic method relatively become the most approximating ones to the acceleration range given in the seismic map of Turkey [TSM, 1996]. Scheme 3 also generates the second best estimate (i.e., following Scheme 6) for the probabilistic approach by confirming the seismic map. Scheme 4, which was developed by incorporating only the prediction equations with the site category parameters, produces the probabilistic and deterministic results that are quite different from each other. While Scheme 4 produces moderate accelerations from the deterministic estimations, it relatively estimates high PGA values for the probabilistic method. Scheme 5, which was composed of the prediction equations without any site soil parameter, produces the unique accelerations for both the soil and rock sites. In Scheme 5, the deterministic PGA values are greater than the probabilistic results. As for Scheme 6, which was constructed dependent upon the authors’ common selection reflecting an intersection set of the schemes, it also seems to estimate the acceleration values well.
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in addition to the well-estimations due to Scheme 3) confirming with the seismic map of Turkey [TSM, 1996]. It is seen that the estimated PGA results from Scheme 6 are considerably close to the results of Scheme 3. As a consequence of the Venn schemes discussed above, the PGA results of Schemes 3 and 6 have been obtained fairly being consistent with the Turkish seismic map [TSM, 1996]. Thus, the construction concerns included with the expert’s recommendation (i.e., only newer prediction equations, an intersection set of the schemes) in these schemes, as well as the prediction equations employed, could be potentially beneficial for the seismic hazard assessment of Gaziantep city in practice. However, it should be emphasized that as the attenuation equations and Turkish seismic map [TSM, 1996] are modified or improved with the new additional strong ground motion data, the applicability of the proposed schemes including the attenuation equations could be enhanced with a better interpretation.

On the observations of all the incorporated prediction equations of the Venn schemes (Table 2, Figs. 6–8), it is found that the equations of Inan et al. [1996], Aydan et al. [1996], and Aydan [2001] generally estimate high predictions. While the equation of Gülkan and Kalkan [2002] generates the highest PGA values for the probabilistic method, it gives relatively small PGA values for the deterministic approach. As for the confirmation with the seismic map of Turkey [TSM 1996], the equations of Ansal [1997], Özbeş et al. [2004], Ulutaş and Özer [2003], Kalkan and Gülkan [2004], Ulusay et al. [2004], Akkar and Bommer [2007], and Güllü et al. [2008] (i.e., the new or recent ones, the intersection ones) could be considered to produce plausible and reasonable results for the Gaziantep city. But, it should be reminded that these findings reflect the available experimenter’s concerns of the attenuation equations, thus they could be revised upon extensive expertise of experimenter on the equations. Even though the study with its findings deal with one limited area (i.e., Gaziantep, Turkey), its methodology could be offered for different tectonic regions around the world. As compared with the previous tools [Scherbaum et al., 2004, 2009; Ghasemi et al., 2008], which are proposed for selection of attenuation equations, the methodology of weight factor applied in this study also appears to contribute at assistance to the suitability of attenuation equations, however, with a considerably less effort than the previous ones.

Herein, within the attenuation equations, a particular note could be beneficial for the prediction equation of Gülkan and Kalkan [2002]. Through the seismic hazard assessment using conventional procedure [Cornell, 1968], it can be said that the equation of Gülkan and Kalkan [2002] overpredicts the PGA values for the conventional probabilistic method (Table 3) such that the PGA values are 1.34 g and 0.89 g for the soil and rock sites, respectively. The main reason for the overestimation is likely that this equation gives very high PGA values for the small magnitude earthquakes by including little regard to the source-to-site distance. Together with the application of total probability theorem for the magnitude-distance bins, the PGA values become higher. On the other hand, for the conventional deterministic method (Table 3), the equation of Gülkan and Kalkan [2002] seems to yield fairly reasonable results (i.e., 0.17 g for soil sites and 0.11 g for rock sites). Thus, in order to prevent such situations of large differences between the probabilistic and deterministic methods in the applications of logic tree, Bommer et al. [2005] suggest using the weighting factors that change according to different magnitude-distance bins rather than using a constant set of relative weights. They propose assigning very low or zero weights for the magnitude-distance pairs which are poorly represented by the prediction equation involved. However, the practical application of their method is extremely difficult and dramatically increases the calculation effort as the number of prediction equations becomes larger. It seems to be more applicable to such a situation which incorporates only one prediction equation into hazard assessment rather than a set of equations. In that case, changing weights can be assigned to different magnitude-distance bins. However, as for the
present study, only a single weight was assigned to each equation because of the difficulties reported by Bommer et al. [2005].

Relevant to the discussions of the results obtained from present study, it is worth mentioning that selection of the attenuation models and assignment of weight factors are still not an obvious task, although some methods have been presented recently [Scherbaum and Kühn, 2011]. It is reported that there is no standard procedure that describes how the weighting factors of related approaches should be constructed. Also, it is not clear yet what the factor weight should be assumed to represent as well as how the weights should be assigned [Delavaud et al., 2012a, 2012b]. Nonetheless, the efforts due to the practices for treatment of uncertainty in attenuation equations using weighting factors provide an alternate point of view for seismic assessment. Moreover, since one of the major sources of uncertainty in the seismic hazard analysis arises from attenuation models [Cotton et al., 2006], any quantitative framework for their treatment similar to the weighting factors is of great value and should always be welcome. It is important to realize that using the weighting factors does not only give a quantitative measure to the candidate attenuation equations independently from each other, but also helps to identify the considered models within the categorization of experimenter’s concern [Delavaud et al., 2012a]. This relatively supports the capturing of the perceived epistemic uncertainty in seismic hazard analysis. However, it should be noted [Bommer and Scherbaum, 2008] that due to the lack of a standard procedure, the potential pitfalls regarding the selection of attenuation models and assignment of the weighting factors always become a rational expectation. Naturally, this indicates that experts are greatly important since they have the particular knowledge about the behavior and trend of attenuation models. Their knowledge is crucial to capture epistemic uncertainty [Delavaud et al., 2012a, 2012b]. Therefore, it is important to remember that as the expert’s knowledge about the seismicity of region increases, more reliable weight assignment could be performed for the weighting factors in future works. But, here it is more important to emphasize that even though the approach of the weighting factor appeared to provide some beneficial aspects in the point of less effort and less consideration for the actual selection of attenuation models as compared with the conventional seismic hazard methodologies [Sabetta et al., 2005; Scherbaum et al., 2005], as a general and conclusive remark of Sabetta et al. [2005], it is reported that the effect of selection of attenuation model is much more important than the weighting scheme adopted. It is indicated [Sabetta et al., 2005] that the selection of a specific attenuation model for the seismic hazard assessment of a region has a greater impact than the expert judgment applied in assigning weighting factors. Therefore, as an overall of Sabetta et al. [2005], it is strongly recommended that the weighting factors should be considered as an assistant tool primarily, throughout the present study.

7. Conclusion

In this article, the integration of the various concerns of the experimenter on the attenuation equations has been undertaken using the methodology of weight factors via Venn schemes in order to see their impact on seismic hazard assessment. As a consequence of the effort given to this work, the seismic hazard study, which performed through the comparison of attenuation equations with the methodology applied and the findings obtained, provides useful information for Gaziantep. Based on the findings obtained, the following points could be presented as the main conclusions. (i) The experimenter concerns of using new
equations (Scheme 3) and intersection ones (Scheme 6) with the expert opinion of weighting factors appear to be accurate for suitability of attenuation equations for seismic hazard study of Gaziantep. Thus, the attenuation equations PE 3, 6-11 could be more offered for estimation of PGA in seismic hazard assessment. (ii) The methodology of the weighting factors incorporated with the Venn diagrams could be considered as an assistance tool for investigation of appropriate attenuation equations in seismic hazard studies. However, the applicability of the methodology is limited to expert knowledge about seismicity of region as well as strong ground motion data related to attenuation equation. As more knowledge and data become available for the study region, the methodology could be improved to result in more contributions on the interpretation of appropriate attenuation equations.

The methodology of weighting factors with the Venn schemes proposes a different view to construction of the ground-motion logic tree part of the seismic hazard analysis. The attempt performed in this work could also be helpful for the researchers who intend an extensive study for the city. The weight factors assigned can be used to complement expert’s knowledge about the attenuation models in seismic hazard assessment for future studies.

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