J. Eng. Technol. Sci., Vol. 49, No. 4, 2017, 457-471 

# Development of Nationwide Vs30 Map and Calibrated Conversion Table for Indonesia using Automated Topographical Classification

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**Abstract**. A nationwide $Vs_{30}$ map for Indonesia was developed based on automated topographic classification from 90-m grid digital elevation data and their correlation with $Vs_{30}$. Automated topographic classification has been proposed by Iwahashi and Pike (2007) and a procedure to convert topographic class into $Vs_{30}$ maps has been developed by Imamura and Furuta (2015) based on Vs data from J-SHIS (Japan Seismic Hazard Information System). In order to be suitable for Indonesia, calibration work according to Imamura and Furuta's procedure should be conducted since the geotechnical conditions in Japan may not be the same as in Indonesia. This paper presents adjustment of the $Vs_{30}$ correlation by Imamura and Furuta to convert topographic class into $Vs_{30}$ and construct a $Vs_{30}$ map of Indonesia. This correlation was calibrated by using Vs data from BMKG (Indonesian Agency for Meteorological, Climatological, and Geophysics) as well as standard penetration test logs that were collected by the authors. Utilization of local field measurement data will certainly enhance the reliability of the $Vs_{30}$ map. The developed nationwide $Vs_{30}$ map will be very useful for disaster mitigation programs and for preliminary design of earthquake resistant buildings and infrastructure in Indonesia.

**Keywords:** *automated topographical classification; conversion; seismic hazard maps; standard penetration test;* $Vs_{30}$.

## 1 Introduction

Disaster mitigation programs and design of earthquake resistant buildings and infrastructure usually require an earthquake hazard map at ground surface. Development of earthquake hazard maps at ground surface involves predicting shaking intensity on bedrock from seismic hazard analysis and estimating the ground amplification factor from a local site characteristics study.

Received February 15th, 2017, Revised July 31st, 2017, Accepted for publication September 26th, 2017.
 ISSN: 2337-5779, DOI: 10.5614/j.eng.technol.sci.2017.49.4.3

Multiplication of the ground shaking intensity on bedrock with the amplification factor yields the ground shaking intensity at ground surface. Earthquake shaking intensity on bedrock for the entire region of Indonesia has been estimated and mapped in [1]. Figure 1 shows peak ground acceleration (PGA, maximum considered earthquake geometric mean) on bedrock in Indonesia with 2% probability of exceedance in 50 years as reported by [2] and officially issued in SNI 1726:2012. However, this national standard does not provide a ground amplification map or an earthquake shaking intensity map at ground surface.

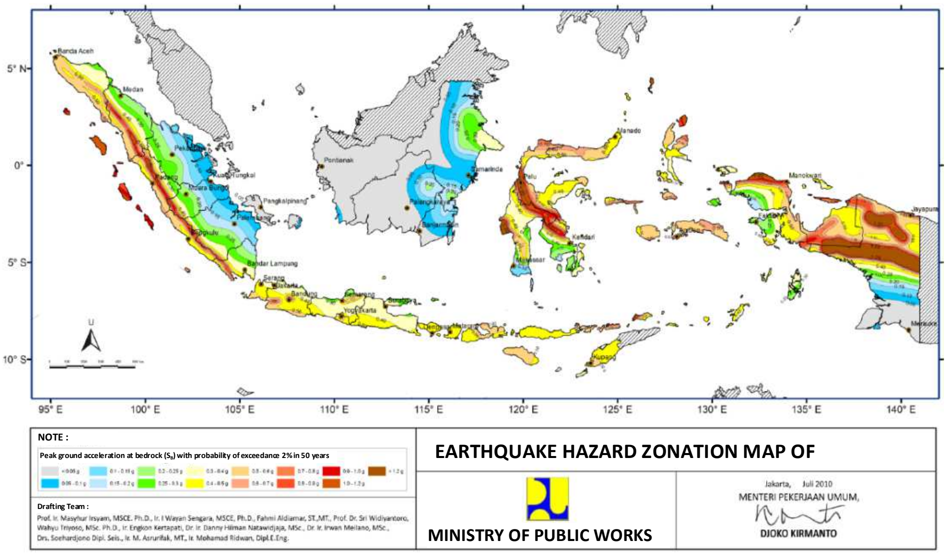



**Figure 1** Peak ground acceleration on bedrock (SB) in Indonesia with probability of exceedance 2% in 50 years (SNI 1726:2012).

One of the required parameters for determining the ground amplification factor is the averaged shear wave velocity in the upper 30 m of soil from the ground surface ($Vs_{30}$ or AVS30). Ideally, shear wave velocity measurement is conducted directly in the field, however, there are also empirical formulas available that correlate it with other geotechnical parameters, such as $q_c$ from cone penetration tests, $N_{SPT}$ from SPT, slope gradient, geological properties, geomorphological type, etc. Measurement of $Vs_{30}$ for the entire country in order to develop nationwide ground amplification maps requires a substantial amount of funding and a lot of time and therefore is not considered effective or efficient in urgent disaster risk reduction.

A recent study [3] proposed estimation of $Vs_{30}$ based on its correlation with automated topographic classification developed by Iwahashi and Pike. The automated topographic classification map for Japan resembles the official Japan Engineering Geomorphologic Classification Map (JEGM), whereas $Vs_{30}$ characteristics for each geomorphologic class in Japan have already been obtained in [4]. Results from these two researches were employed by Imamura and Furuta to generate a conversion table to convert topographic class maps directly into $Vs_{30}$ maps. This method is considered to be very efficient for developing national $V_{s30}$ maps because it only requires a digital elevation model (DEM) and the correlation between topographical class and $Vs_{30}$.

Imamura and Furuta proposed a draft of a $Vs_{30}$ map for Indonesia based on the correlation between the topographic class map of Japan using a 250-m grid DEM and Vs data from J-SHIS. In order to be suitable for Indonesia, calibration work according to Imamura and Furuta's procedure must be conducted since geotechnical conditions in Japan may not be the same as in Indonesia. This paper presents a modification of the $Vs_{30}$ correlation by Imamura and Furuta to convert topographic class into $Vs_{30}$ to construct a $Vs_{30}$ map for Indonesia. This correlation was calibrated by using $Vs_{30}$ data from BMKG as well as SPT logs that were collected by the authors. Utilization of local field measurement data will improve the reliability of the $Vs_{30}$ map. A nationwide $Vs_{30}$ map is not only very useful for estimating earthquake shaking intensity at ground surface, but it can also be used for disaster mitigation programs and for preliminary earthquake resistant designs in Indonesia.

## 2 Topographic Classification for Indonesia

The region classification method developed by [5] is based on three terrain characteristics from DEM: slope gradient, local convexity, and surface texture. Slope gradient is the steepness and flatness of the terrain, whereas local convexity is the average occurrence of convex terrain within a 3 x 3 cell grid. Similar to local convexity, surface texture is the average occurrence of 'peak' and 'pit' in DEM within a 10-cell radius.

The topographic classification process by Iwahashi and Pike works by comparing the value of slope gradient, local convexity, and surface texture to the average value per unit area (threshold). For example, suppose the entire area of Indonesia is A1, then the national average value of slope gradient, local convexity, and surface texture will be S1, C1, and T1 respectively. Cells with slope gradient larger than S1 are classified into the first cluster (class 1 to class 4), after which further division within the cluster depends on the ratio between the local convexity value and C1 and between the surface texture value and T1. The remaining area with slope value smaller than S1 is A2. Average values in this area (S2, C2, and T2) are set for classification in the next cluster (class 5 to class 8). This process is repeated until the classification reaches 24 topographic classes.

Topographic classification of Indonesia was carried out by using 90-m grid DEM data downloaded for free by the authors from the Consultative Group on International Agriculture Research (CGIAR) website, http://srtm.csi.cgiar.org/. Calculation of slope gradient, local convexity, surface texture, and topographic classification of Indonesia was performed by the authors based on Iwahashi and Pike, as described in more detail in [6,7]. The result of topographic classification of Indonesia is presented in Figure 2; it divides the region into 24 classes.

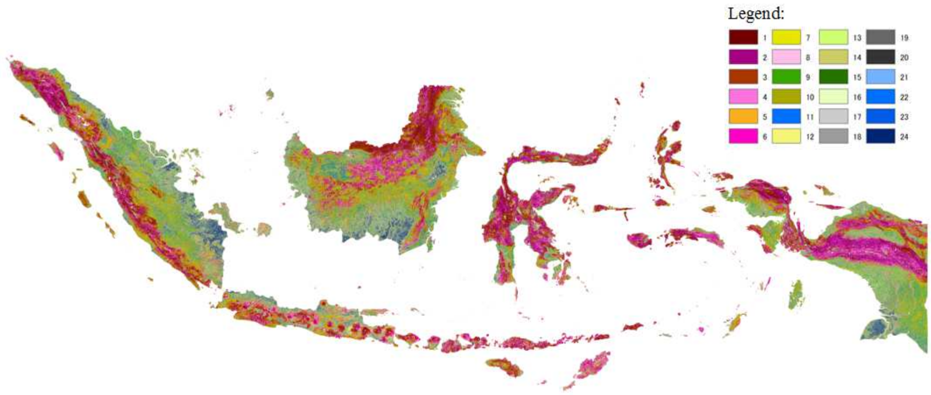



**Figure 2** Result of topographic classification of Indonesia using 90-m grid DEM data based on the Iwahashi and Pike method.

## 3 Calibration using Field Test Data in Indonesia

Utilization of data from local field measurements is intended for calibration and adjustment of the correlation between topographic class and $Vs_{30}$ for the Indonesia region. In total, there are 136 $Vs_{30}$ data from field measurements conducted by BMKG scattered all over the country. $Vs_{30}$ can also be estimated from SPT values using empirical correlation. SPT logs were therefore incorporated in this study. There are 513 SPT-logs available from an earthquake microzonation study of Jakarta City conducted by [8] and 333 SPT-logs from several soil investigation reports in Indonesia. The locations of $Vs_{30}$ and SPT data are presented in Figure 3. $Vs_{30}$ is derived from $N_{SPT}$ values using the correlation formula proposed in [9] and [10] respectively as shown in Eqs. (1) and (2) below:

$$Vs = 85.3\, N_{SPT}^{0.341} \text{ m/s} \quad (1)$$

$$Vs = 96.9\, N_{SPT}^{0.314} \text{ m/s} \quad (2)$$

## 4 $Vs_{30}$ Data Processing

The data from field measurements in Indonesia were divided into two groups. The first group consisted of BMKG data, and the second was a combination of BMKG and SPT data, called COMB data. Since the spatial location of every data was known, each $Vs_{30}$ data could be correlated with its corresponding topographic class. Hence, a graphic of the $Vs_{30}$ values versus the corresponding class could be developed. By following Imamura and Furuta, mean and median of $Vs_{30}$ for every topographic class was calculated. The result of the calculation using the BMKG data is presented in Figure 4, while Figure 5 represents the same correlation for the COMB data. The median of the BMKG data fell below the median of Imamura and Furuta, notably in the topographic classes with the highest slope (Class 1 to Class 4). Theoretically, terrain with a high natural slope consists of relatively strong material, therefore it is expected to have a high $Vs_{30}$ value.

Both the mean and the median of the COMB data resulted in a poor correlation, being much lower than the median value of Imamura and Furuta. The majority of mean and median was around 200 m/s or less. This low $Vs_{30}$ value is attributed to the fact that the COMB data utilize the correlation from Eqs. (1) and (2), which estimate the value of Vs from $N_{SPT}$. $Vs_{30}$ values that are derived from these formulas may not exceed ~415 m/s, therefore combining SPT with BMKG data will decrease the mean and median values.

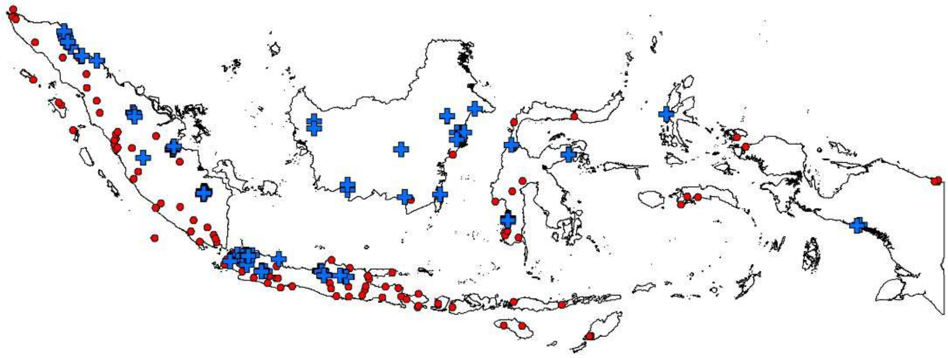


**Figure 3** Locations of measurements by BMKG (circles) and SPT-logs (crossess).

Imamura and Furuta convert the topographic class map into a $Vs_{30}$ map by assigning each class to a certain $Vs_{30}$ value, where the value is obtained from the mean or median calculation. The mean and median from Figures 4 and 5 cannot be employed in the conversion process because they are not reasonable compared to the theory and existing research by Imamura and Furuta based on

Japanese data. The authors then performed an additional calculation to find another type of statistical value that could be used for both the BMKG and the COMB data. Utilization of the midpoint between minimum and maximum (middle range value or mid value) for each topographic class resulted in a better correlation with a similar trend as from Imamura and Furuta. A summary of the statistical value (mean, median, mid value) from each data sets is presented in Table 1.

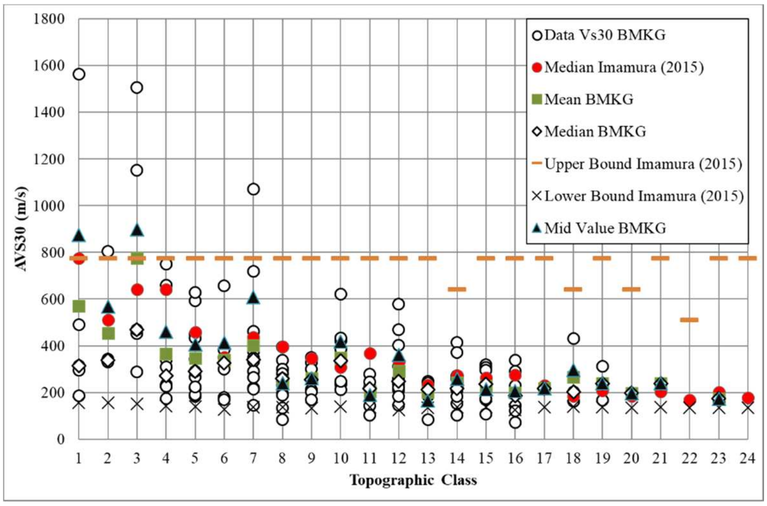



**Figure 4** Median $Vs_{30}$ value by Imamura and Furuta compared to calculated statistical $Vs_{30}$ based on data from BMKG.

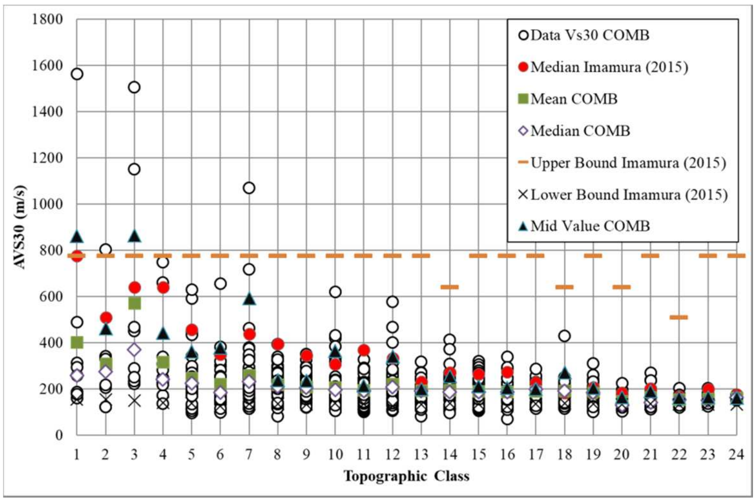



**Figure 5** Median $Vs_{30}$ value by Imamura and Furuta compared to calculated statistical $Vs_{30}$ based on data from COMB.

**Table 1** Statistical values of $Vs_{30}$ from field test (m/s).

| Topographic Class | Imamura & Furuta | Mid Value BMKG | Median BMKG | Mean BMKG | Mid Value COMB | Median COMB | Mean COMB |
|---|---|---|---|---|---|---|---|
| 1 | 776 | 875 | 314 | 570 | 863 | 258 | 404 |
| 2 | 510 | 568 | 339 | 453 | 464 | 275 | 311 |
| 3 | 641 | 898 | 470 | 774 | 865 | 371 | 573 |
| 4 | 641 | 462 | 271 | 365 | 443 | 242 | 317 |
| 5 | 458 | 406 | 290 | 347 | 363 | 226 | 248 |
| 6 | 351 | 413 | 325 | 340 | 379 | 185 | 223 |
| 7 | 438 | 608 | 342 | 402 | 594 | 232 | 260 |
| 8 | 396 | 239 | 260 | 247 | 239 | 212 | 221 |
| 9 | 347 | 260 | 256 | 260 | 236 | 208 | 210 |
| 10 | 309 | 417 | 336 | 349 | 365 | 196 | 209 |
| 11 | 369 | 190 | 217 | 204 | 215 | 193 | 195 |
| 12 | 333 | 362 | 248 | 293 | 342 | 210 | 222 |
| 13 | 262 | 165 | 213 | 202 | 201 | 193 | 193 |
| 14 | 273 | 259 | 218 | 242 | 256 | 188 | 195 |
| 15 | 264 | 213 | 235 | 228 | 213 | 188 | 191 |
| 16 | 274 | 206 | 187 | 199 | 206 | 188 | 188 |
| 17 | 229 | 217 | 217 | 217 | 201 | 200 | 192 |
| 18 | 184 | 297 | 203 | 266 | 273 | 191 | 193 |
| 19 | 208 | 239 | 239 | 239 | 206 | 185 | 185 |
| 20 | 184 | 197 | 197 | 197 | 165 | 130 | 149 |
| 21 | 203 | 239 | 239 | 239 | 192 | 141 | 165 |
| 22 | 169 | 169* | - | 169* | 163 | 154 | 156 |
| 23 | 201 | 173 | 173 | 173 | 165 | 153 | 158 |
| 24 | 178 | 178* | - | 178* | 163 | 163 | 163 |

## 5 $Vs_{30}$ Map of Indonesia

Three $Vs_{30}$ maps were developed from Figure 2. The first map was constructed based on the median value from the conversion table by Imamura and Furuta, which uses the Vs measurement from J-SHIS. The map is presented in Figure 6 using the same color pattern as used by Imamura and Furuta in developing their draft of a $Vs_{30}$ map of Indonesia. Figure 6 is almost identical to the draft of the $Vs_{30}$ map of Indonesia by Imamura and Furuta. This map has a smoother profile due to the finer grid in our digital elevation data. This figure proves that the procedure used by the authors to develop an automated topographical classification complies with Imamura and Furuta. Figure 6 was then divided into different site classes B, C, D, and E according to the criteria of SNI 1726:2012. The result is shown in Figure 7.

The second $Vs_{30}$ map was developed using the mid value of the BMKG data. The map was then converted to site class according to SNI 1726:2012. The result is presented in Figure 8. The same procedure was also applied to the third map, which was developed using the mid value of the COMB data. The result is shown in Figure 9. Because there are no available data from BMKG for class 22 and 24, the median value from Imamura and Furuta was used to fill in the missing data. Table 1 shows that the deviation of $Vs_{30}$ for class 22 and class 24 for every data set was very small.

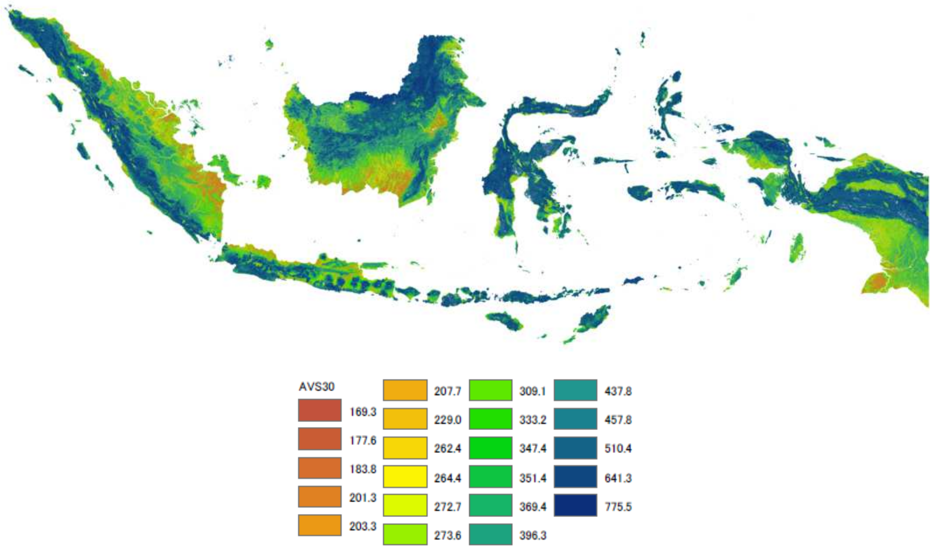



**Figure 6** $Vs_{30}$ map of Indonesia based on the conversion table by Imamura and Furuta.

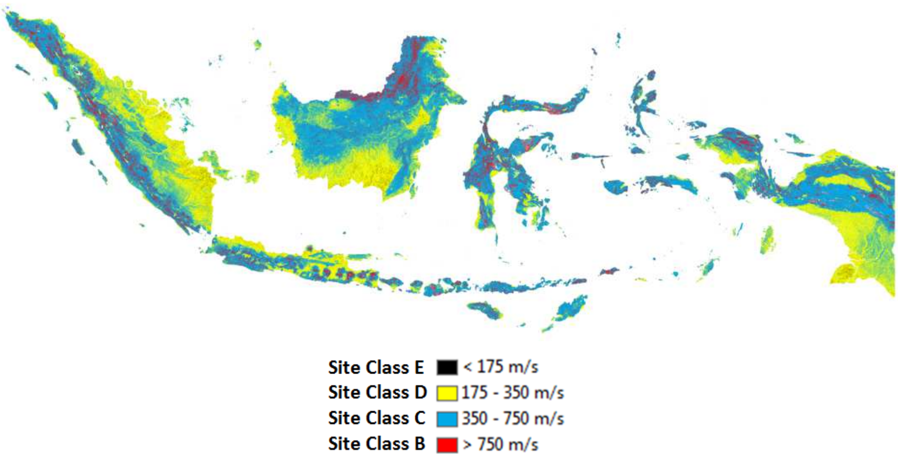



**Figure 7** Site class map of Indonesia based on the conversion table by Imamura and Furuta with site classification according to SNI 1726:2012.

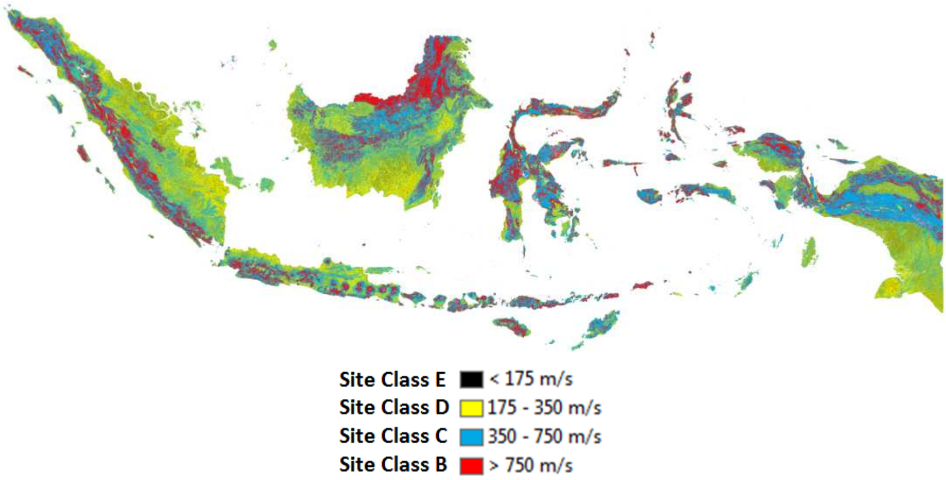



**Figure 8** Site class map of Indonesia based on the conversion table from the mid value of the BMKG data with site classification according to SNI 1726:2012.

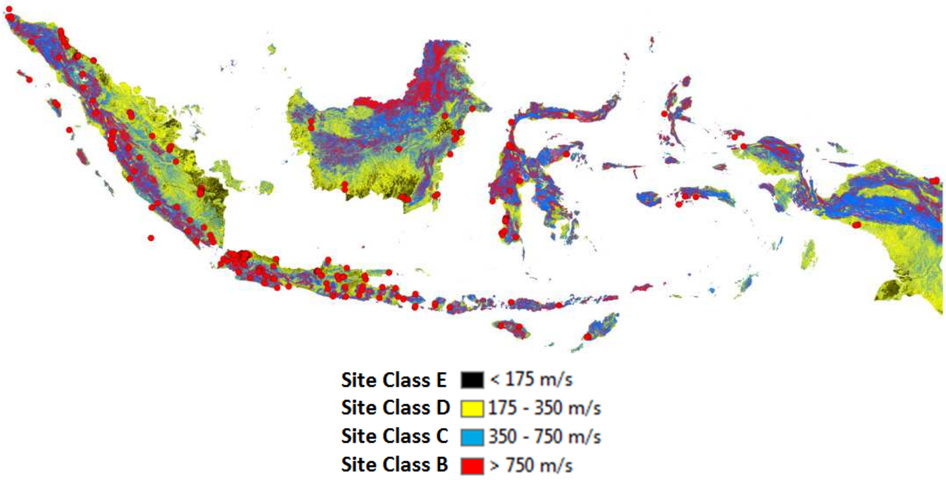



**Figure 9** Site class map of Indonesia based on the conversion table from the mid value of the COMB data with site classification according to SNI 1726:2012.

## 6 Verifications and Calibrated Conversion Table for Indonesia

Figures 7, 8 and 9 indicate that the major difference between each map is the distribution of site classes D and E. This difference is important for earthquake resistance design because it can greatly affect the ground amplification factor. In order to better verify the suitability of the conversion table for Indonesia, a comparison between $Vs_{30}$ from the conversion table and from other $Vs_{30}$/site class related studies that have been conducted before in Indonesia is required.

Two previous studies concerning the development of a $Vs_{30}$ map for Indonesia were used to verify the converted map, i.e. earthquake microzonation studies for Jakarta and Semarang respectively. The site class map of DKI Jakarta reported in [8] is presented in Figure 10.

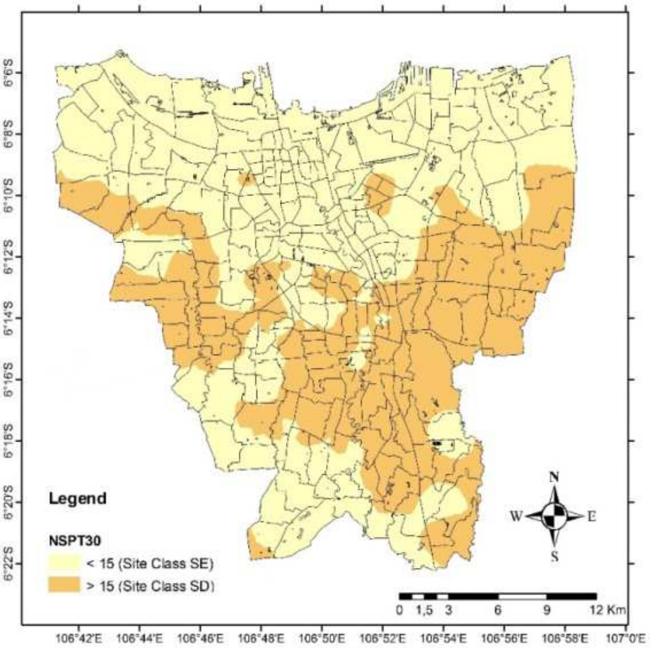
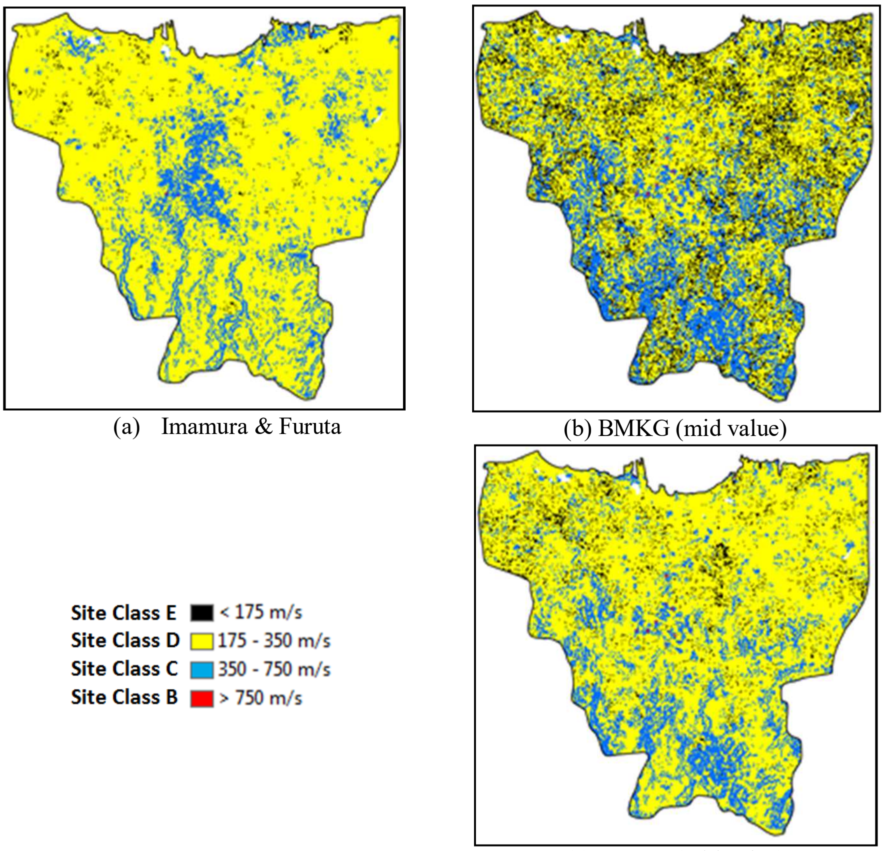



**Figure 10** Site class distribution of Jakarta based on NSPT-30 proposed in [8].

The site class criteria from [1] were adopted from ASCE 2010. Ridwan suggested that Vs criteria for site classification in SNI must be revised due to incompatibility with field conditions in Indonesia [11]. Figure 12 gives a converted site class map for DKI Jakarta with adjustment of Vs criteria based on correlation with $N_{SPT}$. It can be expected that the presence of soft soil is more visible in Figure 12. Conversion of the Imamura and Furuta data in Figure 12(a) still does not show the dominance of soft soil in DKI Jakarta. On the contrary, the dominance of soft soil from COMB (Figure 12c) is considered to be excessive. Out of the three maps, the converted $Vs_{30}$ map from the mid value of the BMKG data (Figure 12 (b)) gives the result closest to Figure 10.



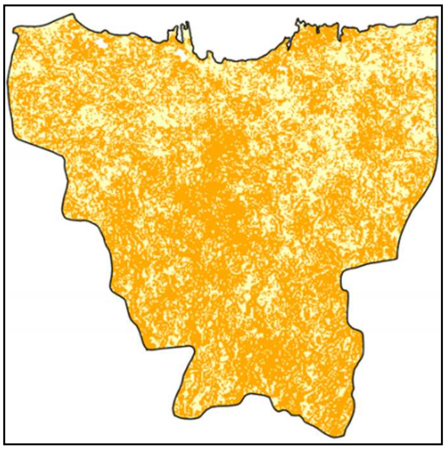

(a) Imamura & Furuta

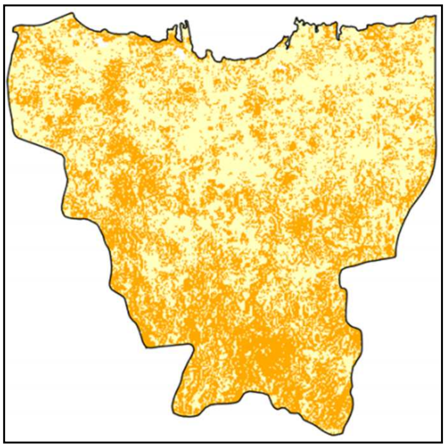
(b) BMKG (mid value)

(c) COMB (mid value)

**Figure 11** Site classes of Jakarta based on Imamura and Furuta, the mid value of BMKG data, and the mid value of COMB data.

The second verification was conducted by using the result of the microzonation study of Semarang City conducted by Partono (Figure 13) [12]. The converted $Vs_{30}$ map of Semarang is presented in Figure 14. Using the same classification, the converted $Vs_{30}$ maps display the same profile as in Figure 13. The lowland and shores with $Vs_{30}$ ranging from 125 to 250 m/s are located in the northern part of the city in both figures, as well as the highland in the southern part ($Vs_{30}$ > 250 m/s), which indicates that the estimated $Vs_{30}$ is generally close to the actual $Vs_{30}$ for Semarang. The $Vs_{30}$ map using the median of Imamura and Furuta is shown in Figure 14(a) and indicates a clear separation between two typical terrains. This data set also has the highest $Vs_{30}$ estimation. Figure 14b and Figure 14(c) are alike: the northern parts of the city mainly consist of low $Vs_{30}$ (125 to 250 m/s), whereas the southern parts has higher $Vs_{30}$.

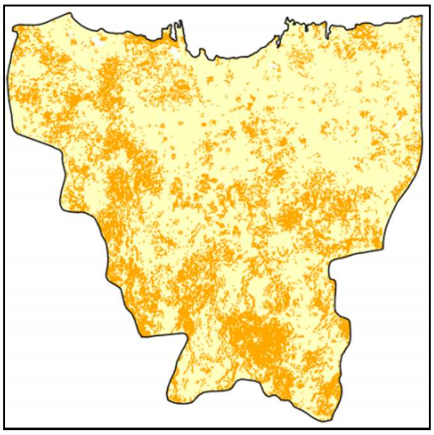




(a) Imamura and Furuta

(b) BMKG (mid value)





(c) COMB (mid value)

**Figure 12** $Vs_{30}$ of Jakarta after adjustment of soft soil criteria.

Based on Figures 10, 12, 13 and 14, it can be concluded that the conversion table from Imamura and Furuta tends to overestimate $Vs_{30}$. In other words, soil consistency from the converted map seems to be stiffer than the actual condition. Also, the $Vs_{30}$ maps from the conversion table considering field data in Indonesia are closer to the maps of Semarang and Jakarta from microzonation studies. After considering the results of this verification, a modified Imamura and Furuta conversion for Indonesia based on the mid value BMKG is proposed in Table 2 as well as the site class map of Indonesia based on this conversion table shown in Figure 8.

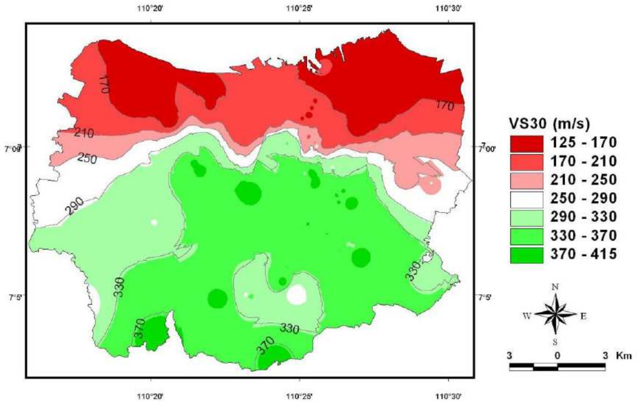



**Figure 13** $Vs_{30}$ Map of Semarang City proposed by [12].

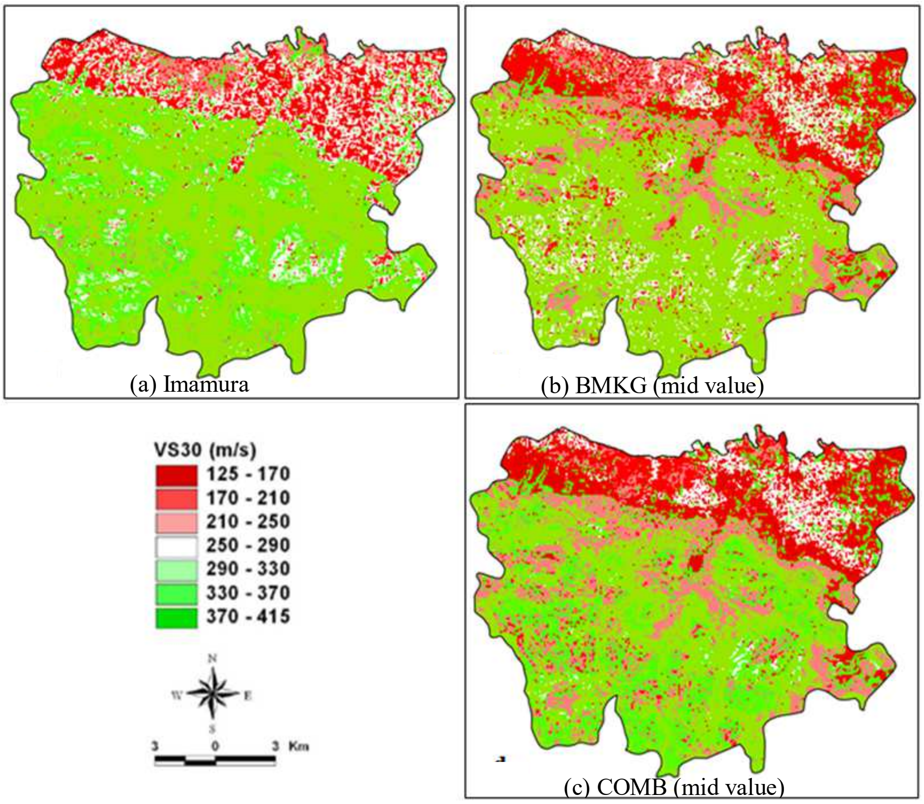



**Figure 14** Converted $Vs_{30}$ map of Semarang.

**Table 2** Proposed $Vs_{30}$ conversion table for Indonesia.

| Topographic Class | AVS30 (m/s) | Topographic Class | AVS30 (m/s) |
|---|---|---|---|
| **1** | 875 | **13** | 165 |
| **2** | 568 | **14** | 259 |
| **3** | 898 | **15** | 213 |
| **4** | 462 | **16** | 206 |
| **5** | 406 | **17** | 217 |
| **6** | 413 | **18** | 297 |
| **7** | 608 | **19** | 239 |
| **8** | 239 | **20** | 197 |
| **9** | 260 | **21** | 239 |
| **10** | 417 | **22** | 169 |
| **11** | 190 | **23** | 173 |
| **12** | 362 | **24** | 178 |

## 7 Conclusion

The conversion table by Imamura and Furuta was modified and adjusted using field test data from Indonesia. Conversion from topographic class to $Vs_{30}$ by directly using values by Imamura and Furuta tends to give overestimated $Vs_{30}$, i.e. the soil seems stiffer than the actual condition. On the other hand, conversions by involving local measurements from BMKG and COMB data were closer to previous $Vs_{30}$ related studies in Indonesia. Out of the three conversion tables, the mid value of the BMKG data gave the best results. Therefore, the conversion table from the mid value of BMKG is proposed for the Indonesian region. A nationwide $Vs_{30}$ map for Indonesia was also developed in this study. This map is very useful for disaster mitigation programs and preliminary design of earthquake resistant buildings and infrastructure in Indonesia.

## Acknowledgements

This research was supported by the Institute for Research and Community Services and the Research Center for Disaster Mitigation, Institut Teknologi Bandung. The authors would also like to thank to Mr. Ariska Rudyanto of BMKG who has provided the recent BMKG $Vs_{30}$ database as well as technical discussions.

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