GIS AND REMOTE SENSINGTECHNOLOGIES FOR TOPOGRAPHIC CHARACTERIZATION OF SEISMIC STATIONS

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ABSTRACT

Topographic Amplification Factor (TAF) due to ground surface irregularity could be one of the reasons of earthquake wave amplification and unexpected damage of buildings or other tangible structures located on the top of hills in many previous studies. Though geodesists define shape of the Earth but it also could be important for seismologists to define topographic amplification factor of each seismic station with precise feedback and the formulation of new ground motion prediction equations. Topographic Position Index (TPI) is a spatial-based approach that helps classification of topographic positions which can contribute to seismic wave amplification (e.g. ridges or upper slopes) at different radii. This paper presents TPI tool of GIS to improve the fast characterization of seismic networks in Iran.

1. INTRODUCTION

The creation of coordinates was a good opportunity for mankind to establish an easier communication and better understanding of surroundings. But it was not enough for what humans want to know about the environment until datums were created. In fact, coordinates and datums are complementary for each other or in other words, coordinates without a specified datum are vague. It means that questions like “Height above what?” and “Where is the origin?” remain without answer. Thus, the heights and an origin (starting point) are fundamental components of a datum. Without a datum, coordinates are like chess pieces without a chessboard. We can arrange them and analyze them, but without the framework, all analyses would be useless. Geospatial Information System (GIS) basically works with coordinates and datums. They enable geographic datasets to use common locations for integration (Booth and Mitchell, 2001). Rather than being completely independent, GIS has gradually developed by connecting a number of discrete information into a whole box that is greater than the sum of its components. The flexible structure of GIS technology increases its applications and the development of GIS has relied on innovations made in many different disciplines.

On the other hand, developments in remote sensing technologies have led to digital elevation models (DEMs) being freely available with worldwide coverage. DEMs created from these technologies (e.g. ASTER 30m or SRTM 90m) have enormous applications in soil sciences, earthquake studies, etc (Liu et al., 2012; Pessina and Fiorini, 2014; Ren et al., 2014; Song et al., 2012).

2. STUDY AREA

2.1. TECTONIC SETTING AND SEISMICITY

Iran is a vast country between Arabia (with northward movement) and Eurasia (slab) plates. GPS constrains show that continental convergence and active crustal shortening of the Arabian plate with respect to the Eurasian slab plate (Masson et al., 2006; McClusky et al., 2000; Vernant et al., 2004). The convergence of these plates results in the emergence of many thrusts and strike slip faults in Iran with a considerable amount of casualties due to earthquake disaster as one of the earthquake prone countries in the world (Berberian, 2014). Statistical analysis of the events with five-year intervals confirms that the number and accuracy of events were increased from the 20th century until now (Zare et al., 2014).

2.2. SEISMIC NETWORKS

In this study Iranian seismic stations (180 stations) are divided into 3 groups according to their operating organizations. 1- The IGUT seismic network belongs to the Institute of Geophysics in the University of Tehran established in 1995 (120 stations with sub-networks). The main purpose of the network is fast and reliable announcements of both magnitude and location of earthquakes happening all around the country due to fair coverage of the stations (Motaghi and Ghods, 2012). As well as, earthquake catalog and instant information of earthquakes greater than M=1 can be obtained from the website (http://irsc.ut.ac.ir/). 2- The IIEES broad band network with 30 stations has been established by the International Institute of Earthquake Engineering and Seismology (1998) for mainly research purposes (e.g. monitor seismicity of the country, estimation of crustal velocity models, and study source characteristics). Information about earthquake seismic waveforms with magnitude greater than 4.5 and earthquake catalog are available on the website of the IIEES (www.iiees.ac.ir/english) (Ansari and Amini Hosseini, 2014). 3- The Geological Survey of Iran (GSI) temporarily operated 30 stations in north and south of Iran mostly for special purposes in Alborz and Zagros blocks to study the variability of ground motions (Fig. 1) (Nemati et al., 2013).

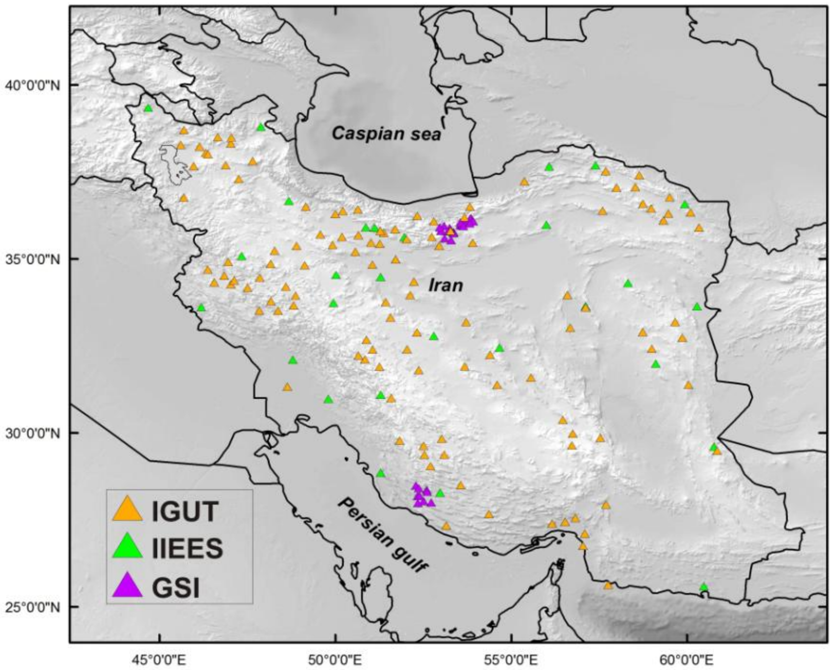

Figure 1. ASTER shaded relief map of Iran.

3. MATERIALS AND METHODS

3.1. TOPOGRAPHIC AMPLIFICATION FACTOR (TAF)

At each epicenter, so called "source effects" are the focal mechanism, size and direction of wave propagation (Allen, 2007). The produced seismic waves after seismic activity start to travel through a medium that affect the amplitude and damping shear wave velocity of the propagating seismic waves and they eventually are affected by soil conditions, near-surface geology, and topography when they reach to the Earth's surface.

As discussed, the Topographic Amplification Factor (TAF) due to irregular shape of the Earth could be one of the reasons of seismic wave amplifications beside other factors like near-surface geology and etc. Several studies have been done about TAF effects, for instance through field experiments (Davis and West, 1973) and analysis of instrument records (Celebi, 1987). Also remote sensing data have been used for TAF effects and the obtained results prove that seismic waves are dispersed at the topographic discontinuities, leading to amplification of seismic response at some ridges (Pessina and Fiorini 2014). From an observational perspective, TAF is usually mixed with near-surface geology effects, thus it is often difficult to separate amplification phenomenon to separate factors. That is why standard seismic building codes have usually neglected the TAF effects. Among the few codes containing TAF, the Eurocode8 recommends ST as the frequency-independent amplification factor which was adopted by the Italian seismic code into four classes of topographic amplification based on the height and the slope angle.

3.2. ELEVATION DATA

New advances in remote sensing technologies have made available Digital Elevation Models which form topographical data for scientific objectives including hydrology, geology, civil applications and seismology. De Reu et al. (2013) did a topographic classification for a geo-archaeological project in NW

Belgium using a DEM-based analysis on high-density LiDAR (Light Detection And Ranging) data between 2001 and 2004. Ridge assessment on DEM with different resolutions (10*10 m2, 20*20 m2 and 40*40m2) was carried out by Pessina and Fiorini (2014) and an ad hoc GIS tool (multi-function procedure via ArcToolbox) was created for the fast detection of ridges using ASTER data in Italy and Switzerland. Noticeable specifications of ASTER data for researchers like multiple imagery over the same area, convenient access and high-resolution near-global coverage makes it different than other elevation data sources. The ASTER database is comprised of 22600 tiles and in this paper over 300 ASTER GDEM V2 (1°-by-1°) tiles for land facet evaluation of Iran using an extension tool of ArcGIS are freely obtained and merged together using a georeferenced mosaicking tool for covering of the whole study area (http://gdem.ersdac.jspacesystems.or.jp). Each GDEM tile bin provides two files, an elevation model file and a quality assessment (QA) file. Both files comprised of 3601*3601 matrices, corresponding to the 1°-by-1° data area. The mosaic-output (30m posting) created for entire Iran is oriented to the WGS84 and Earth Gravitational Model 96 (EGM96) in GeoTiff format.

3.3. TOPOGRAPHIC POSITION INDEX (TPI) AND DATA PROCESSING

Known as Topographic Positioning Index (TPI), has a clever and simple algorithm which measures the difference between elevation of a central cell of a DEM (Z_0) and the average elevation value of the neighborhood around the cell ($\overline{Z}$) according to a radius (R) which is defined by user's purpose (Fig. 2) (Weiss, 2001):

$$TPI = Z_0 - \overline{Z} \tag{1}$$

$$\overline{Z} = \frac{1}{n_R} \sum i \in R^{Z_i}. \tag{2}$$

Positive values depict that the central cell is higher than its surrounding and negative values depict that it is lower. The higher-cell or lower-cell along with the slope of the cell can be used to classify the cell into slope positions. If it is considerably higher than the surrounding neighborhood, then it is likely to be at/or near the top of a hill or ridge. On the contrary, significantly low values mean that the cell is at/or near the bottom of a valley. Large R values mainly reveal major landscape units, while smaller values highlight smaller features, such as minor valleys and ridges. Thus, TPI basically depends on the scale of the projects (Fig. 2) (Jenness et al., 2013). Therefore in order to characterize the record stations in Iran territory, a small-scale project has been assumed and coefficient factor in all stations is considered to be one. This study goes through the presented method of Weiss (2001) which classifies the landscape into six discrete slope position classes (1- ridge area, 2- upper slope, 3- steep slope, 4- gentle slope, 5-lower slope and 6- valley) using a Standard Deviation (SD) of TPI (Table 1).

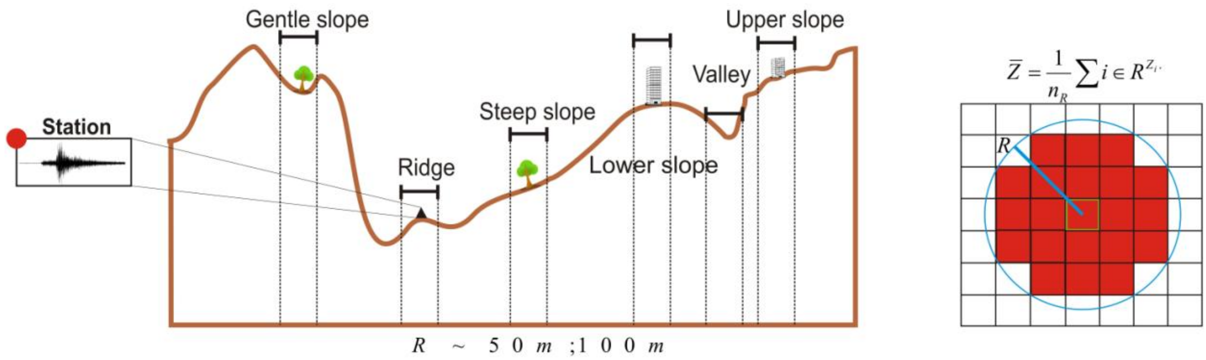

Figure 2. Left figure: Schematic definition of a small-neighborhood topographic position classification based on Weiss (2001). Right figure: An example of a circular neighborhood defined by a specific radius length for TPI analysis.

Table 1. Classification of the landform into slope position classes based on Weiss (2001).

Landform classification	Description
Ridge	$Z_0 > 1SD$
Upper slope	$SD \geq Z_0 > 0.5SD$
Steep slope	and slope $> 5\circ$ $0.5SD \geq Z_0 \geq -0.5SD$
Gentle slope	and slope $\leq 5\circ$ $0.5SD \geq Z_0 \geq -0.5SD$
Lower slope	$-0.5SD > Z_0 > -1SD$
Valley	$Z_0 < -1SD$

Usually the TPI analysis can be done within a normal physical memory (or RAM) but this may not always be possible after merging a large number of ASTER tiles into one large GeoTiff image which represent relatively complex features that contain millions of pixels (columns = 79206 and rows = 68402. This issue can be solved using a powerful computer with 64GB memory (RAM), multi-core (quad-core-i7) processing and a 1TB HDD to make a suitable interaction between elevation data and TPI analysis (e.g. for data loading into ArcGIS environment, geo-processing and results storage). The TPI raster was calculated using a circular style for 50m and 100m neighborhood sizes (Fig. 2) (see Jenness et al., 2013 for different neighborhood styles) and the results for six classes are presented in the next section.

4. RESULTS

Fig. 3 shows the statistical results in percentage terms of the topographic positions and effects of neighborhood radius on topographic classification. The valley and ridge are the largest categories with percentages ranging between approximately 31% (50m), 36% (100m), 31% (50m) and 33% (100m) respectively. For radius 50m, the rest of the categories are lower slope (5%), gentle slope (22%), steep slope (4%), upper slope (7%) and for radius 100m each of the four categories are 4%, 17%, 7% and 3% respectively. By increasing the radius of 50m to 100m, the trend lines move down for lower, gentle and upper slopes. The ridge and valley categories mostly are detected in the Alborz & Azerbaijan, Zagros and Central Iran block due to the mountainous nature of these blocks. Nevertheless, some categories were not recognized very well. For example unexpected lower percentage of lower or gentle slopes in Lut and Central Iran blocks which contain two main deserts of Iran remains a question why these categories were not detected properly. It seems that for both radius sizes (50 and 100m), detectable lower slope is unsatisfactory and it depends to the extent of certain landscape features.

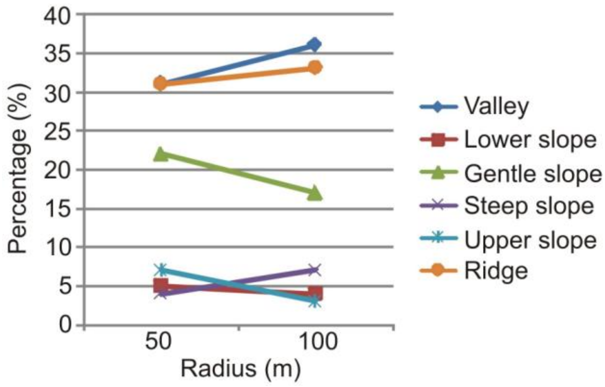

Figure 3. Percentage of topographic position classes based on TPI analysis for radii 50m and 100m.

Individual analysis of the landscape in radius size 50m shows that for IGUT stations, about 43% of the stations are classified as gentle slopes, 18% as ridges, 16% as upper slopes. Twenty-three percent of the remaining stations are distributed between valley, lower slope and steep slope classes. At the same radius, 43% of the IIEES stations are classified as ridges, 13% as lower slopes, 13% as gentle slopes and the rest of the stations are distributed between the remaining 3 categories (valley, steep slope and upper slope). At the GSI network (with almost homogeneously distribution between recognized categories), thirty-three percent of the stations are classified as valleys, 20% as gentle slopes, 17% as ridges, 13% as steep slopes, 10% as upper slopes and 7% as lower slopes (see details in Fig. 4). Overall, 23% of the all stations are located in ridge areas based on TPI analysis with 50m radius. The ridge position manifests itself in the radius 100m more than radius 50m, so that 72.5% of the IGUT stations are recognized as ridges. At the IIEES network, 63% of the stations are placed in ridge positions. But at the GSI network, 57% of the stations are recognized as valleys, 20%, 13%, 7%, and 3% are classified as ridges, steep slopes, upper slopes and lower slopes respectively. As said before, TPI is a scale-dependent analysis and generally as the neighborhood size (radius) changes, the obtained results also change. Although the chosen radii (50m and 100m) are small-scale, the interpretation of the classified stations depends on defined ground motion equations and standard procedures used in station implementations.

5. CONCLUSION AND SUMMARY

Generating TPI maps using accurate DEMs with different radii is one of the useful/fast approaches for landscape characterization and slope position classification. In this paper for characterization of the record stations, at the first step TAF assumed as an independent site effect in Iranian seismic networks, then using a merged ASTER data, a TPI classification carried out under defined criteria by Weiss (2001) which classifies the landscape into six discrete slope position classes. A circular neighborhood method by a radius length extending outward from the cell center has been used for TPI raster maps. In this study various radii from 50m to 1000m (50m increment) were tested but for seismological purposes only radii 50m and 100m were taken into account.. The TPI results are the first topographic classification of the study area that shows that the valley and ridge classes were the largest categories in Iran territory for both 50m and 100m radii. Although these classes were detected well in the Alborz & Azerbaijan, Central Iran and Zagros blocks lower/gentle slopes are not detected well in the Lut and Central Iran which shows TPI analysis has some shortcomings for detection of more complex textures.

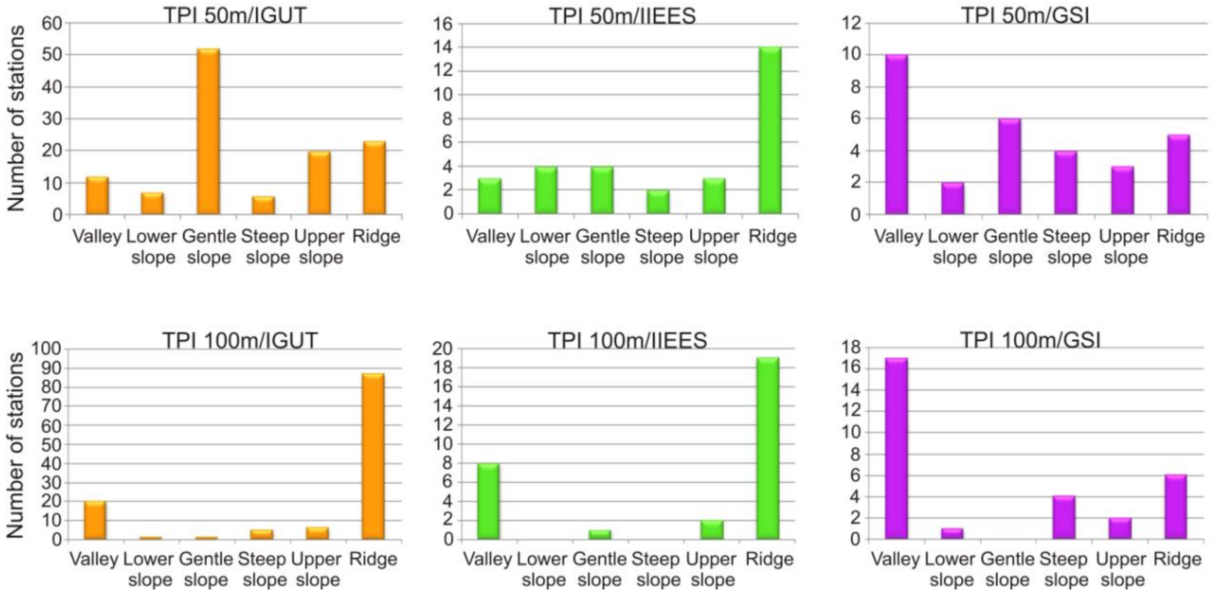

Figure 4. Number of seismic stations based on TPI analysis for different topographic position classes and Different neighborhood sizes (50m and 100m).

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