SELECTING 3D URBAN VISUALISATION MODELS FOR DISASTER MANAGEMENT: FETHIYE TSUNAMI INUNDATION CASE

S. Kemec[(1)], S. Duzgun[(1)], S. Zlatanova[(2)], D.I. Dilmen[(3)], A.C. Yalciner[(4)]

(1) Middle East Technical University, Department of Geodetic and Geographic Information Technologies, Ankara, Turkey (skemec@metu.edu.tr)
(2) Delft University of Technology, OTB, Section GIS Technology, Delft, Netherlands
(3) University of Washington, Earth and Space Sciences, Seattle, WA, United States
(4) Middle East Technical University, Civil Engineering Department, Ocean Engineering Research Centre, Ankara, Turkey

Abstract:
Urban 3D visualisation rarely considers integrated data visualisation in disaster management. In general, such methods should incorporate interoperable approaches and data to avoid duplicating efforts and to reduce costs. To achieve such interoperability, it is important to investigate the link between the types of potential hazards and the needs of the appropriate 3D model. Then again, risk communication is one of the key components for managing tsunami risk. 3-D Visualization of the tsunami inundation has paramount potential for being an effective visual risk communication tool. This paper presents the application of the rule-based approach to derive the relation between the hazard type and the level of detail, for 3D dynamic inundation visualization model for tsunami in Fethiye Bay of Turkish Southern Coast. The 3D urban model features (and the spatial resolution) considered in this approach are compliant with the level of detail (LoD) definitions specified in CityGML.

Keywords: *3D Urban Modelling, Visualisation, CityGML, Disaster Management*

1. INTRODUCTION

At the present time more than half of the world population currently lives in cities and that many economic assets are concentrated in urban areas. As a matter of course, the natural disaster vulnerabilities increase due to the growing complexity of urban processes. Disaster risk is a function of hazards, elements of risk and vulnerability. Risk is defined as the expected losses, including lives, personal injuries, property damages, and economic disruptions, due to a particular hazard for a given area and time period (WMO 2002). Risk assessment is one of the key elements of a natural disaster management strategy as it allows for better mitigation and preparation. It provides input for decision making, and it increases risk awareness among decision makers and other stakeholders (U.S. HHS 2002). Communication of the risk to the public body or other user groups is at least as important as the risk assessment. The main purpose of this is to demonstrate the application of the 3D risk communication tool generation framework. Previous studies have shown that the presentation of hazards, vulnerability, coping capacity and risk in the form of digital maps has a higher impact than traditional analogue information representations (Martin and Higgs 1997). Digital maps are increasingly being used by disaster managers. Many authors believe that 3D visualisations have the potential to be an even more effective communication tool (Kolbe et al. 2005, Marincioni 2007, Raper 1989, Zlatanova et al. 2002, Thomas et al. 2007). 3D graphical representations significantly reduce the amount of cognitive effort and improve the efficiency of the decision-making process (Kolbe et al. 2005, Zlatanova 2008). However, to achieve an appropriate 3D visualisation, two aspects must be ensured: appropriate presentation and appropriate tools for interaction. The use of 3D spatial data for the whole disaster management process is a new, but quite attractive, topic in geosciences. There have been several studies on the use of 3D geographic information for modelling hazard phenomena and corresponding urban environments. In this paper, disaster management framework, proposed by Kemec et al. (2009a) is adapted for the tsunami inundation in the 3D urban visualization models. The suggested framework establishes a link between the disaster type and several components of the 3D urban visualization. The framework considers the issues of resolution of the 3D visualization, the time/effort needed to create a model, and the availability of software and source data. The definition of an appropriate urban model is handled as a decision-making problem by applying a decision rule approach that enables the ranking of alternatives. In principle, the characteristics of urban models are associated with the disaster impact area and the features of the urban areas exposed to disaster. Therefore, a relationship is established between the urban model and the tsunami event. This paper is organised into four sections. After this introduction chapter the next section provides the needed background information. Section 3 introduces the application of the Fethiye Tsunami inundation case. The paper concludes with a discussion of the given application, with the definition of the future works in the section 4.

2. BACKGROUND

2.1. The Framework

This paper represents an application of previously cited 3D urban visualization model for disaster management framework (Kemec et al. 2009a), which consists of the following four groups of parameters: 1) User/Elements at Risk, 2) Hazard Assessment, 3) Analysis of Data and Process Requirements and 4) Needs Assessment for Visualization (data and processes).

User/Elements at Risk: A user might be interested in different sets of risk elements, which depend on the components of the urban environment. For example, an insurance company may have interests concerning the buildings, while utility companies might be mostly concerned with the effect on their networks. This is to say that the objects to be considered (and included) in a particular 3D model have to be selected with respect to the user.

Hazard Assessment: It refers to the determination of the three characteristics of the 3D urban model, which are Hazard Characteristic Medium, Indoor/Outdoor Resolution and Data Representation. Hazard Characteristic Medium is the hazard related feature in visualization that could be a sea surface object in a tsunami case. Indoor/Outdoor Resolution defines the abstraction levels of each modelling object where, low spatial resolution would mean a low LoD, while high spatial resolution would mean a high LoD. Data Representation involves the data and procedures needed for a specific model.

A*nalysis of Data and Process Requirement:* Here, the alternatives to 3D data representations such as boundary (surface) or volume approaches (e.g. voxel) should be evaluated. When visualization objects and their characteristics are defined, they are fed into the stages to specify efforts needed for establishing model objects with data and process efforts.

Needs Assessment for Visualization: The tangible needs proved with data and processes dimensions are assessed at this phase.

The five hazard assessment parameters (with indoor penetration) are used to achieve outputs (indoor/outdoor resolution, hazard characteristic medium, data representation), the first being the so-called hazard prevalence index of different hazard types. This index is obtained from the parameters of frequency, duration, speed of onset and spatial dispersion. According to this method, a hazardous event that occurs frequently, with a long duration and fast speed of onset, over a large area causes the most pervasive effect to the urban environment. The hazard prevalence value is used with the land vulnerability, urban areal extent and the population density parameters of the target city to evaluate the LoD level of the desired 3D urban model. When a hazard occurs in an urban area that settled on a highly vulnerable terrain, with a high areal extent and low population density, it causes pervasive effect to this environment. Indoor and outdoor resolutions (or LoD) are obtained from the hazard prevalence intensity index (the result of the hazard prevalence index and urban parameters evaluation) and indoor penetration parameters. Decision rule is summarized in the Equations 1 and 2.

$$I_p = [(((s_o + d + f) / 3) + s_d) / 2) \text{ x } (v + u_{ae} + p) / 3)] \quad (1)$$

Where, I_p is hazard prevalence intensity index which is the product of hazard prevalence parameters that s_o is speed of onset, d is duration, f is frequency, s_d spatial dispersion and urban evaluation parameters that v is land vulnerability, u_{ae} is urban areal extent and p is population density parameters.

$$D = I_{pnorm} + i/2 \quad (2)$$

Where, D is detail decision, I_{pnorm} normalized hazard prevalence intensity index and i is indoor penetration.

2.2. GIS-Based tsunami inundation mapping

The scientific investigations on GIS-based tsunami inundation mapping in Fethiye can be divided into three phases. First phase is the “Analytical and Experimental Studies on Tsunamis”, the second phase is “Numerical simulation of tsunamis” and the last phase is the “GIS-based mapping applications of tsunamis”. The analytical and experimental studies on tsunamis are ongoing since 1967 (Yalciner et al. 2002). Numerical simulations of tsunamis are essential to accomplish basic aspects of wave generation, propagation and inundation. The combination of a graphical user interface with geospatial data capabilities linked with numerical modeling software of tsunamis has provided modelers a new platform to transfer numerical modeling results into geographical information. There are several types of numerical models developed for estimating numerical simulation of non-linear waves of tsunamis. Numerical modeling software employed in this study is NAMI DANCE, developed in C++ programming language by Russian and Turkish Scientists in combination of identical computational procedures and the tool TUNAMI-N2. The model solves the governing equations by the finite difference technique with leap-frog scheme. It can compute the wave propagation at all locations, even at shallow and land regions within the limitations of grid size (Zahibo et al., 2003).

Inundation areas form multiple tsunami scenarios can be overlaid within GIS allowing for spatial comparison of scenario output. Furthermore, with the incorporation of additional geospatial datasets (buildings, population etc.) both risk and damage assessments associated with a tsunami can be easily assessed. According to Zerger (2002), modeling of inundation for risk management strategies is important for evacuation planning, developing urban zoning that accounts for inundation, using as an educational tool to inform citizens of the risks present in their community, cost-benefit analysis for developing mitigation strategies and managing post-disaster recovery. The integration of GIS and tsunamigenic earthquake data can be done in three ways: i) tsunamigenic earthquake data can be input for a model independent form GIS. ii) The results of model can be integrated with spatial and nonspatial data of the selected region. The data can be used as input to GIS. iii) Both input and output can be integrated into GIS.

3. APPLICATION OF THE FRAMEWORK FOR THE FETHIYE TSUNAMI CASE

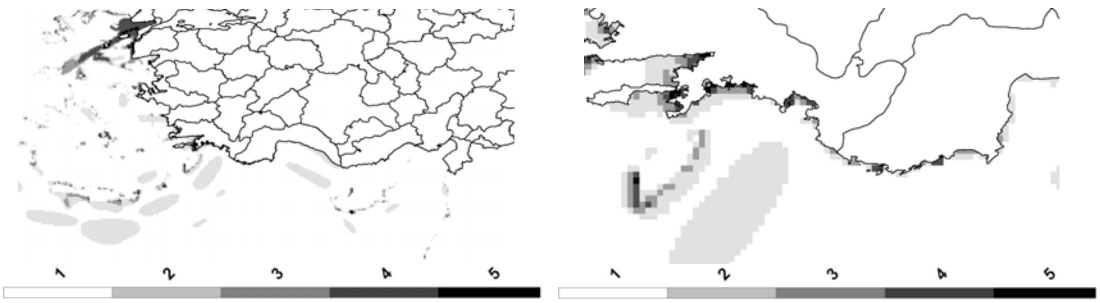
The main aim of the study was 3D dynamic tsunami inundation visualization for Fethiye city centre shoreline. Fethiye is a city of Mugla Province in the Aegean region of Turkey with about 68,000 inhabitants (2008). It is one of Turkey's well-known tourist centres. For 3D dynamic inundation visualization of computed tsunami propagation, coastal amplifications was performed to simulate and understand the tsunami effect specifically in Fethiye Bay at Southern coast of Turkey. Numerous earthquakes and associated tsunamis in history in the Mediterranean Sea seem as the precursor of the future similar events (Altinok, Ersoy 2000). The fault zones around eastern Mediterranean basin are Hellenic Arc, North Anatolian Fault Zone, East Anatolian Fault Zone, Cyprus Arc, and Dead Sea Fault. At the centre of the Aegean Sea there is a series of volcanic systems almost parallel to the trench and forming the internal arc (Milos, Antimilos, Antiparos, Santorini, Christiana, Colombus, Kos, Yali, Nisiros and others). As a part of the city centre, the pilot area has relatively high socio-economic asset concentration (Ozer et al. 2009).

3.1. Defining User/Elements at Risk:

The users were academia; they were experts in the tsunami field but non-GIS experts. In general, they need relatively realistic run-up visualizations. The basic elements at risk were considered to be buildings again. To construct a realistic visualization environment, the objects were defined as Buildings, Relief and the water element (tsunami waves).

3.2. Hazard Assessment:

A probabilistic approach was applied to find the tsunami hazard zones to compute *v* attribute. According to this approach, 35 source faults that presumably cause tsunami for Turkish coasts, appraised. Two-weight parameter was generated by using these sources' mathematical tsunami model results. These parameters were total tsunami height and number of tsunami occurrence for each pixel. For Aegean and Mediterranean seas surrounding Turkey, a final tsunami hazard zone map (figure 1a) was achieved with summation of two standardized input. Fethiye district coasts (figure 1b) were in the third severe hazard zone on the scale of 1-5, hence, *v* was assigned a value of 3.



(a) **(b)**

Figure 1. (a) Turkey Aegean and Mediterranean seas tsunami hazard zones, (b) Fethiye and near surroundings hazard zones for land vulnerability (v) attribute

Evaluation of the attributes *p* and u_{ae} was conducted for 339 settlements in Turkey. The relation between areal extent and the needs of the model detail was not linear; therefore, the areal extent adds complexity to the urban system, necessitating a more detailed modelling approach. Fethiye, with a population density of 2.62 per/ha, was classified as *p* = 5 (Table 1 and figure 2a). In this approach, high population density values map to low *p* attribute values, indicating that they require intensive modelling approaches.

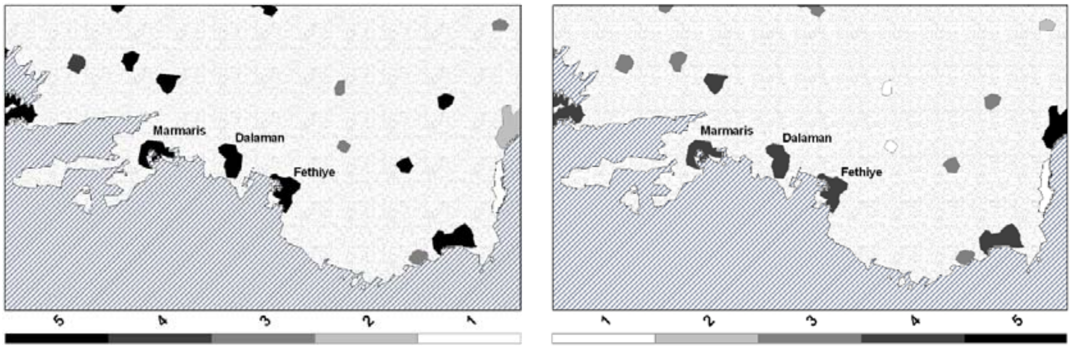
Table 1. Distribution of population density values

Classification	# of settlements	%	p
0.65 < pop_dens ≤ 4.47	**108**	**0.31**	**5**
4.47 < pop_dens ≤ 5.30	**46**	**0.14**	**4**
5.30 < pop_dens ≤ 9.12	**119**	**0.35**	**3**
9.12 < pop_dens ≤ 26.74	**64**	**0.19**	**2**
26.74 < pop_dens ≤108.05	**2**	**0.01**	**1**

The value of u_{ae} for Fethiye was 4 with its areal extent of 19345 hectares (Table 2 and figure 2b).

Table 2. Distribution of areal extents

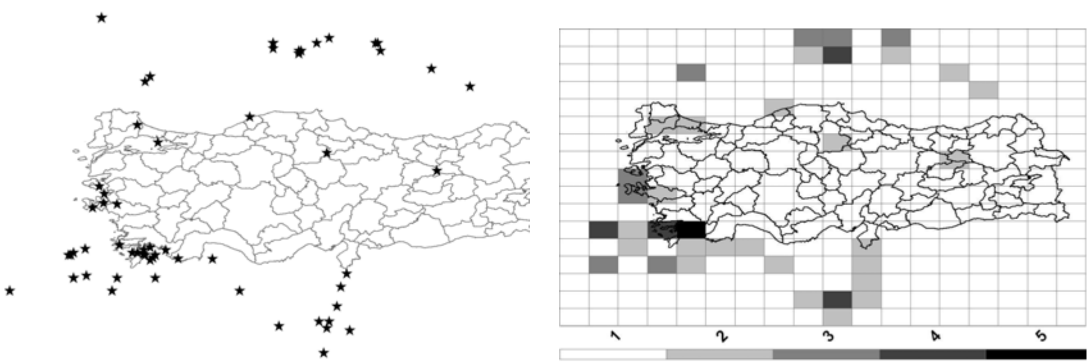
Classification	# of settlements	%	u_{ae}
726 < area size ≤ 4516	**90**	**0.27**	**1**
4516 < area size ≤ 5089	**22**	**0.06**	**2**
5089 < area size ≤ 8880	**108**	**0.32**	**3**
8880 < area size ≤ 33940	**98**	**0.29**	**4**
33940 < area size ≤ 199632	**21**	**0.06**	**5**



(a) (b)

Figure 2. Values of the p (a) and uae (b) attributes for Fethiye and nearby areas

Tsunamis observed on and near Turkish coast are listed at (Altınok and Ersoy 2000). Geographical coordinates of listed records (figure 3a) were used to determine the relative frequency distribution of tsunamis. Generated point map constitutes the base for the Quadrant analysis. The generated frequency map values were again categorised into five classes, numbered 1-5 (Figure 3b). According to the results, Fethiye's tsunami *f* value was 5.



(a) **(b)**

Figure 3. (a) Earthquake caused to tsunami for Turkish coast's (b) Relative frequency distribution of tsunamis across Turkey

The other temporal hazard attributes were *d* and s_o were derived from empirical comparisons. Compared to other natural hazards, tsunami could be classified as hazards of medium duration and medium speed of onset (table 3). Therefore, the *d* and s_o attributes were both given values of 3 on the scale of 1-5.

Table 3. Different natural hazards so and d parameters (source Kemec et al. 2009b)

Disaster	Speed of onset (immediate precursor period)	Duration (impact)
Earthquake	**Seconds**	**Seconds**
River flood	**15 hours**	**36 hours**
Dam breaching	**Minutes**	**Hours**
Tsunami	**Couple of hours (it depends the depth of water and distance V=** $\sqrt{g.h}$ **)**	**Couple of hours (for well drained lands)**
Forest fire	**Hours**	**Hours – days**
Tornado	**Minutes**	**Minutes**
Hurricane	**Several Days**	**Several Hours**
Drought	**Gradual (moths - years)**	**Months – Years**
Soil and water pollution	**Gradual depends on the amount of chemical disposal**	**Days – Months**

Tsunami s_d map (figure 4) was generated using the same dataset which is published in (Altınok and Ersoy 2000). Kernel density function (obtained using ESRI ArcGIS software, as in the *f* calculation) was applied. Fethiye was in the highest earthquake occurrence zone, so the attribute value of s_d was 5.

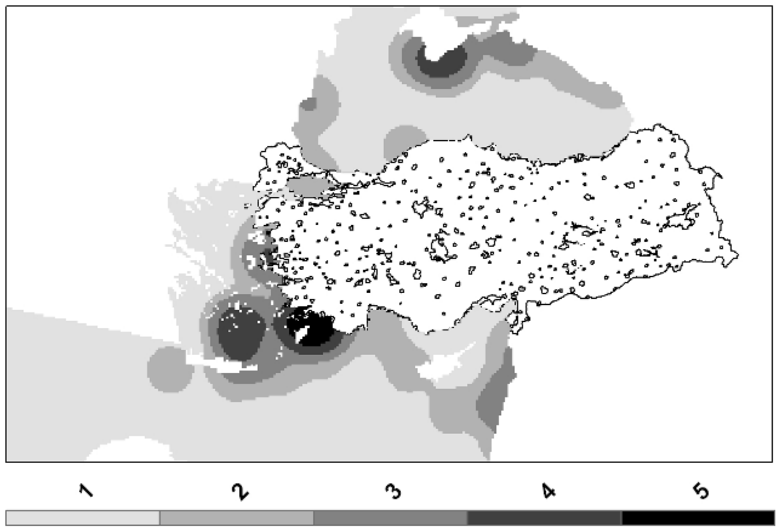


Figure 4. Tsunami s_d classification for Turkish coasts

Table 4 represents the attribute values for the Fethiye Tsunami case. The decision rule was applied using these values to determine the level of detail needed for the urban model.

Table 4. Fethiye tsunami attributes

Criteria	**U**			**H**				
Sub-criteria				**H_t**			**H_s**	
Attribute	**v**	**u_{ae}**	**p**	**F**	**d**	**s_o**	**s_d**	**i**
Value	**3**	**4**	**5**	**5**	**3**	**3**	**5**	**1**

$$I_v = [(((3 + 4 + 5) / 3) \times (((5 + 3 + 3) / 3) + 5) / 2)] = 17.33 \quad (3)$$

Entering these attribute values into equation (1):

$$I_{vnorm} = ((17.33 - 25) / (0 - 25)) \times 4)_{round} = (1.23)_{round} = 1 \quad (4)$$

And normalizing the calculated value of I_v :

$$D = 1 + (1/2) = 1.5 \quad (5)$$

The result of the decision rule was that the detail level of the urban model (D) required for this specific type of disaster and this particular city should be 1.5. We noted that *i* took a value of one here, and the D value was with a half part, because there was an indoor penetration. The levels of detail are defined with respect to the developments of CityGML. In our case 1.5 means that the building objects are represented as simple boxes but with information about floors. Note that such a level of detail is not defined in CityGML.

3.3. Analysis of Data and Process Requirements:

The model objects defined were represented with LoD1.5. Figure 5 represents the results of the data and process requirement analysis for the case. The black letters denote object representations, and the red letters denote initial data types.

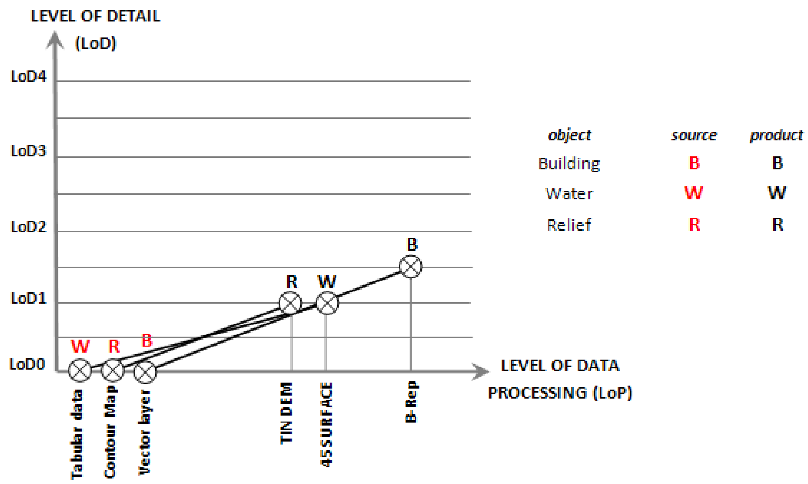
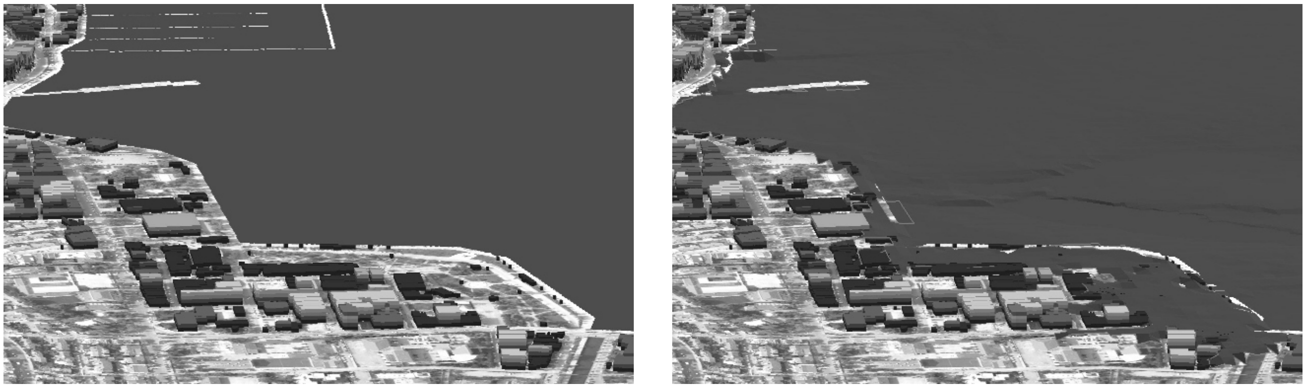


Figure 5. Cross-section of framework for an earthquake case

3.4. Needs Assessment for Visualisation:

The 3D models required by the rule-based approach can be obtained relatively easy from existing data, which are readily available in many municipalities. In our case, the available data were as follows: vector layers from Municipality, street and building footprint layers and 1/25000 digital contour maps. Process steps to develop an urban model were: 2.5D DEM generation from digital contour maps, generation of LoD1.5 buildings by using building height information, draping of city furniture, tree points, road data and building models with a terrain model, 45 different tsunami mathematical model result sea surfaces (40 seconds interval for 30 minutes) (hazard characteristic medium) (figure 6).



(a) (b)

Figure 6. General view from the 3D city model generated for Fethiye tsunami case (a) t =0 seconds, b) t=320 seconds)

4. CONCLUSIONS

In this study, 3D urban visualization model for disaster management framework (Kemec et al. 2009a) and its decision rule (Kemec et al. 2009b) were employed for Fethiye tsunami inundation visualization case. Eight attributes were incorporated into that decision rule to establish a link between the hazard type and the level of spatial detail needed in a 3D urban model for visualizing 3D inundation. According to the model, the parameters needed to be estimated are: hazard-related (s_o - speed of onset, d - duration, f - frequency, s_d - spatial dispersion and i - indoor penetration) and urban related (v - land vulnerability, u_{ae} - urban areal extent and p - population density).

This particular case confirmed the validity of the decision rule for tsunami case. Using this rule the technical disaster decision-maker group can use it as a tool to decide on the needed levels of details in the 3D model representations. In addition, it provides indications about the indoor features for a particular disaster simulation and/or visualization application. Future work will concentrate on several more disasters to validate the decision rule.

The study has also shown that a GIS based analysis could constitute one of the future works, definition of accessibility of the essential community facilities which significantly impaired due to transportation infrastructure damage during a tsunami. In the decision rule a multi-zonal evaluation approach of different city districts could constitute another future work. With such an approach more detailed analysis of city could be possible.

References

Altınok, Y. and Ersoy, Ş., 2000, Tsunamis observed on and near Turkish coast, Natural Hazards, Vo1.21, No 2-3, 185-205

Kemec, S., H.S. Duzgun, and S. Zlatanova, 2009 a, A Conceptual Framework for 3D Visualization to Support Urban Disaster Management, Joint Symposium of ICA Working Group on CEWaCM and JBGIS Gi4DM, Cartography and Geoinformatics for Early Warning and Emergency Management, Prague

Kemec, S, S. Zlatanova and S. Duzgun, 2009 b, Selecting 3D urban Visualisation models for disaster management: a rule-based approach, in Proceedings of TIEMS 2009 Annual Conference, June 9-11, Istanbul, Turkey, pp. 99-110

Kolbe, T.H., Gröger G., Plümer L., 2005, CityGML-Interoperable Access to 3D City Models, Oosterom, Zlatanova, Fendel (Eds.): Proceedings of the Int. Symposium on Geo-information for Disaster Management on 21-23 March 2005 in Delft, Springer Verlag

Marincioni, F., 2007, Information Technologies And The Sharing Of Disaster Knowledge: The Critical Role Of Professional Culture, Disasters, 31(4): 459−476. Blackwell Publishing, USA

Martin, D., and Higgs, G., 1997, The Visualization of Socio-Economic GIS Data Using Virtual Reality Tools, Transactions in GIS, vol.1, no.4, p.255

Ozer C., D.I. Dilmen, S. Kemec, A.C. Yalciner, A. Zaytsev, A. Chernov, I. Insel, E. Pelinovsky, H.S. Duzgun, 2009, "GIS Based Inundation Mapping, Examples from Mediterranean and South China Sea", South China Sea Tsunami Workshop 3 SCSTW3, in Penang, Malaysia

Raper, J.F., 1989, The 3D Geoscientific Mapping and Modeling System: A Conceptual Design, In Raper, J.F. (eds.) Three dimensional Applications in Geographical Information Systems, London, Taylor and Francis, p.11-20

Thomas D.S.K., Ertugay, K. and Kemec, S., 2007, "The Role of Geographic Information Systems/Remote Sensing in Disaster Management" in Handbook of Disaster Research, Rodriguez, H., Quarantelli, E.L., and Dynes, R. (Eds.) New York: Springer, Pages: 83-96

U.S. Department of Health and Human Services, 2002, Communicating in a Crisis: Risk Communication Guidelines for Public Officials, Washington, D.C.: Department of Health and Human Services WMO (World Meteorological Organization), (2002) Guide on Public Understanding and Response to Warnings, WMO, Geneva

Yalciner A.C, Demirbas E., Pelinovski E.N., Imamura F., Synolakis E.C., (2002) ,"Amplitude Evaluation and Runup of Solitary Waves on a Sloping Plane", Kamchatsky Tsunami Workshop.

Zahibo N., E. Pelinovsky, A. C. Yalciner, A. Kurkin, A. Koselkov, and A. Zaitsev, 2003, "The 1867 Virgin Island Tsunami", Natural Hazards and Earth System Sciences, (2003) 3: 367–376

Zerger A., 2002, "Examining GIS decision utility for natural hazard risk modeling,Environmental Modeling and Software", Elsevier, pp.287-294.

Zlatanova, S., A.A. Rahman and M.Pilouk, 2002, 3D GIS: current status and perspectives, in Proceedings of the Joint Conference on Geo-spatial theory, Processing and Applications, 8-12 July, Ottawa, Canada, 6p. CDROM

Zlatanova, S., 2008, SII for Emergency Response: the 3D Challenges, In: J. Chen, J. Jiang and S. Nayak (Eds.); Proceedings of the XXI ISPRS Congress, Part B4-TYC IV, July 2008, Beijing, pp. 1631-1637

Author Biography

PhD Candidate, Serkan Kemec, Middle East Technical University, Graduate School of Natural and Applied Sciences, Department of Geodetic and Geographic Information Technologies, Ankara, Turkey, +90 (312) 210 54 16, skemec@metu.edu.tr

Associate Professor, H. Sebnem Duzgun, Middle East Technical University, Graduate School of Natural and Applied Sciences, Department of Geodetic and Geographic Information Technologies, Ankara, Turkey, +90 (312) 210 26 68, duzgun@metu.edu.tr

Associate Professor, Sisi Zlatanova, Delft University of Technology, OTB, Section GIS Technology, Jaffalaan 9, 2628 BX, Delft, The Netherlands, +31 (0)15 27 82714, s.zlatanova@tudelft.nl

Professor Ahmet Cevdet Yalciner, Middle East Technical University, Civil Engineering Department, Ocean Engineering Research Centre, Ankara, Turkey, +90 (312) 210 54 38, tsunami@metu.edu.tr

Graduate Student, Derya Itır Dilmen, University of Washington, Earth and Space Sciences, Seattle, WA, United States, didilmen@yahoo.co.uk