Current landscape of Spatial Decision Support Systems (SDSS) and Software Applications for Earthquake Disaster Management in Turkey

Penjani Hopkins NYIMBILI and Turan ERDEN, Turkey

Key words: earthquake, disaster and emergency management, geographic information systems (GIS), spatial decision support systems (SDSS), multi-criteria decision making (MCDM)

SUMMARY

Earthquake disasters pose significant risks for millions of people causing devastating loss of lives and damage to the infrastructure resulting in huge socio-economic and environmental losses worldwide. In the last decade, recent catastrophic earthquake events have underscored the importance of the increasing need for effective disaster management in considering appropriate planning, responses and strategies, with time and complex decision-making, being vital across the four phases of the disaster and emergency management (DEM) life cycle - preparedness, mitigation, response and recovery. In this paper, selected spatial decision support systems (SDSSs) related to the geographic information system (GIS)-based applications in earthquake DEM, ranging from scenario or simulation based, early warning and rapid response and loss estimation systems, have been analysed. These have been generalised into global systems to include HAZTURK, QLARM, SELENA, DBELA, CATS, PAGER and regional and local systems comprising of ELER, HAZUS-MH, KOERILoss, MAEviz, EQRM and LNECLOSS. From the analysis of SDSS usage worldwide, but especially in Turkey, HAZTURK has been recommended for implementation of earthquake risk and loss estimation studies in Turkey based on its significant comparative advantages over other SDSSs and the suitability and applicability to the local conditions of Turkey, which have been discussed in this research. Key challenges that need to be addressed, range from issues in spatial data acquisition, quality, interoperability, data exchange and lack of coordination among relevant institutions involved in earthquake DEM and recommendations, as well as future functional improvements of HAZTURK software, have been characterised for successful implementation in Turkey.

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1. INTRODUCTION

Worldwide, in the last decade or so, earthquake disasters have caused the death of over half a million people (Armaş and Rădulian 2014), and continue to pose serious risks to human lives resulting in widespread damage. It is generally expected that earthquakes will cause the deaths of many people in urban regions in the near future in larger numbers than recorded in the past (Bilham 2009). Numerous notable hotspots for impending catastrophic earthquakes are prevalent (Dilley 2005). For instance, the megacity of Istanbul in Turkey, with its estimated more than fifteen million inhabitants, is at a 30-70 % probability risk of a major earthquake (Mw $\geq$ 7) taking place in the next thirty years (Parsons 2004). All risk management undertakings are structured within the Disaster and Emergency Management (DEM) cycle, a repetitive process that consists of four (4) phases namely, preparedness, mitigation, response and recovery, all of which are inter-related as shown in Figure 1 (NCHRP RRD 2009).

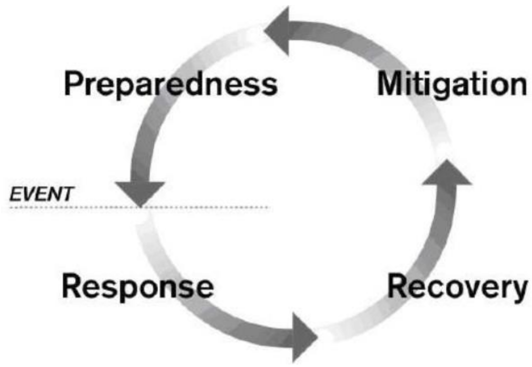

Figure 1 Disaster and emergency management (DEM) life cycle (NCHRP RRD 2009)

GIS can be a powerful tool used for the purposes of analysis, because each phase in the emergency management life cycle is geographically and spatially inter-related (Erden and Coskun 2010). SDSS may be used for a selection of optimum locations for response teams, the design of evacuation routes or for allocating evacuees to shelters (NRC 2007). The Multi-criteria Spatial Decision Support System (MC-SDSS), a category of SDSS, is based on the concept of integrating GIS and MCDA, resulting from the need to make GIS capabilities more suited to enhancing decision-making and planning (Sugumaran et al. 2011). In many MC-SDSS applications, the most popular and easiest methods of MCDM such as Weighted Sum Model (WSM), Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are applied (Malczewski 1999; Olyazadeh et al. 2013).

The aim of this study is to research SDSS within the framework of DEM, examine the current landscape of the main SDSS tools used worldwide and their application for earthquake studies with particular reference to the experience, usage and future trends for implementation in Turkey.

2. BACKGROUND

2.1 Overview and benefits of SDSS for earthquake disaster management

SDSS are composed of a spatial database system, decision model for scenario and predicting decision outcomes and a graphical user interface for output display. DEM of earthquake risks is a process that involves pre-, co- (during) and post-seismic phases as depicted in Figure 2 (Böse 2006; Erdik et al. 2014).

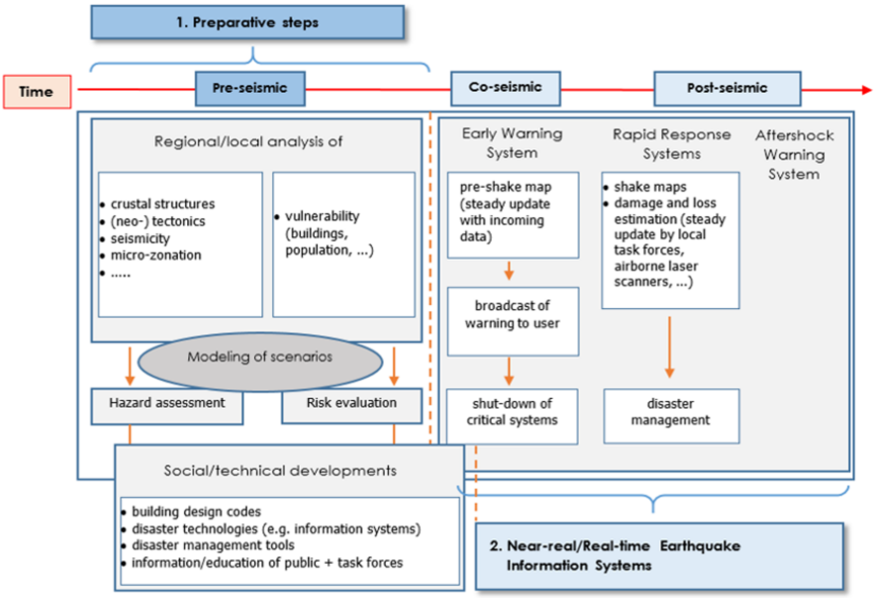

Figure 2 Pre-, co- and post- earthquake risk DEM activities (Böse 2006; Erdik et al. 2014)

SDSSs assist in the function of building regional multi-disciplinary databases as a basis for developing earthquake scenarios, both as a preliminary planning tool (pre-disaster phase) and to communicate earthquake risks, warnings/alerts effectively, to support emergency efforts in real or near real-time and identify high-risk zones through display (post-disaster phase) (Levi et al. 2015). SDSSs, that are scenario or simulation-based, are used in the planning and preparedness stages within the pre-seismic phase (pre-disaster) for conducting earthquake hazard assessment and risk evaluation against local/regional vulnerability and socio-technical development analyses (Erdik et al. 2014). For hazard assessment, in pre-disaster geological observations, GIS can address the need for analysis of quantitative observational parameters on landforms, land cover and tectonic features (Philip 2007).

A review of some of the works relating to SDSS usage in earthquake management are characterized. Gheorghe and Armaş (2015) discuss a case study of use of SDSS for seismic risk in Bucharest, Romania. The main objective of the research was to identify a suitable shelter within a highly populated historical centre. Tang and Zhao (2012), in their study, presented a distinctive DSS system for earthquake risk assessment and mitigation. Rasekh and Vafaeinezhad (2012) propose a SDSS for resource allocation in an earthquake search and rescue (SAR) operation for an earthquake prone district in Tehran, Iran. Pollino et al. (2011), in their study, applied SDSS for earthquake early warning and post-event emergency management.

2.2 Global SDSS

The global near real-time loss estimation SDSSs have a worldwide application range and are included in the summary in Table 1.

SELENA (Molina and Lindholm 2005) is a post-disaster open source software relying on the principles of capacity spectrum methods (CSM). The principal analysis flowchart of using SELENA is as shown in Figure 3 (Molina et al. 2010).

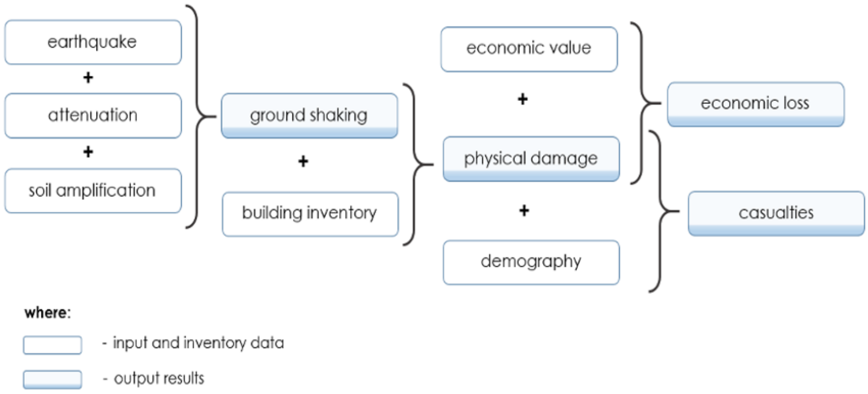

Figure 3 Principle flowchart of analysis using SELENA (Molina et al. 2010)

HAZTURK (Hazards Turkey), was developed by Karaman et al. (2008), based on a modification to the MAEviz in conformity with the data structure of Turkey. Components of hazard, fragility and inventory, which form the foundation of loss assessment studies for earthquakes, are encompassed in HAZTURK (Karaman et al. 2008).

Other global SDSSs for earthquake risk and loss estimation include: DBELA (Displacement-Based Earthquake Loss Assessment) (Crowley et al. 2004); EmergGeo/NHEMATIS (Natural Hazards Electronic Map and Assessment Tools Information System), modelled after HAZUS (Daniell 2009; Erdik et al. 2014); CATS (Consequence Assessment Tool Set) (Daniell 2009); OpenQuake (Silva et al. 2013); OpenRisk (Porter and Scawthorn 2007), modelled after HAZUS and also uses the USGS earthquake loss estimation software called ResRisk (Daniell 2009); GDACS (Global Disaster Alert and Coordination System) (Erdik et al. 2014; GDACS 2017); QLARM/, formerly QUAKELOSS (World Agency of Planetary Monitoring Earthquake Risk

Reduction) (Trendafiloski et al. 2011) (Erdik et al. 2014); PAGER (Prompt Assessment of Global Earthquakes for Response) (Erdik et al. 2014; Wald et al. 2010).

2.3 Regional and local SDSSs

There exists quite a number of regional systems (specific to regions) and local systems (specific to a facility, city or country) in several parts of the world, with capabilities of evaluating damage and casualties in near real-time, after occurrence of major earthquakes (post-disaster phase) (Erdik and Fahjan, 2006). These regional and local systems are included in the summary provided in Table 2.

Table 1 Summary list of selected global SDSS for earthquakes

SDSS	*Region applicable*	*Developer/ Owner*	*Operating System Used*	*Platform*	*Open Source (Yes/ No)*	*Programming language for development*	*Data categories*	*Essential district features*	*Scenario and/or simulation-based (Yes/No)*	*User – friendly interface (Yes/ No)*	*Outputs*
SELENA	Europe, Worldwide	NORSAR		ESRI ArcGIS	Yes	Matlab, C++	Socio-economic, lifelines, building and population	Earthquake	Yes	Yes	GIS graphic display of predicted losses – building, damage
HAZTURK	Turkey, Worldwide	Karaman et al. 2008	Windows	ESRI ArcGIS		Java	Socio-economic, geology, topography, building inventory/fragility	Earthquake	Yes	Yes	Hazard maps for earthquake spectral acceleration, PGA, PGV hazard outputs
DBELA	Europe, Worldwide	ROSE School/EU-Centre		GIS	Yes	Matlab, Fortran	Socio-economic, building stock, exposure	Earthquake	Yes	Yes	Earthquake loss (building stock) estimates
Emergeo/ NHEMATIS	Worldwide	EmerGeo, EPC	Windows	ESRI ArcGIS Google	Yes		Socio-economic, lifelines, building and facility types	Earthquake	Yes	Yes	Damage and injury maps, GPS locations

								Secondary earthquake effects			
CATS	USA, Worldwide	Daniell 2009, FEMA, DTRA	Windows	ESRI ArcGIS	Yes		Demographic, infrastructure	Earthquake, hurricane, explosives, ground failure, tsunami, fire and ground shaking	Yes	Yes	Scenario maps, assessment of disaster effects on infrastructure and population
OpenQuake	Worldwide	GEM, Silva et al. 2013		Web-based	Yes	Python	Socio-economic, building	Earthquake	Yes	Yes	Dyanamic maps, socio-economic and damage assessment/analysis reports
OpenRisk	Worldwide	AGORA, USGS, OpenSHA		UML	Yes	Java	Socio-economic	Earthquake	Yes	Yes	Social and economic loss estimation reports

Table 1 Summary list of selected global SDSS for earthquakes (***continued***)

SDSS	***Region applicable***	***Developer/ Owner***	***Operating System Used***	***Platform***	***Open Source (Yes/ No)***	***Programming language for development***	***Data categories***	***Essential district features***	***Scenario and/or simulation-based (Yes/No)***	***User – friendly interface (Yes/ No)***	***Outputs***
GDACS	Worldwide	OCHA/ EC		Web-based			Demographic, socio-economic, hazard information	Natural disasters incl. earthquake	Yes (Early Warning System)	Yes	Maps, alerts, risk analysis reports of expected disaster impact via GDACS website
QLARM/ QUAKELOSS	Worldwide	WAPMERR	Windows		Yes	Java, C++, XMF	Socio-economic, population, soil, exposure and vulnerability	Earthquake	Yes (Early Warning System)	Yes	Post-earthquake alerts, loss estimation reports. shake maps
PAGER	Worldwide	USGS, FEMA		Web-based	Yes	Matlab	Building, economic and fatality loss models, population inventories and fragilities	Earthquake Secondary hazards – Landslide, liquefaction	Yes (Early Warning System)	Yes	Alerts, shake maps, population earthquake exposure and risk maps, google earth

maps/map data files

ELER was developed through a Joint Research Activity 3 (JRA3) of the EU Project NERIES (NEtwork of Research Infrastructures for European Seismology), (Erdik et al. 2008). ELER, consists of two modules of analysis, namely; Earthquake Hazard Assessment (EHA) – and Earthquake Loss Assessment (ELA). The ELA module estimates earthquake losses (damage and casualties) using three levels of analysis, level 0, 1 and 2 as shown in Figure 4 (Erdik et al. 2014). The availability of demographic and building inventory data essentially control the differentiation of these three analysis levels (Demircioglu et al. 2009; Erdik et al. 2010).

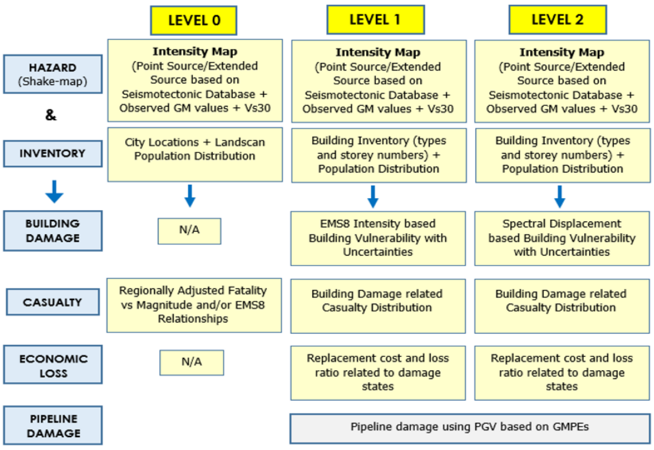

Figure 4 The three (3) levels of analysis incorporated in the ELER software (Erdik et al. 2014)

The rest of the selected main SDSSs include: HAZUS-MH (Hazards United States Multi-hazard) (NIBS and FEMA 2003), built on ESRI ArcGIS platform with an enhanced version, HAZUS-MH MR2, released in 2006 (Erdik et al. 2014); LNECLOSS (Sousa et al. 2004), (Zonno et al. 2009); KOERILoss/ StrucLoss (Kandilli Observatory and Earthquake Research Institute Loss Estimation/ Earthquake and Structural Department of Gebze Institute of Technology) (Erdik and Aydinoglu 2002; Erdik et al. 2003a,b); MAEviz (Mid-America Earthquakes visualization) (MAE 2009).

Other regional SDSSs include: EPEDAT (Early Post-Earthquake Damage Assessment Tool) (Eguchi et al. 1997); EQRM (EarthQuake Risk Management) (Robinson et al. 2005, 2006); CAPRA-GIS (Central American Probabilistic Risk Assessment) (Anderson 2008); SIGE/ ESPAS (Earthquake Scenario Probabilistic Assessment) (Di Pasquale et al. 2004); QuakeIST (Ferreira et al. 2014) and RiskScape (Schmidt et al. 2007).

Some examples of local SDSSs used in earthquake emergency management and disaster mitigation consist of: TELES (Taiwan Earthquake Loss Estimation System) (Yeh et al. 2006); READY (Real-time Earthquake Assessment Disaster System in Yokohama City, Japan) (Midorikawa 2005); SUPREME (Super-dense Real-time Monitoring of Earthquakes) (Inomata and Norito 2012; Yamazaki et al. 1995).

Example of local systems used in Turkey are: IERREWS (Istanbul Earthquake Rapid Response System and Early Warning System) (Erdik et al. 2002, 2003) designed and operated by Bogazici University (Erdik et al. 2014); and IGDAS (Istanbul Natural Gas Earthquake Response System) (Bıyıkoglu et al. 2012), developed by Istanbul Gas Distribution Company (IGDAS) and is a near real-time risk mitigation system to prevent casualties and economic losses arising from natural gas in an event of an earthquake (Erdik et al. 2014).

Table 2 Summary list of selected regional and local SDSSs for earthquakes

SDSS	***Region applicable***	***Developer / Owner***	***Operating System***	***Platform***	***Open Source (Yes / No)***	***Programming language for development***	***Data categories***	***Essential district features***	***Scenario and/or simulation-based***	***User – friendly interface (Yes/ No)***	***Outputs***
ELER	Europe	JRA-3, NERIES	Windows Linux MacOS Solaris	Google	Yes	Matlab	Socio-economic, demographic	Earthquake	Yes	Yes	Loss maps, rapid earthquake damage and casualty estimates
HAZUS-MH	USA	FEMA, NIBS		ESRI ArcGIS	No	C++ Visual Basic Microsoft SQL	Socio-economic, population, building inventory	Earthquake Flood, tropical storm, fire	Yes	Yes	Loss maps, building, socio-economic loss reports/analysis
EPEDAT	USA	EQE International	Windows	MapInfo	No		Housing, demographic, lifeline network, satellite and aerial surveys post-earthquake data	Lifeline damage models	Yes	Yes	Damage (buildings, lifelines), casualty predictions
EQRM	Australasia	Geoscience Australia			Yes	Python Matlab	Social demographics, building inventory, hazard data	Earthquake	Yes	Yes	Earthquake loss and seismic hazard/risk models
CAPRA-GIS	Central America	EIRD	Windows	Web 2.0 ILWIS 3.4	Yes	Visual Basic	GIS and remote sensing, topographic data for hazards	Natural hazards – earthquake, flood	Yes	Yes	Earthquake loss estimation/tools via disaster risk

				Other GIS							information platform
SIGE/ ESPAS	Europe	OSSN	Windows Unix	GIS systems	No	Visual Basic	Socio-economic, population, lifeline and facility/building inventory	Earthquake	Yes	Yes	Rapid approx. Damage estimation maps/reports, lifeline, facility, statistical GIS/GPS/GPRS maps
KOERILoss/ StrucLoss	Turkey, Europe	KOERI, Bogazici University	Windows Unix	MapInfo GIS	No	MapBasic Matlab Excel	Building, demographic (social- impact classes)	Earthquake	Yes	Yes	GIS display of building damage, socio-economic losses
LNECLOSS	Europe	LNEC	Windows	GIS	No	Fortran	Socio-economic, building, soil and bedrock data	Earthquake	Yes	No	Disaster scenario of socio-economic loss

Table 2 Summary list of selected regional and local SDSSs for earthquakes (***continued***)

SDSS	***Region applicable***	***Developer / Owner***	***Operating System***	***Platform***	***Open Sour***	***Programming language***	***Data categories***	***Essential district features***	***Scenario and/or***	***User – friendly***	***Outputs***

					ce (Yes / No)	*for development*			*simulation-based*	*interface (Yes/No)*	
QuakeIST	Europe	IST, University of Lisbon		All GIS ESRI ArcGIS QGIS Other GIS	No	C++	Socio-economic	Earthquake	Yes	Yes	Maps and measurements of impact in urban systems
RiskScape	Australasia	NIWA and GNS	Windows	In-built GIS	Yes	Java	Socio-economic, population, building, lifeline, detailed soil and geology maps, remote sensing and LIDAR data	Earthquake, Tsunami Landslide	Yes	Yes	Socio-economic loss, damage estimates
MAEviz	USA	University of Illinois	Windows	In-built GIS (ESRI ArcGIS)	Yes	Java	Building, bridges and gas networks	Earthquake	Yes	Yes	Earthquake risk assessment for building, bridges and gas networks, spatial data/visual info. Reports
TELES	Taiwan	NCREE	Windows	MapInfo	No	C++	GIS data of inventory – earthquake hazard, geological maps and analysis	Earthquake	Yes	Yes	Maps and tables of earthquake damage and casualty estimates
READY	Japan	Yokohama City					Strong motion accelerographs, borehole strong motion system	Earthquake	Yes	Yes	Seismic intensity map of damage assessment and locations

							installations locations/network				
SUPREME	Japan	Tokyo Gas Company					City gas network, building inventory	Earthquake	Yes	Yes	Earthquake risk analysis from gas pipe damage assessment
IERREWS	Turkey	Bogazici University, Turkey	Windows	GIS	Yes	Matlab C++	Strong motion network, building inventory, fragility curves, seismotectonic and soil database	Earthquake	Yes (Early Warning System)	Yes	Loss and shake maps – earthquake rapid response and loss information
IGDAS	Turkey	IGDAS	Windows	GIS	Yes	Matlab C++	Natural gas pipeline network, socio-economic, demographic, building stock, near real-time hazard data	Earthquake	Yes (Early Warning System)	Yes	Ground shaking and damage distribution maps in natural gas infrastructure and building stock

2.4 SDSS experience in Turkey

Following the severe earthquake that affected urban areas of the Marmara Region of Turkey in 1999, there have been a lot of comprehensive studies undertaken of earthquake risk and loss assessment using; ELER, through the Euro-Mediterranean region (Erdik et al. 2010; Ansal et al. 2009); HAZTURK software, developed based on MAEviz (Karaman et al. 2008a) and other studies for seismic risk assessments in Istanbul (Ansal et al. 2009; Atakan et al. 2002; Sahin et al. 2016). KOERILoss, has been used in Istanbul, Izmir, Bishkek and Tashkent regions and in relation to the Istanbul Earthquake Rapid Response System (IERRS) (Erdik et al. 2014). Significant applications of MAEviz, were carried out for Zeytinburnu District (Elnashai et al. 2008). The success of CATS was tested for the earthquakes in regions around the world that include Izmit and Duzce, in Turkey. CATS, besides earthquake disasters, also takes into account ground failure, tsunami, and fire (Daniell 2009). An application of DBELA methodology was conducted in the Marmara region, for earthquake loss assessment and impact on building stock (Bal et al. 2008; Bommer et al. 2006). A comparative study by Strasser et al. (2008) used a European earthquake loss estimation SDSS for damage estimation for an earthquake scenario in Istanbul. HAZTURK was applied in a proposed study by Unen et al. (2010) for undertaking analysis of seismic performance of the utility lifeline networks in Zeytinburnu. For the 2011 Van earthquake event that occurred in Eastern Turkey, an evaluation of SDSS for rapid loss assessment revealed that ELER-based rapid loss assessment results proved to be very close to the final losses (CEDIM 2011; Erdik et al. 2012; Wenzel et al. 2012). MegaIST (Megacity Indicator System for Disaster Risk Management) was proposed in a study by Mentese et al. (2015). Perilis (2012), using ELER, conducted a study for rapid earthquake risk assessment on an urban scale as applied to Istanbul. From a study by Sahin et al. (2016), a new version of an integrated earthquake simulation (IES) SDSS for Istanbul was developed after the originally developed system in Japan to be applied to the Zeytinburnu district.

3. CONCLUSIONS AND FUTURE DEVELOPMENTS

Past and recent catastrophic earthquake occurrences in the world have underscored the need for development of geospatial and decision model systems such as SDSS to aid in effective DEM. GIS tools are used to establish the core of SDSSs for emergency managers and decision makers. SDSSs are supported by mapping and visualisation methods for easier interpretation of outputs.

In this paper, an introduction of SDSS and MCDA integration, MC-SDSS, is given within the framework of a DEM cycle and background concepts. Selected previous works and SDSS applications related to earthquake risk assessment and loss estimation have been examined. The types of SDSS involved in earthquake DEM are applied pre-, during- and post-earthquake phases. Future developments of SDSS should be focused on decreasing the degree of uncertainty and increasing the accuracy and reliability of earthquake risk and loss estimations as well as more accurate models used for reducing risk vulnerability from socio-economic losses.

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BIOGRAPHICAL NOTES

Penjani Hopkins Nyimbili graduated from the University of Zambia (UNZA) – Geomatic Engineering in 2008 and has been a research/teaching assistant at UNZA since 2009. He is a professional and licensed engineer and has over 8 years work experience in various engineering consultancies and firms ranging from construction, mineral exploration, mobile and fibre telecommunications, renewable energy sectors. He has also attained several trainings and certifications from countries that include South Africa, UK, India, China and Japan. He has an MSc in Geomatics Engineering from Istanbul Technical University (ITU) in Turkey. He is currently undertaking his PhD study in Geomatics Engineering from Istanbul Technical

University (ITU). He is interested in GIS, Disaster and emergency management, planning, Spatial Decision Support Systems, Multi-criteria Decision Making and related subjects.

Publications: **Nyimbili P H, Demirel H, Şeker D Z, Erden T (2016)**, In: ‘‘Structure-from-Motion (SFM) – Approaches and Applications’’ (Antalya, 2016), Selçuk International Scientific Conference on Applied Sciences Conference Proceedings Volume II, pp.260-267, ISBN 978-605-65700-3-2, Nobel Akademik Yayıncılık Eğitim Danışmanlık Tic. Ltd. Şt, Turkey; **Nyimbili P H, Erden T (2018)**, In: ‘‘SDSS and Software Applications for Earthquake Disaster Management with Special Reference to Turkey’’, Natural Hazards Journal, 90(3):1485-1507. https://doi.org/10.1007/s11069-017-3089-7; **Nyimbili P H, Erden T, Karaman H (2017)**, In: ‘‘Integration of GIS, AHP and TOPSIS for Earthquake Hazard Analysis’’, Natural Hazards (Under Publication Review, D-17-00995).

Awards: **Certificate of Award for Best Poster Presentation**; Presentation Title: ‘Structure-from-Motion (SFM) – Approaches and Applications’, Selçuk International Scientific Conference on Applied Sciences, Antalya, Turkey; September 2016; Turkish Government Scholarship: Msc (2014 – 2017), PhD (2017-2021);

Membership: Registered Engineer (R.Eng.) of the Engineering Institute of Zambia (EIZ), Practising License No. 006027, Member of the Surveying Institute of Zambia (SIZ), Associate Member of the Zambia Institute of Marketing (AZIM), Member of the African Strategic Research Center (AFSAM), Turkey, Member of the Board of European Students of Technology (BEST).

CONTACTS

Mr Penjani Hopkins Nyimbili
Istanbul Technical University
Faculty of Civil Engineering, Department of Geomatics Engineering, 34469
Istanbul
TURKEY
Tel. +90 553 012 48 40
Fax + 90 212 285 3833
Email: nyimbili@itu.edu.tr/ penjahop@gmail.com
Web site: www.itu.edu.tr