



MULTI-CRITERIA DECISION MAKING FOR SMALL/MEDIUM NUCLEAR DESALINATION SITE SELECTION: EGYPT CASE STUDY

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ABSTRACT

Construction of nuclear desalination plants requires the assessment of several siting criteria taking into consideration technical and environmental aspects. This paper identifies criteria for siting small/medium nuclear-powered desalination plants. A selection ranking matrix was formulated where the proposed siting areas were assigned scores pertinent to each weighed selection criterion. The proposed areas were then statistically evaluated based on their weighed scores using Wilcoxon signed-rank method for a conceptual case study in Egypt (as a typical developing country) to identify priority areas for implementing small/medium nuclear-powered desalination plants.

Keywords: nuclear desalination, developing countries, multi-criteria decision making, Wilcoxon signed-rank method.

1. INTRODUCTION

Rapid advances in nuclear reactor design and improvements regarding safety and hazard control features led to the evolution of a recent spectrum of small/medium scale nuclear reactors. The rationale behind using small/medium scale nuclear reactors to empower large scale desalination plants is based on its significant competitive prices, stable performance, small footprint etc. [1-3]. For small/medium reactors, the specific capital cost of a nuclear reactor decreases with size, due to reduction in investment activities [4, 5].

Using small/medium nuclear reactors requires a proper selection of a nuclear desalination plant site, based on criteria different from those applicable to large scale nuclear plants [4, 5]. In spite of the qualitative and quantitative aspects governing the structure of the proposed siting criteria, it is rather difficult to develop siting considerations to accommodate the willingness or at least the conservative acceptability of the served communities.

The estimated area required for constructing a desalination plants is about 1-2 m² per m³/d, and the land requirements for nuclear power plant range from 1-4 km² per 1 GW (e) electrical plant. A combined nuclear power/desalination plant will demand an area equivalent to less than 2% of the sum of the individual areas of each of the desalination and nuclear plants [6, 7].

The previous experience acquired from the application of established siting criteria adopted to large nuclear reactors has been reviewed, analyzed, and re-evaluated to suit the small/medium scale nuclear reactor technology employed for powering large scale desalination plants. The development of tailored siting criteria should cope with the latest development in small scale nuclear power technology that is directed to powering large scale desalination plants. Safety is the most important criterion in evaluating the options. All reactors must meet a minimum safety level, but those that are more inherently safe are more likely to win government and public support [8].

Site selection criteria of nuclear powered desalination include but are not limited to; safety features, financial indicators, siting consideration, environmental impact, etc. The main safety design features are; inherent and passive safety control; reactor shutdown systems, systems for decay heat removal and depressurization, cooling systems for reactor vessel and contaminant, seismic design, core damage frequency/large early release frequency, emergency planning zone radius, and hazardous events [9]. In the new advanced designs, the improvement in safety features focus on maintaining long continuous automated operation for at least 24 hours without the need for intermittence either to take emergency actions or to manually operate an action [8].

Nuclear desalination plants have several technical and environmental features that should be managed properly. These features are controlled and managed by implementing a proper construction plan that takes site specific measures to avoid or minimize environmental damage resulting from construction and operational activities.

Technical features include characteristics of selected reactor type and proposed operation, desalination plant type and operational reliability [10-15]. In addition, geologic and seismic siting criteria that should be studied include: vibratory ground motion, tectonic surface deformation, non-tectonic deformation, earthquake recurrence rates, fault geometry and slip rates, site foundation materials, and seismically induced floods and water waves, and population density including exclusion area, low population zone and population center distance. Furthermore, the selected sites should provide a ready source of cooling water for the essential service water system of the plant.

Environmental impacts that should be considered include but are not limited to; disturbance of the natural habitat of several species which affects the ecological balance of the region, radioactive emissions from exhaust gases that should be treated properly before release into the environment to ensure that radioactive levels are in



accordance to environmental regulations, greenhouse effect, and human health hazards [16-21]. Nuclear desalination plant can impact marine environment through seawater intake and effluent discharge as both processes are included in power and desalination plants [10, 22].

This paper identifies the site selection of small/medium nuclear desalination plants in Egypt. The adopted criteria are weighed and ranked based on local and regional considerations that are both technical and environmental. A selection ranking matrix is constructed where the proposed siting areas are assigned scores that correspond to each selection criterion. The formulated matrix is then used to evaluate the proposed siting areas according to the statistical Wilcoxon signed-rank method.

2. METHODOLOGY

2.1 The study area

To demonstrate the site selection proposed methodology a selection ranking matrix was formulated for conceptual case study in Egypt. Three main regions were selected to establish the multi-criteria decision analysis supported by Wilcoxon signed rank sum method. These regions are coastal strips in North Sinai governorate, in Matrouh governorate, and in the Red Sea governorate. Sites with low seismic activity are considered viable for constructing desalination plants powered by small/medium sized nuclear reactors. Figure-1 illustrates the proposed areas for siting nuclear desalination plants in Egypt as indicated on the seismic hazard distribution map.

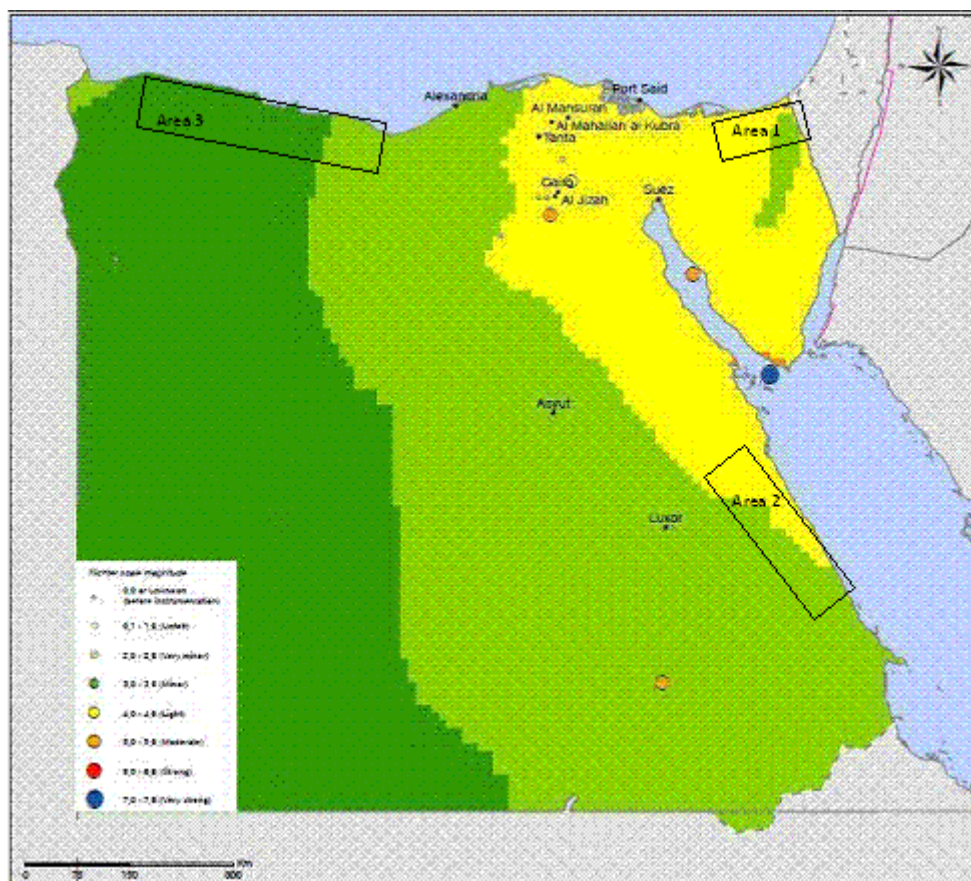


Figure-1. Proposed areas for siting small/medium nuclear desalination plants, as located on the seismic hazard distribution map of Egypt [41].

2.2 Multi-criteria decision making

Multi-criteria decision making method supported by ranking method to evaluate and rank different sites examined for nuclear desalination using small/medium reactors. The proposed siting criteria follows IAEA guidelines which address the following key issues in the scope of small scale nuclear desalination site selection criteria [23-33]:

- Identification of the site of both nuclear power plant and desalination system.

- Selection of optional sites that have acceptable criteria.
- Evaluation of site safety against possible events, such as earthquake, flooding and accidents.
- Effect of accidents, such as airplane crashes and explosions.
- Effect of the plant on the population distribution under normal and accident conditions.
- Effect of the plant on environment.

In the light of expert opinion and literature review based on small/medium scale nuclear reactor installation



incorporated with RO desalination plant; the parameters adopted selection criteria in this study include: hazard probability, site stability, proximity, grid availability, site backup, phased expansion, impact on environment, meteorological aspects, cooling water availability, waste characteristics, load rejection, mitigation measures and transportation. These criteria were designed to determine the suitable site according to IAEA guidelines [34, 35].

Each selection criteria were given weighing factors, taking into consideration the conditions in Egypt [36-39]. These factors were set in compliance with IAEA siting requirements selection criteria for the three proposed areas [41-48]. The impact of each criterion on the environment was also taken into consideration while assigning the weighing factor.

2.2.1 The Wilcoxon signed rank sum test

The Wilcoxon signed rank sum test is a non-parametric or distribution free test, used to test the null hypothesis that the median of a distribution is equal to some value. Each siting area was given a score that corresponds to each siting criterion. Afterwards, the weighed score (x), for each siting area was calculated by multiplying the score by the weighing factor relevant to each criterion. Siting areas were then evaluated using Wilcoxon Signed-Rank sum method [40] according to the following equation (1)

$$W = |\sum$$

$$W = \left| \sum_{i=1}^{N_r} [\text{sgn}(x_{2,i} - x_{1,i}) \cdot R_i] \right| \quad (1)$$

For $N_r \geq 10$, a z-score can be calculated as

$$z = \frac{W - 0.5}{\sigma_W}, \sigma_W = \sqrt{\frac{N_r(N_r + 1)(2N_r + 1)}{6}}$$

Where x_i is the weighed score and this is the multiple and of the score and weighing factor, N_r is the rank of the score, and W is the absolute sum of the signed ranks. Figure-2 represents the adopted methodology in this study.

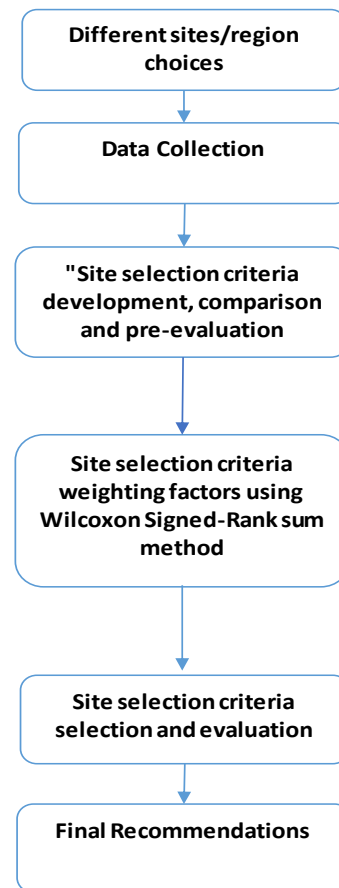


Figure-2. The methodology flow diagram.

3. RESULTS AND DISCUSSIONS

The design of nuclear desalination plants takes into consideration the interaction between the dual purpose plant and the environment by examining specific characteristic of the site as pollution, geology, hydrology, topographic meteorology and seismology. The proposed areas are the coastal strips in North Sinai governorate, in Matrouh governorate, and in the Red Sea governorate. Considering the use of small sized reactor power plant with desalination, coastal strips on the Gulf of Suez with light possible seismic hazard (4-4.9 on Richter scale or less) could be considered. The Red Sea, Gulf of Suez, and Gulf of Aqaba were excluded due to seismic risks as well as geological characteristics. Relatively high wind speed could also have an influence on the plant sites as well as the presence of protected areas. Table-1 presents the selection criteria for pre-evaluation of the three proposed areas.

Table-2, shows the ranking matrix for the proposed siting areas, where each site is assigned a score corresponding to a given selection criterion. Also included in the table are weighing factors pertaining to the selected criteria. These are based on technical and environmental aspects, and have a total weighing factors sum of 100. For each proposed siting area, one of five scores (1, 2, 3, 4 and 5) is assigned for evaluation, with the higher score referring to better conditions. The multiplicand of the



weighing factor for each selection criterion and the score corresponding to each criterion.
for each siting area yields the weighed score, x ,

Table-1. Pre-evaluation criteria for proposed siting areas [41-52].

Parameter	Area 1 Sina Peninsula	Area 2 Red Sea Governorate	Area 3 North Coast Zone
Hazard probability	High hazard probability	Medium hazard probability	Low-medium hazard probability
Site stability	coastal strips on the Gulf of Suez with light possible earthquakes (4-4.9 on Richter scale)	Low-medium seismic activity	Very low seismic activity
Proximity	Low population, different touristic villages, and industrial zones	Low population, different touristic villages, and new industrial zone	Moderate population, different touristic villages, and industrial zones, close to relatively large cities
Grid availability	Available	Medium availability	Available
Site backup	Medium	Low	High
Relevant projects	Small/ medium desalination plants	Small/ medium desalination plants	Medium desalination plants
Phased expansion	Expansion may be restricted by seismic and strategic studies	Expansion may be restricted by seismic studies	Future expansion is applicable due to vast space along the coastal area
Impact on environment	Some restrictions in preserved areas	Some restrictions in preserved areas	Environmental restrictions in historical and preserved areas
Meteorological events	Sandstorms, dense haze and flooding	Arid subtropical zone, seasonal sandstorms, dense haze and flooding	Seasonal sandstorms and dense haze
Meteorological aspects	Moderate	Moderate	Moderate
Cooling water	Available according to site specs	Available according to site specs (high salinity, tidal effects)	Available according to site specs
Waste specs/disposal	Standard, effluent cooling water discharged into Mediterranean Sea, solid wastes disposed of out of Sinai	Standard, effluent cooling water discharged into Red Sea, solid wastes disposed of out of Red Sea	Standard, effluent cooling water discharged into Mediterranean Sea, solid wastes disposed of locally
Load rejection	Medium	Medium	Low
Mitigation measures	High	Medium	Medium
Transportation	Low	Low	Medium-high

**Table-2.** Ranking matrix for the three proposed siting areas based on the indicated selection criteria.

Item	Modified weighing factor	Score		
		Site 1	Site 2	Site 3
Hazard probability	15	2	3	4
Site stability	15	2	3	4
Proximity	5	2	2	3
Grid availability	5	4	2	4
Site backup	5	3	2	4
Relevant projects	5	3	3	4
Phased expansion	5	2	3	4
Impact on environment	6	3	3	3
Meteorological events	6	2	2	4
Meteorological aspects	6	4	4	4
Cooling water	5	4	3	4
Waste specs/disposal	6	2	2	3
Load rejection	6	3	3	4
Mitigation measures	5	1	2	2
Transportation	5	2	2	4

Table-3 gives the weighed scores x_1 , x_2 and x_3 for siting areas 1, 2 and 3, respectively. The signed ranks W_{1-2} , W_{1-3} and W_{2-3} for area combinations (1-2), (1-3) and (2-3), respectively are also presented, along with the sum of

the positively signed ranks (W^+) and the negatively signed ranks (W^-) for each siting area. Whichever of W^+ or W^- had been smaller was compared to the critical values at probability level ($p = 0.05$).

Table-3. Summary of Wilcoxon Signed-Rank test analysis.

Item	Weighed score			Signed rank		
	x_1	x_2	x_3	W_{1-2}	W_{1-3}	W_{2-3}
Hazard probability	30	45	60	-14.5	-14.5	-14.5
Site stability	30	45	60	-14.5	-14.5	-14.5
Proximity	10	10	15	-	-6.5	-5.5
Grid availability	20	10	20	13	-	-11
Site backup	15	10	20	10.5	-6.5	-11
Relevant projects	15	15	20	-	-6.5	-5.5
Phased expansion	10	15	20	-10.5	-11.5	-5.5
Impact on environment	18	18	18	-		-
Meteorological events	12	12	24	-	-13	-13
Meteorological aspects	24	24	24	-	-	
Cooling water	20	15	20	10.5	-	-5.5
Waste specs	12	12	18	-	-9.5	-8.5
Load rejection	18	18	24	-	-9.5	-8.5
Mitigation measures	5	10	10	-10.5	-6.5	-
Transportation	10	10	20	-	-11.5	-11
Total	39	39	55	$W^+ 34$ $W^- 50$	$W^+ 0$ $W^- 110$	$W^+ 0$ $W^- 114$



The W^+ values given in Table 3 for area combinations (1-3) and (2-3) are less than the critical values at $p=0.05$, while W^+ value for area combination (1-2) is greater than the critical value at the same significance level. Given the total weighed scores for siting areas 1, 2 and 3 which are 39, 39 and 55, respectively, it could be inferred that siting area 3 is superior to areas 1 and 2. This is also evident from the statistical analysis which confirmed that there is significance difference between siting areas 1 and 3, and areas 2 and 3. However, there is no significant difference between siting areas 1 and 2.

4. CONCLUSIONS

Wilcoxon signed-rank statistical method was applied for site selection among three proposed sites. The ranking method employed in the present study provides a reliable guidance for siting small/medium nuclear-powered desalination plants. The presented analysis concluded that the western coastal area in Matrouh governorate is the most appropriate area for siting such plants in Egypt as a typical developing country. Further extensive investigation on various specific sites within the recommended area of Matrouh is necessary for identifying potential sites where nuclear desalination plants can be implemented based on a phased development plan. The adopted procedure could provide a reliable technique for preliminary siting of desalination/nuclear plants in developing countries.

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REFERENCES

- [1] 2002. Status of design concepts of nuclear desalination plants, IAEA-TECDOC-1326.
- [2] Use of Nuclear Energy for Desalination Position Statement 62 March 2005 American Nuclear Society, Outreach Program (708) 352-6611.
- [3] 2012. Geoffrey Rothwell, Small Modular Reactors: Costs, Waste and Safety Benefits. National Energy Policy Institute.
- [4] M.D. Carelli, P. Garrone, G. Locatelli, M. Mancini, C. Mycoff, P. Trucco b, M.E. Ricotti. 2010. Economic features of integral, modular, small-to-medium size reactors, Progress in Nuclear Energy. 52: 403-414.
- [5] Safaa Abdelraouf Ahmed, Heba Ahmed Hani, Ghada Ahmed Al Bazedi, Mayyada M. H. El-Sayed, Abdelghani M. G. Abulnour. 2014. Small/medium nuclear reactors for potential desalination applications: Mini review, Korean J. Chem. Eng. 31(6): 924-929.
- [6] Rashed S.M. 2000. Nuclear Power and Environment; Comparative Assessment of Environmental and Health Impacts of Electricity Generating Systems, Atomic Energy Authority, Cairo (Egypt); pp. 291-310. International conference on hazardous waste sources, effects and management; Cairo (Egypt).
- [7] IAEA-TECDOC-1561, 2007. Economics of Nuclear Desalination: New Developments and Site Specific Studies, Final Results of a Coordinated Research Project 2002–2006, International Atomic Energy Agency, IAEA-TECDOC-1561.
- [8] World-nuclear-org, <http://www.world-nuclear-org/info/inf33.html> (last visited June 2014).
- [9] Kuznetsov V., Likhov A. 2011. Current Status, Technical Feasibility and Economics of Small Nuclear Reactors, OECD.
- [10] Frauke Urban, Dr. Tom Mitchell. 2011. Climate change, disasters and electricity generation. London: Overseas Development Institute and Institute of Development Studies.
- [11] M. Damian. 1992. Nuclear Power: The Ambiguous Lessons of History. Energy Policy 20, 596.
- [12] 2012. Anthony Andrews, Peter Folger, Nuclear Power Plant Design and Seismic Safety Considerations, Congressional Research Service.
- [13] Youcef Bouaichaoui, Abderrahmane Belkaid, Sid Ahmed. Amzert. 2012. Economic and Safety Aspects in Nuclear Seawater Desalination, Procedia Engineering. 33: 146-154.
- [14] N. Kopytko and J. Perkins. 2011. Climate Change, Nuclear Power, and the Adaptation-Mitigation Dilemma. Energy Policy. 39, 318.
- [15] A. Bond *et al.* 2003. Environmental Impact Assessment and the Decommissioning of Nuclear Power Plants - a Review and Suggestion for a Best Practicable Approach. Environmental Impact Assessment Review 23, 197.
- [16] IAEA. 2012. Climate change and nuclear power 2012, International Atomic Energy Agency.



- [17] Eko Susanto. 2013. The Effectiveness of Environmental Impact Assessment for Nuclear Power Plant, *Applied Ecology and Environmental Sciences*. 1(4): 61-66.
- [18] M.V. Ramana. 2009. Nuclear Power: Economic, Safety, Health, and Environmental Issues of Near-Term Technologies. *The Annual Review of Environment and Resources*. 34:127-52.
- [19] 1996. IAEA-TECDOC-918, Health and environmental aspects of nuclear fuel cycle facilities. International Atomic Energy Agency, IAEA-TECDOC-918.
- [20] Mark Holt. 2014. Anthony Andrews, Nuclear Power Plant Security and Vulnerabilities, Congressional Research Service 7-5700.
- [21] IAEA. 2009. Design features to achieve defence in depth in small and medium sized reactors. International Atomic Energy Agency.
- [22] R. W. Beck. 2002. Criteria for Preliminary Screening of Areas for Potential Seawater Demineralization Facilities - Task C.1., Seawater Demineralization Feasibility Investigation Contract SE459AA, Special Publication SJ2004-SP8.
- [23] A. I. Bayoumi and H. I. Lotfy. 1989. Modes of structural evolution of Abu Gharadig Basin, Western Desert of Egypt as deduced from seismic data. *Journal of African Earth Sciences*. 9(2): 273-287.
- [24] Ilya Prutkin, Ahmed Saleh. 2009. Gravity and magnetic data inversion for 3D topography of the Moho discontinuity in the northern Red Sea area, Egypt. *Journal of Geodynamics*. 47: 237-245.
- [25] Amr Z. Hamouda. 2011. Assessment of seismic hazards for Hurghada, Red Sea, Egypt, *Nat Hazards*. 59:465-479.
- [26] A. EL-Sayed, I. Korrat and H. M. Hussein. 2004. Seismicity and Seismic Hazard in Alexandria (Egypt) and its Surroundings. *Pure appl. geophys*. 161: 1003-1019.
- [27] Sherif El-Hady, Elsayed Abdel-Azeem Fergany, Adel Othman, Gad El Kareem Abdrabou Mohamed. 2012. Seismic microzonation of Marsa Alam, Egypt using inversion HVSR of microtremor observations, *J Seismol*. 16:55-66.
- [28] A. El-Sayed, F. Vaccari and G. F. Panza. 2011. Deterministic seismic hazard in Egypt, *Geophys. J. Int*. 144: 555-567.
- [29] Mohamed M. Megahed. 2009. Feasibility of nuclear power and desalination on El-Dabaa site. *Desalination*. 246: 238-256.
- [30] Y.M. Ibrahim, M.M. Megahed and S.S. Motayaser. 2004. Strategies and options for electricity generation in Egypt up to 2020. 5th International Conference on Nuclear Option in Countries with Small and Medium Electricity Grids Dubrovnik, Croatia.
- [31] Ibrahim I. Kutbi, Zeinab A. Sabri' and Abdo A. Hussein. 1986. Selection for Desalination Processes for Dual-Purpose nuclear plants, *Desalination*. 58: 113-134.
- [32] Jane Ebinger Wind Energy Leads Renewables in Journey to a Sustainable Future, but Still a Long Way to Go, <http://web.worldbank.org/>.
- [33] Mortensen N.G., J.C. Hansen, J. Badger, B.H. Jørgensen, C.B. Hasager, L. Georgy Youssef, U. Said Said, A. Abd El-Salam Moussa, M. Akmal Mahmoud, A. El Sayed Yousef, A. Mahmoud Awad, M. Abd-El Raheem Ahmed, M. A.M. Sayed, M. Hussein Korany, M. Abd-El Baky Tarad. 2005. Wind Atlas for Egypt, Measurements and Modelling 1991-2005. New and Renewable Energy Authority, Egyptian Meteorological Authority and Risø National Laboratory. ISBN 87-550-3493-4. p. 258.
- [34] 2001. IAEA-TECDOC-1235. Safety aspects of nuclear plants coupled with seawater desalination units, IAEA-TECDOC-1235.
- [35] P.E. Juhn, J. Kupitz, J. Cleveland, B. Cho, R.B. Lyon. 2000. IAEA activities on passive safety systems and overview of international development, *Nuclear Engineering and Design*. 201: 41-59.
- [36] Mazleha Maskin, Update on nuclear energy programme in Malaysia, Malaysian Nuclear Agency (Nuclear Malaysia), Ministry of Science, Technology & Innovation (MOSTI) Malaysia, 2010
- [37] Stephen P. Schultz. 2011. Interregional Workshop on Advanced Nuclear Reactor. Technology for Near Term Deployment, Vienna, Austria.



- [38] Martin Lusticky. 2011. Benchmarking as a quality enhancement method of regional Planning in tourism. *Journal of Global Management*. 2(1).
- [39] IAEA-TECDOC-1642, Environmental Impact Assessment of Nuclear Desalination, IAEA-TECDOC-1642, International Atomic Energy Agency, Vienna, 2010.
- [40] Lind, D.A., Marchal, W.G., Wathen, S.A. 2012. *Statistical Techniques in Business and Economics*, 15th Edition, McGraw Hill, New York.
- [41] World Health Organization. 2011. Egypt: Seismic hazard distribution map, World Health Organization 2011, <http://www.who-eatlas.org/eastern-mediterranean/countries/egypt/egypt-seismic-map.html>.
- [42] Deif A.; Abou Elenean K.; El Hadidy M.; Tealeb A.; Mohamed A. 2009. Probabilistic seismic hazard maps for Sinai Peninsula, Egypt. *Journal of Geophysics and Engineering*. 6(3).
- [43] Abuo El-Ela A. Mohamed, M. El-Hadidy, A. Deif, K. Abou Elenean. 2012. Seismic hazard studies in Egypt, *NRIAG Journal of Astronomy and Geophysics*. 1(2): 119-140.
- [44] David Michel, Amit Pandya, Mohamed El Raey, Coastal Zones and Climate Change. 2010. *Impacts and Implications of Climate Change for the Coastal Zones of Egypt*, Library of Congress Control Number: 2009939156.
- [45] Mohamed M. Nour El-Din. Proposed Climate Change Adaptation Strategy for the Ministry of Water Resources & Irrigation EGYPT (2013), Joint Programme for Climate Change Risk Management in Egypt, UNESCO-Cairo Office.
- [46] Kamal Abdel-Rahman, Abdullah M. S. Al-Amri, Abdel-Moneim E. 2008. Seismicity of Sinai Peninsula, Egypt, *Arabian J. of Geosciences*.
- [47] K. A. El-Adham, S. T. El-Hemamy. 2006. Modelling of seismic hazard for the El-Dabaa area, Egypt, *Bull Eng Geol Env*. 65: 273-279.
- [48] El-Hefnawy, M. A., Amer M. A. 1989. Seismic Structural Analysis at Abu Darag Area, Gulf of Suez, Egypt, *GeoJournal*. 18.4 393-397.
- [49] Mohamed H. Khalil, Sherif M. Hanafy. 2008. Engineering applications of seismic refraction method: A field example at Wadi Wardan, Northeast Gulf of Suez, Sinai, Egypt, *Journal of Applied Geophysics*. 65: 132-141.
- [50] Sherif El-Hady & Elsayed Abdel-Azeem Fergany. 2012. Adel Othman & Gad ElKareem Abdrabou Mohamed, Seismic microzonation of Marsa Alam, Egypt using inversion HVSR of microtremor observations, *J Seismol*. 16:55-66.
- [51] Amr Z. Hamouda. 2011. Assessment of seismic hazards for Hurghada, Red Sea, Egypt, *Nat Hazards*. 59:465-479.
- [52] A. El-Sayed, I. Korrat and H. M. Hussein. 2004. Seismicity and Seismic Hazard in Alexandria (Egypt) and its Surroundings, *Pure appl. geophys*. 161: 1003-1019.