



# A Multi-criteria GIS Based Methodology for Smart Cities Site Selection

Nada A. Fashal<sup>1</sup>, Ghada A. El Khayat<sup>1</sup>(✉), Boshra B. Salem<sup>2</sup>,  
and Saleh M. El Kaffas<sup>3</sup>

<sup>1</sup> Faculty of Commerce, Alexandria University, Alexandria, Egypt  
ghadaek@gmail.com

<sup>2</sup> Faculty of Science, Alexandria University, Alexandria, Egypt

<sup>3</sup> Faculty of Computers and Information, Arab Academy for Science  
and Technology and Maritime Transport, Alexandria, Egypt

**Abstract.** Building a Smart City (SC) is a practically irreversible decision that needs large investments. The success of a smart city in realizing its objectives of economic prosperity largely depends on its ability to reach its full potential; which in turn depends on its location. This research contributes a site selection method for SCs that satisfies the decision maker's criteria. Through the analysis of relevant literature, the main criteria to be considered when locating a SC were identified. Interviews with subject matter experts enabled retaining the most relevant criteria to the Egyptian reality. Layers corresponding to these criteria were built in a Geographic Information System (GIS). The Intersect process was then applied to perform site selection and identify the region respecting the decision maker's criteria. The developed GIS-Based Multi-Criteria Evaluation (MCE) methodology was tested on a study area that spans Alexandria, El Beheira and Matrouh governorates in Egypt. The prototype developed is a very beneficial instrument that enables facts based decision making as opposed to the current subjective practices used in selecting a SC location.

**Keywords:** Geographic Information Systems (GIS) · Smart Cities (SC) · Knowledge Precincts (KP) · Site selection · Multi-Criteria Evaluation (MCE) · Decision support · Location analysis

## 1 Introduction

A Smart City (SC) can be defined as a territory with high capacity for learning and innovation, which is built in the creativity of its population, its institutions of knowledge creation, and its digital infrastructure for communication and knowledge management [1]. SCs are the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities. A Smart City is based on a promising mix of human capital, infrastructural capital, social capital and entrepreneurial capital [2]. It operates over four main dimensions: the intelligent city, the digital city, the open city and the live city [3]. A Smart City is an area where a mass of technological activities has structural benefits for individuals and companies located in there [4–6].

A Knowledge Precinct (KP) is a smaller form of a Smart City. Its contemporary practice moves from work focused knowledge precincts e.g., science and technology parks, innovation parks to multi-activity focused Knowledge Community Precincts where people, work, live, play, and cyber within their boundaries, as in Crossroads Copenhagen, Helsinki Digital Village or Singapore One-North [7, 8]. During the last few decades, the knowledge economy has been the essential boost of the global and local economic development [9]. The concept of Knowledge City (KC) has evolved from concepts such as ‘knowledge clusters’ [10, 11], ‘ideopolis’ [12], ‘technopolis’ [13, 14], ‘science city’ [15], ‘learning city’ [16], ‘intelligent city’ [17], ‘sustainable city’ [18] and finally ‘smart city’ [19]. The meaning of SC involves several definitions depending on the meanings of the word “smart”: intelligent city, knowledge city, ubiquitous city [20], sustainable city, digital city [20, 21], etc. Many definitions of Smart City exist, but no one has been universally agreed upon [22].

To achieve their planned social and economic impact, the SCs, or KPs have to be well-located and planned in a way that integrates services of different kinds and from different sectors and to do this researchers need to use Geographic Information Systems (GIS) which form, more and more, a backbone for the location analysis problems. Geographic Information Systems can be defined as computer systems designed for capturing, storing, checking, integrating, manipulating, analyzing, and displaying all forms of geographically referenced information since it derives information from digital maps. [22–25]. The term “location” is defined as locating a business, facility or a group of facilities of a specific size and type in an area [23]. Building SCs is being considered by many countries in the recent years as an important arm of development. Egypt’s ICT strategy (2012–2017), adopted four main goals, which are: (supporting democratic transformation, fostering digital citizenship, supporting sustainable social development and finally fostering knowledge-based national economy. For the last goal to be achieved, the strategy set several steps, among them was working to increase the number of SCs/KPs to reach 20 areas all over the Egyptian society. Egypt has already developed a number of SCs/KPs. Evaluation of existing SCs/KPs is also important as [24] argues that most of the KPs within the Arab region have failed to achieve their goals. Location analysis tools are needed to locate new SCs. These are modeling, formulation, and solution tools for a class of problems of siting facilities in some given space within a pre-established set (site selection) or without (site search) to identify the most suitable location for the decision maker [25–27].

This research aims to develop a selection method that satisfies the decision maker’s criteria when selecting a location for SC. This is done through investigating a set of criteria for site selection of Smart Cities, developing a GIS-Based multi-criteria evaluation methodology for the site selection and testing the proposed methodology on a case study. The rest of this paper is organized as follows. Section 2 presents the main related concepts and reviews recent studies related to GIS, Smart Cities and site selection. Section 3 introduces the proposed GIS-based Methodology for Smart City site selection. It also handles the proposed approach and prototype development. Section 4 presents the results of the study and the discussion is given in Sect. 5. Finally, the conclusion and future work are included in Sect. 6.

## 2 Background and Literature Review

In this section, a review of the related literature is provided. The section is organized as follows: Sect. 2.1 presents GIS and its components, GIS data models are defined in Sect. 2.2. In Sect. 2.3 the role of GIS in Location Analysis is discussed. In Sect. 2.4 the Multi-criteria Decision Making (MCDM) is demonstrated; then in Sect. 2.5 MCDM and its relation to GIS is further explained. The elements guiding the location of SCs are discussed in Sect. 2.6.

### 2.1 GIS and Its Components

GIS is taking over and extending the role of spatial data storage which was previously played by maps. Once spatial data is represented in digital form it becomes very much easier to perform analyses and to make changes to them. Operations can be applied without reference to any graphic map [28]. The GIS has four main components: hardware, software, data, and liveware (People) [29]. Data processing systems use hardware and software components to process, store and transfer data [30].

### 2.2 GIS Data Models

The GIS’ graphical interface is linked to a relational database, which presents data as a series of layers. So, according to the stored data model in the geodatabase, one can distinguish vector and raster approaches [31]. Most GISs have the capability of converting raster to vector and vector to raster. Spatial data types are used to represent geometric data. These include point, line, and polygon [32] as shown in Fig. 1.

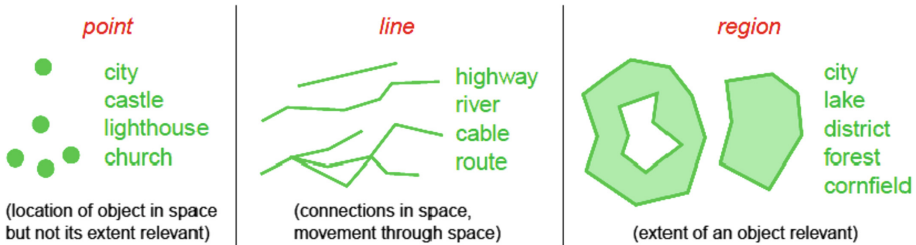


Fig. 1. Fundamental abstractions for modeling single, self-contained objects [32]

### Vector Data Model

In this model, entities in the real world are divided into clearly defined features represented by point, line, or polygon geometry. The simplest vector features are points that are represented by an x (easting) and y (northing) values and possibly z (for elevation). Lines are one dimensional and defined by x, y coordinates. A polygon is a two-dimensional representation defined by a series of points and line segments connecting the points with the start and ending points being the same x, y location [33].

## **Raster Data Model**

This model defines the space into an array of cells, each having a value that represents some aspects of the real world (e.g. elevation, land use) [34].

### **2.3 GIS Role in Location Analysis**

The GIS have been used in urban planning throughout the past decades. The applications of GIS vary according to the different stages, levels, sectors, and functions of urban planning [35]. Recent advances in the integration of GIS with planning models, visualization, and the Internet will make GIS more useful to urban planning. An advantage of geographical spatial data is that it can be analyzed and worked with easily. GIS and Remote Sensing, the two variants of digital spatial data, work side by side in urban planning. Spatial decision problems require the evaluation of a large number of alternatives based on many criteria; hence they are multi-criteria in nature [36].

GIS has an extraordinary role in the development and implementation of the concept of SCs; as the intelligence of a city should be measured by its ability to produce favorable conditions to get urban operators (citizens, organizations, private companies, etc.) actively involved into socio-spatial innovation dynamics [3]. Citizen involvement can be realized through group decision making procedures that can be followed using artificial intelligence technologies [37]. The GIS tools used in KPs location problems are presented in [38]. GIS tools are used in conjunction with other systems and methods such as decision support systems (DSS) and methods for MCDM to solve location problems [39]. In MCDM, the different factors considered for making the decision can possibly interfere, which can influence the decision results [40]. This can be taken into account in cognitive modeling methods.

### **2.4 Multi-Criteria Decision Making (MCDM)**

Multi-criteria decision making (MCDM) can be defined as “the process of making decisions while having multiple, usually conflicting, criteria” [41]. MCDM is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multi interests and perspectives [42].

MCDM can be grouped into two main sections: multiple attribute decision making (MADM) and multiple objective decision making (MODM). MADM is used when the decision maker has to choose only one alternative from a set of discrete actions, but MODM is a continuous decision problem. MADM is often referred to as multi-criteria analysis (MCA) or multi-criteria evaluation (MCE) [31]. These terms MCDM, MCDA, MADM, and MADA are used interchangeably. In this work, we adopt MCA to identify suitable locations for building a SC.

### **2.5 MCDM and GIS**

A literature review was conducted regarding the GIS-based multi-criteria decision analysis (GIS-MCDA) approaches from 1990 to 2004. There are five generic steps of the GIS-based MCDA process regardless of the variations between the GIS-MCDA frameworks: (1) The goal(s) an individual (or group of individuals) seeks to achieve

and the corresponding evaluation criteria for the alternative courses of action; (2) the decision-maker or a group of decision-makers involved in the decision-making process along with their preferences; (3) the set of decision alternatives (4) the set of states of nature; and (5) the set of consequences associated with each alternative-criterion pair [43]. GIS provide a powerful platform for performing logical and mathematical analyses that use the weights of each map layer. However it does not have the capability of objectively assigning the weights to each map layer [44].

Different contributions used GIS in conjunction with MCDM. These include applications in forestry [45], landfill site selection [46], locating optimal sites to the hillside development [47], wind turbine farm site selection [48], river catchment management [49] and site selection of aquifer recharge with reclaimed water [50]. In order to consider weights, MCDA and overlay analysis using GIS were used for siting landfill [51]. MCDA process that combines GIS analysis with the Fuzzy Analytical Hierarchy Process (FAHP) was used to determine the optimal location for a new hospital in Tehran. GIS was used to calculate and classify governing criteria, while FAHP was used to evaluate the decision factors and their impacts on alternative sites [52]. GIS-MCDA continued to be an interesting area of research throughout the last decade and contribution tackled a diverse set of problems from different sectors [53].

## 2.6 Elements Guiding Smart Cities Site Selection

There are five intangible key elements and principles that judge the nature and potential for building KPs in towns. The five elements are: (MIXED-USE ENVIRONMENT: helps living and working purposes, CENTRALITY: provides accesses to different infrastructure, services, and amenities, BRANDING: forms new niche markets and marks the name of the emerging knowledge city with a landmark development such as Barcelona city, LEARNING AND PLAYING: suggests the existence of Urban play-field, R&D facilities, places of interaction, and technological innovation and creativity hubs, CONNECTIVITY: happens through tacit knowledge, face-to-face interaction, places of interaction, and social networking between the citizens [54]. These five elements are reflected in the criteria identified in the following section and used in the study. A more comprehensive review on SCs location analysis is found in [55].

## 3 Proposed GIS-Based Methodology for Smart Cities Site Selection

The current study applies to the Alexandria Region; which includes: Alexandria Governorate, El Beheira Governorate, and Matrouh Governorate in Egypt, as shown in Fig. 2. Data relevant to this region was obtained from bodies holding statistics such as Ministry of Housing, Utilities and Urban Communities, General Organization for Urban Planning, Strategic Plan for Alexandria Region Project; and from experts in the field. Table 1 provides the criteria used in this study and their respective values for smart cities at the local, regional, and international levels. The land cover criterion was

also considered in this study but is excluded from the comparison table as it was found suitable for all the studied cities. In order to undergo MCE, interviews were conducted with subject matter experts in Egypt including officials and scholars who work in SC projects and representatives of the Ministry of Communications and Information Technology to identify the relevant criteria presented below.



**Fig. 2.** Study area

### *Preparing Criterion Maps*

The first step in the study is to prepare the criterion maps. The thresholds upon which the criteria will be treated were estimated according to secondary sources and expert opinion. The criteria considered are **Land Cover**; which is the classification of land according to what activities take place on it or how humans occupy it, **Soil Type**; which refers to the different sizes of mineral particles in a particular sample, **Elevation**; which is the height of a geographic location above or below a fixed reference point, **Proximity to High Ways**, **Proximity to Residential Areas** and **Proximity to Universities and Proximity to Airports**. Table 2 shows the used criteria and the threshold of every criterion. The open street map basemap was added to the GIS project. The geodatabase contains seven layers corresponding to these different criteria that were then added to the project as shown below from Figs. 3, 4, 5, 6, 7 and 8.

**Table 1.** Comparison between local, regional, and international SCs

Criteria	Egypt		Regional			International		
	Smart Village Giza	Borg El Arab's Technological Zone	Smart Dubai	Abu Dhabi (Masdar)	Riyadh	Japan (Yokohama) (YSCP)	Europe (London)	USA (New York)
Elevation <a href="https://www.latlong.net/">https://www.latlong.net/</a>	28 m	18 m	0 m	7 m	638 m	13 m	15 m	7 m
Soil type	Highly calcareous, gypseous and saline <b>Parent material:</b> Argillaceous sandstone of the continental terminal	<b>Other quaternary formations</b>	Torripsammments	Torripsammments	Jurassic	<b>Parent material:</b> Weathered volcanic ash material of Tertiary formation	<b>Parent material:</b> peat	Aquic +UDIC soil
Proximity to high ways	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Proximity to residential areas	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proximity to universities	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proximity to airports	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

**Table 2.** Threshold of criteria

Criterion	Threshold
Land cover	Bare rock - Bare soil stony
Soil type	Bare soil stony - Bare rock with thin sand layer
Elevation	From 0–100
Proximity to high ways	Buffer 5 km
Proximity to residential areas	Buffer 30 km
Proximity to universities	Buffer 30 km
Proximity to airports	Buffer 30 km

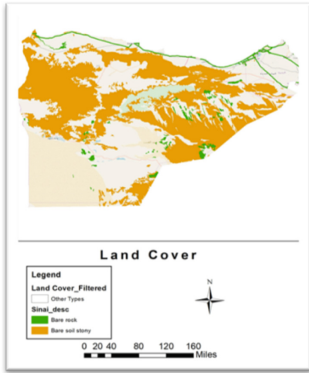


Fig. 3. Land cover

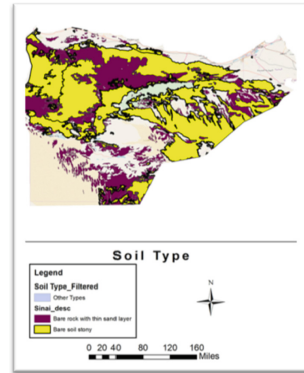


Fig. 4. Soil type

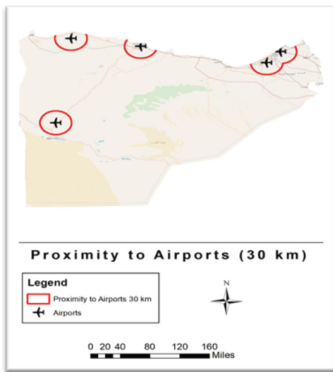


Fig. 5. Proximity to airports

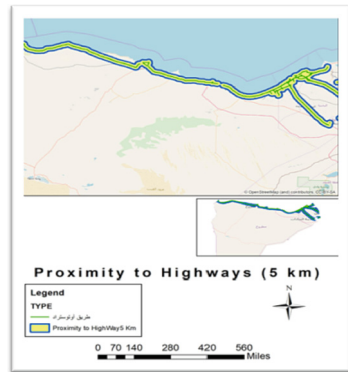


Fig. 6. Proximity to highways

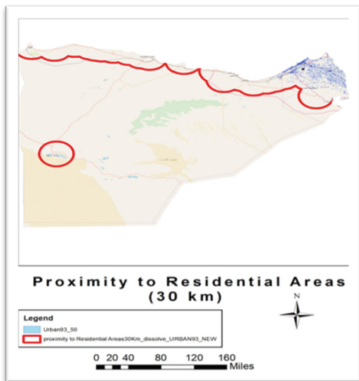


Fig. 7. Proximity to residential areas

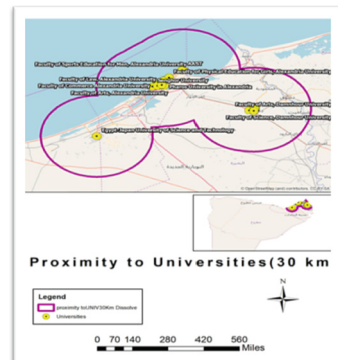


Fig. 8. Proximity to universities



### Data Processing

The second step is the data processing procedure for generating criterion maps based on the following GIS functions. **Buffer** which is one of the proximity analysis tools that can create influence zones for points, lines and polygons. The influence zone is shown in Fig. 9 [56]. The second function **Intersect** is an overlay analysis tool that computes a geometric intersection of the Input Features and will be used for the spatial analysis.

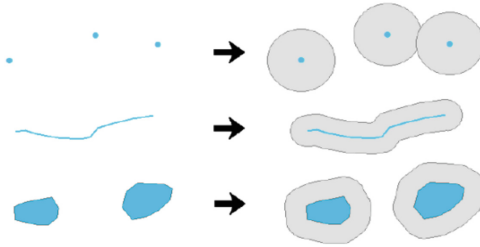


Fig. 9. The influence zone [56]

### Spatial Analysis

This third step consists of the MCE and the overlay. The MCE model includes standardization of spatial data from its original format into a general format to be ready for analysis [57]. Various spatial input layers can be combined when MCE is used in a GIS-based environment to facilitate decision making [58]. The overlay was realized applying the **Intersect** function over the four proximity layers after filtering the three other layers according to the chosen threshold. The complete process of intersect is shown in Fig. 10.

### Software

ArcMap10.5, used in this work, is the main component of Esri's ArcGIS suite of geospatial processing programs. It allows the user to explore data within a data set, symbolize features, and create maps. ArcMap is a kind of Desktop GIS. It performs several powerful tasks such as creating and editing maps, analyzing the maps and their relevant spatial data, create graphs and reports, etc. Google Earth which is a free online geographical tool that allows users to navigate the globe and create customized maps [59] was also used. It displays a 3D representation of the Earth based on satellite imagery allowing users to see cities and landscapes from various angles and allowing them to explore the entire globe by inputting coordinates, or names of the locations. In order to do so, a kml file was created in Google Earth Pro desktop application and then it was imported to a shapefile in ArcMap environment.

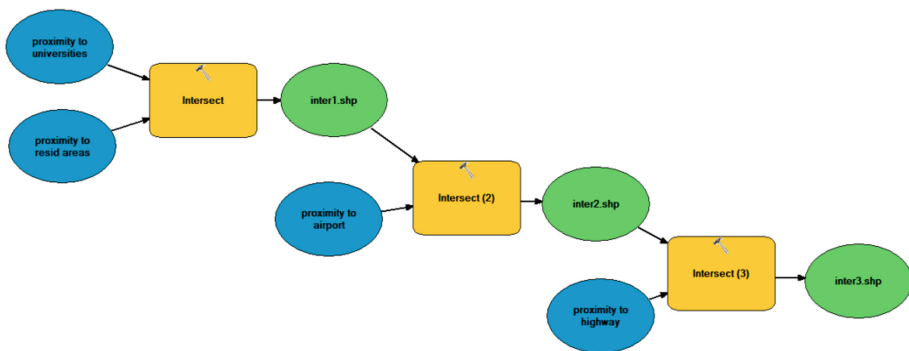


Fig. 10. The complete process of intersect

### 4 Results

The area defined by the outer red polygon in Fig. 11 satisfies the seven criteria considered in this research and provides a wide area where decision makers can locate new SCs.

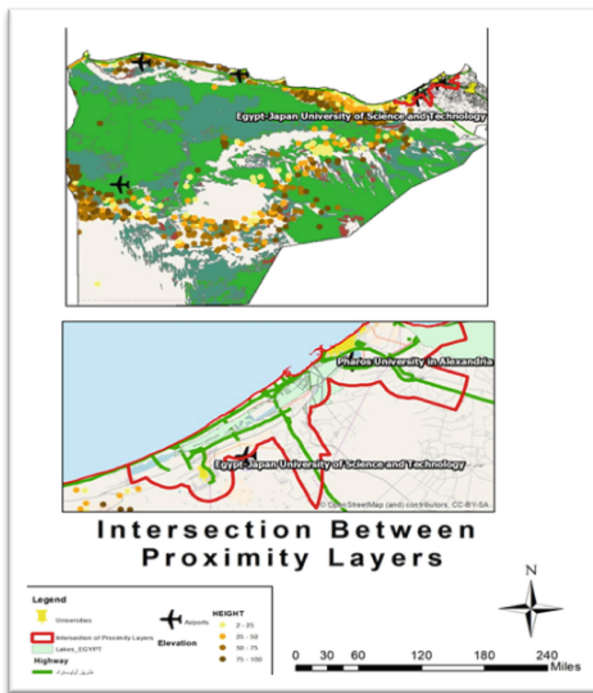


Fig. 11. Intersect between proximity layers (Color figure online)

## 5 Discussion

In this paper, the selection criteria used for locating a Smart City were identified to be land cover, soil type, elevation, proximity to universities, proximity to airports, proximity to residential areas, and proximity to highways. SC site selection is considered a crucial decision as it is difficult to reverse because of the high cost of relocation and the potential waste of time and effort. In this paper the site selection of the smart city was addressed considering strengths and capabilities that GIS offers such as the ability to visually analyze sites and to display data and information on a map which helps better interpret relationships within a specified area. Since Decision Making is a subjective case, criteria are chosen by concerned experts. Thus, it is impossible to arrive to the same results using data obtained from different experts. Another way for getting criteria is using an aggregate measure representing the opinion of a group of experts obtained through applying techniques such as Delphi technique.

## 6 Conclusion and Future Work

This paper contributed a GIS-based MCE methodology to meet the requirements of SC site selection. The spatial model considers a number of criteria of interest to the decision maker. First criterion maps were prepared; data processing and GIS spatial analysis involving MCE were undergone and the overlapping area is the area to be proposed to the decision maker. The development of the proposed system was carried out using ArcGIS 10.5 with Spatial Analyst extension as well as Google Earth Pro. The proposed system was tested to determine the potential sites for SCs in the identified study area in Egypt.

A big region was identified where it is suitable to build a SC. Interestingly, an area such as the Abis region in Alexandria seems to be an excellent candidate location for a SC. However, it never attracted the decision makers' attention. It is also recommended to do further detailed studies on the identified area in this research to assess the feasibility of establishing a SC on one of its sites.

The proposed methodology can be introduced to the Central Agency for Public Mobilization and Statistics in Egypt (CAPMAS) to adopt it nationwide and to add more data relevant to other criteria potentially of interest to decision makers. These may include proximity to healthcare institutions, proximity to telecommunication hubs, electrical distribution hubs as well as proximity to railway junctions as well as developed railway stations.

Future work includes building and developing a dynamic prototype where the user can input the criteria of interest to the ArcMap project. The interface can also have buttons for different analysis and conversion tools embedded in ArcMap.

Another future avenue of research is testing the proposed methodology in a real environment, on an existing smart city to evaluate whether the location chosen by the decision makers was appropriate or not. The proposed methodology may be integrated with weight setting methodologies that can improve the output to the decision maker. These include the Analytical Hierarchy Process AHP. Finally, the described approach was used for the location of SCs which is the focus of this paper. However the

methodology is generic enough to be applied to the selection of industrial and residential areas, among others. The relevant criteria of interest to the concerned decision maker would then be used.

**Acknowledgement.** The authors would like to thank Mr. Ahmed El-Sobky (ITIDA and Chairman of Silicon Waha), Dr. Mohamed Meheina (Bibliotheca Alexandrina), Dr Walaa Sheta (Dean of the Institute of Informatics) and Eng. Mohamed Hanafy (ITI) who acted as subject matter experts in this research.

## References

1. Komninos, N.: Intelligent cities: variable geometries of spatial intelligence. *Intell. Build. Int.* **3**(3), 172–188 (2011)
2. Kourtit, K., Nijkamp, P.: Smart cities in the innovation age. *Innov. Eur. J. Soc. Sci. Res.* **25** (2), 93–95 (2012)
3. Roche, S.: Geographic Information Science I: why does a smart city need to be spatially enabled? *Prog. Hum. Geogr.* **38**(5), 703–711 (2014)
4. Chan, K., Lau, T.: Assessing technology incubator programs in the science park: the good, the bad and the ugly. *Technovation* **25**(10), 1215–1228 (2005)
5. Westhead, P., Batstone, S., Martin, F.: Technology-based firms located on science parks: the applicability of Bullock's 'soft-hard' model. *Enterpr. Innov. Manag. Stud.* **1**(2), 107–139 (2000)
6. Yigitcanlar, T.A., Martinez-Fernandez, M.C.: Making space and place for knowledge production: knowledge precinct developments in Australia (2007)
7. Yigitcanlar, T.A.: Knowledge-based urban development. In: Mehdi, K.-P. (ed.) *Encyclopedia of Information Science and Technology*, 3rd edn, pp. 7475–7485. IGI Global, Hershey (2015)
8. Yigitcanlar, T., Velibeyoglu, K., Martinez-Fernandez, C.: Rising knowledge cities: the role of urban knowledge precincts. *J. Knowl. Manag.* **12**(5), 8–20 (2008)
9. Yigitcanlar, T.: Evolving definition of knowledge cities. *Int. J. Knowl.-Based Dev.* **8**(1), 1–4 (2017)
10. Huggins, R.: The evolution of knowledge clusters: progress and policy. *Econ. Dev. Q.* **22**(4), 277–289 (2008)
11. Luis Arbonies, A., Moso, M.: Basque Country: the knowledge cluster. *J. Knowl. Manag.* **6** (4), 347–355 (2002)
12. Garcia, B.C.: Developing futures: a knowledge-based capital for Manchester. *J. Knowl. Manag.* **8**(5), 47–60 (2004)
13. Scott, A.J.: *Technopolis: high-technology industry and regional development in Southern California* (1993)
14. Smilor, R.W., Gibson, D.V., Kozmetsky, G.: Creating the technopolis: high-technology development in Austin, Texas. *J. Bus. Ventur.* **4**(1), 49–67 (1989)
15. Anttiroiko, A.-V.: Science cities: their characteristics and future challenges. *Int. J. Technol. Manage.* **28**(3–6), 395–418 (2004)
16. Larsen, K.: Learning cities: the new recipe in regional development. Organisation for Economic Cooperation and Development. *The OECD Observer*, no. 217/218, p. 73 (1999)
17. Komninos, N.: *Intelligent Cities: Innovation, Knowledge Systems, and Digital Spaces*. Taylor & Francis, London (2002)

18. Camagni, R., Capello, R., Nijkamp, P.: Towards sustainable city policy: an economy-environment technology nexus. *Ecol. Econ.* **24**(1), 103–118 (1998)
19. Yigitcanlar, T.: *Technology and the City: Systems, Applications and Implications*. Routledge, New York (2016)
20. Anthopoulos, L., Fitsilis, P.: From digital to ubiquitous cities: defining a common architecture for urban development, pp. 301–306. *IEEE* (2010)
21. Couclelis, H.: The construction of the digital city. *Environ. Plan.* **31**(1), 5–19 (2004)
22. Cocchia, A.: Smart and digital city: a systematic literature review. In: Dameri, R.P., Rosenthal-Sabroux, C. (eds.) *Smart City*. PI, pp. 13–43. Springer, Cham (2014). [https://doi.org/10.1007/978-3-319-06160-3\\_2](https://doi.org/10.1007/978-3-319-06160-3_2)
23. Szymańska, A.I., Plaziak, M.: Enterprise and classical factors of its location on the market. *Procedia-Soc. Behav. Sci.* **120**, 13–22 (2014)
24. Alraouf, A.A.: Knowledge cities: examining the discourse smart villages, internet cities or creativity engines. *Plan. Malaysia J.* **4**(1), 31–48 (2006)
25. Revelle, C.S., Eiselt, H.A., Daskin, M.S.: A bibliography for some fundamental problem categories in discrete location science. *Eur. J. Oper. Res.* **184**(3), 817–848 (2008)
26. Vito, A., Giuseppe, D., Guido, S.: A decision based support system based on GIS technology. In: Nilmini, W., Eliezer, G. (eds.) *Encyclopedia of Healthcare Information Systems*, pp. 383–390. IGI Global, Hershey (2008)
27. Captivo, M.E., Clímaco, J., Fernandes, S.: A bicriteria DSS dedicated to location problems. In: *Encyclopedia of Decision Making and Decision Support Technologies*, vol. 1, pp. 53–60 (2008)
28. Jones, C.B.: *Geographical Information Systems and Computer Cartography*. Routledge, London (2014)
29. Chakraborty, D., Sahoo, R.: *Fundamentals of Geographic Information System*. Viva Books, New Delhi (2007)
30. Huisman, O., De By, R.: *Principles of Geographic Information Systems*. ITC Educational Textbook Series, vol. 1, p. 17 (2009)
31. Belka, K.: Multicriteria analysis and GIS application in the selection of sustainable motorway corridor. *Institutionen för datavetenskap* (2005)
32. Schneider, M.: *Spatial data types: conceptual foundation for the design and implementation of spatial database systems and GIS* (1999)
33. Sugumaran, R., Degroote, J.: *Spatial Decision Support Systems: Principles and Practices*. CRC Press, Boca Raton (2010)
34. *Information Resources Management Association: Geographic Information Systems: Concepts, Methodologies, Tools, and Applications: Concepts, Methodologies, Tools, and Applications*. Information Science Reference (2012)
35. Yeh, A.G.-O.: Urban planning and GIS. *Geogr. Inf. Syst.* **2**(877–888), 1 (1999)
36. Chakhar, S., Mousseau, V.: Spatial multicriteria decision making. In: *Encyclopedia of Geographic Information Science*, pp. 747–753 (2008)
37. Raikov, A.N.: Strategic planning of science city socioeconomic development. In: Alexandrov, D.A., Boukhanovsky, A.V., Chugunov, A.V., Kabanov, Y., Koltsova, O. (eds.) *DTGS 2017. CCIS*, vol. 745, pp. 295–306. Springer, Cham (2017). [https://doi.org/10.1007/978-3-319-69784-0\\_25](https://doi.org/10.1007/978-3-319-69784-0_25)
38. Fashal, N.A., El Khayat, G.A.: A survey on knowledge precincts location problems and their GIS tools. In: *Proceedings of ICT in Our Lives, Alexandria, Egypt, 19–21 December 2015*, pp. 59–64 (2015)
39. Rikalovic, A., Cosic, I., Lazarevic, D.: GIS based multi-criteria analysis for industrial site selection. *Procedia Eng.* **69**, 1054–1063 (2014)

40. Raikov, A.N., Avdeeva, Z., Ermakov, A.: Big data refining on the base of cognitive modeling. *IFAC-PapersOnLine* **49**(32), 147–152 (2016)
41. Xu, L., Yang, J.-B.: Introduction to multi-criteria decision making and the evidential reasoning approach. Manchester School of Management Manchester (2001)
42. San Cristobal, J.R.: Multi Criteria Analysis in the Renewable Energy Industry. *Green Energy and Technology*. Springer, Heidelberg (2012). <https://doi.org/10.1007/978-1-4471-2346-0>
43. Malczewski, J.: GIS-based multicriteria decision analysis: a survey of the literature. *Int. J. Geogr. Inf. Sci.* **20**(7), 703–726 (2006)
44. Nyeko, M.: GIS and multi-criteria decision analysis for land use resource planning. *J. Geogr. Inf. Syst.* **4**(04), 341–348 (2012)
45. Phua, M.-H., Minowa, M.: A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. *Landscape Urban Plan.* **71**(2–4), 207–222 (2005)
46. Chang, N.-B., Parvathinathan, G., Breeden, J.B.: Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. *J. Environ. Manage.* **87**(1), 139–153 (2008)
47. Chandio, I.A., Matori, A.N.B.: Land suitability analysis using geographic information systems (GIS) for hillside development: a case study of Penang Island (2011)
48. Van Haaren, R., Fthenakis, V.: GIS-based wind farm site selection using Spatial Multi-Criteria Analysis (SMCA): evaluating the case for New York State. *Renew. Sustain. Energy Rev.* **15**(7), 3332–3340 (2011)
49. Chen, H., Wood, M., Linstead, C., Maltby, E.: Uncertainty analysis in a GIS-based multi-criteria analysis tool for river catchment management. *Environ. Model Softw.* **26**(4), 395–405 (2011)
50. Pedrero, F., Albuquerque, A., do Monte, H.M., Cavaleiro, V., Alarcón, J.J.: Application of GIS-based multi-criteria analysis for site selection of aquifer recharge with reclaimed water. *Resour. Conserv. Recycl.* **56**(1), 105–116 (2011)
51. Sumathi, V., Natesan, U., Sarkar, C.: GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Manag.* **28**(11), 2146–2160 (2008)
52. Vahidnia, M.H., Alesheikh, A.A., Alimohammadi, A.: Hospital site selection using fuzzy AHP and its derivatives. *J. Environ. Manage.* **90**(10), 3048–3056 (2009)
53. Yalcin, M., Gul, F.K.: A GIS-based multi criteria decision analysis approach for exploring geothermal resources: Akarçay basin (Afyonkarahisar). *Geothermics* **67**, 18–28 (2017)
54. Bajracharya, B., Too, L., Imukuka, J.K., Hearn, G.N.: Developing knowledge precincts in regional towns: opportunities and challenges (2009)
55. El Khayat, G.A., Fashal, N.A.: Inter and intra cities smartness: a survey on location problems and GIS tools. In: Sami, F., Khaoula, M. (eds.) *Handbook of Research on Geographic Information Systems Applications and Advancements*, pp. 296–320. IGI Global, Hershey (2017)
56. Pucha-Cofrep, F., Fries, A., Cánovas-García, F., Oñate-Valdivieso, F., González-Jaramillo, V., Pucha Cofrep, D.: *Fundamentals of GIS* (2018)
57. Hansen, H.S.: GIS-based multi-criteria analysis of wind farm development, pp. 75–78. *CiteSeer* (2005)
58. Jankowski, P.: Integrating geographical information systems and multiple criteria decision-making methods. *Int. J. Geogr. Inf. Syst.* **9**(3), 251–273 (1995)
59. Ellen, Y., Nicholas, S.: A learner-centered approach to technology integration: online geographical tools in the ESL classroom. In: Jared, K., Grace, O. (eds.) *Handbook of Research on Learner-Centered Pedagogy in Teacher Education and Professional Development*, pp. 1–22. IGI Global, Hershey (2017)