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Geographic Information Systems (GIS) for the Urban Sustainable Development Decisions

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Abstract. According to the Earth Summit Agenda 21, mentions that we need to establish the concept of information systems and utilizing them in the sustainable development process of the city. The municipalities, local governments, and resource users should gain from new information technologies that provide them with the know-how they need to manage their environments and resources sustainably. So, making decisions based on geography is basic to human thinking such as; where we go, what will it shall be like, and what shall we do when we get whether not it can be applied to sustainable development. Therefore, we find that in the 21st century most of public organizations have started to use Information Technologies, and also the municipalities have been utilizing technological developments as tools for their services. Serving, deciding and using city resources efficiently will be easier by using a Geographic Information Systems (GIS) based Urban Information System (UIS).

The paper will review the concept of urban sustainable development and how it is influencing responses to increasing population growth in cities. It will address the role of GIS-based for sustainable development in terms of local and municipal governance. Moreover, it is to show how GIS can be used in the assessment and modeling of urban sustainability, how sustainable development at urban level is measured? Finally the paper reviews the intersection of GIS and urban sustainability through empirical research by building a GIS model to examine how Riyadh city can be develop of sustainably. It will test the priorities of urban development for the city to preserve the resources available..

1. Literature Review

There is a weak of literature that touches on both the specific topics of GIS and urban sustainability. For example, Lee (2007) argued that the urban population of the world increased nearly four times between 1950, when the global urban population was 732 million, and 2000, when it was 2.8 billion.

As said by the United Nations Human Settlements Programme (UNHABITAT 2006), 90 percent of the world's urban growth will happen in the developing world, with the total world urban population reaching 5 billion people by 2030.

This growth is not expected to slow down in this currant century. The cities growth rapidly in both developed and developing countries, puts a massive stress on ecosystems near and far, impairing the services that those ecosystems provide for people in both urban and rural areas. Marten (2001) stated that if these ecosystems are excessively exploited for long periods, they can be crippled and the services they provide destroyed forever.

According to Lee (2007) said urban sustainability allows for decision-makers to generate urban living patterns and habitats for people that are in homogeneity with natural energy and resource flows. They can also take advantage of economies of scale to ensure efficient resource use and higher quality of life for all of residents.

So, we need to understand the dynamics of a particular urban region, the interrelationships between population, land use, transportation, economics, environment, and other factors is crucial to effectively develop policies and determine where best to invest funding to create more sustainable urban environments. Campagna (2006), mentions that to understand these dynamics, the gathering, organizing, analysis, and dissemination of the myriad of social,

economic, and environmental information for decision- and policy-making is vital to the goal of creating more sustainable cities.

For that reason, the use of GIS is a necessary assessment tool to measure urban sustainability and ensure that quantitative, place-based information is available to decision-makers. The following section of the paper will review the definition of the main terminologies of the paper.

1.1. Sustainable Development: Definition

Sustainable development concept aims to achieve equilibrium between the human needs and economic developments within the parameters of environmental protection through efficient use of natural resources to ensure trade off between desired production - consumption levels.

Portney (2003, p. 3), said that Sustainable development is a term with many definitions, leaving, for some, an unclear vision of what it actually is. Indeed, some have argued that "it has come to mean so many different things to so many different people that it probably does as much to promote confusion and cynicism as positive environmental change".

Newman (2005), argues that due to the inherent complexity of human and natural systems, our approaches to sustainable development must be flexible and dynamic.

Also, Beatley and Manning note (1997, p. 3) that "there is a general sense that sustainability is a good thing (and that being unsustainable is a bad thing), but will we know it when we see it?" One idea that has been put forward to resolve this is that sustainable development must be approached as a dynamic process rather than a specific goal.

Moreover, The World Commission on Environment and Development (WCED - 1987) mentions to that Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

In view of the urban growth and its impact on sustainable development, we will find that the report of WCED-1987 referred to the fact that urban growth was already exploding in the latter half of the 20th century and, based on projections at the time of the report's publication; there was ample evidence that growth was going to continue to accelerate. As previously stated, we find that the municipalities need to identify priorities for urban development for the city to take advantage of the natural resources available at the moment and preserve it for future generations.

1.2. Geographic Information Systems & its Capabilities

Over the last half of the 20th century, as processors have become more powerful and GIS software has become easier to use, computers have become the platform of choice for geographic analysis and the modern GIS.

As Keranen (2008), stated that the purpose of a GIS is to gather, store, analyze, visualize, and disseminate geographic data for use in the decision making process.

Mitchell (1999) said that GIS allows decision-makers to locate where things are on the earth's surface, how many there are and how dense they might be. He added that data can be analyzed to determine what is located inside a certain area or near a point of concern, and models can be created to determine how things have changed over time.

As Davis (2003, 1) notes "everything human beings do takes place at a particular location on the earth: every activity, thing, trend, issue, or phenomenon has a geographic component to it." By tying specific issues, such as urban sustainability, to specific locations, they are seen in a more concrete perspective. Rather than being some abstract theory, the analytical and visualization capabilities of a GIS can bring issues from the realm of the conceptual into the real world, allowing decision-makers to gain a new perspective on the work they need to do. This geographic component brings an important perspective to the assessment of urban sustainability because earlier studies were missing a grounding of the assessment that neither numbers, tables, nor graphs can provide.

1.3. Sustainable development & GIS relation

According to sustainable development definition, sustainable development policies encompass three general policy areas: economic, environmental and social. The relation among them shown in Fig. 1. (P-3)

In order to create effective sustainability policies for our urban cities, decision-makers need the best and most accurate information possible upon which to formulate these policies. In order for this information to be useful, it needs to be timely, relevant, and place-based. Therefore, ICSU (2002, 5) stated that "Through the use of geographic information systems … we can establish geographic

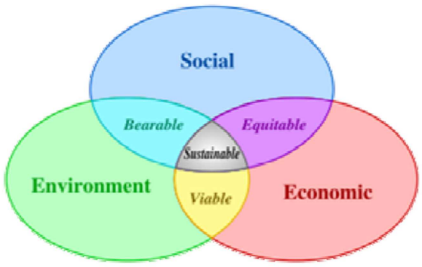


Fig. 1. Sustainable scheme. Source: Wikipedia, 2007.

location, define context, and apply spatial models to translate problems into terms associated with the decision-making process" for sustainable development.

When the proper data are available, however, urban systems can be analyzed both for their current sustainability as well as for opportunities to enhance sustainability. Urban systems are highly complex, and the amount of data needed to gain an accurate understanding of them is equally large and complex. With the rapid increases in computer processing power and the increasing sophistication of GIS software, it is becoming easier to create reliable, accurate models with GIS for developing policies and plans for urban sustainability. Mitchell (2004) argued that while most of the work in this area has focused on mapping, great potential exists for the use of GIS in urban modeling for sustainable urban development. So, proper GIS benefits could be categorized in 3 headings:

1. Efficiency: Data sharing, fast data process, data/cost ratio
2. Effectiveness / validity: Consistency between up-to-date information and decision support
3. Transparency: Accessibility to each facility.

2. Sustainable Development: Model preparing methodology

The purpose of this section of the study is to determine how geographic information systems (GIS) can be used to assess urban sustainability and inform urban sustainability policy. The primary source of data used in the present investigation was captured form Riyadh development Authority (ADA). Also, these data used and integrated with the satellite images. So, the database structure designed on the basis of secondary data that have been provided for Riyadh development Authority and it has been linked to the digital map of the city.

Therefore, this part of the research designed to benefit from the potential of GIS software (ArcGIS) to formulating a model for measuring the priorities of metropolitan cities for the urban sustainable development. This will contribute to the sustainability of the city in terms of the preservation of areas for the protection of future development and works to reduce indiscriminate development through the establishment of limits to the stages of development of the city through the monitoring of the most important variables, plans and strategies. It will support planners to build a reference scenario based on sustainable progress. During this phase, the research will be addressed in a series of steps which would contribute to the formulation of the final scenario of the development plan progress to ensure the sustainability of the city. Figure 2 shows the scheme of data integration. The model design goes through three key phases are :

- Identifying of the key elements that affect the formulation of priorities for city development.
- Formulating of the model builder to determine the development priorities of the city
- Query Model-builder in an ArcGIS program environment.

2.1. Limitation of research to build the model:

There is some research limitations affecting the outcome of the model designed to identify priorities for urban development of Riyadh city (study area). The research limitations are as follows:

- Limitation of study's criteria data
- The data for areas beyond the urban development boundary is not available. This lets to the author neglect this area.
- Most of the available data is general and not specific to the sub-municipal level.

2.2. Identification of the key elements that affect the formulation of priorities for city development.

There are various elements impacting on the model builder to define the priorities development of the city such as, the current situation of the city, particularly the key elements affected by a factor of growth and development of the city. So, the study addressed three main aspects effecting on the model builder. These main aspects are urban aspects, social aspects, and economic aspects, each one of them has sub-elements. The relationship between the main elements and sub-elements shows in Fig. 3. Moreover, the study formulated a mathematical model based on the concept of Normalized rank and weight model to measure each criterion as shows in Table 1.

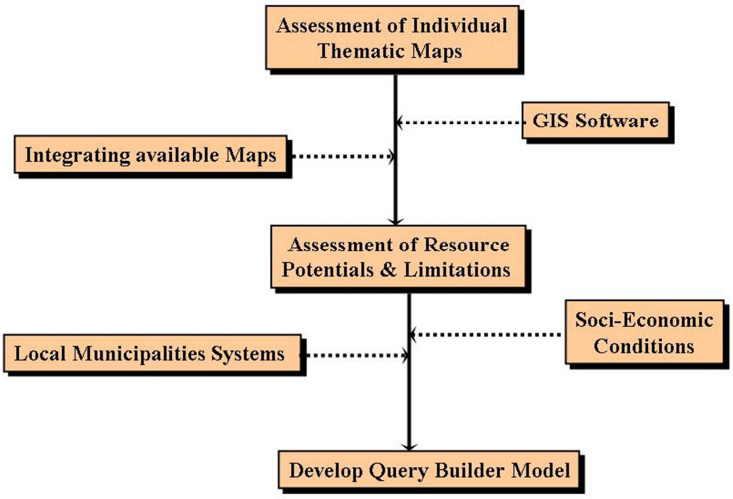


Fig. 2. The Scheme of Data Integration.

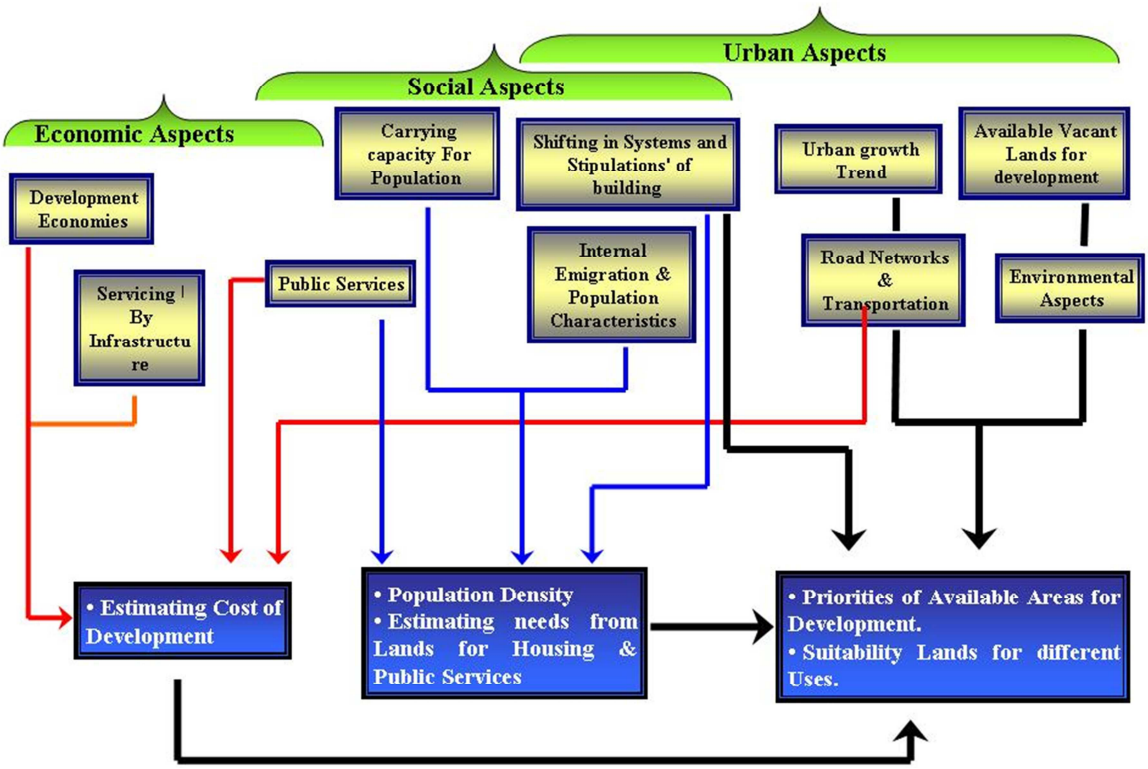


Fig. 3. The Main Elements of the Model.

Table 1. Normalized rank and weight of model criteria

criteria	Straight Rank	Rank Sum	
		Weight	Normalized Weight
Land planned to small pieces	1	35	0.0568
Unplanned territory into small pieces	2	34	0.0552
Land suitable for development	3	33	0.0536
Areas currently serviced by all networks	4	32	0.0519
Areas currently serviced by Water, electricity, and sewage	7	29	0.0471
Areas currently serviced by Water, and electricity Networks	9	27	0.0438
Areas currently serviced by Water Networks	12	24	0.0390
Areas currently serviced by electricity Networks	14	22	0.0357
Areas underway to establish network projects	19	17	0.0276
Areas will establish network projects in the next five year plan	20	16	0.0260
Areas will establish network projects in the longterm plan (10 & 20 years plan)	27	9	0.0146
Areas currently serviced by all Public Services	6	30	0.0487
Plans available at them all public services	13	23	0.0373
Plans currently serviced by the religious services, educational and health	15	21	0.0341
Areas with the greatest consumption of vacant lands	8	28	0.0455
Target areas that will develop it through the Riyadh strategic plan	30	6	0.0097
Areas with high traffic density routes and bottlenecks	33	3	0.0049
Areas with good road network	11	25	0.0406
Areas will serve with the road network in the current five-year plan	21	15	0.0244
Areas will serve with the road network in the next five-year plan	26	10	0.0162
Areas will serve with the road network in the longterm plan	32	4	0.0065
Areas with low-cost infrastructures	10	26	0.0422
Areas with low-cost vacant lands	16	20	0.0325
The population Economic capacity.	22	14	0.0227
Municipalities with a high percentage of immigration	17	19	0.0308
Municipalities with a Medium percentage of immigration	24	12	0.0195
Municipalities with a Low percentage of immigration	29	7	0.0114
Municipalities in the proportion of those in age of marriage is high	18	18	0.0292
Municipalities in the proportion of those in age of marriage is Medium	25	11	0.0179
Municipalities in the proportion of those in age of marriage is Low	31	5	0.0081
Municipalities with high population densities in the future	19	17	0.0276
Municipalities with Medium population densities in the future	23	13	0.0211
Municipalities with Low population densities in the future	28	8	0.0130
Natural Protected Areas	34	2	0.0032
The main valleys areas	35	1	0.0016

Consequently, their relations with each other to determine the features of the model in which the stages can be identified for development and progress of the city, according to the requirements of the city, according to their perceptions of current and expected to form the pattern of urban development and the future of the city. The most important of these elements as shown in Fig. 3, are:

2.2.1. Land available for development:

- Land planned to small pieces.
- Unplanned territory into small pieces
- Land suitable for development.

2.2.2. Network service infrastructure (electricity - water - sewage - Telecommunication):

- Areas currently serviced by network.
- The establishment of ongoing projects for the network.
- Areas in the next five-year plan.
- Areas in the long-term five-year plans (if available every 5 or 10 years).

2.2.3. Public Services (education, health, mosques, security …etc.):

- Areas currently served as public services.
- The schemes available to all public services.
- Schemes available by religious services, education and health.

2.2.4. Urban growth trends:

- Areas with the greatest rates of consumption of vacant lands.
- Target areas according to the development of comprehensive strategic plan for the city.

2.2.5. Road network:

- Areas with high traffic density routes and bottlenecks.
- Areas with a good network.
- Extended road network in the current five-year plan.
- Extended road network for the next Five-Year Plan.
- Extended road network in the distant future.

2.2.6. Development Economics:

- Areas in which the cost of utilities is low.
- Areas of low land costs.
- Financial capacity of the population.

2.2.7. Absorption of population:

- Size of the population projected for the period from 1425 - 1430 H, • 1430 - 1435 H,
- 1435 - 1440 H, and
- 1440 - 1445 H.

2.2.8. Change in the regulations and construction guidelines:

- Areas that have been changed and the requirements of building regulations, thus leading to high densities and the change in population size.

2.2.9. The natural environment:

- Areas of natural reserves.
- Key areas of the valleys.
- Areas with rugged topography

2.2.10. Social aspects:

- Change in family size.
- Distribution of population by age.
- Migration.

Based on the main elements which mentioned above, the study formulated the relationship between these elements and the goals of development stage plan for Riyadh city to lead to the sustainability of the urban environment of the city. These elements structured for them an attribute database and joined to the spatial database of Riyadh city (Digital map). They represent the evaluation criteria, which was built on it the basis of the evaluation model for the study. Hence, the Fig. 4 shows the relationships between these elements and the stage development plan goals. These goals are:

- Increase the land available for development.
- Achieve the demand for housing.
- Use facilities and services of the existing and proposed.
- Reduce costs of development.
- Reduce the pressure on the existing road network and to benefit from the proposed road network.
- The reduction of sprawl on environmentally-sensitive areas.

2.3. Formulation of the model builder to determine the development priorities of the city.

The query builder is a model controller of the analytical methodology in order to reach the stages of development in accordance with the five-year plans. The model divided into three stages, as shown in Fig. 5. The flowing part of the research shows the stage of the model and how it is implemented in the model.

The first stage is the analysis of spatial and attributes data. This stage analyzed the spatial Relationship for a group of urban studies layers such as:

1- Land available for development.

2- Network service infrastructure (public utilities).

3- Public services.

4- Urban growth trends

5- The road network.

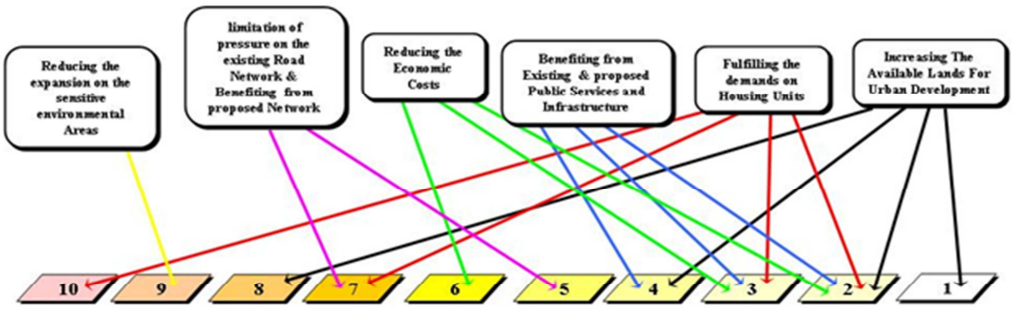
The second stage will project the future population forecast on the results of spatial and attributes analysis, this to know the spatial carrying capacity and measurement of the cost of spatial development and social considerations. This stage contains the following spatial database layers:

6- Economic Development.

7- Absorption of population.

8- The natural environment.

9- The social aspects.



Evaluation Criteria

1. Available Vacant Lands for development
2. Utilizing by Infrastructure
3. Public Services
4. Urban growth Trend
5. Road Networks & Transportation
6. Development Economies
7. Carrying capacity For Population
8. Shifting in Systems and Stipulations' of building
9. Physical environment
10. Internal Emigration & Population Characteristics.

Fig.4. Relationship between the goals and evaluation criteria of the various planning stages.

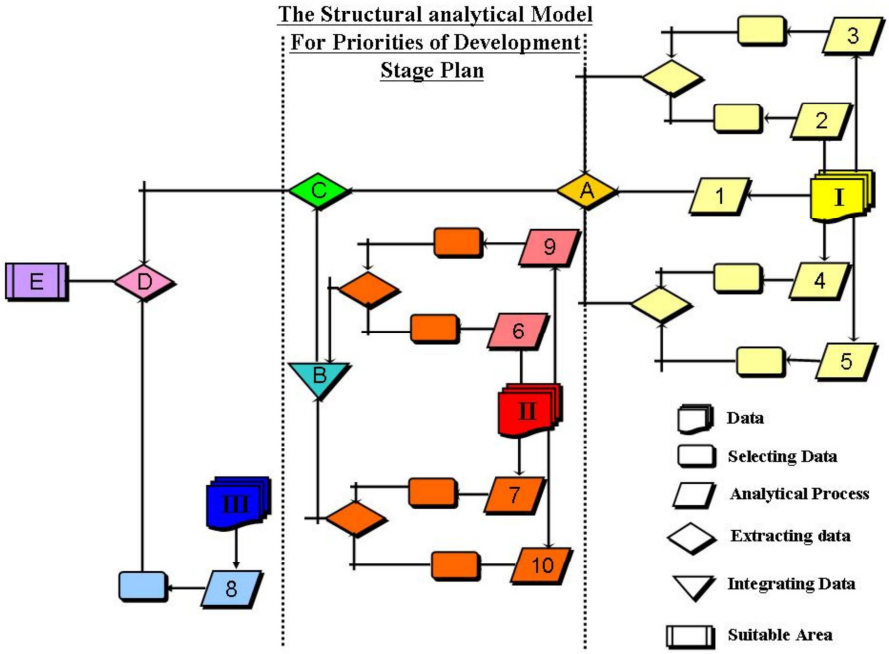


Fig. 5. The Structural Analytical Model for Priorities Urban Development.

The final stage Focused on linking areas that have been reached stages represented in the content of the five-year plan and link them to any future change in the regulations and requirements for construction. Because this changing will making significant impacts on the formulation of development stage plan.

2.3. Query Model-builder in ArcGIS program environment.

The study formulated all components of these phases within ArcGIS Program. It design query builder structural model to reach out the priorities of urban development for the city to maintain its sustainability. Therefore, the researcher designed the model of query builder that is reflected in Fig. 6, which was applied to experimental data available for the city of Riyadh and the results shown by the attached map number (1), which shows only the priorities of the urban development of the city, according to the model designed

Conclusions

- GIS has a very important role to play in the assessment of urban sustainability and in formulating sustainable urban policies.
- Urban sustainability is a multifaceted concept, and no one department or organization can develop sustainability policy on its own.
- According to literature reviewed, we need to begin moving our cities in a more sustainable direction. This is becoming more and more urgent with each passing day.
- The improved use of visualization in applying geographic information technology to local scale problems will benefit from future research and development. We found these techniques to increase awareness, giving decision-makers new knowledge about the likely outcomes of their decisions.
- Much of the success or failure in applying GIS to sustainable development in less-developed countries will depend on technology and data access.
- The geographic information systems are proving to be an extremely effective combination of tools and skills to acquire, process, analyze, and manage geographic data to support decision-maker to improve the understanding and insight in relation to sustainable development problems.
- The significant challenges are currently standing in the GIS models. For example, we can mention the difficulty of deploying efficient data and metadata management practice within large-scale projects in operational contexts.

Recommendations

- It is an unavoidable fact that GIS is a very powerful tool for public management, besides all other application area.
- There must be a link between applied research and decision makers in the city's sustainable development work
- The urban planning decision makers should offer to develop pilot projects that demonstrate how the methodologies would benefit the decision-makers.
- Education programs that relate to urban sustainability need to incorporate coursework with GIS.
- We need to build Urban Information Systems (UIS) and integrated with Environmental Information Systems (EIS) to benefit from integration technology in the urban sustainable development.

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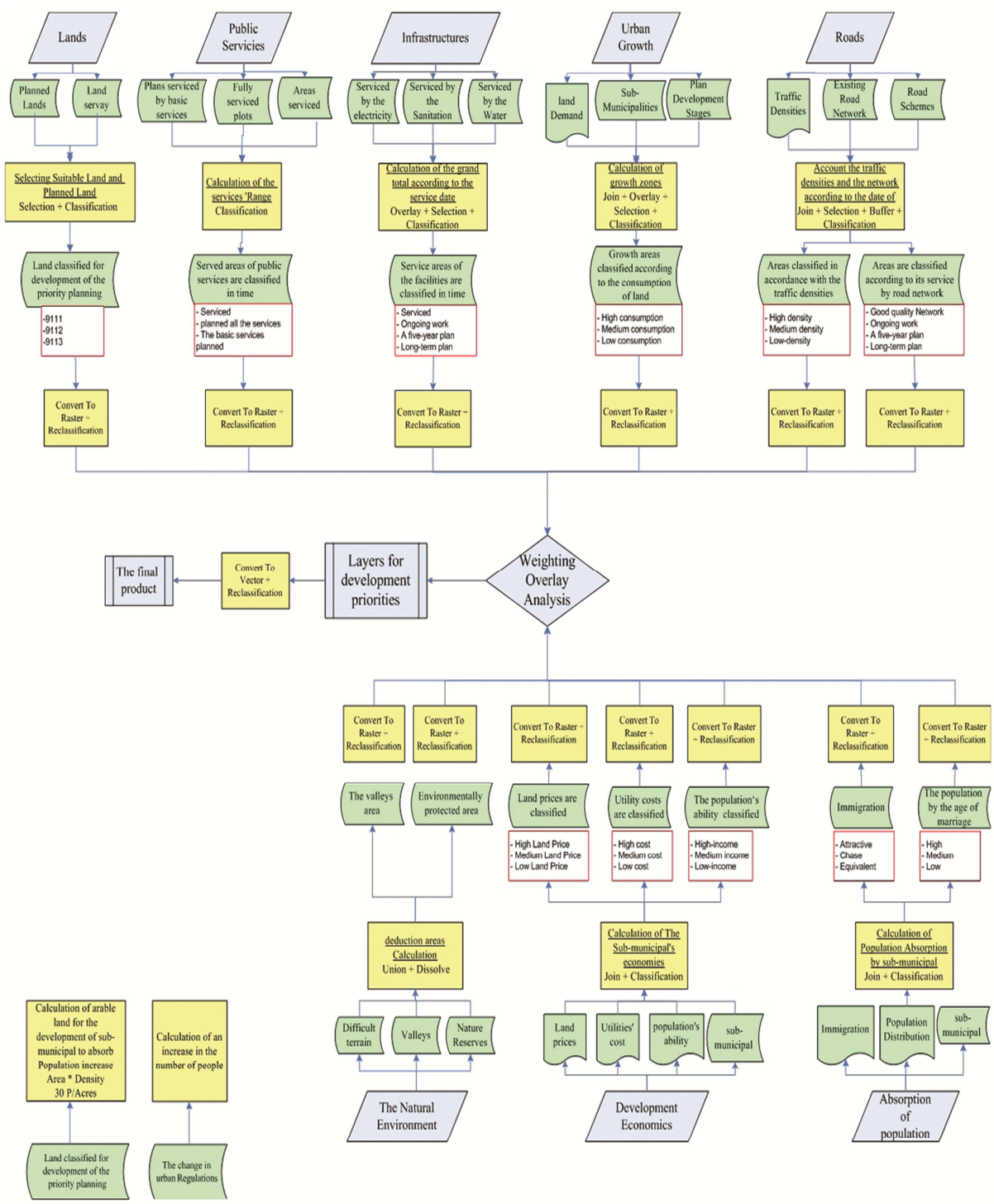
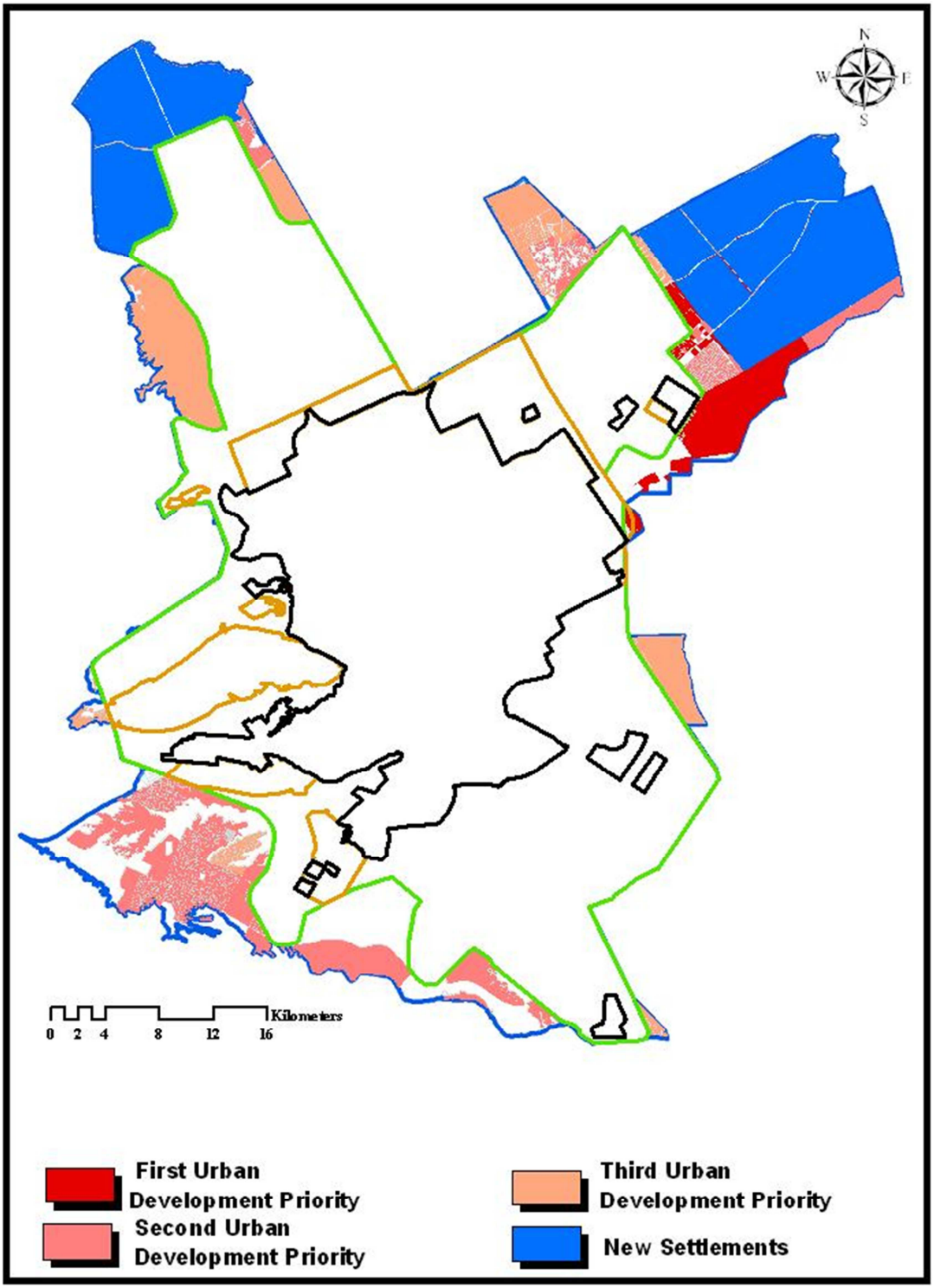


Fig. 6. The Design of Query Builder Model in ArcGIS Format.



Map (1) the urban development priorities.

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نظم المعلومات الجغرافية من أجل قرارات لتنمية عمرانية مستدامة

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ملخص البحث. وفقا لمؤتمر قمة الأرض لجدول أعمال القرن ٢١ ، والذي أشار إلى أننا بحاجة إلى ترسيخ مفهوم نظم المعلومات والاستفادة منها في عملية التنمية المستدامة للمدينة. وينبغي على البلديات ومؤسسات الحكم المحلي، ومستخدمي الموارد أن يستفيدوا من تكنولوجيا المعلومات الجديدة التي توفر لهم المعرفة الفنية اللازمة لإدارة البيئة والموارد على نحو مستدام. وتوفر لهم بيئة تساعدهم في اتخاذ قراراتهم على أساس البعد المكاني من خلال نظم المعلومات الجغرافية والتي تؤسس الفكر الإنساني في عملية اتخاذ القرار حيث تطرح أسئلة مثل ؛ أين نذهب ، وماذا يجب أن يكون عليه الحال ، وماذا نفعل عندما نصل إلى، وهي تطبق في المناطق الحضرية لضمان استدامتها. ولذلك ، نجد أن في القرن الحادي والعشرون معظم المؤسسات العامة قد بدأت في استخدام تكنولوجيا المعلومات ، وكذلك المجالس البلدية واستخدمت التطورات التكنولوجية بوصفها أداة لخدماتهم، حيث تساهم في إدارة واستخدام الموارد الطبيعية للمدينة بكفاءة وسيكون أسهل من خلال استخدام نظام المعلومات الجغرافية القائم على نظام المعلومات الحضرية. وسوف تستعرض هذه الورقة مفهوم التنمية الحضرية المستدامة ، وكيف أنها تؤثر على الاستجابة لتزايد النمو السكاني في المدن. وستكون موجهة لدور نظم المعلومات الجغرافية على أساس تحقيق التنمية المستدامة في مجال الإدارة المحلية والبلدية. وعلاوة على ذلك، سيوضح البحث كيف يمكن استخدام نظم المعلومات الجغرافية في تقييم ووضع نماذج للاستدامة في المدن، وكيف تقاس. وأخيرا، يستعرض البحث كيفية دمج مفهوم الاستدامة مع نظم المعلومات الجغرافية والحضرية من خلال دراسة تطبيقية تقوم على بناء نموذج لنظم المعلومات الجغرافية لدراسة الكيفية التي يمكن أن تكون لمدينة الرياض تنمية مستدامة من خلال اختبار أولويات التنمية الحضرية للمدينة للحفاظ على الموارد المتاحة.