APPLICATIONS OF GIS

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ABSTRACT

The geographic information system (GIS) has a very important applications in the newly word, because it is used in every daily works for several organizations and people.

This paper concerns with the Geographic information system (GIS), which mainly describes how GIS can be used to help make better management decisions, a Case study bout Assessment of Groundwater Quality in the Gaza Strip, Palestine Using GIS Mapping was provided in this paper to describe how GIS can be used as a decision making tool.

Also, it introduces what are GIS, and how it works, and the practical benefits and problems of their use. In particular, a successful GIS seeks to provide practical support for those considering using GIS.

These Topics will be covered in this paper in some brief manner:

A. An introduction to GIS
B. Definitions of GIS
C. Components of GIS
D. Views of GIS
E. Functions of GIS
F. Sources of GIS data
G. Planning a GIS project
H. Benefits of GIS
I. An ideal GIS
J. Key for successful GIS
K. Key for unsuccessful GIS
L. Applications of GIS
N. Conclusion and comment
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Introduction

One of the first historically an application of GIS in epidemiology is in the 1832; The French geographer Charles Picquet represented the 48 districts of the city of Paris by halftone color gradient according to the percentage of deaths by cholera per 1,000 inhabitants.

In 1854 John Snow depicted a cholera outbreak in London using points to represent the locations of some individual cases, possibly the earliest use of a geographic methodology in epidemiology. His study of the distribution of cholera led to the source of the disease, a contaminated water pump (the Broad Street Pump, whose handle he had disconnected, thus terminating the outbreak) within the heart of the cholera outbreak. While the basic elements of topography and theme existed previously in cartography, the John Snow map was unique, using cartographic methods not only to depict but also to analyze clusters of geographically dependent phenomena. Figure (1) shows the John Snow distribution of cholera map.

The early 20th century saw the development of photo-zincography, which allowed maps to be split into layers, for example one layer for vegetation and another for water. This was particularly used for printing contours – drawing these was a labour intensive task but having them on a separate layer meant they could be worked on without the other layers to confuse the draughtsman. This work was originally drawn on glass plates but later plastic film was introduced, with the advantages of being lighter, using less storage space and being less brittle, among others. When all the
layers were finished, they were combined into one image using a large process camera. Once color printing came in, the layers idea was also used for creating separate printing plates for each color. While the use of layers much later became one of the main typical features of a contemporary GIS, the photographic process just described is not considered to be a GIS in itself – as the maps were just images with no database to link them to. Figure (2) shows a GIS layers.

The year 1960 saw the development of the world's first true operational GIS in Ottawa, Ontario, Canada by the federal Department of Forestry and Rural Development. Developed by Dr. Roger Tomlinson, it was called the Canada Geographic Information System (CGIS) and was used to store, analyze, and manipulate data collected for the Canada Land Inventory – an effort to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, waterfowl, forestry and land use at a scale of 1:50,000. A rating classification factor was also added to permit analysis.

**Definition of Geographic information system (GIS)**

GIS combines three words: Geography + information + System. Geography relates to all the features and processes that occur on the surface of the earth. Information is the heart of GIS, where vast amount of data are stored and analyzed. Finally, the system is what connects everything – the computer, the data, and a human operator – all working together to ask questions, discover answers, and display them in ways that promote understanding of what it means to live on the earth. (ESRI, 2000)
There are many definitions that describe the geographic information system (GIS).

**A GIS is designed for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to analysis.** (Stanley, 1989, cited in Allan and Fred, 1997)

This definition is abroad and applies to a wide variety of methods for sorting, accessing, and manipulating geographic information; it does not limit GIS to the computer environment. An important concept is that a GIS does not have to reside in a computer environment. One could argue that a printed state highway map is a GIS because it provides information about geographic phenomena and objects (the distribution of the highways); information about the highways (road classification, pavement type, and number of lanes); a method of storage (the paper map), and means of analysis (the interaction between the map graphic and a person).

**The GIS in a more precise manner as a computer tool for managing geographic feature location data and data related to those features.** (Allan and Fred, 1997)

This definition express the GIS as a tool for managing data which describes an element in our world by answer about a two question: where feature are (geographic coordinate data), and what they are like (attribute data), figure (3) describe the how GIS describe an element in our world.

![Figure 3](image)

**Figure (3) Describe the how GIS describe an element in our world**

**A GIS is simply a computer system with the associated software for collecting, storing, manipulating, analyzing, and presenting geographic data about things that can be represented in a map.** (Christie et al., 2004)
This definition implies that the GIS is a computer system with a software to manipulate and analyze the data which is collected and stored into a database and then presented this data in a digital maps.

**The components of GIS**

There are five components for the geographic information system (GIS), which are:

1) **DATA**

Davis (2001a) said that the geographic data and information are the heart of GIS. Here there are two fundamental components of the geographic data: Space (expressed as spatial data) and qualities (attribute data), both of these data are stored in databases, which the central working component of GIS.

Davis (2001b) also said that GIS uses information as the core, not data (it is GIS not GDS), information is the primary purpose of GIS, not just data. Data is the input; information is the output.

The terms data and information are often conveniently interchanged without real loss of meaning, but an important difference can exist. It is to use the terms correctly, particularly in GIS work we will point out to the important differences among several terms associated with data and information.

- **Datum**: a single number or fact; a single entry in the database. A datum can be a number, letter, or text. Although the term is correctly used as a singular of data, it is not commonly used to control points for establishing a geographic reference for the world sphere, an important aspect of a curate GIS coordinate.

- **Data**: a collection of facts in the database, multiple entities. In the illustration, the list of numbers constitutes the data. The word datum is a singular and data is plural. Proper grammar of terms is "datum is" and "data are".

- **Data set**: a data set is a collection of related data, usually associated with a specific topic, such as population. Various measures and types of data may exist in the data set, but normally they should relate to the central theme.

- **Information**: the meaning or interpretation of data. Information is the knowledge obtained from data and implies explanations or significance of the collective facts or numbers. For example a statistical measure is information concerning a string of numbers (data). The total and average measures of a group of data offer meaning and are therefore the informational aspects of the small database.

Table (1) shows the concepts of datum, data, and information.
Table 1) the concepts of datum, data, and information

<table>
<thead>
<tr>
<th>Sample site</th>
<th>Measurement quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3 ← datum</td>
</tr>
<tr>
<td>B</td>
<td>6 ← datum</td>
</tr>
<tr>
<td>C</td>
<td>4 ← datum</td>
</tr>
<tr>
<td>D</td>
<td>4 ← datum</td>
</tr>
<tr>
<td>E</td>
<td>8 ← datum</td>
</tr>
<tr>
<td>F</td>
<td>5 ← datum</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>30 ← information</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>6 ← information</td>
</tr>
</tbody>
</table>

In general the data split into two types of data:

A. **Spatial data**: spatial data occupies geographic space. It usually has specific location according to some world geographic referencing system (such as latitude-longitude) or address system. Table (2) shows a database contain spatial and attribute data. The addresses in the database have specific locations and therefore considered spatial data, while the owner name and value of the property are non-spatial data they are descriptive characteristics called attribute.

Table (2) A database for spatial and attribute data

<table>
<thead>
<tr>
<th>Spatial data ↓</th>
<th>Non spatial data (attribute data) ↓</th>
<th>Non spatial data (attribute data) ↓</th>
<th>Spatial data ↓</th>
</tr>
</thead>
<tbody>
<tr>
<td>address</td>
<td>Name</td>
<td>Value</td>
<td>Area</td>
</tr>
<tr>
<td>12 OXFORD CRT.</td>
<td>TALIKA</td>
<td>5000</td>
<td>600</td>
</tr>
<tr>
<td>14 OXFORD CRT.</td>
<td>TALIKA</td>
<td>7000</td>
<td>600</td>
</tr>
<tr>
<td>16 OXFORD CRT.</td>
<td>DRANA</td>
<td>6000</td>
<td>700</td>
</tr>
</tbody>
</table>

***Spatial: Geographically referenced data, identified according to location.

The spatial data also split into two types:

a. **Raster data**: a layer of grid cells, each cell called pixel. These cells are constant in size and are generally square, although rectangular, and equilateral triangles have also been used. The location of cells (pixels) is addressed by row and column number.

The spatial resolution of a raster is the size of one of the pixels on the ground. At 100m resolution, a square area 100 km on a side requires a raster with 1000 rows by 1000 columns or one million pixels, at 10m resolution, the same area requires 10,000 columns by 10,000 rows or one hundred million pixels.

If one computer byte (requiring eight bits or binary digits to integer numbers between 0 and 255), the storage needed is 100 megabytes, this is a considerable amount of space for a single map or image.

In raster mode, points are represented as single pixels and lines by strings of connected pixels.
The raster mode is used for data that has not distinct shape, such as rainfall, wind, and earth gravity fields.

Figure (4) shows a raster presentation of real world data.

![Raster Presentation of Real World](image)

**Figure (4) A raster presentation of real world**

*Vector data:* the vector mode is well-suited for representing maps, points, lines, and polygons, and symbols on maps are difficult to capture with fidelity in a raster without making the pixels very small, resulting in high storage costs.

In the vector mode, points are represented as pairs of spatial coordinates, lines as strings of coordinate pairs, and areas as lines that form closed loops or polygons.

**B. Attribute data**

Attribute data are not location specific, it can be found anywhere, even in more than one place (the owner can possess multiple properties). They are descriptions about the spatial data, for example, someone is the owner of one address, but he or she could own, or move to, another address. The address does not change, but the owner and value might.

**2) Software**

- **ESRI:** Products used by 77% of GIS professionals. ArcView, ArcGIS, ArcSDE.
- **IDRISI:** Proprietary GIS product developed by Clark Labs.
- **Geomedia:** (INTERGRAPH), Products, used by 18% of GIS professionals.
- **Autodesk:** World (Autodesk)
- **Mapinfo Pro:** Products, used by 20% of GIS professionals
- **GeoConcept:** (Geoconcept)
3) **Hardware**

Figure (5) shows the components of the hardware component.

![Image of hardware components]

**Figure (5) The components of the hardware component**

4) **People using GIS**

- **Government**: Tax maps; economic development; housing; law enforcement; health
- **Science**: Meteorology; biology; geology; geophysics; education
- **Business**: Retailing; marketing
- **Logistics**: Transportation; disaster preparation
- **Environment**: Land-use changes; water quality; pesticide monitoring; soil erosion; air pollution

**The three views of GIS**

A geographic information system describes three views, which are as follow:

1. **The Geodatabase or database view**: A GIS is a spatial database containing data sets that represent geographic information in terms of a generic GIS data model (features, raster, topologies, networks, and so forth), as shown in figure

2. **The Geovisualization or map view**: A GIS is a set of intelligent maps and other views that shows features and feature relationships on the earth's surface. Various map of views of the underlying geographic information can be constructed and used as "Windows into the database" to support queries, analysis, and editing of the information.

3. **The Geoprocessing or model view**: A GIS is a set of information transformation tools that derives new geographic data sets from existing data sets. These geoprocessing functions take information from existing data sets, apply analytic functions, and write results into new derived data set.

Figure (6) shows the three views of GIS
GIS Functions

The GIS functionality can be subdivided into four main components or subsystems: data input, data storage and management, data manipulation, and analysis, and data output.

1- **Data Input**: data input refers to the process of identifying and gathering the data required for a specific application. The process involves acquisition, reformatting, georeferencing, compiling, and documenting the data. The data input component converts data from their raw or existing form into one that can be used by a GIS.

The data required for a particular project are usually available in different forms that include analog maps, tables, charts, and existing digital data sets, maps, aerial photos, satellite images, surveys, and other sources in digital format.

GIS systems typically provide alternative methods of data input, including keyboard entry for non-spatial (attribute) and occasionally locational data, manual locating devices (e.g., digitizers and computer mouse), automated devices (e.g., scanning or importation of existing data files (conversion directly from other digital sources).
A. **Digitizing**

The digitizing process involves encoding analog data (hard-copy maps or graphics) into digital data. This method uses a digitizing table and mouse with a cursor to trace and record points, lines, and polygons needed for a particular data set figure (7).

![ Digitizing Table ](image)

**Figure (7) Digitizing Table**

Digitizing is an efficient method to use when just a few maps with minimal geographical data need to be captured. The problem with this method of data input is that most maps are generated for the purpose of displaying data/information to the user and do not always depict the spatial location of objects exactly. Most digitizing errors can be attributed to poor map bases and scale. Human error is also a concern and can cause significant error, depending on a number of factors that influence the ability to trace lines on a constituent basis for long periods of time. Therefore, the accuracy of any GIS database is directly related to the quality of the digitizing processes. (Arnoff, 1989, cited in Malezewski, 1999).

B. **Scanning**

A scanner converts an analog source document into digital raster format by using either a flat-bed scanner or a drum-scanner (Pazner et al., 1993, cited in Malezewski, 1999).

Figure (8) shows the flat-bed and drum scanner.

![ The flat-bed and drum scanner ](image)

**Figure (8) The flat-bed and drum scanner**
It is used in GIS to input map and photo information. The quality of this information is related to the quality of the scanner and the quality of the base map being scanned. Unlike in the digitizing process, the user has limited control as to what type of data will be picked up during the scanning process. The scanning method is generally chosen when large amounts of data need to be captured. For example, a map with thousands of polygons or with larger irregularly shaped features is a good map to scan. Errors may occur during the scanning process due to resolution, the source documentation, and geographical feature interpretation.

2- Data storage and management.

The data storage and management component of a GIS includes those functions needed to store and retrieve data from the database. The methods used to implement these affect how efficiently the system performs operations with the data. (Antrnnucci et al. 1991, cited in Malezewski, 1999).

Most GIS systems are database oriented. The database can be defined as collection of non-redundant data in a computer organized so that it can be expanded, updated, retrieved, and saved by various uses. It is important, however, to view a GIS database as more than a simple medium for storing data and information. The GIS database can be thought of as a representation or model of real world geographical systems. To this end it is useful to make a distinction between geographical entities and objects.

A geographical entity is a term used with respect to an element of a real world system; that is, entities are contained in geographical space. An object is a GIS representation of a geographical entity. For example, geographical entities such as towns, highways, and states are represented in GIS databases in the form of point, line, and areal (polygon) objects. The objects are described by locational or spatial data, which records the location of a given object (point, line, or polygon), and attribute or non-spatial data, which describes characteristic of the object.

A GIS based decision analysis requires representation of a real world geographical system in a digital format. The problem is that the real world geographical systems are too complex for even the most advances information systems, and they must therefore be simplified this simplification of reality is referred to as data model. A GIS database is a collection of spatially referenced data that acts as a model of reality.

The concept of a GIS database represents a particular view of the reality.

A. Managing and store spatial data

Spatial data represented at the physical level are arranged in one of two methods for a GIS: Raster and Vector.

Data in raster format are stored in a two dimensional matrix of uniform grid cells (pixels), normally square or at least rectangular, on a regular grid. Each cell is supposedly homogenous in that the map is incapable of providing information at any resolution finer than the individual cell. Areas are made up of continuous pixels with the same value as shown in figure (9)
Figure (9) Pixels made up areas

Lines are made by connecting cells into a one pixel thick line. Points are single cells, which mean that all the area represented by the cell becomes unavailable for other spatial entities. All spatial objects have location information inherent to where they lie in the grid. The size of the grid can vary, and therefore the spatial resolution of the data is determined by the grid size. The higher the level of resolution, the greater the detail that can be distinguished on an image. Raster data resolution may vary from sub meter to many kilometers.

Data in vector format are entities represented by strings of coordinates. A point is one coordinate; that is; points on a map are stored in the computer with their exact coordinates. Points can be connected form lines or chains. Thus a line is represented as a number of coordinates along its length. Chains can be connected back to the starting point to enclose polygons or areas. A polygon is represented as a set of coordinates at its corners. Figure (10) shows the model for storage spatial data.

For example, a point that represents a village or town may have a database entry for its name, size, services, and so on. A line that represents a road may have a database entry for its route number, traffic capacity, emergency route, and so on. A polygon that represents an administrative unit may have a database entry for the various socioeconomic, environmental, and population characteristics.
Figure (10) Shows the model for storage spatial data

For example, a point that represents a village or town may have a database entry for its name, size, service, and so on. A line that represents a road may have a database entry for its route number, traffic capacity, emergency route, and so on. A polygon that represents an administrative unit may have a database entry for the various socioeconomic, environmental, and population characteristics.

B. Managing and store attribute data

As mentioned earlier, geographical objects are described by two types of data: locational data, which relate the objects to their location in geographic space, and attribute data, which describe other properties of the objects apart from their locations. GIS typically employ database management system (DBMS) strategies for handling these two types of data, most standard databases are classified according to a model of how the data are viewed by user. A great number of data models have been proposed, such as flat data structure, hierarchical, network, relational, and object-oriented models (De Mers, 1997a, cited in Malezewski, 1999).

The most popular data models: relational and flat data models, these types of files are particular importance for GIS-based multi criteria decision analysis. The relational model is the most popular database used to organize data in GIS. The flat data model is a convenient way to store and process data for multi criteria decision making (Kirkwood, 1997, cited in Malezewski, 1999).

3- Data manipulation and analysis

The distinguishing feature of GIS systems is their capability of performing an integrated analysis of spatial and attributes data. The data are manipulated and analyzed to obtain information useful for a particular application. There are an enormously wide range of analytical operations available to GIS users, and a number of classifications of those operations have been suggested (Good, 1987, cited in Malezewski, 1999).
A GIS manipulation and analysis functions which called fundamental (Basic) functions. These functions considered to be useful for a wide range of applications.

The fundamental functions include measurement, (re)classification, scalar and overlay operations, and neighborhood and connectivity operations. Many popular GIS systems, such as ARC/INFO-Arc View, IDRISI, GRASS, Geomedia, MapInfo, SPANS, and Trans-CAD have the capability to perform most if not all, of the basic analytical functions.

a. Measurement

The measurement functions enable the calculations associated with point, lines, areas, and volumes (De Mers, 1997b, cited in Malezewski, 1999). The simplest measurement functions on points or lines enumerate that the total number of points and/or lines within a polygon. The latter operations are called the point-in-polygon operation and the line-in-polygon operation, respectively. The point-in-polygon operation determines the points of a data layer that are contained in a specific polygon of another data layer, while the line-in-polygon operation identifies lines that are contained in a particular polygon. These operations can be used to identify the number of traffic or crime incidents in a given area, or to determine the highway segments that pass through an urban area.

The line measurements involve distance operations, these operations include measurement of the distance between two points a long straight or curvilinear line, for example, the length of a bus route or an emergency route can be determined using the line measurement function.

The area measurements, there are two basic area measurements, the area of a polygon, measuring the extent of an object, and the perimeter of a polygon area, calculating the distance around the object. A measurement of a flood area is an example of area measurement, while the perimeter operation can be useful in measuring the length of a dike system to contain the flood.

Volumetric measurement, is the fourth category of measurement, this operation is more complex than point, line or area measurement. It can be performed either by means of a cross-section technique or through overlays of multiple surfaces.

Many GIS systems have the capability to measure real-world distances and areas; this can be done in an interactive fashion by using a mouse to draw the line between two points or by drawing a polygon. In vector-based GIS, the distance can be obtained by drawing a straight line between points, and the system calculates the length of that line automatically. The raster GIS may calculate the number of cells separating two points or the number of cells in an area rather than the real-world distances or areas (Panzer et al.1993, cited in Malezewski, 1999). To obtain real-world measurements, the number of cells has to be converted into distance or area. The precision of such measurements is limited to the cell size.

b. (Re)classification

Reclassification and classification operations transform the attribute data associated with a single map layer (De Mers, 1997c, cited in Malezewski, 1999).
They involve the grouping of objects into classes according to the new values assigned to the objects of the input data according to certain locational and non-locational attribute values. Classification implies the recognition of pattern and organization in the data being considered for a particular analysis.

The reclassification involve a comparison operations to the attribute data, these operations determine whether or not a relationship holds between the value associated with a particular object and a specified or derived constant value (threshold value). The list below specifies the basic comparison operations:

a. Equal to (=)
b. Greater than (>)
c. Less than (<)
d. Greater than or equal (≥)
e. Less than or equal (≤)

c. **Scalar operations**

This class of operations makes use of a single, uniform value, a scalar data layer. It is constructed by assigning the value desired to each location on the data layer. The output data layer contains new attribute values, depending on the type of operation and a constant value (scalar). The fundamental scalar operation includes:

1. Addition (+): adds a specified constant to each attribute value on the input layer.
2. Subtraction (-): subtracts a specified constant to each attribute value on the input layer.
3. Multiplication (×): multiplies a specified constant to each attribute value on the input layer.
4. Division (÷): divides a specified constant to each attribute value on the input layer.
5. Exponentiation (^): raises each value on the input layer to a specified exponent.

Beside these fundamental algebraic operations, a number of algebraic and statistical operations can be performed using overlay procedures, examples of these types of operations include:

1. Average: the average value at corresponding locations in input layers A and B is calculated.
2. Power: the value at each location in input layer A is raised to the power of the value at the corresponding location in input layer B.
3. Rank: the values at corresponding locations in input layers A and B are ranked.
4. Minimum: the minimum value at corresponding locations in input layers A and B is identified.
5. Maximum: the maximum value at corresponding locations in input layers A and B is identified.
An example of an algebraic overlay is given in figure (11). It shows the minimum overlay procedures for two layers. Each cell of the output layer is the minimum of the values contained in corresponding cells of the two input layers.

![Figure (11) A minimum algebraic overlay](image)

The minimum overlay operations identify the minimum value for each location of the two input maps and assign this value to a corresponding location on the output layers.

**4- Data output**

The data output component of GIS provides a way to see the data or information in the form of map, table, diagrams, and so on. The output sub system displays to users the results of GIS data processing and analysis. The result may be generated in the hard copy, soft copy, and electronic format. Maps are the most standard output format but frequently are accompanied by tabular display. A variety of output devices are used, including monitors, pen plotters, electrostatic plotters, laser printers, line printers and dot matrix printers and plotters. Results, particularly in the map forms, are often modified or enhanced interactively through cart- graphic map composition functions to add elements such as legends, titles, north narrow, scale bar, color modification, and symbology adjustment.

In general, types of output can be classified into four categories:

1. Text output: tables, lists, numbers or text in response to queries; the results might be a list or table of selected objects with attributes; queries might result in numerical results (e.g., totals, distances, areas, counts).
2. Graphic output: maps, screen displays, diagrams, graphs, perspective plots, and so on; interactive graphics devices allow users to pint to objects and identify them in their correct spatial context.

3. Digital data: stored on disk or tape, or transmitted across a network.

4. Other, not yet commonly used: such as computer-generated sound and video clips

**Sources of GIS data**

GIS data comes from many sources and in a variety of formats; therefore, a project has a great flexibility in the types of data it can use.

1. **Maps**: the most common type of geographic data is from existing maps. In the near future, digital data will probably be the dominant input.

2. **GPS (Global Positioning system)**: a special satellite system that provides highly accurate location and elevation data from anywhere in the world. GPS is a valuable part of field data.

3. **Imagery**: remote sensing, such as satellite or aircraft digital imagery, provides a major source of GIS data this can also include scanned pictures, such as air photos or field photography.

4. **Reports (text data)**: reports and text documents dealing with spatial subjects, such as a soil survey or research from another project.

5. **Tabular data**: lists of numeric data, such as descriptive, census, or economic data.

**Planning a GIS project**

These are fundamental steps of a GIS analysis project:

**Step 1: Identify your objectives**

The first step of the process is to identify the objective of the analysis.

You should consider the following questions when you are identifying your objectives:

- What is the problem to solve? How is it solved now?
- Are there alternate ways to solve it using a GIS?
- What are the final products of the project? Reports, working maps, presentation-quality maps?
- Who is the intended audience of these products? The public, technicians, planners, officials?
- Will the data be used for other purposes?
- What are the requirements for these?

This step is important because the answers to these questions determine the scope of the project as well as how you implement the analysis.

**Step 2: Create a project database**

The second step is to create a project database. This step consists of designing the database, automating and gathering data for the database, and managing the database.
A. **Designing** the database includes identifying the spatial data you will need based on the requirements of the analysis, determining the required feature attributes, setting the study area boundary, and choosing the coordinate system to use.

B. **Automating** the data involves digitizing or converting data from other systems and formats into a usable format as well as verifying the data and correcting errors.

C. **Managing** the database involves verifying coordinate systems and joining adjacent layers.

Creating the project database is a critical and time consuming part of the project. The completeness and accuracy of the data you use in your analysis determines the accuracy of the results.

**Step 3: Analyze the data**
The third step is to analyze the data. Analyzing data in a GIS ranges from simple mapping to creating complex spatial models.

**Step 4: Present the results**
The fourth step is to present the results of your analysis.

- Your final product should effectively communicate your findings to your audience. In most cases, the results of a GIS analysis can best be shown on a map.
- Charts and reports of selected data are two other ways of presenting your results. You can print charts and reports.
- Separately, embed them in documents created by other applications, or place them on your map.

**Benefits of GIS**

There are several benefits for GIS; this is a brief summary of these benefits:

1- The data is better organized.
2- The data is stored in a central place, eliminating duplicate maps sets and duplicate map changes.
3- GIS users have constant access to the most current data available they can also retrieve if faster and more easily.
4- Maps and reports are more consistent and have a higher graphic quality.
5- Graphic (spatial) data and non-graphic (attribute) data are explicitly linked and can be analyzed simultaneously.
6- Users have flexibility in selecting the data they want to view, analyze, or present.
7- Cost and time saving.
An ideal GIS

For a GIS to be ideal and efficient in its work it must sustain the following properties:

1. **Open data policy**
2. **Standardization**
3. **Data/information sharing**
4. **Networking**
5. **Multidisciplinary**
6. **Interoperable procedure**

Key for successful GIS

1. **Data input**: selection of geospatial data digitizing method
2. **Consensus of supporters**: top managers staff/engineers
3. **Customizing software**: model building education package
4. **Education and training**: decision makers, professionals, technicians
5. **Data sharing**: reduction of cost wide use of database
6. **Maintenance of database**: data quality updating

Key for unsuccessful GIS

1. **Lack of vision**: no objective, no target, no goal
2. **Lack of support by decision makers**: personal conflict no continuity
3. **Lack of expertise**: mis-selection, misuse, no consultation
4. **Lack of user’s access**: no training, no manual, no use participation
5. **Lack of system analysis**: no system approach, no restructure
6. **Lack of long term plan**: no version up, no updating.

Applications of GIS

“The application of GIS is limited only by the imagination of those who use it.”  (Jack Dangermond, President of ESRI).

1. **Highways**

What is the fastest way to get to a fire?

What are the best routes for your school buses in order to get everyone home the fastest?
2. Atlas maps and national boundaries

What is the political reconstruction of Russia’s boundaries?
3. **Emergency**

What is the fastest route to the Hospital?

![Image](image1.png)

**Figure (14) The faster route**

4. **Public Utilities**

Is it safe to dig here?

![Image](image2.png)

**Figure (15) The safe dig place**
5. **Agriculture**

How can I improve food production?

![Image of agriculture data and analysis](image)

**Figure (16) Improve food production**

How can I improve food production?

6. **Marketing**

How can I optimize my Marketing Campaign?

![Image of marketing data and analysis](image)

**Figure (17) Improve food production**

Abstract

A Geographical Information System (GIS) tool was used to construct thematic maps for groundwater quality in the Gaza Strip. Environmental data were integrated and an overall picture about the spatial variation in the groundwater quality of the Gaza Strip was defined. The integrated spatial maps helped to refine information on land use, soil types, depth to groundwater table, environmental “hot spots”, and contaminant concentrations of the study area. The GIS maps showed not only contaminant distributions but also illustrated the need to improve the groundwater quality management methods. Several contaminants pose great problems in the water of Gaza. Integration of water data and GIS maps for all parameters revealed that there is probably no drinking water in Gaza according to the WHO standards. Moreover, the new maps of 2008 could be used as base-line for water planners and policy makers as well as guidelines for the Palestinian people to manage and protect their groundwater. Increased water demand from population and economic growth, environmental needs, land use changes, urbanization, groundwater mining, deterioration of water quality, pollution from local and diffuse sources, environmental hot-spots and impacts on public health and ecosystems are all factors that can create a severe water quality crisis as well as water shortage problems.

Location

Gaza Strip is located along the coast of the eastern Mediterranean Sea Stretches over a distance of approximately 45km from Beit Hanoun city in the north to Rafah City in the south. Its width varies between 7 and 12km and the total area is about 363 km2.

Population

The estimated population is around 1.5 million inhabitants that mean the area is highly populated due to the high growth rate (MoP, 2010).

Introduction

A Geographic Information System (GIS) is an important tool for integrating spatial data with other information. It allows one to analyze the integrated data and to represent the information spatially facilitating planning of resource development, environmental protection and scientific research. This capability makes GIS a powerful tool for groundwater assessments. GIS not only provides tools for interpolating measured values of water quality parameters from specific locations, but also enables one to link water quality with land use, soil characteristics, and other relevant information. In addition, GIS provides sophisticated map-generation capabilities, useful in communicating results of data analysis.
The Gaza Strip region is a fragile ecosystem suffering from increasing environmental assaults due to escalating population growth and limited availability of natural resources to support development. Groundwater is, perhaps, the most precious natural resource in the Gaza Strip as it is the only natural source of fresh water. Therefore, groundwater contamination can pose serious health and economic threats to the population that relies on this water for drinking, agriculture, and industry uses. The aquifer of Gaza is extremely susceptible to surface-derived contamination because of the high permeability of sands and gravels that compose the soil profile of Gaza. It has already deteriorated in terms of quantity and quality as a result of over-exploitation and direct and indirect contamination.

The main objective of the current study is to use GIS to compare water quality data and related information collected during an eight-year monitoring program for groundwater quality in the Gaza Strip. A secondary objective is to portray the contaminant distribution in the groundwater of the Gaza Strip in easily viewed maps for use by the public and decision makers.

**Study area**

The Gaza Strip is one of the most densely populated areas in the world (4138 people per km² ;). For administrative purposes, the area has been divided into five regions: North, Gaza, Middle, Khan-Younis and Rafah (Figure 18). Approximately 85% of the population of the Gaza Strip drink from municipal groundwater wells and 15%, mostly in agricultural areas, use private wells to supply their drinking water.

![Figure (18) Gaza base map](image-url)
The study area is part of the coastal zone in a transitional area between a temperate Mediterranean climate to the east and north and an arid climate of the Negev and Sinai deserts to the east and south. As a result, the Gaza Strip has a characteristic semi-arid climate. The hydro-geological features of the Gaza aquifer are well known. The coastal aquifer consists primarily of Pleistocene age Kurkar Group deposits, including calcareous and silty sandstones, silts, clays, unconsolidated sands, and conglomerates. Near the coast, coastal clays extend about 2-5 km in land, and divide the aquifer sequence into three or four sub-aquifers, depending upon the location. Towards the east, the clays pinch out and the aquifer is largely unconfined. Within the Gaza Strip, the total thickness of the Kurkar Group is about 100 m at the shore in the south, and about 200 m near Gaza city. At the eastern Gaza border, the saturated thickness is about 60-70 m in the north, and only a few meters in the south near Rafah. Local perched water conditions exist throughout the Gaza Strip due to the presence of shallow clays.

**Water Quality Maps**

Data for these studies were based on periodic fieldwork conducted by the Palestinian Water Authority for groundwater samples collected from predetermined locations of existing water wells in collaboration with Dr. Shomar who assisted with study design and was responsible for chemical analysis.

The sampling locations were integrated with the water data for the generation of spatial distribution maps of selected water quality parameters including electrical conductivity (EC), total dissolved solids (TDS), Cl⁻, F⁻, NO₃⁻, SO₄²⁻, total hardness, Ca²⁺, Mg²⁺, Na⁺, K⁺, total Fe, total Cr, and total Zn. The water data were linked to the sampling locations using the basic geodatabase creation function of ArcGIS 9.2 software. The depth to water table (Figure 6) is based on the monitoring results of 500 groundwater wells. Data were obtained from both field surveys and databases of the Palestinian Water Authority.

**Results**

Owing to the large data set obtained from the analysis of 170 water samples for eight years, each having 27 parameters, this section focused on elements exceeding the World Health Organization (WHO) standards. Addition-ally, total Cr, Zn and Fe were presented to establish baseline values. Figures 7-20 showed the distribution of each parameter and the WHO standard. Maps showing land use, soil types, environmental hot-spots and socio-economic were included because these factors have direct and indirect impacts on groundwater quality.
A. *Land use*

The area of the Gaza Strip is 363 km\(^2\) of which about

<table>
<thead>
<tr>
<th>ID</th>
<th>Land use type</th>
<th>Area Km(^2)</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Airport</td>
<td>7.5</td>
<td>2.05%</td>
</tr>
<tr>
<td>1</td>
<td>Built-up</td>
<td>54</td>
<td>14.79%</td>
</tr>
<tr>
<td>2</td>
<td>Cultivated</td>
<td>157.5</td>
<td>43.15%</td>
</tr>
<tr>
<td>3</td>
<td>Existing Industrial Area</td>
<td>0.9</td>
<td>0.25%</td>
</tr>
<tr>
<td>4</td>
<td>Wastewater Treatment Site</td>
<td>0.45</td>
<td>0.12%</td>
</tr>
<tr>
<td>5</td>
<td>Fisheries Site</td>
<td>0.3</td>
<td>0.08%</td>
</tr>
<tr>
<td>6</td>
<td>Harbour</td>
<td>0.35</td>
<td>0.10%</td>
</tr>
<tr>
<td>7</td>
<td>Important Natural Resource 1</td>
<td>24</td>
<td>6.58%</td>
</tr>
<tr>
<td>8</td>
<td>Mawasi</td>
<td>14.5</td>
<td>3.97%</td>
</tr>
<tr>
<td>9</td>
<td>Natural Resource 2</td>
<td>62</td>
<td>16.99%</td>
</tr>
<tr>
<td>10</td>
<td>Nature Reserve</td>
<td>26.5</td>
<td>7.26%</td>
</tr>
<tr>
<td>11</td>
<td>Proposed Treatment Site</td>
<td>1.1</td>
<td>0.30%</td>
</tr>
<tr>
<td>12</td>
<td>Recreation</td>
<td>6.1</td>
<td>1.67%</td>
</tr>
<tr>
<td>13</td>
<td>Roads</td>
<td>9.8</td>
<td>2.68%</td>
</tr>
<tr>
<td></td>
<td>Total Area</td>
<td>365</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure (19) Major land use sectors in the Gaza Strip.
25% is urbanized. Table 3 and Figure 19 show the distribution of land use in the Gaza Strip based on estimated figures for 2008 and the available literature. About 40% of the land is being used for agriculture, most of which is in the eastern half of Gaza where population densities are low (Figure 3). The land use data were obtained from the analysis of aerial photographs taken in 2008. The industrial sector was discussed in detail in Shomar. With an average population density of 4,091 people/km², Gaza is one of the most densely populated areas in the world. About 80% live in the built-up areas shown on the map.
B. Environmental Hot Spots

In addition to the major pollution point sources of overloaded wastewater treatment plants, unprotected solid waste dumping sites and Wadi Gaza (Figure 21), hot spots appear sporadically in many locations due to Gaza’s inability to maintain adequate infrastructure. For example, frequent electricity outage or blackout causes paralysis of wastewater pumping stations and results in untreated wastewater infiltrating homes and streets. The lack of gasoline and diesel causes solid waste to accumulate in the streets without transportation to the dumping sites.

Figure (21) Environmental hot spots.
**C. Soil Types**

The Gaza Strip has several major soil types (Figure 22) including Arenosolic, Calcaric, Rhegosolic, and Calcaric Fluvisolic soils. Arenosolic (sandy) soils of dune accumulations are Regosols without a marked profile. The soils are moderately calcareous (5-8% CaCO₃), with low organic matter, and are physically suitable for intensive horticulture. Calcaric Arenosols (loessy sandy soils) can be found some 5 km inland in the central and southern part of the Strip, in a zone along Khan Younis toward Rafah, parallel to the coast. This belt forms a transitional zone between the Arenosolic soils and the Calcaric (loess) soils. Typical Calcaric soils are found in the area between the city of Gaza and the Wadi Gaza and contain 8-12% CaCO₃. Arenosolic Calcaric (sandy loess) soils are transitional soils, characterized by a lighter texture.
These soils can be found in the depression between the Calcareous (Kurkar) ridges of Deir El Balah. Apparently, windblown sands have been mixed with Calcareous deposits. Deposition of these two types of windblown materials originating from different sources has occurred over time and more or less simultaneously. These soils have a rather uniform texture. Another transitional form is the Arenosols over Calcaric soils. These are loess or loessial soils (sandy clay loam) that have been covered by a layer (0.20-0.50 m) of dune sand. These soils can be found east of Rafah and Khan Younis. Fluvisols (alluvial) and Vertisols (grumosolic), which are dominated by loamy clay textures, are found on the slopes of the northern depressions between Beit Hanoun and Wadi Gaza. Drilling east of El Montar ridge revealed that alluvial deposits of about 25 m in thickness occur. At some depth, calcareous concentrations are present. The CaCO$_3$ content can be approximately 15-20%. Some of the soils have been strongly eroded, and the reddish-brown sub-soils may be exposed on the tops of ridges and along slopes. The alluvial sediments are underlain by a calcareous layer.

\textit{D. Water Table}

The depth to water table (Figure 23) varies between few meters in the west (very closed to the sea) to about 120m at some locations in the east.

\textbf{Figure (23) Groundwater depth in the Gaza Strip 2008.}
E. Electric Conductivity

With relatively small, localized exceptions, the EC of municipal wells increases from north to south (Figure 24). The lowest EC value was 1,198 μS/cm and the highest was about 3,800 μS/cm. The most deteriorated and salty water was in the eastern regions of Khan Younis and Rafah with an average EC in the private groundwater wells of 5,000 μS/cm.

F. Total Dissolved Solids

Figure 25 illustrates that groundwater in most of the Gaza Strip exceeds the WHO TDS standard, which is 1000 mg/L. The TDS and EC maps show similar patterns as both parameters indicate the concentration of dissolved solids in water. The high TDS value in the eastern parts of Khan Younis (3000-4000 mg/L) makes water in the area undrinkable. More than 50% of the sampled groundwater showed TDS of more than 2000 mg/L.

G. Anions (Chloride, Nitrate, Fluoride and Sulfate)

All wells in Gaza had at least one parameter of Cl⁻, NO₃⁻, F⁻ and SO₄²⁻ exceeding the WHO standards of 250, 50, 1.5 and 250 mg/L, respectively. Chloride concentrations (Figure 26) corresponded to EC. The lowest value of Cl⁻ at a municipal well was 35 mg/L whereas the highest value was 2652 mg/L for a well in Khan Younis. Water meeting the WHO Cl⁻ standard was found
in less than 5% of sample wells, primarily in the northern parts and scattered in more isolated areas in the rest of Gaza.

The map of nitrate (Figure 27) for the year 2008 confirms previous findings that almost 90% of the groundwater wells of the Gaza Strip have NO\textsubscript{3}\textsuperscript{-} concentrations two to eight times higher than the WHO standards.

Except for the north area, the average concentration of fluoride in the groundwater in the Gaza Strip (Figure 28) is higher than the WHO standards (which is 1.5 mg/L). The most fluoride contaminated areas are Khan Younis (average 2.7 mg/L) and Rafah (average 2 mg/L) and this is consistent with the previous study of Shomar et al. The F concentration increases from north to south.

Most of the wells in Gaza have SO\textsubscript{4}\textsuperscript{2-} concentrations exceeding the permissible WHO standard (Figure 29). The highest levels of SO\textsubscript{4}\textsuperscript{2-} were in Khan Younis and the southeast, where the average concentration is 380 mg/L.

**H. Cations (Hardness, Calcium, Magnesium, Sodium and Potassium)**

Most of the cations Ca\textsuperscript{2+}, Mg\textsuperscript{2+}, Na\textsuperscript{+} and K\textsuperscript{+} show concentrations higher than the WHO standards of 50, 30, 200 and 10 mg/L, respectively.

Dissolved calcium and magnesium in water are the two most common minerals that make water “hard”. Based on the water hardness classification of 0 to 60 mgCaCO\textsubscript{3}/L as soft, 61 to 120 mgCaCO\textsubscript{3}/L as moderately hard, 121 to 180 mgCaCO\textsubscript{3}/L as hard, and more than 180 mgCaCO\textsubscript{3}/L as very hard, most groundwater in Gaza is hard to very hard (Figure 30).
As water hardness is determined primarily by Ca\(^{2+}\) and Mg\(^{2+}\), not surprisingly, the areas with highest levels of Ca\(^{2+}\) and Mg\(^{2+}\) (Figures 31 and 32) also have the hardest water. The average concentration of Ca\(^{2+}\) was 93 mg/L while the average concentration of Mg\(^{2+}\) was 48 mg/L. Areas between Gaza and the northern region and middle region wells showed the highest levels of both Ca\(^{2+}\) and Mg\(^{2+}\) and the results were 262 and 128 mg/L, respectively.

The lowest Na\(^+\) levels were found in the north, and the highest levels were in the areas of Khan Younis and Rafah (Figure 33).

Most wells had average value of K\(^+\) that was less than 5 mg/L; however, few wells showed levels of K\(^+\) more than 15 mg/L (Figure 34).

![Figure (28) Sulfate concentrations in the groundwater of the Gaza Strip 2008.](image)

![Figure (29) Fluoride concentrations in the groundwater of the Gaza Strip 2008.](image)

I. Trace Elements (Fe, Cr and Zn)

Total concentrations of Fe, Cr and Zn were detected in all wells of the Gaza Strip at concentrations lower than the WHO standards of 300, 50, and 3000 μg/L, respectively (Figures 35, 36 and 37).

The average concentrations of Fe, Cr and Zn in the groundwater of Gaza were 30, 75 and 15 μg/L, respectively.
Figure (31) Groundwater hardness in the Gaza Strip 2008.

Figure (30) Calcium concentrations in the groundwater of the Gaza Strip 2008.
Figure (32) Sodium concentrations in the groundwater of the Gaza Strip 2008.

Figure (33) Magnesium concentrations in the groundwater of the Gaza Strip 2008.
Figure (35) Potassium concentrations in the groundwater of the Gaza Strip 2008.

Figure (34) Iron concentrations in the groundwater of the Gaza Strip 2008.
Discussions

Deterioration of water quality and water scarcity is perennial problems in the region. As these maps indicate, the problem is particularly acute in Gaza where all groundwater wells have at least one parameter exceeding the WHO standards and about 90% of wells have salinity exceeding the WHO standard of 250 mgCl/L. The Gaza aquifer is impacted by contaminants from seawater intrusion, wastewater, manure and natural occurrence. As the maps illustrate, as one goes from north to south in Gaza, the water quality deteriorates with city of Rafah having the poorest water quality. The U.S. Census Bureau estimates that Gaza’s population is growing at about 4% per year making it among the fastest growing areas in the world. The need for more water to meet the needs of the growing population, a dropping water table and significant challenges in maintaining and improving infrastructure for handling human wastes and managing agricultural and industrial pollutants sets the stage for continued deterioration.

1. Land Use and Environmental Hot-Spots

The sand dunes in Gaza protect the coastal areas against the sea and have a natural water cleaning capacity. This protection, however, is diminishing due to sand being removed without permission and extensive sand quarrying practices in the Gaza Strip. Currently, about 60-80% of the domestic wastewater is discharged into the environment without treatment at the source, after collection from cesspits, through the effluent of the sewer system or at the overloaded treatment plants.
Gaza’s three wastewater treatment plants are outdated and overloaded with excess inflow of wastewater. For example, the largest, south of Gaza City, was designed to treat 42,000 cubic meters (CM) per day, the amount produced by 300,000 people, but now faces a daily in-flow of more than 60,000 CM. As an emergency measure to prevent sewage from overflowing, barely treated wastewater is now piped to the coast, where the dark gray liquid flows along the beach. Additionally, 40% of Gazans are without access to a centralized sewage-disposal system contributing to the burgeoning cesspits. A 40-hectare lake of sewage that has formed in northern Gaza is a menace to people at the surface and to the aquifer beneath.

The treatment plants have been destroyed more than once as a result of the turbulent political situation. Beit-Lahia wastewater treatment plant flooded in March 2007, killing several people, displacing thousands of people, and destroying homes and killing animals. Several groundwater wells in the areas surrounding the waste-water treatment plants have been closed completely due to the presence of fecal coliforms, detergents and elevated nitrate concentrations.

Solid wastes (including sludges) are disposed in dumping sites with no groundwater protection measures and elevated levels of several heavy metals were found in the agricultural wells in the eastern part of Gaza surrounding the central solid waste dumping site.

In the study of Shomar et al., the water quality in the area of Wadi Gaza was seriously contaminated by several pollutants as the Wadi itself is currently polluted with wastewater and illegally dumped solid wastes.

2. Water Table and Groundwater Flow

Depth to water (Figure 23) indicates a regional ground-water flow direction from east to west. The most important source for recharge is the rainfall, which varies annually between 200 mm in the south and 400 mm in the north. Most of rainfall evaporates. The annual recharge varies between 20 and 40 MCM. Another 15 to 35 MCM laterally flows from the eastern boundaries of the Gaza Strip, while irrigation and leaky pipes are estimated to return 40 to 50 MCM, for a total annual recharge of 75 to 125 MCM. The depth to water table generally shows a continuity of groundwater flow from east to west. Lateral inflow is important to the overall water balance in the Gaza Strip. The amounts of lateral inflow and outflow are subject to annual change due to varying hydrogeological parameters and human activities, such as rainfall and pumping. However, average annual groundwater lateral inflow and outflow can be estimated based on different approaches. Since the groundwater level for the area of study is monitored monthly, a groundwater level contour map was created based on the data of the years 2006-2008.

3. Groundwater Quality

The groundwater aquifer’s only natural output is the eight MCM per year that should flow into the Mediterranean, providing a crucial barrier against the intrusion of seawater. Thus, if no more than about 100 MCM were tapped from the aquifer per year, it could last indefinitely. But Gaza’s 4000 wells remove as much as 160 MCM yearly. This estimated 60 MCM annual water deficit is why
the water table is dropping rapidly and currently reaches 13 meters below sea level in some places. Saltwater from the Mediterranean, as well as deeper pockets of brine in the aquifer itself, flow in to fill the gap. As shown in Figure 26 (chloride concentrations), the saltwater intrusion is well under way in much of the region with “hot spots” in the coastal areas and to the south.

The occurrence of saline (brackish) water in both the south and east is most likely due to the fact that the annual rainfall in the south is lower than that in the north (200 and 400 mm, respectively). Also, the unconfined nature of parts of the aquifer in the Gaza Strip suggests an open system (unconfined) for the natural recharge, especially in the dunes area along the Mediterranean coast. The other parts of the aquifer are of a confined to semi-confined nature. Although the structural geology, which may play a significant role in this regard, is neither well documented nor well understood, hydro-geological barriers are assumed to be present, especially in the middle of the Gaza Strip. These barriers separate the two chemical faces in the north and south.

Since most of the wells do not meet all the WHO standards for drinking water, the water in Gaza is currently not suitable for drinking. The accelerating rate of salt-water intrusion alone could make the Gaza aquifer unusable for agriculture, industrial and domestic non-drinking water uses within two or three decades. But there may be far less time available. The aquifer is also being contaminated with a cocktail of pollutants from Gaza’s sewage and agriculture. Given the large numbers of groundwater pollutants, an integrated approach to managing water resources is essential. Such an approach would include conservation, land use regulation, and control of human waste and agricultural and industrial pollutants.

**Conclusions**

1. No groundwater in Gaza meets all WHO drinking water standards and is, therefore, not safe for human consumption.
2. Areas of high nitrate concentrations are found in the vicinity of wastewater discharging areas, solid waste dumping sites and Wadi Gaza. Chloride is elevated in the coastal areas as a result of seawater intrusion and in the eastern areas as a result of upcoming and over pumping. Areas naturally contaminated with high concentrations of F−, Ca2+, Mg2+ and SO42− occur as expected due to the underlying soil chemistry, geology and hydrogeology.
3. Integrating environmental and related data using GIS and using maps to illustrate areas of contamination can facilitate the development of an integrated approach toward groundwater protection in Gaza. Minimally, such an approach needs to include management of land use, wastewater and solid waste disposal, monitoring groundwater contamination, and regulating groundwater use.
4. Geography, politics, and war are conspiring to make the Gaza Strip a worst-case scenario for water-resource planners. Without immediate action, water that is currently unfit for human consumption will not be suitable for other uses likely.
Conclusion and comment

After all of that we have describe we can say that the GIS is the century decision making tool, that can help decision makers to develop many scenarios for specific topic and it can direct them to choose the best scenario which can save the time and cost.
REFERENCES:


