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## **GIS Based System for Evaluating Groundwater Quality in the Gaza Strip**

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**DEDICATION**

To  
**My Beloved Parents**

My Little Motivators  
**Amal and Nour**

Brothers **Farid, Mohammed** and Sister **Sana**

**and**

**My Wife**

## ABSTRACT

Problems in Gaza water supply and sanitation have recently reached crisis levels, and are largely connected to the deteriorating economical, political and security situations. The potable water supply in the Gaza Strip will be depleted in 5-10 years.

This calls for strengthening the Palestinian Environmental Programmes by adaptation of sustainability which is rapidly becoming a key decision driver in local and regional planning, while planning is based on information, more than 80 percent of information is geographically referenced, as faced with an overabundance of raw information, Gaza water planners are awakening to the value of geographic analysis and spatial visualization.

Inclusion of information technology as part of the tools for WRM is becoming a necessity using the advances in computer technologies which made geographic information services a reachable goal, based on resources such as the MapWinGIS to support GIS functions in totally unique GIS-enabled applications, this will increase the quality of information provided to WRM and decision-makers, thus development of a tailored, process-based GIS application will be of great help.

This application product is a prototype developed, using Visual Basic, map objects and map files generated from ARCInfo. It has a set of menus and buttons with which managers may query the geographic database. In this instance, data files supplied by CMWU have been integrated with the map files prepared by PWA into a geographic database. Monitoring of chloride as water quality indicator with respect to current practices may then be followed while information accessed by managers as well as decision-makers can be updated.

The easier it is to extend a GIS platform, the more usable it will be for scientists and engineers who are not programmers. Thus, providing spatial solutions needs to be domain-specific and easy-to-use through incorporating the power of a comprehensive GIS into a user-friendly experience.

## ملخص الدراسة

المشاكل التي يعاني منها قطاع غزة في مجالي المياه و الصرف الصحي قد وصلت إلى مستويات خطيرة، مرتبطاً ذلك بشكل أساسي بالإقتصاد المهترئ إلى جانب الوضع السياسي و الأمني. مصادر المياه الصالحة للإستخدام الآدمي سوف تنضب خلال 5 - 10 سنوات.

يدعونا ذلك إلى تقوية البرامج البيئية الفلسطينية بتبني مبدأ الإستدامة التي أصبحت محرك أساسي للتخطيط محليا وعالميا، و حيث أن التخطيط يعتمد على المعلومات فإن 80 بالمائة من المعلومات هي ذات بعد جغرافي، و بمواجهة الكم الكبير من المعلومات فإن مسؤولي التخطيط في غزة على وعي متنامي لأهمية التحليل و التقييم الجغرافي لهذه المعلومات.

دمج تكنولوجيا المعلومات كإحدى الأدوات لمسؤولي مصادر المياه أصبح ضرورة باستخدام التقدم في تكنولوجيا الحوسبة الذي جعل الحلول البرمجية المعدلة عل أساس جغرافي عبارة عن هدف ممكن الوصول إليه، بالإعتماد على موارد مثل MapWinGIS لتوفير إمكانات نظم المعلومات الجغرافي في تطبيقات متخصصة و مستقلة. هذا سوف يرفع من مستوى دقة المعلومات التي يتم توفيرها لمسؤولي مصادر المياه و متخذي القرار، لذلك تطوير نظام موجه مبني على نظم المعلومات الجغرافي سوف يكون ذو منفعة كبيرة.

هذا التطبيق هو نموذج مصغر تم تطويره باستخدام لغة البرمجة Microsoft Visual Basic و عناصر دعم الخرائط، إلى جانب خرائط مستخرجة باستخدام ArcInfo. يشمل النظام مجموعة من القوائم و المفاتيح التي تتيح لمسؤولي هذا القطاع الإستعلام من خلال قاعدة البيانات الجغرافية. من هذا المنطلق، فإن البيانات و الملفات المزودة من مصلحة مياه الساحل و الخرائط التي تم تطويرها سابقا عن طريق سلطة المياه وضعت جميعا في قاعدة بيانات جغرافية واحدة. بحيث تكون متابعة الكلورايد كمؤشر لجودة المياه أخذا في الإعتبار السياسات الحالية شيئا ممكنا مع المحافظة على البيانات المضطع عليها من مسؤولي قطاع المياه. بمن فيهم صناع القرار محدثة.

كلما كان إطار هذا النظام سهلا كلما زاد استخدامه من طرف المهندسين و الباحثين من غير المبرمجين. لذلك تطوير حلول على أساس جغرافي يجب أن يعتمد على قطاعات مركزة شاملا قوة هذا النظام في إطار سهل للمستخدم.

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## LIST OF ABBREVIATIONS

<b>ADO</b>	ActiveX Data Objects: A data access interface that communicates with OLE DB-compliant data sources to connect to, retrieve, manipulate, and update data).
<b>AI</b>	Artificial Intelligence
<b>APIs</b>	Application Programmer Interfaces
<b>CL</b>	Chloride
<b>CMWU</b>	Coastal Municipalities Water Utility
<b>ES</b>	Expert System
<b>ESRI</b>	Environmental Systems Research Institute
<b>GIS</b>	Geographic Information System
<b>GRASS</b>	Geographic Resources Analysis Support System
<b>IAWQ</b>	Indexed Assessment of an aquifer's Water Quality
<b>KBS</b>	Knowledge-Based System
<b>KS</b>	Knowledge System
<b>MCL</b>	Maximum Concentrations Limits
<b>MCM</b>	Million Cubic Meters
<b>Mo Object</b>	MapObjects
<b>MoA</b>	Ministry of Agriculture
<b>MoLG</b>	Ministry of Local Government
<b>NO<sub>3</sub></b>	Nitrate
<b>NWC</b>	National Water Council
<b>OCHA</b>	Office for the Coordination of Humanitarian Affairs
<b>OCX</b>	OCX or ActiveX control is implemented as a dynamic link library DLL module. (One can think of a DLL program as a "subprogram" that can be used by any number of application programs.
<b>ODBC</b>	(Open Database Connectivity) A standard protocol that permits applications to connect to a variety of external database servers or files.
<b>ODBC driver</b>	A dynamic-link library (DLL) used to connect a specific Open Database Connectivity data source with another (client) application.
<b>oPT</b>	occupied Palestinian Authority
<b>PA</b>	Palestinian Authority
<b>PCBS</b>	Palestinian Central Bureau of Statistics
<b>PWA</b>	Palestinian Water Authority
<b>RAD</b>	Rapid Application Development
<b>SSE</b>	Sum of Square Errors
<b>SQL</b>	Structured Query Language, such as SELECT, UPDATE, or DELETE.
<b>TDS</b>	Total Dissolved Solids
<b>UWRL</b>	Utah Water Research Lab
<b>VBA</b>	Visual Basic for Applications
<b>VPN</b>	Virtual Private Network
<b>WAN</b>	Wide Area Network
<b>WBGS</b>	West Bank and Gaza Strip
<b>WHO</b>	World Health Organization
<b>WRM</b>	Water resources manager
<b>WYSIWYG</b>	What You See Is What You Get

## CHAPTER (1): INTRODUCTION

### 1.1. General Background

No new sources have been officially developed in Gaza since Oslo II and heavy over drafting of groundwater has led to groundwater quality decline and seawater intrusion. Only 5-10% of the aquifer is now yielding drinking quality water. The population has responded to water shortages with private well drilling and desalination for domestic supply purposes [1], adding that every year Gaza is extracting more than what it is injecting via rainfall and lateral/vertical groundwater flows into the aquifer.

The salinization of the near shore inland aquifers by infiltrating seawater represents a world wide phenomenon. It becomes a problem in coastal regions such as Gaza where inland fresh groundwaters are hydraulically connected with seawater, additional to the groundwater nitrate problem that is also an international in scope, and local in Gaza, this is due to the fact that Nitrate is not easy to detect and excessive concentrations of nitrate can cause ecological damage and health hazards.

Accordingly, management of limited groundwater resources in such situations is a delicate task and requires special attention.

Geographic Information System (GIS) can be defined as a system for entering, storing, manipulating, analyzing, and displaying geographic or spatial data. The development of Geographic Information Systems GIS is highly influenced by the evolution of information technology; the paradigm of GIS is shifting. Traditional GIS systems provide capabilities to handle georeferenced data, including data input, storage, retrieval, management, manipulation, analysis, and output. However, with closed and centralized legacy architecture, current GIS systems cannot fully accommodate distributed, diverse network environments due to their lack of interoperability, modularity, and flexibility. With advances in computer networking technologies, a distributed geographic information services paradigm becomes a reachable goal [2].

To provide spatial solutions to non-GIS users, developers need the ability to build domain specific, easy-to-use applications that can incorporate the power of a comprehensive GIS

into a user-friendly experience. These applications, if built from scratch, can be an overwhelming development effort and may be time consuming and not cost-effective.

Assessment of current situation of GIS application through out Gaza water resources associations and facilities indicates shortage in means of data manipulation, it became clear also that water resources managers and municipalities' officers are not all familiar with sophisticated applications in GIS such as ArcMap 9 series versions, and do not have much time to learn the GIS software. To develop the application screens, the design of the GIS prototype has therefore been focused on spatial data query, display, with the fact that no prerequisite knowledge of GIS is necessary.

## **1.2. The looming water crisis in Gaza**

Different factors are contributing to the situation of poor quality in Gaza, these are:

### **1.2.1 Climate change, population growth**

The decrease in useable water reserves has also been linked to climatic changes, such as lower rainfall, which have slowed the recharge rate of the aquifer. Other factors are a rapid population growth and increasing suburban sprawl, leaving little space for rainwater catchment areas. Gaza is one of the most densely populated places on earth with 1.6 million Palestinians living in 365 km<sup>2</sup>. Its population is expected to increase by 85 percent to close to three million by 2025 [3].

Desperate to secure safe water resources, the population has responded by drilling private wells - many of them unlicensed - which have further contributed to the degradation of the aquifer, according to the World Bank. The Palestinian Water Authority (PWA), which formulates water policies for the territories, has been effectively suspended in Gaza, as it is a governmental institution of the Palestinian Authority (PA) in the West Bank.

### **1.2.2 Israeli “trap wells” allegation**

“Unlike the West Bank, Gaza is ‘downstream’ of the portion of the aquifer that lies beneath Israel, with lateral groundwater flows coming from Israel into the Gaza portion of the aquifer,” CMWU. “The groundwater underneath Gaza is becoming limited due to Israel’s construction of trap wells [about 27 wells] inside Israel, along Gaza’s eastern political border, siphoning water supplies from the aquifer before they reach Gaza.”

According to the Israeli Water Authority, the Gaza aquifer has no impact on Israel and Israel does not prevent the flow of surface water or groundwater to the Gaza aquifer [3].

### **1.2.3 Blockade**

Since 2005, Gaza's water supply has also been affected by restricted access to power, fuel and spare parts, [1]. Equipment and supplies needed for the construction, maintenance and operation of water and sanitation facilities have been denied entry to Gaza

“Fifty percent of Gaza households use septic tanks to dispose of sewage,” CMWU. “Materials used to line and insulate the septic tanks are unavailable due to the closures.” Water and sanitation conditions worsened further during and after Israel's 23-day offensive which ended on 18 January 2009, due to infrastructure damage. About 10,000 Gaza residents do not have taps in or near their homes and an additional 60 percent of the population - about one million people - do not have continuous access to water, CMWU. Gaza has a master plan for water and sanitation but less than 2 percent of it has been implemented because of the Israeli blockade. Even small relief projects have had to be abandoned due to a lack of materials [3].

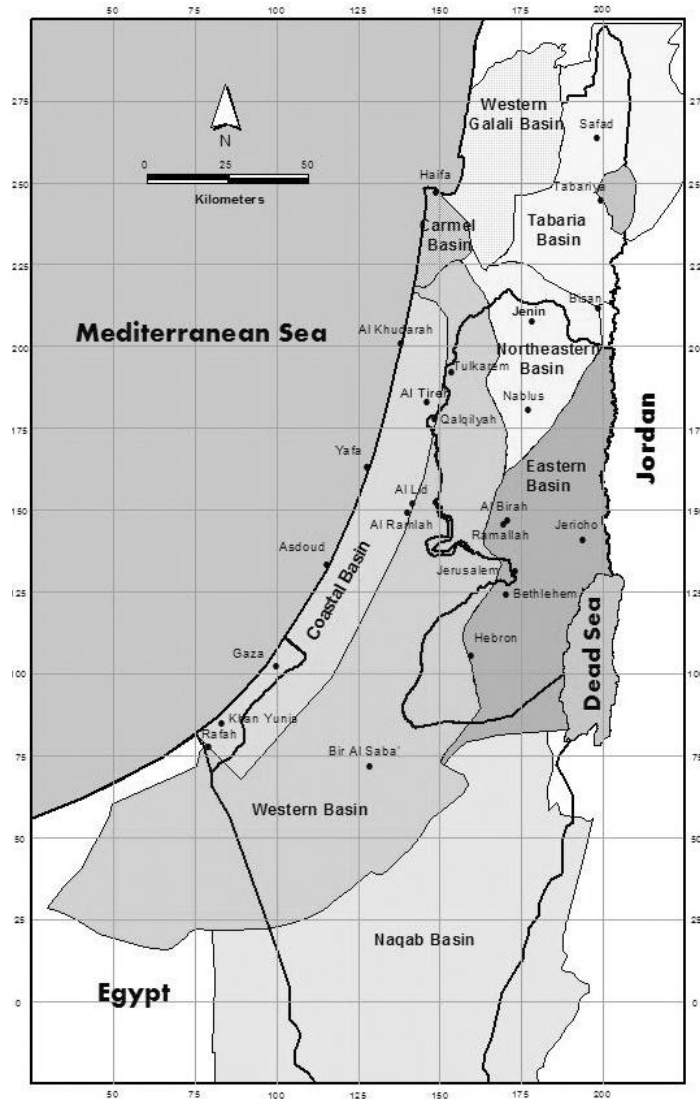
## **1.3 The water resource situation in Gaza**

Gaza's coastal aquifer extends from Haifa in the north to the Sinai desert in the south, and from Mt Hebron in the east to the Mediterranean in the west (Gaza's coastline), Figure 1.1, [1].

The resource is overdrawn and needs to be returned to sustainable levels of extraction. The sole fresh water resource of Gaza is the coastal aquifer, which also runs beneath the coast of Israel. In contrast to the West Bank situation, Palestinian Gaza is “downstream” of the portion of the aquifer that underlies Israel, with flows coming from Israel into the Gaza portion of the aquifer. With normal flows, the current sustainable yield of the aquifer segment underlying Gaza is estimated at about 57 MCM, around 15% of the total yield of the shared aquifer, which is estimated at 360-420 MCM. Abstractions in recent years have been running well above any estimate of sustainable yield. The overdraft is currently (2008) estimated at 100 MCM, almost 200%. As a result, there has been a continual decline in the static water level, water quality has been deteriorating, and there is an increase of seawater intrusion. Now 5-10% of the portion of the aquifer underlying Gaza is



drinkable, with more than 90% of all 150 municipal wells having salt and nitrate levels above WHO standards and so unfit for human consumption. [1]



**Figure 1-1.** Map of shared and non shared groundwater aquifers, [1].

#### **1.4 The water supply situation in Gaza**

Water quality is very poor and small scale desalination – largely private – has emerged as a stop-gap solution. A major problem is water quality, with high concentrations of salts and nitrates, compounds that are difficult and costly to remove from drinking water supplies. Between 5% and 10% of water supplied through the network meets potable standards. The poor quality is linked to aquifer overdraft, and to pollution from wastewater seepage and infiltration of agricultural fertilizers. As a coping strategy, the Gaza market has responded by providing private desalination. There are at least 40 private desalination plants selling

both wholesale by tanker and retail by jerry can, producing about 2,000 m<sup>3</sup> a day. There are also estimated to be more than 20,000 home desalination plants. The feedstock is brackish water from wells. Prices are high: NIS 50/m<sup>3</sup>, but there is no choice. Private production supplements the four public desalination plants run by CMWU (the regional water utility) that produce 1,000 m<sup>3</sup>/day. Now almost everyone who can depends on brackish water desalination for drinking [1].

## **1.5 Problem statement**

Decision-makers in the Gaza strip and non-technical water managers in water resources management and more specifically in ground water quality assessment usually face difficulties in dealing with sophisticated tools of information such as Geographical Information System (GIS) through its adopted applications such as ArcMap, ArcView, Geomedia Professional and other applications that could possibly be used locally.

Custom open GIS applications could act as Decision Support System (DSS) and to some extent as a Spatial Decision Support System (SDSS) which is a computer-based system designed to assist decision system. Typically, such a system will include spatial data relevant to the decision. Expert Systems (ES) are also used to assist decision maker in achieving their goals through proper manipulation of data available.

This lack of an easy-to-use tools in addition to the worsening situation of the ground water available in Gaza through its coastal aquifer, led to management difficulties despite of the availability of large set of data on water related parameters and factors.

## **1.6 Justification of the research**

### **1.6.1 Gaza current situation in water resources development and management**

No new sources have been officially developed in Gaza since Oslo II and heavy over drafting of groundwater has led to groundwater quality decline and seawater intrusion. Only 5-10% of the aquifer is now yielding drinking quality water [3]. The population has responded to water shortages with private well drilling and desalination for domestic supply purposes. The two principal causes of the impacts described above are:

- Failings in water resources development and management that have contributed to the low and declining per capita water resource availability; and

- The low investment rates and weak management of water services that have led to poor access, high costs and negative health and environmental impacts.

Failings in water resources development and management have contributed to the low and declining per capita water resource availability and to inadequate development of new water resources; and sub-optimal management of developed water sources [1].

### **1.6.2 Importance of the research**

Contamination of drinking water has become a major challenge to the Environmentalist in the Gaza, where more and more people are exposed to contamination of drinking water, many issues arise that not only involve premeditating the contaminated water, but also preventing similar situations from occurring in the future.

Supporting applications in the field of water quality are essential tools towards correct assessment of the situation and hence correct decision being made after that, thus, helping to achieve sustainable and balanced system of utilizing current available resources.

By developing an expert system for decision makers and a software by which large number of data can be handled in a user friendly manner, this is needed and possible through out the development of an easy-to-use tool answering specific needs concerning specific water quality parameters is essential especially that the spatial extent of information in use is presented effectively in the application [6].

## **1.7 Research objective and anticipated outputs**

### **1.7.1. Research objectives**

- Making GIS products more affordable and not confined to the exclusive environment of professional GIS software, which is usually quite costly, and requires training and skills.
- Developing an easy-to-use GIS based application that should have a friendly user interface enabling non-technical users maneuvering through indicator parameters of groundwater quality.
- Introducing the use of GIS open source libraries i.e. MapWindow GIS that is commonly used worldwide in different custom applications for the Spatial Decision Support System SDSS that provides the use of selected features from GIS applications

such as spatial distribution , accompanied with very rich set of database and elaborating tools such as charts, diagrams, tables to allow the user to maneuver over large amount of data

- Providing a tool for assessing Chloride (Cl<sup>-</sup>) and Nitrate (NO<sub>3</sub><sup>-</sup>) occurrence and variation from WHO guidelines and limits.
- Assessing groundwater quality based on available data set.
- To some extent, providing a prediction tool for expected future concentrations of parameters.

### **1.7.2. Anticipated outputs**

Anticipated application outputs:

1. Information tool (spatially presented and previewed data)
2. evaluation tool for water quality based on indicators through a time-series approach
3. preview thematic map of ground water quality,
4. Providing a forecast tool for future scenarios and situation based on current trend of change of existing time-series data.

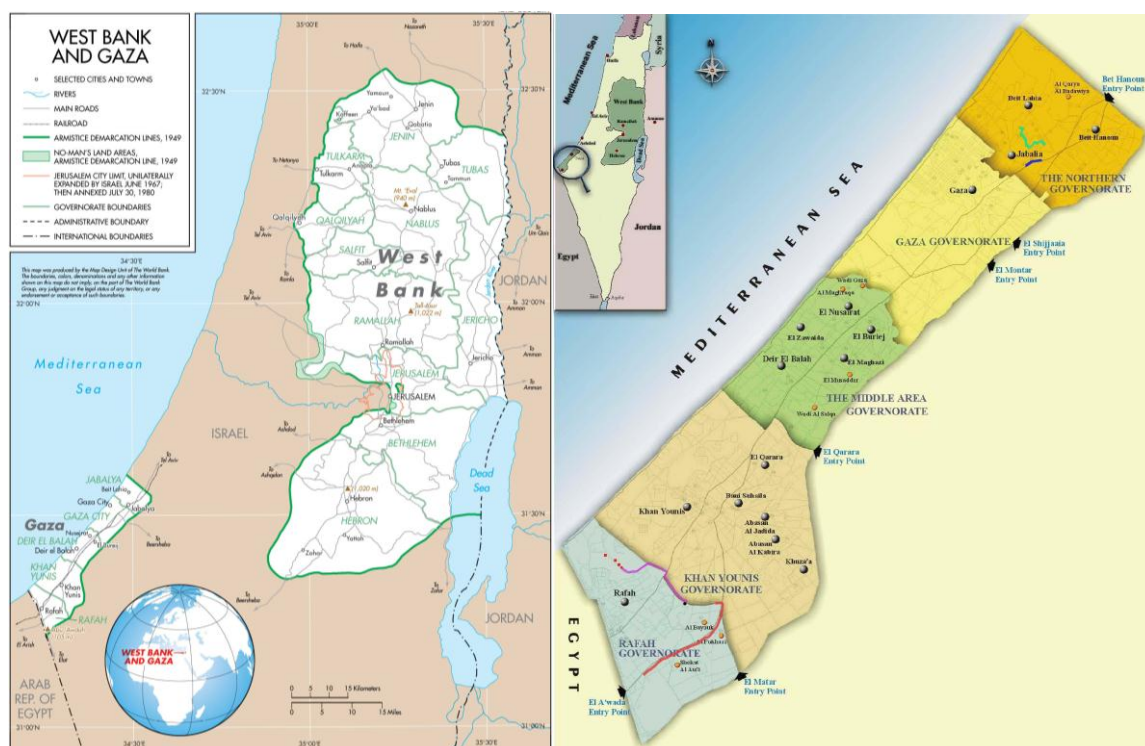
## **1.8 Area of Study**

### **1.8.1 Location and Population**

The Gaza strip is located in the southeastern coast of Palestine with Longitude of 34:21:38 E and Latitude of 31:29:45 N. The area is bounded by the Mediterranean in the west, the 1948 cease-fire line in the north and east and by Egypt in the south (Figure 1.2). The total area of the Gaza strip is 365 km<sup>2</sup> with approximately 40 km long and the width varies from 8 km in the north to 14 km in the south, shown in figure 1.2 [7].

### **1.8.2 Demography**

The population in Gaza strip has reached about 1.8 million in the year 2010 with an annual growth rate of 3.9%. The average population density is almost 2297 person/km<sup>2</sup>. The population density in the refugee camps of the Gaza Governorates ranges from 29 to 100 thousands person/km<sup>2</sup> in the Beach camp, Table 1.1 shows the revised estimates of the population projection in Gaza strip as given by PCBS 2009 [8].



**Figure 1-2.** Gaza strip

**Table 1-1.** PCBS, Population Growth in West Bank and Gaza (2000 to 2025)

Year	West Bank	Gaza	Total
2000	2,017	1,142	3,159
2005	2,541	1,472	4,013
2010	3,061	1,868	4,929
2015	3,517	2,241	5,758
2020	3,962	2,618	6,580
2025	4,409	2,993	7,402

NOTES: Key assumptions—Mortality: Infant mortality rate will decrease by 50 percent between 1995 and 2025 and life expectancy at birth will increase by 6 percent. Migration: Net migration into the Palestinian territories will total 500,000 between 1997 and 2011. Net migration between 2011 and 2025 is assumed to be zero. Fertility: The total fertility rate will decline by 50 percent by 2025.

### 1.8.3 Gaza strip geographical aspect

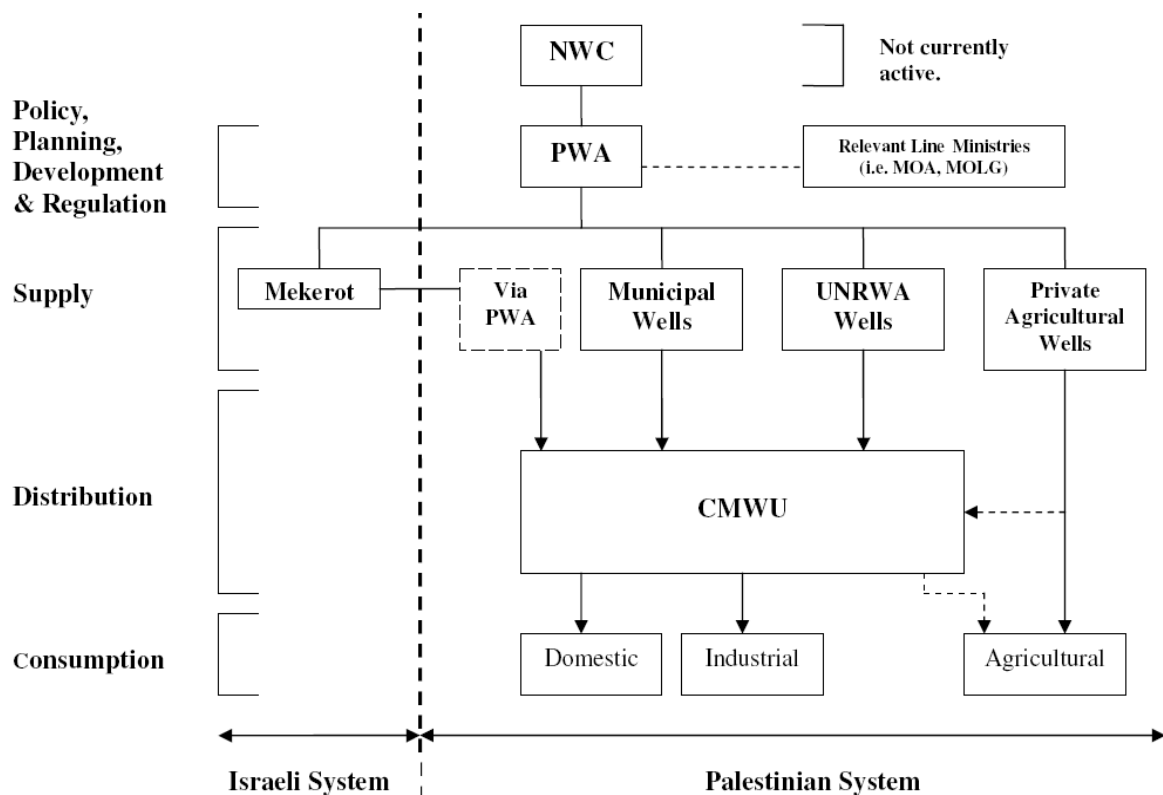
The Gaza strip consists of five Governorates; Northern, Gaza, Middle, Khan Yunis and Rafah. The municipalities or the village councils are responsible for public services, where CMWU and MoLG take the coordination role between the different municipalities and village councils concerning water and sanitation works.

### 1.8.4 Water supply institutions

The key institutional constraint in water supply remains the “jungle of providers”. The basic institutional constraint to improving water supply services has long been identified—the plethora of several hundred organizations, large and small, lacking economy of scale and sourcing water haphazardly. To counter these problems, stakeholders agreed on a new institutional architecture with: (1) PWA as regulator and resource manager; (2) a bulk water supplier (and single interface with Mekorot); and (3) four regional utilities grouping the current suppliers together both institutionally and physically (via bulk connections) [19].

### 1.8.5 Water Institutional Arrangement in Gaza

PWA operations – and water resource management - in Gaza are effectively suspended. PWA developed a relatively strong presence in Gaza, which is now effectively suspended. As a result, PWA’s regulatory function is in abeyance and unlicensed wells are proliferating. The political situation has reduced the effective linkages with Ramallah. Water institutional arrangement is shown in figure 1.4:



**Figure 1-3.** Existing Institutional Arrangement of Water Sector in Gaza [1]

Gaza's CWMU is the most advanced of the regional utilities and some benefits have been won, but the model is now vulnerable to the political and economic situation. Since 1996, work has been going on to create the CWMU, and there are already some gains from the model. Although the recent crises have led some municipalities to hesitate, stakeholder views on the CWMU remain cautiously positive and management say there is still determination that the model will work. However, it cannot function properly under the current crisis situation and hence remains essentially still under test [1].

## **1.9 Scope of the study and logical framework**

The study approach is following this logical framework towards achieving its objectives:

1. Sustainability as common concept for development.
2. Introducing GIS as a technology that should be integrated in water resources system more efficiently in Gaza.
3. Custom GIS applications as new trend that proved its efficiency worldwide.
4. Introducing main parameters governing water quality in Gaza.
5. Describing the logic behind utilizing programming capabilities in integrating mapping and spatial features and rich databases and presentation tools in one platform, easy-to-use and affordable.
6. Discussing practical application of this development into water resources concerned agency (s), i.e. CMWU. Logical frame work for the GIS-Based system development is shown in figure 1.5.

## **1.10 Summary of Methodology**

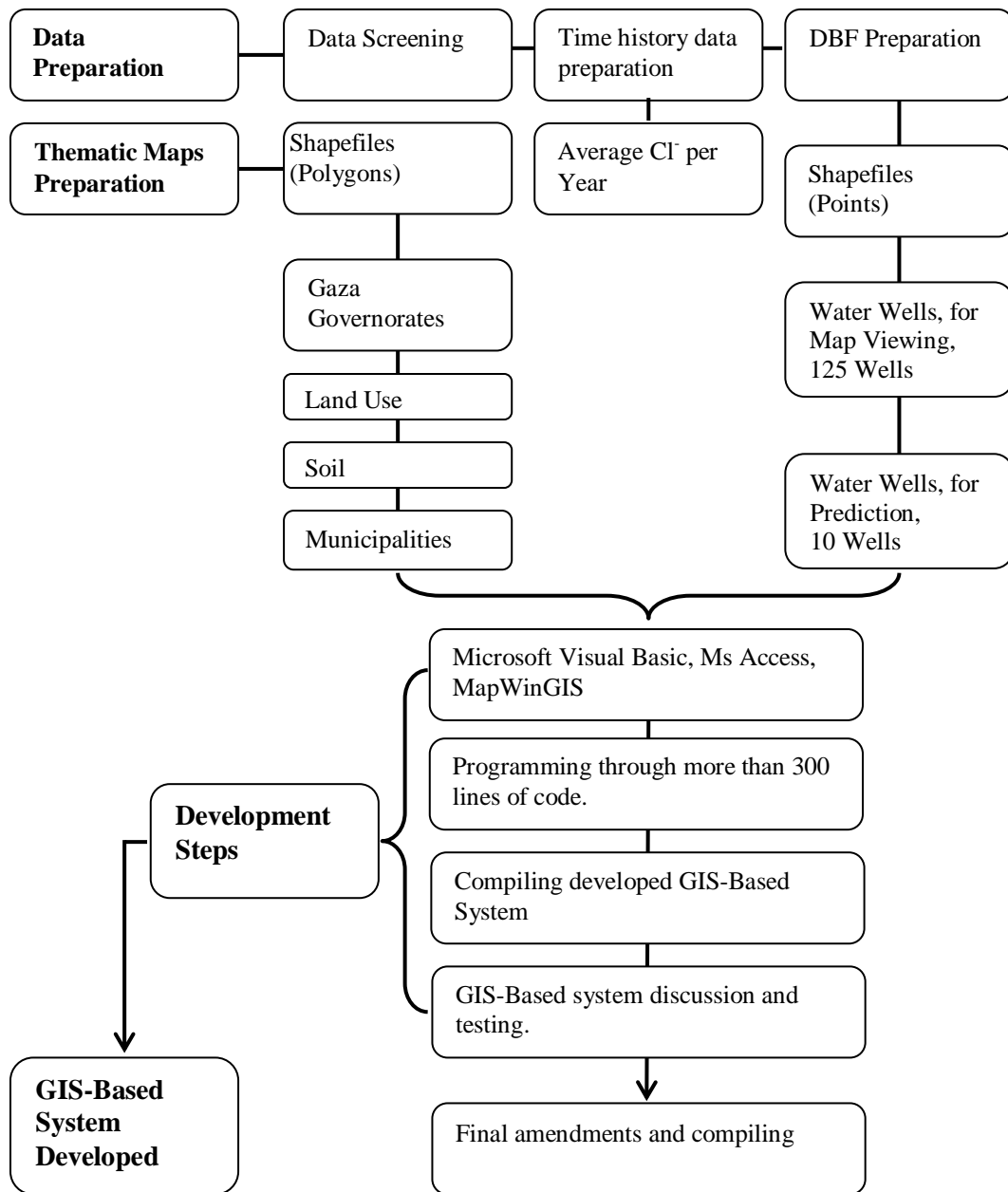
### **1.10.1 Data collection phase**

Data records on monitored chloride parameter over the past decade will be collected from the Palestinian Water Authority (PWA). This data will be based on test results for  $\text{Cl}^-$  and  $\text{NO}_3^-$  for variety of water wells across the Gaza strip (municipal and agricultural).

### **1.10.2 Tools**

Required set of tools needed for this research, included:

- ArcMAP 9.1 (From ESRI)
- Microsoft Visual Basic 6, (From Microsoft)
- MapwinGIS.ocx (Open SourceGIS), and
- Microsoft Access as database engine (From Microsoft).



**Figure 1-4.** GIS-Based system development logical framework.

### 1.10.3 Thematic maps:

Based on available data, thematic maps describing parameters such as landuse, soil and municipal, have been prepared in addition to allocating the locations of water wells as points shape file.

### 1.10.4 Application Structuring and development

At this stage tools should be ready accompanied with filtered and screened set of data and information to precede with developing the application, following is an illustration of the components used within the Microsoft Visual Basic control container as inputs to the container and then output as the developed system, figure 1.6.



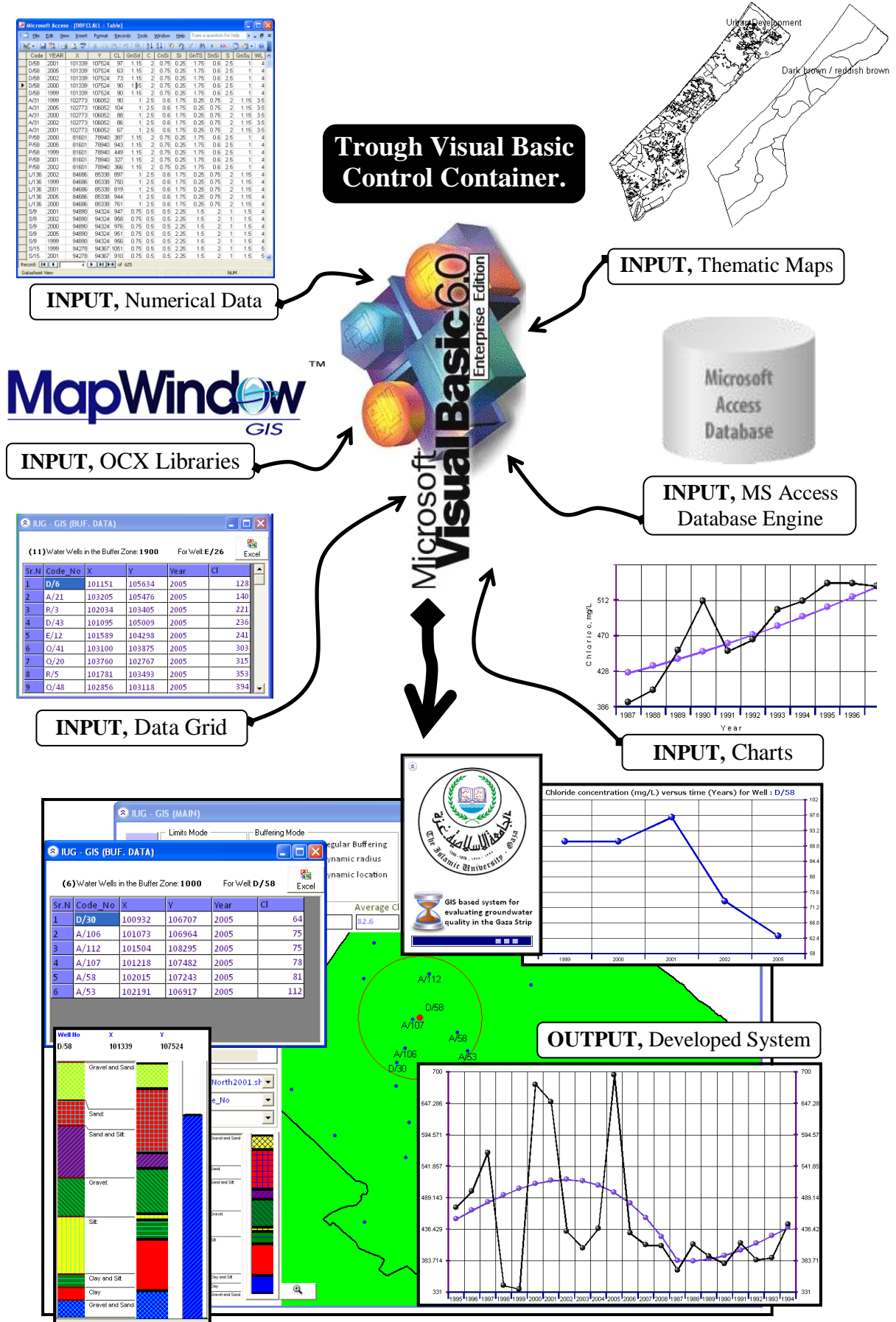


Figure 1-5. System components, Inputs and Outputs

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#### **1.10.5. Application testing and evaluation**

It is intended to introduce the application to water resources managers in the PWA, but due to recent prevailing situation, CMWU (through its planning and GIS unit) will be consulted to measure the effectiveness with regard to its intended use; this will be as an evaluation of the application where comments and suggestion will be considered for a final version.

#### **1.11 Conclusion**

Through the chapter, problem and research justification outlined enabling definition of main outputs and objectives, additional to system components and development methodology covering the tools and methods used.

## **CHAPTER (2): LITERATURE REVIEW**

### **2.1 Introduction**

More than 80 percent of all the information used by local governments is geographically referenced. A key element of the information is its location relative to geographic features, other objects, established boundaries, etc. An information system is a framework by which to ask questions and obtain answers from a data resource. A Geographic Information System (GIS) is a special type of information system in which the database consists of observations on spatially distributed features and procedures to collect, store, retrieve, analyze, and display such geographic data. In the past decade, powerful workstations and sophisticated software combined to bring mapping capability to any desktop. In the last five years, computers have become so powerful that GIS and mapping software will now run on off-the-shelf PCs. Once the province of cartographers and CAD technicians, desktop mapping and GIS are ready to infiltrate almost all areas of water, wastewater, and stormwater system management. The time has come for all the civil engineers involved in the planning, design, construction, and operation of water, wastewater, and stormwater systems to benefit from one of the most promising and exciting technologies of the decade in their profession – the use of GIS [9].

Geographic Information Systems have become popular item on the wish list of municipalities and water agencies [10].

Coupled with custom GIS applications needs, comes then the Sustainability, which is defined in many different ways, but in general it refers to the concept that resources are managed in a way that establishes a long-term balance between production and consumption of those resources, and that production can be maintained at levels that ensure the viability of the underlying resource.

Sustainability in terms of water resources is not only achieved by allocating enough resources and quantities, but moreover, sources with acceptable quality standards are essential to achieve the concept of sustainability.

Before exploring more in the sustainability, one should address the expert systems that are of importance in linking GIS to sustainability terms.

Expert Systems (ES), also called Knowledge-Based Systems (KBS) or simply Knowledge Systems (KS), are computer programs that use expertise to assist people in performing a wide variety of functions, including diagnosis, planning, scheduling and design [11].

## **2.2 Expert Systems and Artificial Intelligence**

### **2.2.1 Expert Systems (ESs)**

ESs are computer programs that are derived from a branch of computer science research called Artificial Intelligence (AI). AI's scientific goal is to understand intelligence by building computer programs that exhibit intelligent behavior [11].

Building an expert system is known as knowledge engineering and its practitioners are called knowledge engineers. The knowledge engineer must make sure that the computer has all the knowledge needed to solve a problem. The knowledge engineer must choose one or more forms in which to represent the required knowledge as symbol patterns in the memory of the computer, that is, he (or she) must choose a knowledge representation. He must also ensure that the computer can use the knowledge efficiently by selecting from a handful of reasoning methods.

Every expert system consists of two principal parts: the knowledge base; and the reasoning, or inference, engine.

The problem-solving model, or paradigm, organizes and controls the steps taken to solve the problem. One common but powerful paradigm involves chaining of IF-THEN rules to form a line of reasoning. If the chaining starts from a set of conditions and moves toward some conclusion, the method is called forward chaining. If the conclusion is known (for example, a goal to be achieved) but the path to that conclusion is not known, then reasoning backwards is called for, and the method is backward chaining. These problem-solving methods are built into program modules called inference engines or inference procedures that manipulate and use knowledge to form a line of reasoning [11].

The most important ingredient in any expert system is knowledge. The power of expert systems resides in the specific, high-quality knowledge they contain about task domains.

### 2.2.2 Benefits to End Users

Primarily, the benefits of ESs to end users include:

- A speed-up of human professional or semi-professional work, typically by a factor of ten and sometimes by a factor of a hundred or more.
- Within companies, major internal cost savings. For small systems, savings are sometimes in the tens or hundreds of thousands of dollars; but for large systems, often in the tens of millions of dollars and as high as hundreds of millions of dollars. These cost savings are a result of quality improvement, a major motivation for employing expert system technology.
- Improved quality of decision making. In some cases, the quality or correctness of decisions evaluated after the fact show a ten-fold improvement.
- Preservation of scarce expertise. ESs are used to preserve scarce know-how in organizations, to capture the expertise of individuals who are retiring, and to preserve corporate know-how so that it can be widely distributed to other factories, offices or plants of the company.
- Introduction of new products. A good example of a new product is a pathology advisor sold to clinical pathologists in hospitals to assist in the diagnosis of diseased tissue.

### 2.3 Sustainability

Sustainable development, as presently understood, had its origin in the World Conservation Strategy. This strategy sets out some now widely accepted principles of environmental sustainability and identified three essential life support systems: soil, air and water.

Water resources projects are sustainable, if water of sufficient quantity and quality at acceptable prices is available to meet demands and quality standards of the region now and in the future without causing the environment to deteriorate.

Water resources come from systems which include rivers, lakes, wetlands and aquifers. The planning for utilization of these resources must be considered in association with their functions in the hydrological cycle and their interactions with the physical, chemical and biological processes in terrestrial ecosystems. Planning and decision making for groundwater development is a continuous dynamic process.

When one addresses the question of sustainable development, the objectives and concerns of development will change over time and the development planning must adjust with the changing conditions. Short term socio-economic gains may have to be traded with long term sustainability, with its varied dimensions. [12].

## **2.4 Principles of Sustainable Groundwater Development**

The goal of environmentally sound and sustainable development of water resources is to develop and manage them in such a way that the resource base is maintained and enhanced over the long term. Groundwater development begins typically with a few pumping wells and initially the groundwater management practice, in many cases, is geared to facilitate usage and development. As development progresses with more and more drilled wells scattered over the basin, issues such as overexploitation, equitable sharing of water and degradation of water quality become apparent in many basins. Thus, the emphasis of groundwater management practice has to be changed so that the available resource is utilized in an efficient, sustainable and equitable manner contributing to the economic and social well being of the broader community. A sustainable groundwater development depends on the understanding of processes in the aquifer system, quantitative and qualitative monitoring of the resource and the interaction with land and surface water development. The following key principles reflect different aspects of concern in the evolution of sustainability in groundwater development:

- (a) Long term conservation of groundwater resources;
- (b) Protection of groundwater quality from significant degradation; and
- (c) Consideration of environmental impacts of groundwater development [12].

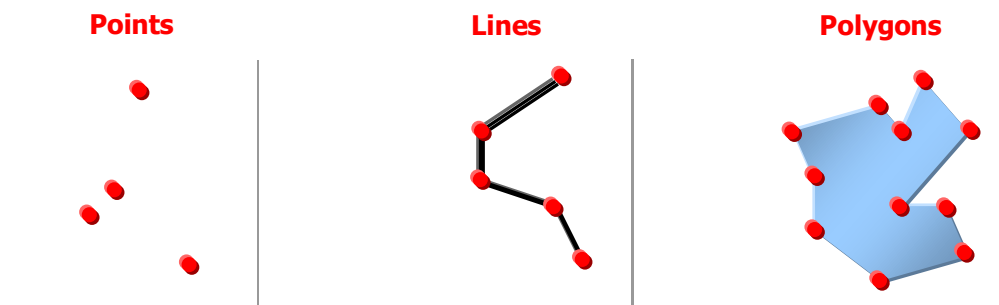
## **2.5 Protection of groundwater quality**

Contamination should be prevented. Successful prevention means that the potential contaminants must be controlled so that they cannot react with the groundwater system. Land use planning is a major form of prevention in which the producers of hazardous wastes are kept away from the areas overlying groundwater resources so that in the event of an accidental leakage, little damage will occur. Once contamination of a local groundwater supply has occurred, action must be taken to find and eliminate the sources, contain the contaminants in the area already affected and restore the water quality of the aquifer [12].

GIS based tools and systems contributing much to having the landuse planning aspect managed properly.

## 2.6 The Geographic Information System (GIS)

A Geographic Information System (GIS) can be defined as a system for entering, storing, manipulating, analyzing, and displaying geographic or spatial data. These data are represented by points, lines, and polygons (Figure 2.1) along with their associated attributes (i.e., characteristics of the features which the points, lines, and polygons represent). For example, the points may represent hazardous waste site locations and their associated attributes may be the specific chemical dumped at the site, the owner, and the date the site was last used. Lines may represent roads, streams, pipelines, or other linear features while polygons may represent vegetation types or land use.



**Figure 2-1.** The 3 elements of geographic data

## 2.7 GIS importance at its three levels

In science and engineering, there are a number of roles that can be served by GIS technologies. As with any class of technologies, there are a variety of ways to employ the tools. The goal, of course, is to be innovative with the application of tools. Therein lies the challenge and the reward for successful work, GIS data is effective in three levels, 1, 2 and 3 [10]:

### 2.7.1 Level (1)

At the lowest level of effort, the GIS data can be used to supply inventory information. The presence or absence of given land cover or water classes, or change in these variables on a spatial basis, can be valuable in planning and management. The variety or quantity of certain land cover or water types can be summarized by a certain watershed to produce

statistics of interest. The capability to store, quantify, and present data on a spatial basis is an inherent characteristic of GIS technologies.

### **2.7.2 Level (2)**

At the highest level of technology, a GIS can provide a spatial database of information to support modeling of phenomena. The GIS supplies the spatial data in a form that can be input to deterministic or statistical models. The spatial power of the GIS database is used in full by the model, and more detailed and spatially averaged results are produced. This represents a high level of integration and achievement that is now seen in the industry. It has taken a while for such applications to develop, however. This is due to the absence of spatially integrated models for water resource phenomena. Many models use spatial data but average or summarize these data by watershed and/or subwatershed, and thereby lose much of the detail of spatial variability that often influences phenomena. This is the same level of detail necessary to provide high quality model simulations. In general, the strength of GIS is that it is possible to process the data sets using any type of numerical analysis procedure. In particular, certain procedures are valuable for data visualization and analysis, including image processing techniques, virtual reality, and simulation modeling. The digital approach to storing and processing spatial or image data is a fantastic boon to these analyses of data, and the capabilities have yet to be fully realized.

### **2.7.3 Level (3)**

Of particular interest is also the application of a GIS in the automation of infrastructure modeling and information management using modern computer techniques and graphics technology to build what is called ‘intelligent infrastructures’. However, this along with the other rewarding applications of a GIS in environmental and water resources engineering cannot be fully conceived by the reader before a terse overview of the basic components and features of any GIS.

## **2.8 Delivering Custom GIS Applications**

Faced with an overabundance of raw information, organizations are awakening to the value of geographic analysis and spatial visualization because of their proven ability to improve operational efficiency and decision making within an organization. May be called business intelligence, analytic applications, or decision support, knowledge workers benefit from software applications that provide them with the information they need to quickly and accurately assess a situation and act accordingly. There are many potential users of



geographic information system (GIS)-enhanced applications who are not GIS professionals and are unequipped to take advantage of the comprehensive tools available on the market without a steep learning curve.

### **2.8.1 Open Source applications**

“When programmers can read, redistribute, and modify the source code for a piece of software, the software evolves. People improve it, people adapt it, people fix bugs. And this can happen at a speed that, if one is used to the slow pace of conventional software development, seems astonishing.” [30].

### **2.8.2 Custom open source GIS applications**

Custom open source GIS applications could act as Decision Support System (DSS) and to some extent as a Spatial Decision Support System (SDSS) which is a computer-based system designed to assist decision system. Typically, such a system will include spatial data relevant to the decision.

### **2.8.3 Solutions for Efficient GIS Development**

The ideal solution to a prolonged GIS development effort is the availability of a component-based development framework that will allow solution providers or an organization's internal developers to rapidly build industry specific GIS applications. A GIS development framework provides the necessary comprehensive spatial functionality for applications and allows the software developer to focus on building application specific logic. ESRI® ArcGIS® Engine is such a GIS framework, created in response to ESRI software users' requests that the rich technology of ArcGIS be productized to enable embedding of spatial functionality in new or existing applications. This will be of particular interest to programmers and project managers who want to embed mapping and GIS functionality in new or existing custom applications and deploy those applications, perhaps in a cross platform environment, in a cost-effective manner [13].

### **2.8.4 Delivering Custom GIS Applications with ArcGIS Engine from ESRI**

#### **2.8.4.1 ArcGIS Engine**

ArcGIS Engine is a complete library of embeddable GIS components and tools packaged together for developers to build new or extend existing custom desktop applications. Using ArcGIS Engine, developers can embed GIS functions into existing applications, such as custom industry specific products, and commercial productivity applications, such as

Microsoft Word and Excel, as well as build focused custom applications for delivering GIS to many users in their organizations [13].

#### **2.8.4.2 Use of ArcGIS Engine**

Many users require focused, industry specific access to GIS from within familiar software applications. They need much less than the general GIS products, yet they may require access to sophisticated GIS logic in their applications [13].

### **2.9 GIS for water utilities**

Although a GIS is often seen as an important technology for water utilities, it is sometimes hard to see the real benefits of a GIS when compared to the high hardware, software, and human implementation costs, this require well defined objectives behind its use.

#### **2.9.1 Water Utilities' Primary Functions**

GIS technology can be utilized by each of the following water utility function groups, but there are considerable differences in the uses and relative advantages of such technology:

- Planning: planning the timed expansion of the water system (future demands).
- Engineering: detailed design and construction of water facilities.
- Operation and Maintenance (O&M): operating and maintaining water transmission and supply facilities.
- Administration: managing the paperwork and dollars associated with operating the water system.

These functions are explained hereunder in more details:

##### **2.9.1.1 Planning**

A water utility's planning group generally performs estimates of future water demands, evaluates the transmission system utilizing these estimates, specifies the required system improvements, and structures a long term capital investment program around these improvements.

##### **2.9.1.2 Engineering**

The engineering group within a water utility is generally responsible for facility design, construction, and mapping. Unlike the planning function, engineering deals with facilities as they are actually built.

### 2.9.1.3 Operation and Maintenance

Operations and maintenance performs work on geographically distributed facilities. The primary need on a daily basis is to manage work crews. The technology required to satisfy this need is a database application that provides work order management, work scheduling, and work history logging.

### 2.9.1.4 Administration

Administrative functions have been computerized for many years and a wide variety of standard applications now exist to serve administrative needs. Although it is certainly possible to integrate administrative data within a GIS, GIS technology does not yield many tangible benefits for water utility administrators.

## 2.9.2 Rational Approach behind using GIS in water utilities

As the above discussion shows, GIS technology can provide a water utility with a flexible capability to store and present geographic information. These features are complementary to applications that solve the problems of specific activities within a utility. The key requirement, prior to making any investment in technology, is to establish and maintain a long-term vision and plan while focusing on short-term benefits. A rational approach to technology investment for water utilities has to focus on two critical points: data maintenance and system modularity.

Data Maintenance, cost is reflected through the following guidelines with regards to cost and longevity, table 2.4:

**Table 2.4:** The Value of Data in GIS systems

Item	Relative Cost	Typical Longevity
Hardware	Moderate to high	5 to 10 years
Software	Low to moderate	10 to 20 years
Data	Very high	50 years or more

The aim of this table is to prove that regardless of what hardware and software environment is chosen for any water utility application, the cost and value of the data is much greater. Therefore, to protect one's investment, evaluation of each application with a view toward insuring that the data is stored in an environment where it can and will be accurately maintained is most crucial.

Before bringing a GIS into a water utility, several questions must be addressed. Can any individual application within the plan be replaced without disrupting other applications and

users? Does the architecture avoid data redundancy? (In other words, is each type of data maintained in only one place?) Is the long term maintenance of all types of data assured? Are the appropriate users maintaining their own data? Are there immediate benefits and what are they?

All in all, water utilities – especially smaller ones – should adopt a slightly conservative approach to acquiring GIS technologies. Emphasis should be placed first on the utility's immediate needs while stressing the issues of long term investment with regards to data collection and management, and then on following a growth path towards a full GIS environment.

Although a GIS is a very potent decision-making tool, it is just a tool. There is a great temptation to rely too heavily on the computer and to stop thinking. There is also a tendency to collect too much spatial data. One more layer of data is not always the answer. Therefore, be warned, and GIS will serve you well! [10]

### **2.9.3 GIS Applications in Water, Wastewater and Stormwater Systems**

Representation and analysis of water-related phenomena by GIS facilitates their management. By using geographic information from mapping, modeling, facilities management, and work order management, a drinking water distribution system manager can develop a detailed capital improvement program or operations and maintenance plan.

The GIS applications that are of particular importance to water, wastewater, and stormwater system managers are: Mapping, Monitoring, Modeling, and Maintenance. These four Ms define the four most important activities in effectively managing water, wastewater, and stormwater systems.

GIS can be used to implement the 4M management strategy in the field of water, wastewater, and stormwater. GIS integrates all kinds of information and applications with a geographic component into one, manageable system. GIS offers integrated solutions in the areas of planning and engineering, operation and maintenance, and finance and administration.

Also, with GIS the possibilities to map, monitor, model, and maintain water, wastewater,

and stormwater systems are endless by applying the power of GIS to manage them through its full potential in solving water-related problems [9].

#### **2.9.4 Groundwater quality assessment using GIS**

Groundwater quality assessment is a key issue to decision makers. Through the use of the developed open GIS system a rapid global "at a glance" appraisal of groundwater quality can be achieved [14].

Assessing the quality of groundwater is important to ensure sustainable safe use of these resources. However, describing the overall water quality condition is difficult due to the spatial variability of multiple contaminants and the wide range of indicators (chemical, physical and biological) that could be measured [15].

Several indicators have been developed to ease the understanding of indicators expressing ground water quality, among these indexes are the following:

##### **2.9.4.1 The groundwater quality index, GQI**

Team in [15], developed a GIS based groundwater quality index (GQI) combining different available water quality data (e.g., Cl<sup>-</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>) and linked them to the World Health Organization (WHO) standards. They applied the proposed index to Nasuno basin, Japan and they related the final GQI map with more data such as the depth to groundwater table, the geomorphologic structures, the land-use types and population density in order to find out which factors control the spatial variability of groundwater quality.

The main part of the GQI represents an averaged linear combination of factors. The weight ( $w$ ) assigned to each parameter indicating its relative importance to groundwater quality, corresponds to the mean rating value of its "rank map". Parameters which have higher impact over groundwater quality (high mean rate) are assumed to be similarly more important in evaluating the overall groundwater quality. High GQI values close to 100 reflect high water quality and index values far below 100 (close to 1) indicate low water quality. [16].

##### **2.9.4.2 Indexed Assessment of an aquifer's Water Quality**

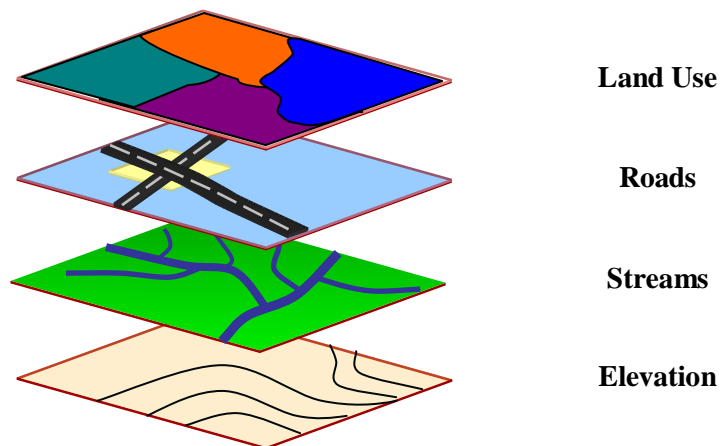
Similar approach to that presented by team in [15], the IAWQ (Indexed Assessment of an aquifer's Water Quality), however their basic assumptions and formulations are generally different from those introduced team in [15], [16].

## 2.10 GIS Analysis Techniques

Once all the necessary existing and new data have been collected then it can all be registered to a common base map. As mentioned, the collection and registering of all these data from various sources can be an expensive, time consuming, and frustrating process. Once completed, however, the analysis can begin. Basic GIS analysis techniques include overlay analysis, modeling, buffering, and network analysis.

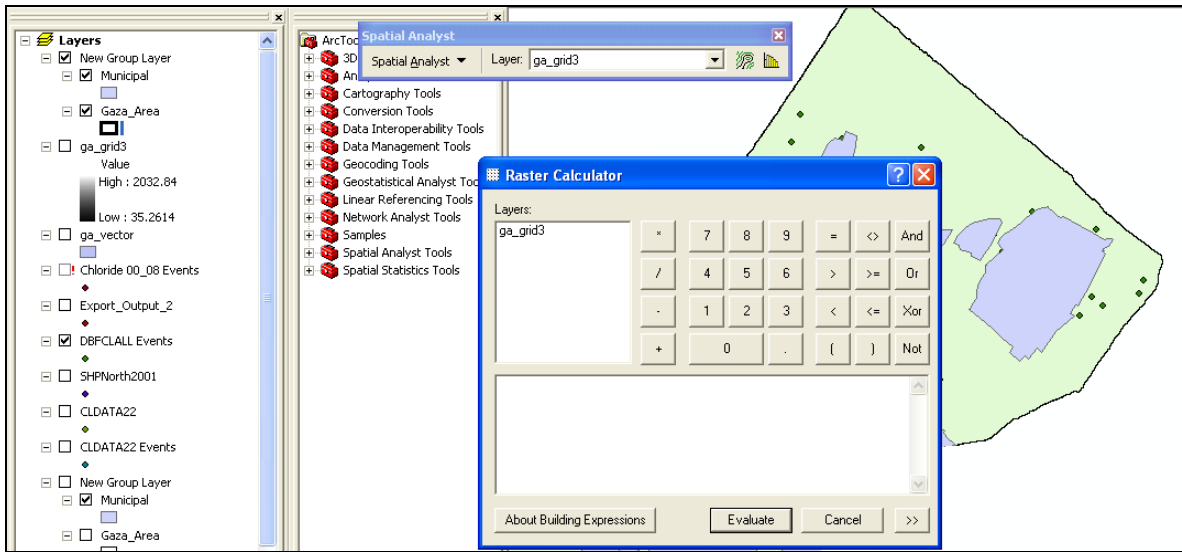
### 2.10.1 Overlay Analysis

The concept of overlaying data layers to obtain certain information is not a new concept to GIS, figure 2.2. Many of us have used tracing paper and colored pencils to produce transparent maps that could lay over the top of each other in order to derive some information; that could be considered a ‘primitive’ GIS. The ability to analyze spatial data separates GIS from mere spatial databases.

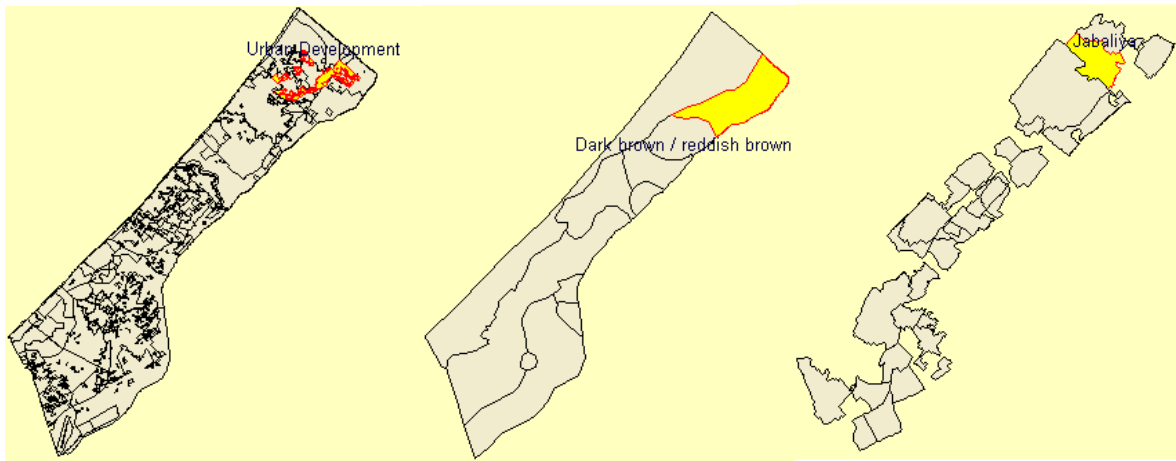


**Figure 2-2.** An example of overlaying various layers in a GIS

The ability to extract specific information from a data layer and combine it with other information from that same or some other data layer depends on the use of Boolean algebra. This procedure involves the use of the operators AND, OR, and NOT to manipulate spatial data by testing to see if a given condition or statement is true or false. It is then possible to combine data layers to form a new layer, which is similar in concept with the Raster Calculator in ArcMap from ESRI, figure 2.3 and 2.4.

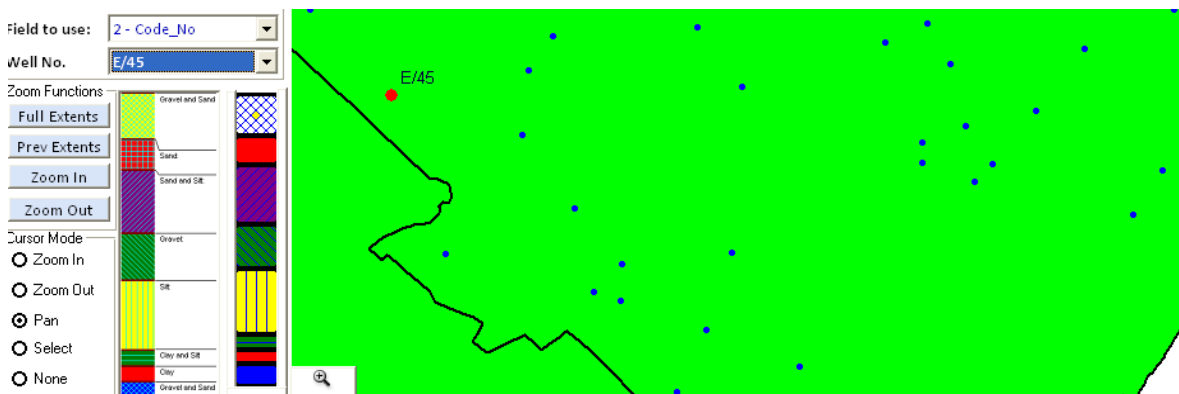


**Figure 2-3.** Raster calculator concept in ArcMAP 9.1



**Well E/45 location indicates:**

Urban Development at Landuse Layer / Dark brown at soil Layer / Located at Jabalia in Municipal Layer



**Figure 2-4.** Obtaining information on same location from differ rent layers

### 2.10.2 Modeling

Primarily, GIS technologies can facilitate input of data sets to simulation models. This may take the form of one or multiple variable or GIS ‘layer’ inputs to models.

Many current and traditional model procedures use summary information in the form of model coefficients. These types of models can also be improved by GIS or remote sensor technologies by conducting tests so that model coefficients can be further defined or refined through improved measurements of their characteristics. A more 'natural' coefficient better defines the behavior of model variables, and allows the modeler to achieve high fidelity between natural systems and their model simulations. Four aspects of modeling spatial information will be discussed here: cartographic modeling, simulation/deterministic modeling, statistical/predictive modeling, and model calibration:

#### **2.10.2.1 Cartographic Modeling**

When the user of spatial information is presented with a problem, the response should be a careful plan of what should be done. A more common response is to rush to the computer and start to work. Instead, cartographic modeling suggests detailed flow charts and careful planning to decide what data are important and how they should be used.

#### **2.10.2.2 Simulation Modeling**

Another aspect of modeling is the simulation approach. In this case, the user tries to simulate some complex phenomenon using a combination of spatial and nonspatial information. This approach typically requires an expert who is knowledgeable enough to build such a simulation or model. It should be noted that rarely in these cases do any two experts agree on exactly how the model should be built.

#### **2.10.2.3 Predictive Modeling**

In this approach, statistical techniques are used to build a model that will be able to predict using the spatial information. The statistical tool used for building such models is most commonly regression analysis. The first step in this process is to collect information about the phenomena one wishes to model. A subset of this information is then used to statistically build the model. This model building is performed by looking at each layer of spatial information and each component of non-spatial information to see which are correlated to the phenomena one wishes to predict. Once the model is built, the model is tested using the remaining information.

#### **2.10.2.4 Model Calibration**

Another valuable use of GIS and related technologies is the calibration of model coefficients in statistical models. Both statistical and deterministic models often consist of a number of sub-model units. Coefficients used in either approach reflect the

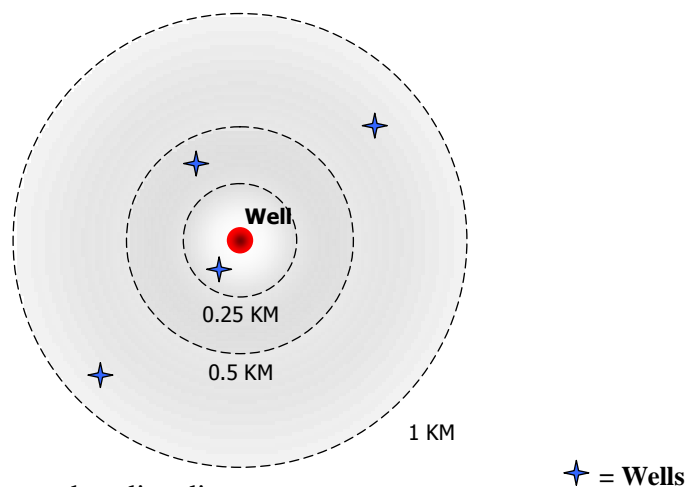


characteristics of nature, and they will adjust the contribution of variables or submodels to the overall model results.

To optimize the model simulation of natural phenomenon, the coefficients need to reflect the reality of the situation. As a given model begins to approximate nature, its further development often takes the path of improving the quality of coefficients. Many times, a number of experiments will be executed to better measure the level of a coefficient and thus to help supply better model predictions.

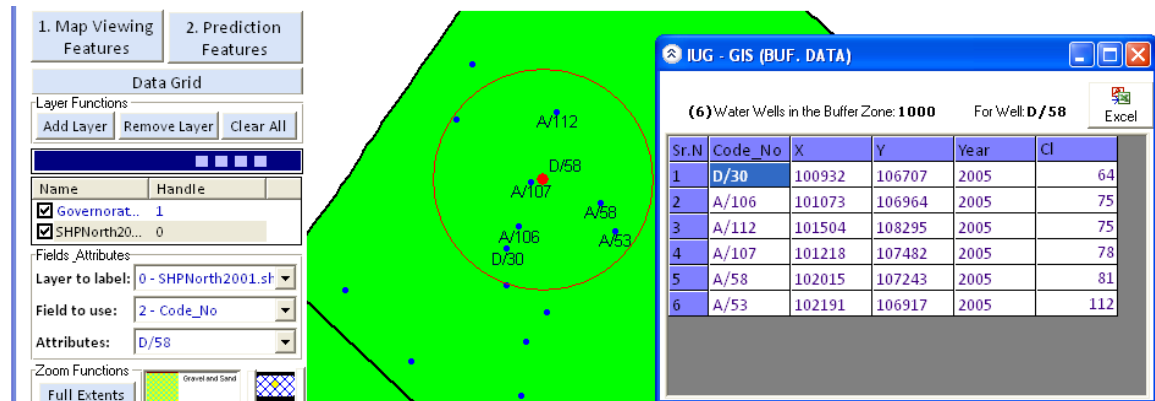
### 2.10.2.5 Buffering

**Buffering** is a technique by which a boundary of known width is drawn around a point or linear feature. Some examples of point buffers may be a zone around a hazardous waste site or around a tree that is a nest for a particular endangered bird. Examples of linear buffers may be an area around a stream to prevent logging or an area around a utility pipeline to prevent digging. A related function is generally referred to as “proximity searches”, figure 2.5.



**Figure 2-5.** User waiver search radius distances

Proximity searches can be used to identify adjacencies between particular features or data classifications. Examples might include identifying all groundwater pollution cases within a specific radius of a given drinking supply well, Proximity search can be used to locate potential sources of contamination, to schedule inspections, to identify monitoring wells or sampling points which might provide relevant data from nearby sites, to identify specific residents or the size exposed populations, or to generate mailing lists for further investigation, figure 2.6 shows the concept in developed system.



**Figure 2-6.** User Buffering feature, available in three levels

### 2.10.2.6 Network Analysis

Network analysis is a technique by which a linear path is identified that represents the flow of some object through the area. Network analysis is especially useful in hydrology, water resources, transportation, and other disciplines that study the flow of an object. This flow is not limited to water but can also be used for vehicles, utility and communication lines.

## 2.11 MapWindow GIS project

In an open source GIS software development paradigm, the availability of a robust, extensible, programming architecture can be critical to project success. Indeed, though tiered-code software development is used throughout the industry (proprietary and open source) modularity, extensibility, and internal transparency are absolutely essential when writing code in a largely volunteer, spatially distributed, programmer community.

### 2.11.1 Introduction to MapWindow project

The purpose of the MapWindow project is to provide a developer toolkit for the Windows platform and a fully functional mapping application. Much of the success of the MapWindow project has been its easy-to-use plug-in programming environment allowing third party developers to quickly extend the application using simple languages such as Visual Basic, VB.NET and C#.

It is presumed that the easier it is to extend a GIS platform, the more usable it will be for scientists and engineers who are not programmers. To cater to this need, proprietary software (e.g. ArcGIS) supports writing plug-ins that extends the capabilities of the software without having to re-compile the binaries or be expert programmers [37].

Component development presents the interesting challenge of trying to anticipate all ways people will use the software, extend it, or incorporate it into projects of their own. The solution is non-obvious because most accepted paradigms for extensibility make the assumption that a project will lie entirely within the open source or proprietary domains. It is also challenging to develop an architecture that is equally suitable to open source development (and hence maximum transparency) and proprietary derivative software (usually with restricted control). The open source aspect of the project also means that the code enabling this extensibility can not be overly complex or future programmers will likely abandon it the first time it conflicts with changes to the project layout or design.

A new user of an open source GIS project might ask the question, “Why write a plug-in when you can simply download the source and modify any aspect of it to suit your needs?” However, plug-in extensibility can be beneficial for open source projects by appealing to non-programmers that want to make small improvements, and by insulating the core application from unstable new additions.

### **2.11.2 Background on MapWindow**

The MapWindow project started in 1998 at Utah Water Research Lab (UWRL) at Utah State University as an alternative to using ESRI MapObjects LT 1.0 for custom GIS applications. MapObjects LT did not support vector editing or raster data management – both key requirements of an important UWRL project. To meet these needs, UWRL researchers created the core MapWinGIS.ocx component, an ActiveX control that provides low level access to geospatial data which can be embedded in third party GIS software. This ultimately led to the development of the extensible MapWindow GIS application to avoid the replication of common GIS software features (e.g. legend, preview map, etc.) This project moved to Idaho State University and was released as fully open source software in January 2004 as “MapWindow GIS 4.x”.

The MapWindow 6.0 project inherits the strong foundation and legacy of several years of development, but is focused on modular components written strictly in C# [37].

### **2.11.3 Other GIS extensibility architectures**

#### **2.11.3.1 ArcGIS**

The ESRI ArcGIS object model, when viewed as a diagram, sprawls out in panoply of interconnected objects, each with a very precisely defined role. This is not open source software but demonstrates implementation of extensibility architecture through various

interfaces. In the Visual Basic for Applications (VBA) Macro development environment that is associated with ArcGIS versions 8.0 and later, directly accessing an object does not expose the majority of its properties or methods. Also, ArcGIS plug-ins can not be used without the proprietary ArcGIS software.

#### **2.11.3.2 GRASS**

Modularity is a major strength for GRASS. As is noted in Open source GIS A GRASS GIS Approach, GRASS 6 is written in the ANSI C programming language and hosts more than 350 modules for management, processing, analysis and visualisation of GIS data. The GRASS development team is actively developing new graphical user interfaces, but the core project is built around a series of completely independent core libraries. The opportunity for open source style extensibility in this setting is obvious. One simply needs to add a new library to the list of libraries and to extend GRASS. There is also recognition that not every user will be an expert coder. To support intermediate level programmers, GRASS accepts script programming. UNIX Shell, PERL and Python scripts are supported, allowing repetitious tasks to be handled through scripting languages.

#### **2.11.3.3 Quantum GIS**

Another open source desktop GIS with a well established plug-in architecture is Quantum GIS. The Quantum GIS plug-in architecture is similar to the MapWindow GIS approach in that new functionality is provided through compiled binaries that are referenced by the software at runtime. A powerful and useful concept in Quantum GIS is the idea of a “Data Provider” plug-in that allows developers to specifically extend the data formats that can be supported by the software.

#### **2.11.4 Logic behind developing MapWindow**

In summary, this project has developed a plug-in extensibility architecture that is modular in order to be used side by side with modular components. It uses a simple component-like drag and drop behaviour that should be very familiar to visual developers. The project makes this possible by using interfaces for each of its classes. The interfaces allow for interchangeability, can provide restricted access to components, and consist of smaller interfaces that can be used where implementing the entire class is not necessary. These interfaces then allow for the addition of run-time classes identified by using system reflection. Because the new classes implement pre-defined interfaces, other components in the architecture can interact with the new classes as if they had a programmatic reference

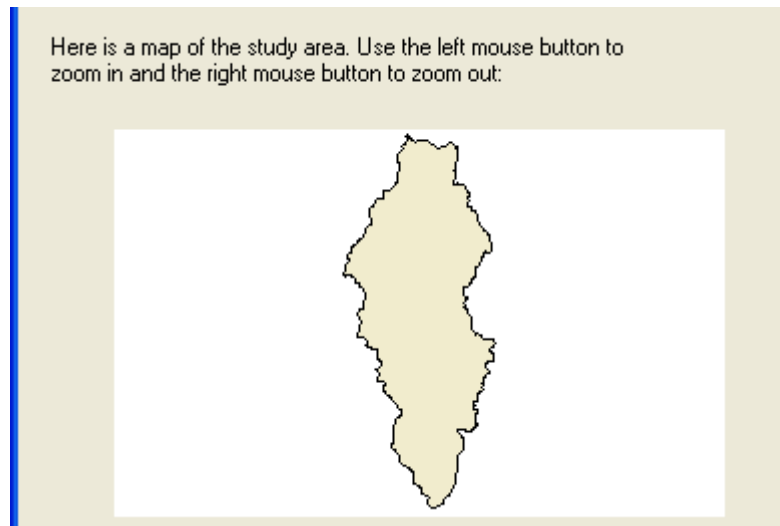
to them. Because the entire project has been built to use interfaces, future developers can exchange literally any part of it with their own classes as long as the classes implement the same interfaces [37].

The steps being taken by this project show an exciting new trend for community code. While mapping projects are abundant, projects that set themselves up to provide components for use by other projects are rarer, and projects that allow those components to be used for free by developers of proprietary software are extremely rare. This approach may prove to be naïve, as many advocates of the GNU general public licence warn. However, producing easy-to-use components that are specifically designed for an environment used predominantly by proprietary developers would be largely useless unless those proprietary developers could use the software. Attempting to create tools that can be used for multiple purposes also presents new problems and perspectives that can lead to solutions that benefit the entire community.

In short, the MapWinGIS.ocx ActiveX control was built to support GIS functions in totally unique GIS-enabled applications, and the MapWindow application was built to help users deploy GIS-enabled applications that can be assembled from pre-built plug-ins and data

#### **2.11.5 Architecture of MapWindow ActiveX Control**

The core MapWindow component is the ActiveX control, "MapWinGIS.ocx". This is an programming object that can be added to a form in Visual Basic, Delphi, or other languages that support ActiveX, providing a built-in GIS data map. It have been optimized for use as a fully functional model interface, not just as a map viewer. This involved speeding up image and grid display, limiting the amount of redrawing that the user sees, and including application programmer interfaces (APIs) for low-level access to grid, shape, table and image data. Here is an example in Visual Basic 6 of the simplest MapWindow project you can build figure 2.7:



**Figure 2-7.** Visual Basic 6, simplest MapWindow usage

The code that adds above shape file to the map is shown in figure 2.8:

```

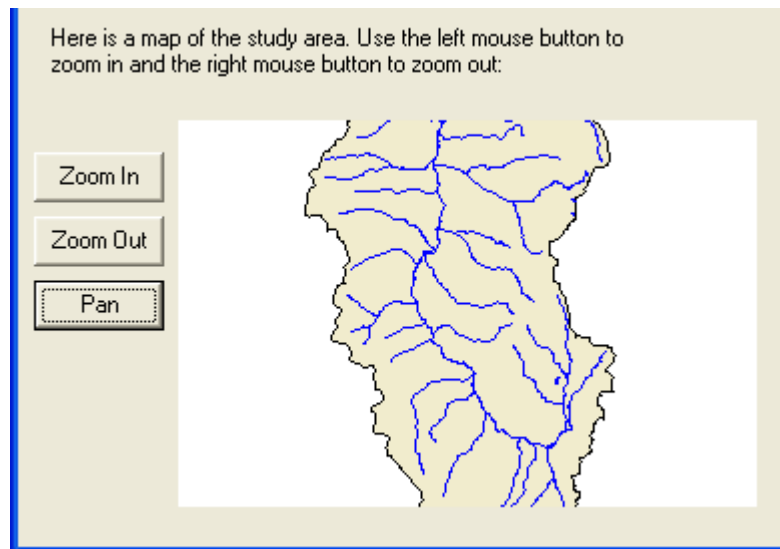
Form Load
Private Sub Form_Load()
    Dim sf As New Shapefile
    sf.Open App.Path & "\basin|.shp"
    Map1.AddLayer sf, True
End Sub

```

**Figure 2-8.** Visual Basic 6, Code for showing a shapfile

With a shape file layer loaded in the map, the user can navigate the map using the left and right mouse buttons to zoom-in and zoom-out. Noting that although this is the simplest MapWindow project one can build, actually the simplest project would be to just put the map on a form and compile with no code. Although the program would start with an empty white box, a user could grab any shape file or geo-referenced bitmap and drop it in the map, and the map will display it.

The MapWindow core component can be more interesting when one add a few layers of data to it and provide other means for navigation. For example, with just a few lines of code, the project above can be extended to display this, figure 2.9:



**Figure 2-9.** Visual Basic 6, adding more shapefiles for MapWindow

The code for the above application is shown in figure 2.10:

```
Private Sub cmdMove_Click(Index As Integer)
    Select Case Index
        Case 0
            Map1.CursorMode = cmZoomIn
        Case 1
            Map1.CursorMode = cmZoomOut
        Case 2
            Map1.CursorMode = cmPan
    End Select
End Sub
```

**Figure 2-10.** Visual Basic 6, Code for showing a shapefile

These are very basic demonstrations, but the idea is that the control can do and how it can be used. Additional functions of the core component ActiveX control include:

- Open, create, edit, and save geo-referenced image, grid, shapefile, triangulated irregular network (TIN), and dbf (shape attribute) data directly;
- View, label, color, highlight, shape file data in the map;
- Perform spatial queries on the data;
- Search for features with specific attributes;
- Dynamically edit the spatial data and immediately see the changes in the map;

- Interact with the data through the map;
- Build TINs from Grids, Images from Grids, Shape files from TINs and Grids, Grids from Shape files, etc.

## 2.12 Future Water Needs for West Bank and Gaza

Future water needs for the major three consuming sectors (municipal, industry and agriculture) were estimated in the scope of future water needs for municipal and industrial sectors based on their current consumption levels and the expected growth in population. According to these calculations, the Palestinian water sector should develop a total amount of around 860 MCM/year by the year 2020. This amount is about three fold the supply available at present, table 2.1[22].

**Table 2-1.** Projected Total Water Needs in MCM/year

Year	2010	2015	2020
Municipal	165	218	268
Industrial	24	31	39
Irrigation	200	370	552
Total for Palestine	389	619	859

The Gaza aquifer - the only fresh water source in Gaza – is already over-extracted (about 3 times the renewable resources); the UN estimates that Gaza will have no drinking water in the next 15 years, at present only 5-10% of the aquifer is fit for human consumption. The UNEP estimates that over \$1.5 billion are needed over 20 years to restore the aquifer back to health, including the establishment of desalination plants to take pressure off the underground water supplies [23].

## 2.13 Chlorides and Nitrates as Groundwater quality indicators

Based on several conducted studies and researches, it has been proved that the main parameters contributing much to the overall quality assessment are Chloride (Cl) and Nitrate (NO<sub>3</sub><sup>-</sup>).

A study of redesigning groundwater quality monitoring network suggested the definition of different monitoring objectives, such as Chloride (Cl) as an indicator of salinity, Nitrate (NO<sub>3</sub><sup>-</sup>) as indicator of pollution from wastewater or Electrical Conductivity (EC) as indicator of the amount of dissolved salts due to saltwater intrusion [19].



Most recent samples collected in 2007 from Gaza water wells showed that 90% of the wells having  $\text{NO}_3^-$  concentration that are several times higher than the WHO of 50 mg/l. [24]

A recent study developed an indexed assessment of an aquifer's water quality (IAWQ) initially using the chemical parameters chloride ( $\text{Cl}^-$ ) and nitrate ( $\text{NO}_3^-$ ), implemented in Israel's Sharon region [16]. Hence, it would be reasonable to consider  $\text{Cl}^-$  and  $\text{NO}_3^-$  as main parameters/indicators of water quality in the Gaza strip, thresholds of these parameters are shown in table 2.2.

**Table 2-2.** Maximum Concentrations Limits (MCL) of  $\text{Cl}^-$  and  $\text{NO}_3^-$ .

Parameter	Abbreviation	Unit	Standards for drinking water	
			National <sup>1</sup>	International <sup>2</sup>
Chloride	$\text{Cl}^-$	mg/l	600	250
Nitrate	$\text{NO}_3^-$	mg/l	70	50

<sup>1</sup> Palestinian National Drinking water standards.

<sup>2</sup> WHO Drinking water standard

State indicator of water quality, [25] =

Actual concentration of a substance - Standard for that substance for specific use (i.e. drinking water)

### 2.13.1 Chlorides and Nitrates in Groundwater

Chloride and nitrate are proven to be good indicators for groundwater quality evaluation since these parameters potentially contributing to salinity and pollution and therefore monitoring is mostly carried out for them in all wells. Chlorides are considered here as representative of salinity, owing to their highly conservative properties (i.e., not subject to adsorption) and their direct relationship with total dissolved solids (TDS). Nitrates, although not conservative, are used here as indicative of anthropogenic pollution mainly from intensive agriculture and domestic sewage disposal [2].

In application development, just chloride will be used as example indicator, while what would be applied as limits identifier, buffering, interpolation, map overlaying, etc.. on chloride would also be applied on Nitrates.

### **2.13.2 Chlorides**

Chlorides are salt compounds present in nearly all natural waters and usually found at low concentrations in groundwater. Its range of concentrations can vary widely. Chlorine in combination with a metal such as sodium is essential for life but high chloride levels can cause human illness and also can affect plant growth at levels in excess of 1000 mg/L. Taste threshold is about 250 mg/L for most people. Therefore, public drinking water standards require chloride levels not to exceed 250 mg/L, recommended World Health Organization WHO level [26].

#### **2.13.2.1 Sources of Chloride in groundwater**

Chlorides in groundwater may come from many processes such as dissolution of rocks containing chlorides, irrigation drainage, seawater intrusion in coastal aquifers, and salt water up coning of ancient seawater (connate water). Also, it may come from application of fertilizers or pesticides, effluent of wastewater treatment plants and industrial waste and from lateral movement of saline groundwater from up gradient areas of the aquifer, or upward movement from connected aquifers. Heavy pumping led to water level declines and changes in flow directions in the aquifers. In some cases, this has induced saline water from the sea or deep brines, to move into and contaminate an aquifer.

### **2.13.3 Nitrates**

Of the inorganic contaminants found in groundwater, nitrate reserves the most attention. Nitrate has been reported above background concentrations in groundwater worldwide and it has been identified to be the most common and widespread chemical contaminant in groundwater. It is commonly associated with diffuse sources such as intensive agriculture, high density housing with unsewered sanitation and point sources such as discharge of sewage effluent onto land. It is highly soluble, very mobile and usually not adsorbed much by soil particles and so it can leach into groundwater if not absorbed by plants. Nitrate (as N) is usually present naturally at least in low concentrations between 0.45 and 2.0 mg /l, Some studies show that groundwater concentrations exceeding an arbitrary threshold of 3 mg/l may be indicative of contamination of natural groundwater as a result of human activities [2].

Decomposition of organic matters in soils, leaching from excess fertilizer application in agriculture area, human and animal excreta, untreated effluents of nitrogenous industries and sewage disposal are potential sources of nitrate contamination in groundwater [2].

### 2.13.4 Means of measuring Chloride and Nitrates:

One of the most widely used approaches to detect the presence of saline water in an aquifer is measurement of chloride and Nitrate concentration within water wells.

### 2.14 Standards for chemicals of health significance

Most recent samples collected in 2007 from Gaza water wells showed that 90% of the wells having  $\text{NO}_3^-$  concentration that are several times higher than the WHO of 50 mg/L. water wells distribution is shown in figure 2.11 [27].



Figure 2-11. Water wells distribution in Gaza, source OCHA, oPT

### 2.14.1 Parameters and substances of aesthetic significance in international guidelines

These parameters are also presented in similar scope in international guidelines as follows:

**Table 2-3.** Standards for parameters in drinking-water, WHO guidelines

Parameter	WHO guidelines <sup>a</sup>	Reasons for consumer complaint	Egypt	Iraq	Jordan	Oman	Lebanon	Morocco	Palestine
Chloride	GVNE <sup>d</sup>	Taste, corrosion	500	250	200 <sup>b</sup> 500 <sup>c</sup>	200 <sup>d</sup> 600 <sup>e</sup>	200	300 <sup>b</sup> 750 <sup>c</sup>	250 <sup>b</sup> 600 <sup>c</sup>

<sup>a</sup> The levels indicated are not precise numbers. Problems may occur at lower or higher values according to local circumstances. A range of taste and odour threshold concentrations is given for organic constituents.

<sup>b</sup> TCU: true colour unit.

<sup>c</sup> NTU: nephelometric turbidity unit is not established.

<sup>d</sup> GVNE: guideline value

N.B. Bahrain, Kuwait and Pakistan, apply relevant WHO guideline values without any modifications.

**Table 2-4.** Standards for chemicals of health significance compared with WHO guidelines

Chemical	WHO guideline value <sup>a</sup> (mg/L)	Remarks	Egypt	Iraq	Jordan	Lebanon	Morocco	Oman	Palestine
Nitrate (as NO <sub>3</sub> <sup>-</sup> )	50	Short-term exposure	44	50	50 (70 <sup>e</sup> )	50 <sup>h</sup>	50	45	50 70 <sup>e</sup>

<sup>e</sup> Maximum allowable in the absence of a better source.

<sup>h</sup> Categorized as undesirable.

## 2.15 Conclusion

Through the chapter previous attempts made for integrating indexes through GIS as indicators for groundwater quality, in parallel with advances in GIS tools that made integrating mapping features in stand-alone applications a possible feature.

## **CHAPTER (3): METHODS AND MATERIALS USED FOR THE GIS-BASED SYSTEM DEVELOPMENT**

### **3.1 Introduction**

In an effort to increase quality performance of evaluating and handling water wells quality indicators mainly chloride, the basic concept behind developing this tool is linking related GIS shape files with MS Access database through key ID attributes presented mainly as well code. In other words, The ability to extract specific information from a data layer and combine it with other information from that same or some other data layer.

### **3.2 Application development environment**

The customization development makes use of the object-oriented approach, in an infrastructure data model, whereby data files like maps and tables, the object libraries of standard office packages like Excel and ACCESS, and of Map Objects, are considered as objects and components of the application development project. The existing functionalities like charting, table display, color palette of other software are tapped for graphic display through referencing, and queries performed through the Structured Query Language (SQL), made available in the Visual Basic (VB) development platform, and a multitasked Windows environment. The Visual Basic programming language has been used as a control container to assemble the multiple controls and components for a Rapid Application Development (RAD).

### **3.3 System Modularity**

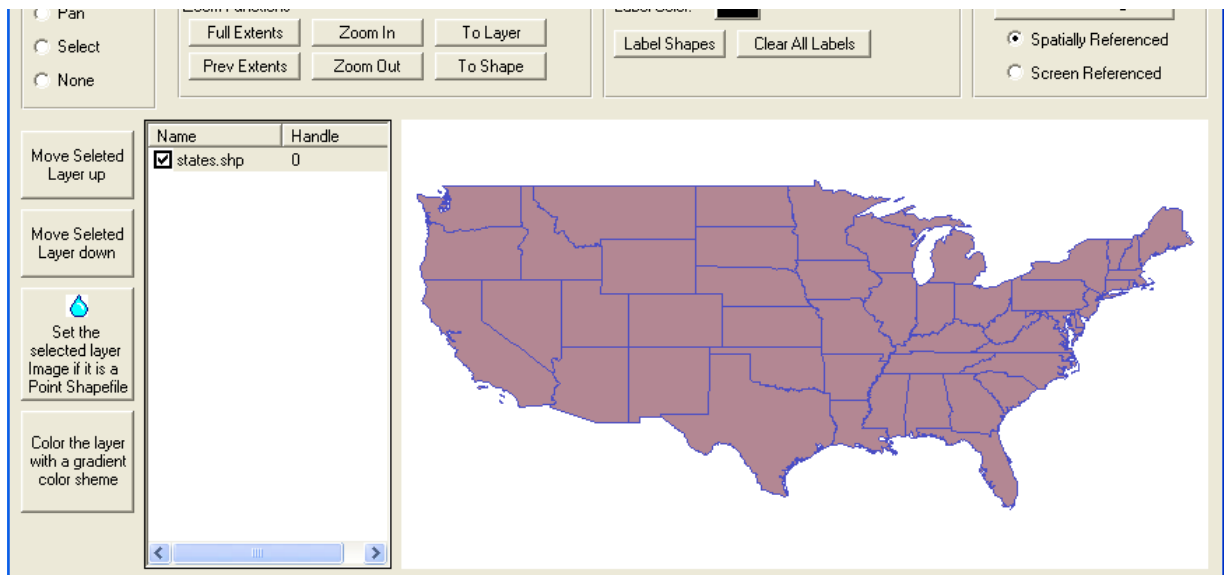
It is common belief that it is possible to build or purchase a single software application that addresses everyone's needs; nowadays GIS is portrayed as such an application. The reality is that there are a wide variety of products available that provide the appropriate solution to specific problems, and a system that effectively integrates these individual solutions will provide more useful functionality sooner and at a far lower cost [10].

The key is to build a modular system from independent applications, with well defined rules for data exchange between applications. A system designed along these lines yields several advantages:

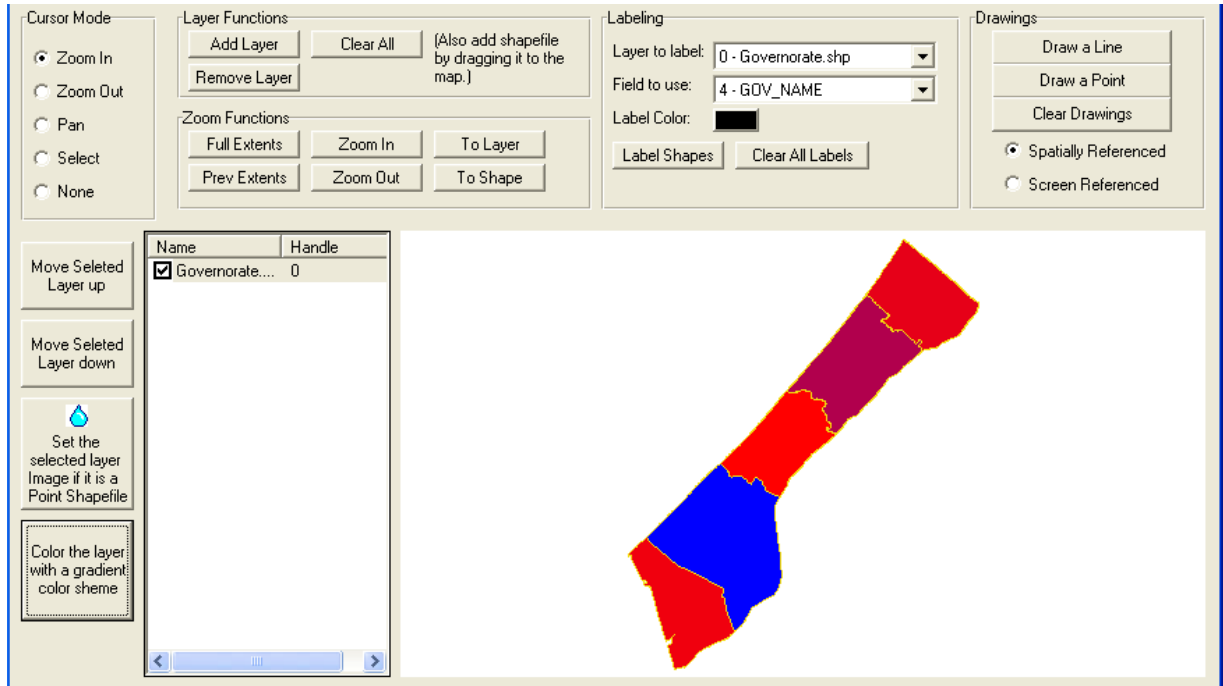
- A choice of products will be available for every key application. It's not necessary to select only what a single application vendor can offer.
- The operation of the system is not dependent on a single component. Any application could be replaced when defective or upgraded when a newer version is available without disrupting the overall system.
- The initial cost is lower, and the applications are useful immediately.

Map objects are a MapWindow product, consisting of a collection of mapping components (Map objects OCX and other programmable ActiveX automation) for application developers, figures 3.1 and 3.2. It provides the possibility to create customized solutions so as to meet the desktop mapping, and GIS needs of common users, through the following:

- Access to a wide range of data formats ranging from standard GIS formats (ARCInfo coverages and ESRI shapefiles) to CAD formats (DXF, DWG, and DGN) to perform spatial queries.
- Display data using classifications (regrouping/categorisation), graduated symbols, and labeling.
- Pan and zoom through each map layers.
- Queries features displayed on the map



**Figure 3-1.** Use of Active X controls in Visual Basic programming environment



**Figure 3-2.** Use of Active X controls and handling other Shapefiles, Gaza governorates

By means of map objects.OCX and a data connection string, the directory containing the different map files, and their related databases are retrieved and read, figure 3.2.

## 3.4 Materials and Methods

### 3.4.1 Data preparation

Data regarding time history of chloride concentration have been collected previously from PWA, and currently from CMWU where information regarding selected wells overall Gaza have been collected. Information regarding 125 wells in the northern area have been possible, chloride concentration for years 1999, 2000, 2001, 2002, and 2005 were recorded (625 records), figure 3.3.

Time series reflecting the period from 1987 to 2008 have been possible for 10 selected wells in the northern area, figure 3.4, to enable conducting mathematical interpolation through polynomial regression of least squared error. The spatial data were prepared with the Arc/Info GIS software, figures 3.5 and 3.6. Minor changes in the geographic database were then done in the desktop module ARCVIEW, as the map files were linked with descriptive database for shape files creation through a common key ID.

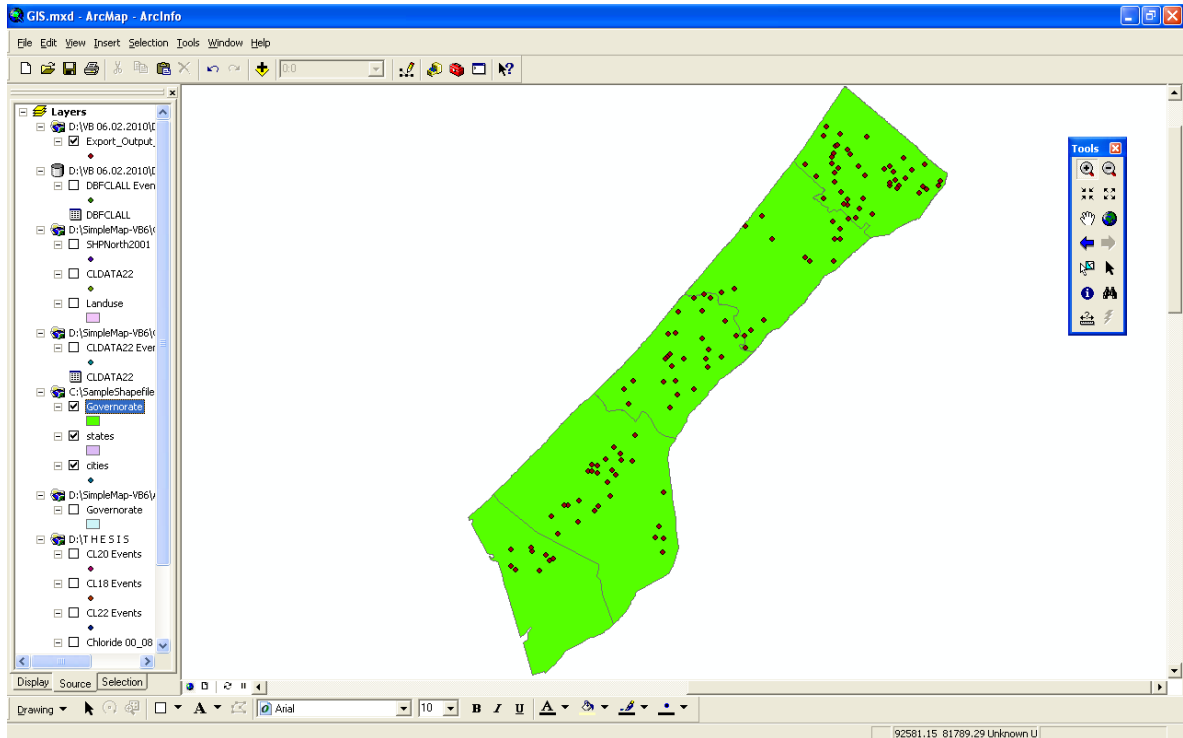
Code	YEAR	X	Y	CL	GnSd	C	CnSi	Si	GnTS	SnSi	S	GnSu	WL
D/58	2001	101339	107524	97	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
D/58	2005	101339	107524	63	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
D/58	2002	101339	107524	73	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
D/58	2000	101339	107524	90	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
D/58	1999	101339	107524	90	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
A/31	1999	102773	106052	90	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
A/31	2005	102773	106052	104	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
A/31	2000	102773	106052	88	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
A/31	2002	102773	106052	86	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
A/31	2001	102773	106052	67	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
P/58	2000	81601	78940	387	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
P/58	2005	81601	78940	943	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
P/58	1999	81601	78940	449	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
P/58	2001	81601	78940	327	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
P/58	2002	81601	78940	366	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
L/136	2002	84686	85338	897	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
L/136	1999	84686	85338	750	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
L/136	2001	84686	85338	819	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
L/136	2005	84686	85338	944	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
L/136	2000	84686	85338	761	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
S/9	2001	94890	94324	947	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
S/9	2002	94890	94324	958	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
S/9	2000	94890	94324	976	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
S/9	2005	94890	94324	951	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
S/9	1999	94890	94324	956	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
S/15	1999	94278	94367	1051	0.75	0.5	0.5	2.25	1.5	2	1	1.5	5
S/15	2001	94278	94367	910	0.75	0.5	0.5	2.25	1.5	2	1	1.5	5

Figure 3-3. Collected information for 125 wells for research study, Map featuring mode.

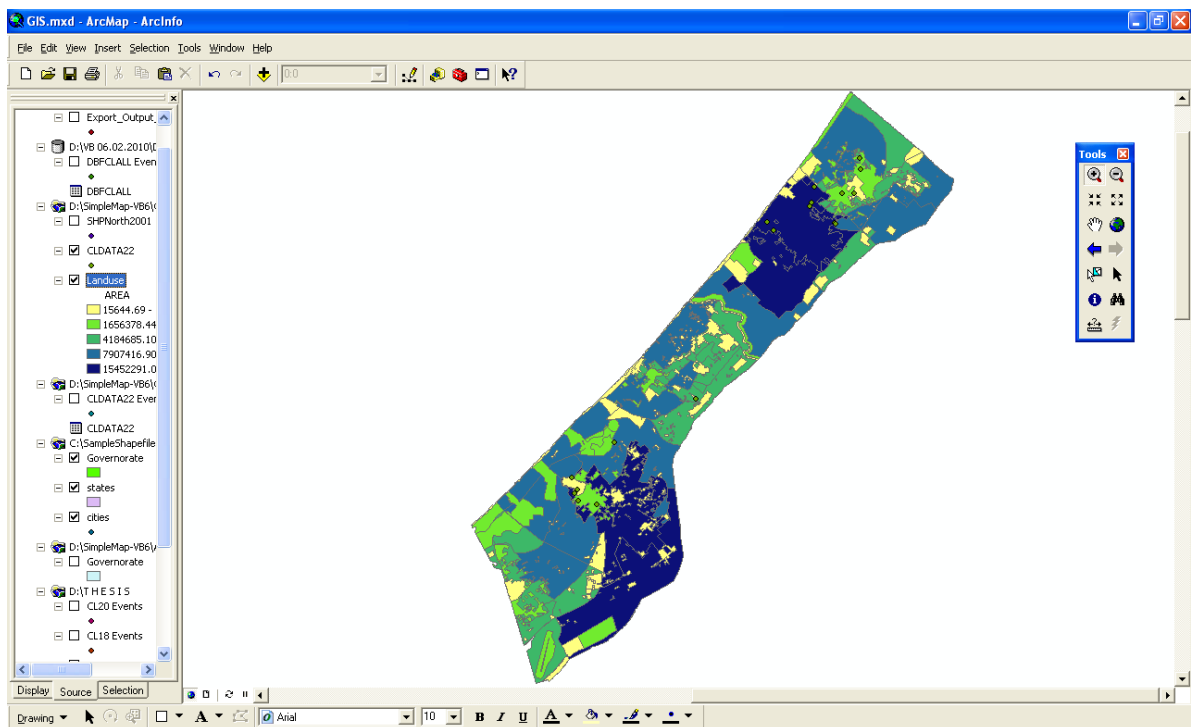
SN	CODE	YEAR	X	Y	CL
397	A_180	1987	102459.2	107033.01	41
398	A_180	1988	102459.2	107033.01	50.5
399	A_180	1989	102459.2	107033.01	49
400	A_180	1990	102459.2	107033.01	49.5
401	A_180	1991	102459.2	107033.01	49
402	A_180	1992	102459.2	107033.01	56
403	A_180	1993	102459.2	107033.01	56
404	A_180	1994	102459.2	107033.01	49
405	A_180	1995	102459.2	107033.01	52.5
406	A_180	1996	102459.2	107033.01	57.8
407	A_180	1997	102459.2	107033.01	35
408	A_180	1998	102459.2	107033.01	52.5
409	A_180	1999	102459.2	107033.01	49
410	A_180	2000	102459.2	107033.01	73.5
411	A_180	2001	102459.2	107033.01	88.46
412	A_180	2002	102459.2	107033.01	102.8
413	A_180	2003	102459.2	107033.01	106.55
414	A_180	2004	102459.2	107033.01	122.6
415	A_180	2005	102459.2	107033.01	137.75
416	A_180	2006	102459.2	107033.01	304.65
417	A_180	2007	102459.2	107033.01	179.1
418	A_180	2008	102459.2	107033.01	174.2
375	A_185	1987	102529.95	106252.12	74.75
376	A_185	1988	102529.95	106252.12	82.25
377	A_185	1989	102529.95	106252.12	87.5
378	A_185	1990	102529.95	106252.12	86
379	A_185	1991	102529.95	106252.12	84

Figure 3-4. Collected information for 10 wells for research study, map prediction mode.





**Figure 3-5.** Shapefile and data preparation for the 125 water wells



**Figure 3-6.** Other shapefiles needed preparation such as landuse, soil and municipalities

### 3.4.2 Database and object controls structure

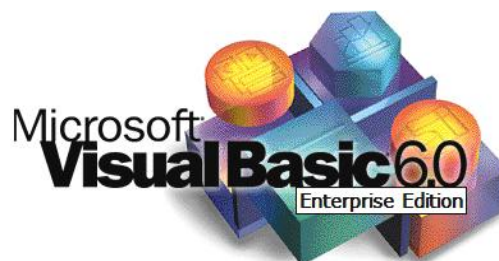
The databases received as excel files that were imported into Microsoft Access 2003, and classified according to years. The key ID is advised through the well code. A similar key

was applied to the map files or shapefiles, figure 3.7.

	Code	YEAR	X	Y	CL	GnSd	C	CnSi	Si	GnTS	SnSi	S	GnSu	WL
	D/58	2001	101339	107524	97	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	D/58	2005	101339	107524	63	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	D/58	2002	101339	107524	73	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
▶	D/58	2000	101339	107524	90	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	D/58	1999	101339	107524	90	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	A/31	1999	102773	106052	90	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
	A/31	2005	102773	106052	104	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
	A/31	2000	102773	106052	88	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
	A/31	2002	102773	106052	86	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
	A/31	2001	102773	106052	67	1	2.5	0.6	1.75	0.25	0.75	2	1.15	3.5
	P/58	2000	81601	78940	387	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	P/58	2005	81601	78940	943	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	P/58	1999	81601	78940	449	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	P/58	2001	81601	78940	327	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	P/58	2002	81601	78940	366	1.15	2	0.75	0.25	1.75	0.6	2.5	1	4
	L/136	2002	84686	85338	897	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
	L/136	1999	84686	85338	750	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
	L/136	2001	84686	85338	819	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
	L/136	2005	84686	85338	944	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
	L/136	2000	84686	85338	761	1	2.5	0.6	1.75	0.25	0.75	2	1.15	4
	S/9	2001	94890	94324	947	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
	S/9	2002	94890	94324	958	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
	S/9	2000	94890	94324	976	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
	S/9	2005	94890	94324	951	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
	S/9	1999	94890	94324	956	0.75	0.5	0.5	2.25	1.5	2	1	1.5	4
	S/15	1999	94278	94367	1051	0.75	0.5	0.5	2.25	1.5	2	1	1.5	5
	S/15	2001	94278	94367	910	0.75	0.5	0.5	2.25	1.5	2	1	1.5	5

**Figure 3-7.** Database files in Access; ID key is the well code

List of OCX (Object Controls) used within Microsoft Visual Basic environment:



- Text boxes: data is bound with the respective database for display results
- Combo boxes: offers possible choice for selection
- Check boxes: Click for display
- Command button: To execute the different functions or events allocated.

- Listbox: To select and display data
- Map control (MapWinGIS.ocx): a box in which map layers (shape files) are loaded.



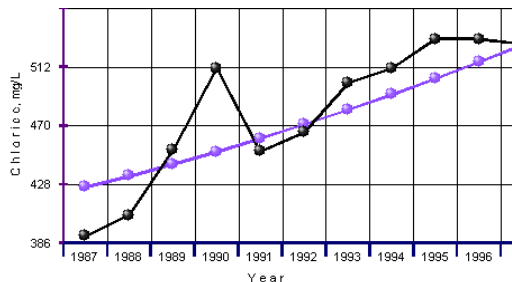
- ActiveX Data Object: Data control which establishes data connection using ODBC.



- (Open Database connectivity) drivers with the database and Structured Query Language (SQL) for data query.
- MSFlexgrid : Flexgrid control which displays the database.

Sr.N	Code_No	X	Y	Year	Cl
1	D/6	101151	105634	2005	128
2	A/21	103205	105476	2005	140
3	R/3	102034	103405	2005	221
4	D/43	101095	105009	2005	236
5	E/12	101589	104298	2005	241
6	Q/41	103100	103875	2005	303
7	Q/20	103760	102767	2005	315
8	R/5	101781	103493	2005	353
9	Q/48	102856	103118	2005	394

- MSChart: Chart control which displays Charts with different modes.



### 3.5 Conclusion

Through the chapter, the tools used and methods adopted have been outlined in relation to developing the system which mainly integrates mapping features with numerical database through out a friendly user interface producing a comprehensive spatially based database serving the objectives of the research.

## CHAPTER (4): RESULTS AND DISCUSSION

### 4.1 Application portability

The whole project, namely the data files (map and tables), program and system files, all ActiveX controls (MapObjects' and VB's), and VB's Data Dynamic Links (\*.dll), are bundled into a distributable package such as a setup program. This has been possible through the Package and Deployment tool of Visual Basic 6.0 version enterprise (Microsoft Corporation), figure 4.1. Therefore the application installation does not require additional training or resource investment from the users. It is a sort of 'plug-n-play' tool.

The installation is done through the set up file, which when double clicked, will auto-install the files into their respective folders: system and dynamic link files (\*.dll) as well as data files. Further the automatic shortcut installation on the desktop invites the user to start the application program.

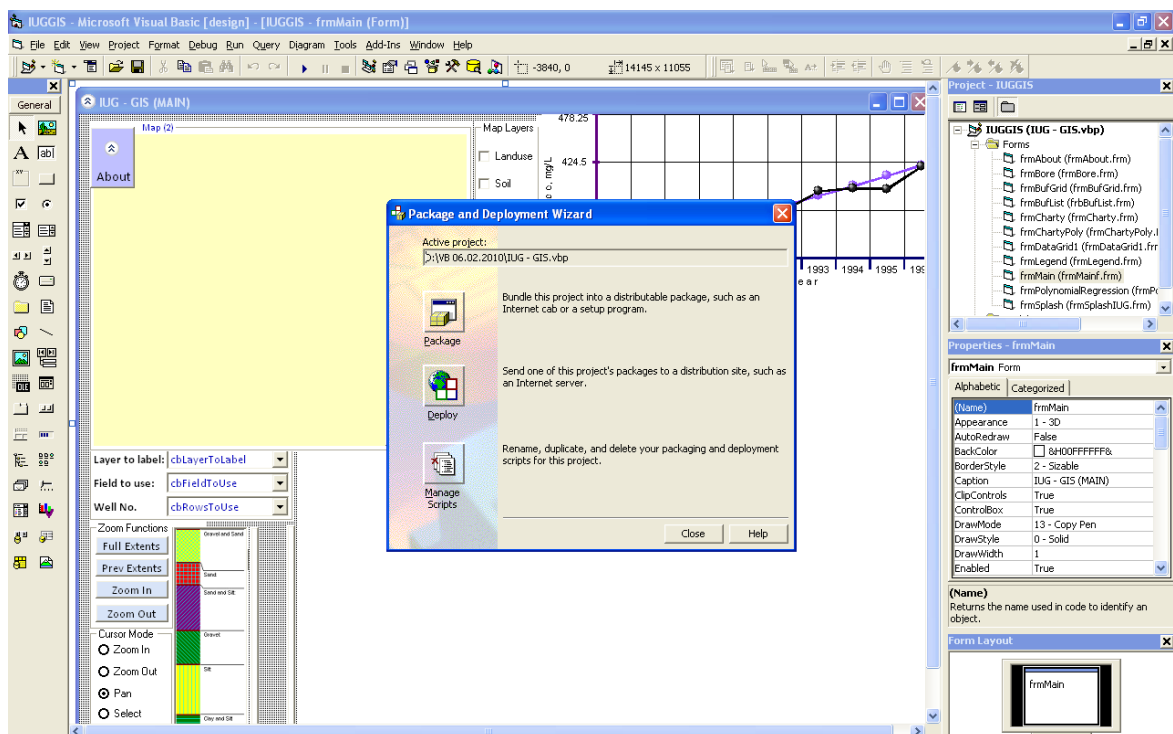


Figure 4-1. Package and Deployment tool of Visual Basic 6.0

### Minimum System requirements for this application installation

As much portable is the system, it also requires minimum resources:

- Operating system: Windows 98 or later.
- Memory space: 16 MB RAM

- Free Hard disk space: 50MB
- Microsoft Excel 97 or later
- Microsoft Access 97 or later
- Data files\* : 5 MB
- System & program files: 10 MB
- Total disk space for setup: 15 MB

\* The size may vary with amount of details collected, and is expected to normally increase with time.

## **4.2 Application overview**

It consists of a user-friendly interface, based on WYSIWYG through figures from 4.2 to 4.17, where the user easily moves across the different screens, with the help of clickable icons, combo boxes, pull down menus for dynamic mapping of the area of interest, and eventual hard prints output of data grids through MS Excel.

Through the outlined button in figure 4.2, the user is able to load the needed maps by one click, application will read the path where the shapfiles are stored and load them into the map.

Attributes presented in the well ID will be loaded into the combo box for Attributes label.

As full code resulted in more than 300 lines, partial code of this functionality, provided through Appendix B.

In figure 4.3, outlined buttons, are used to enable the user to zoom in and out, full extent or previous extent, identical to available previewing pan as in ESRI ArcMAP. This will provide the user with rich map maneuvering tool menu.

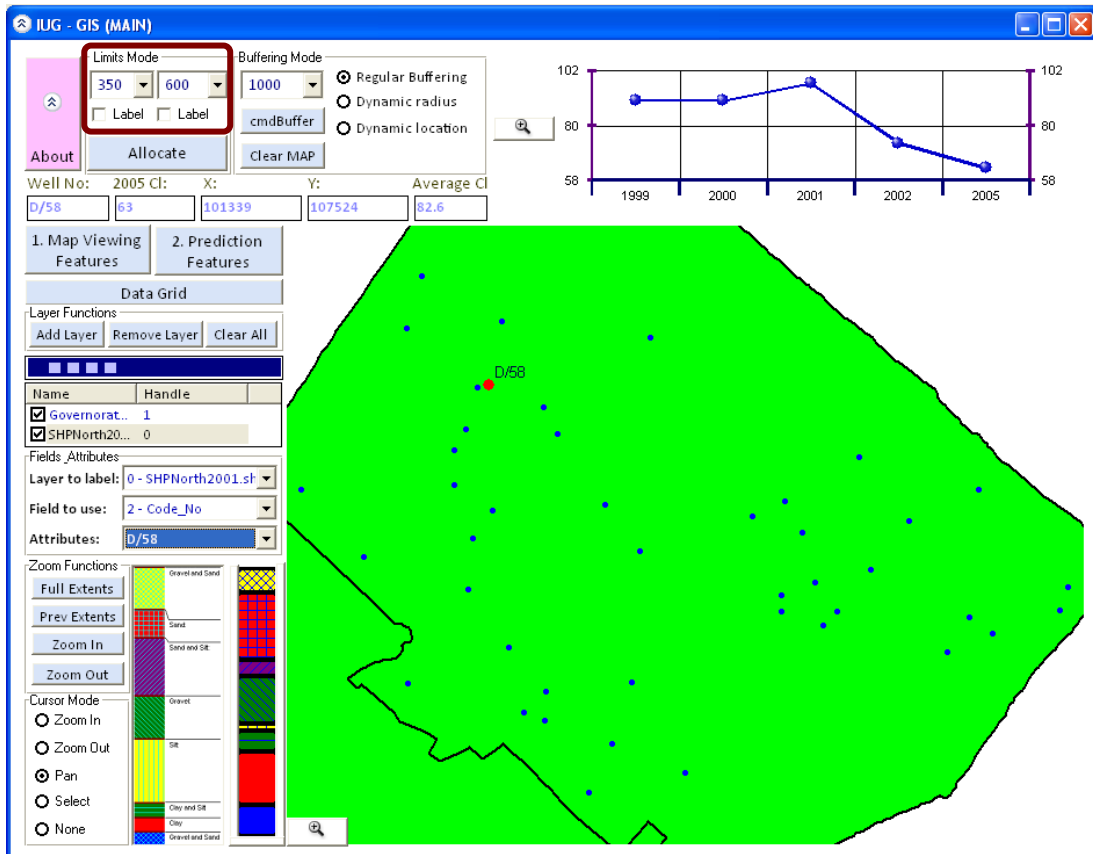


Figure 4-2. Map Viewing Features main screen

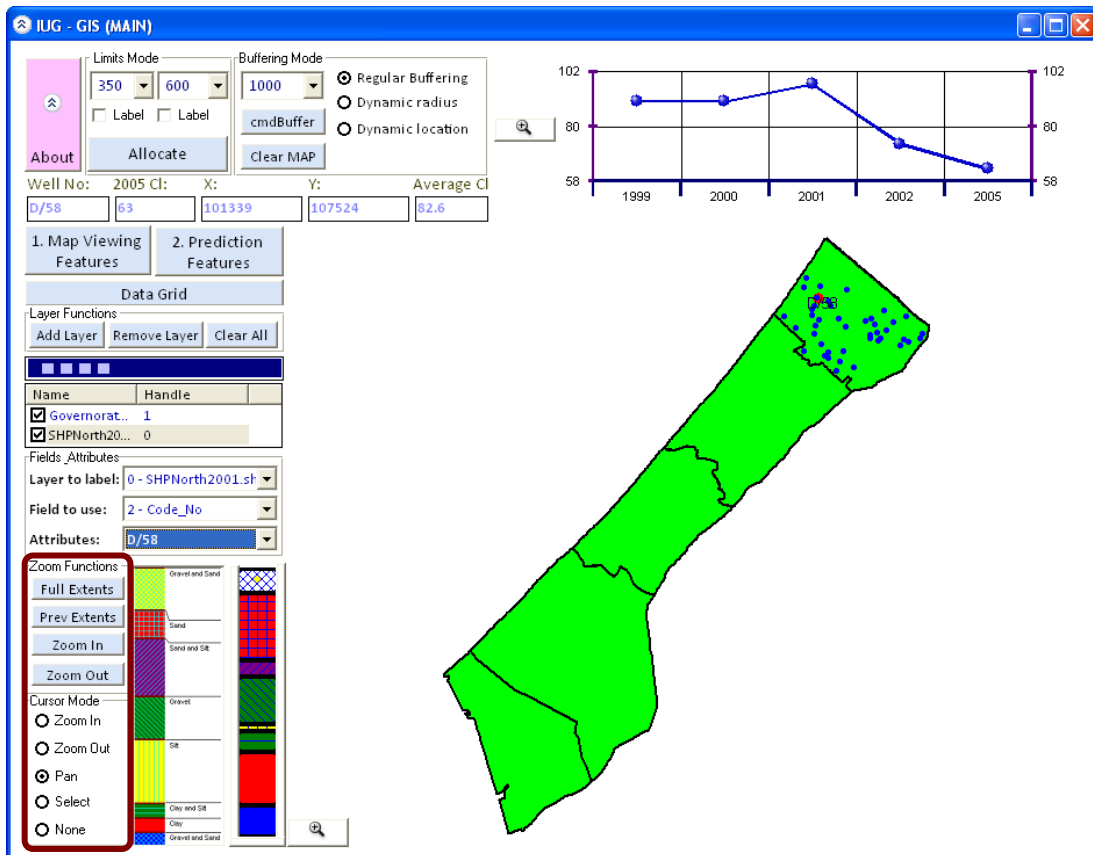
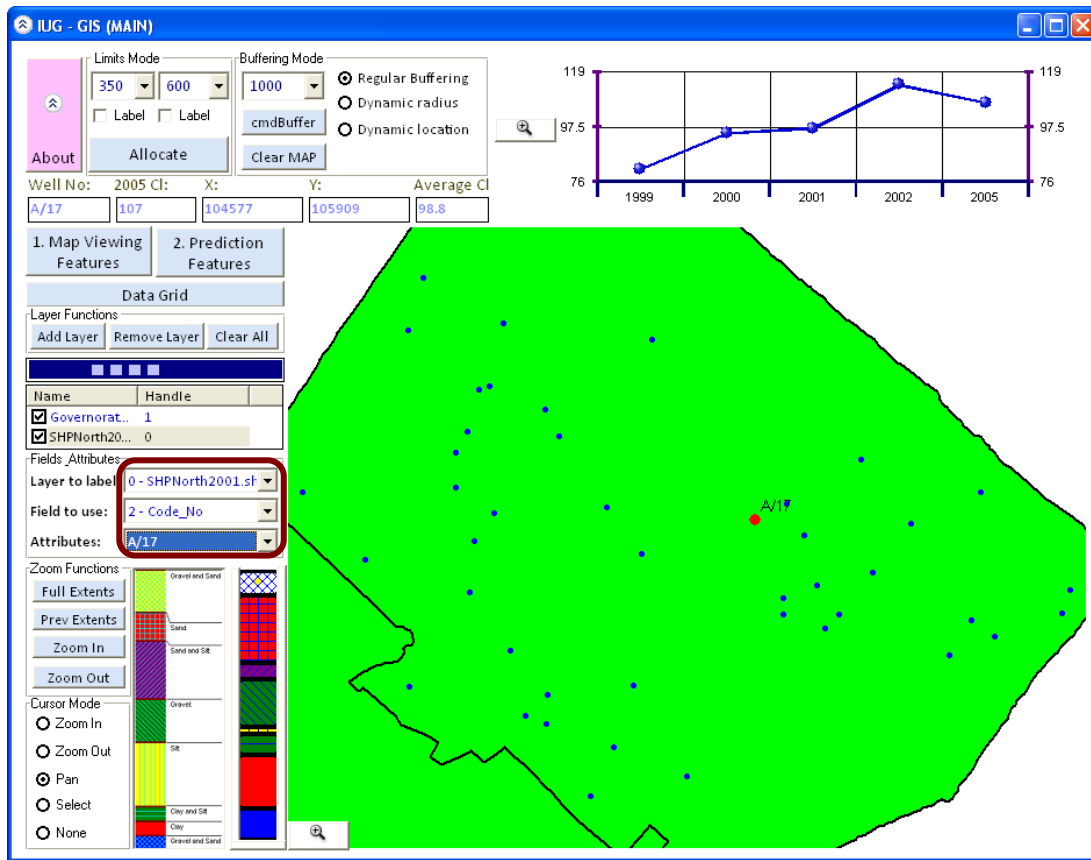


Figure 4-3. Scaling capabilities of integrated mapping system (full scale)

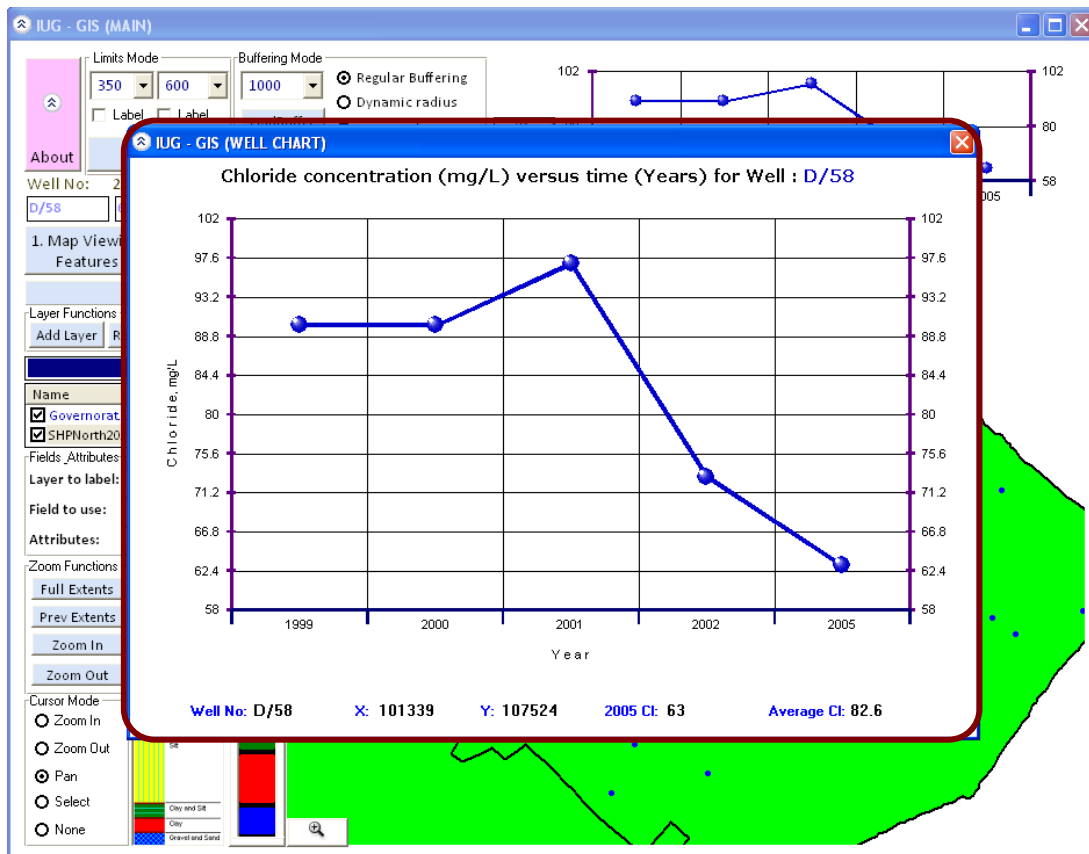
In figure 4.4, exploring through listed well, is giving the user ability to manipulate with every well data, obtain, time-series chart, log-plots, etc...



**Figure 4-4.** Exploring through listed wells

Through spatial and map viewing user can maneuver through the list and obtain information on subject well.

Choosing from a list could be developed further if the user is allowed to directly select the subject well from the map by just a mouse click.



**Figure 4-5.** Well time series through a friendly charting system.

In figure 4.5, the functionality is about previewing time series history of the chloride concentration over a defined period of time. This is presented in a very friendly chart.

This gives the user preliminary understanding of the severity of the case in hand. Accompanying the chart also is average chloride concentration for the listed years.

In figure 4.6, Log-plots or Bore-holes are very important when explanations needed in cases water quality indicators (concentration) are far beyond its normal threshold. It is presented in a very indicative graphical way. It enables previewing strata types, thicknesses.

In figure 4.7, Log-plots or Bore-holes with an extended legend indicating a definition of each strata and its possible composition.



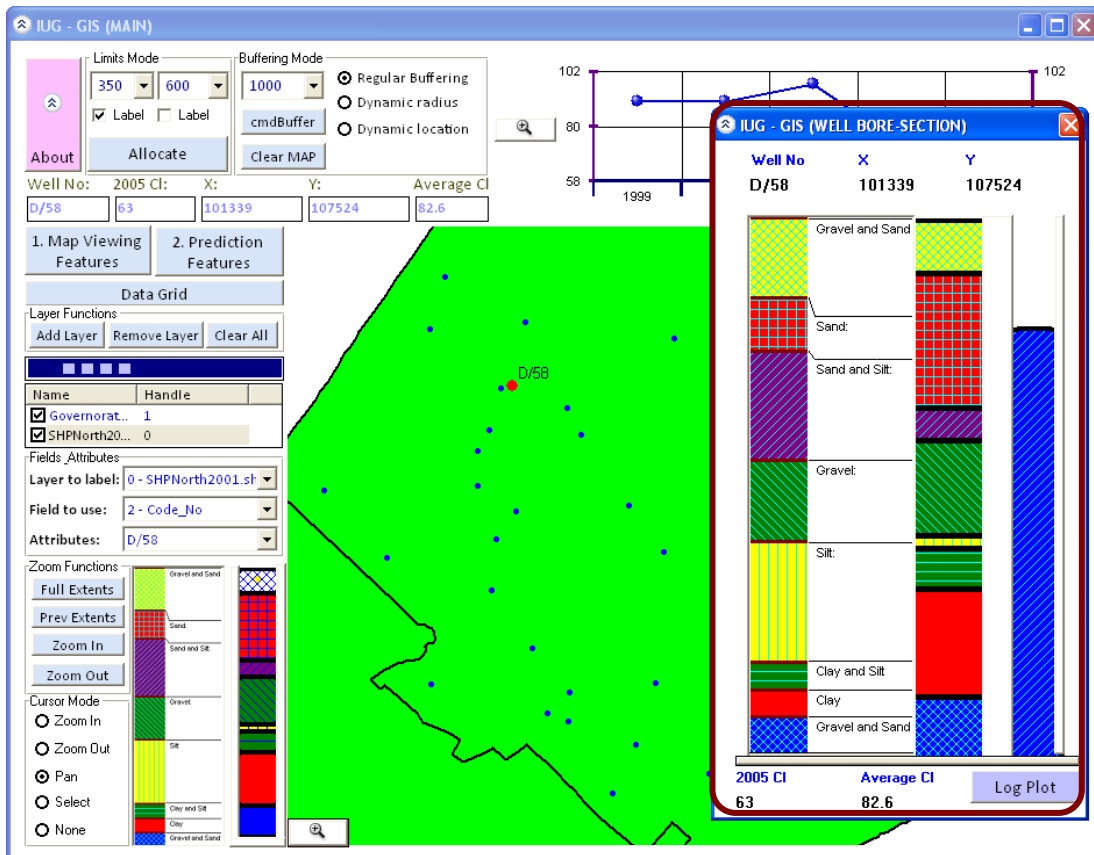


Figure 4-6. Bore-log presented to describe different soil strata for the subject well.

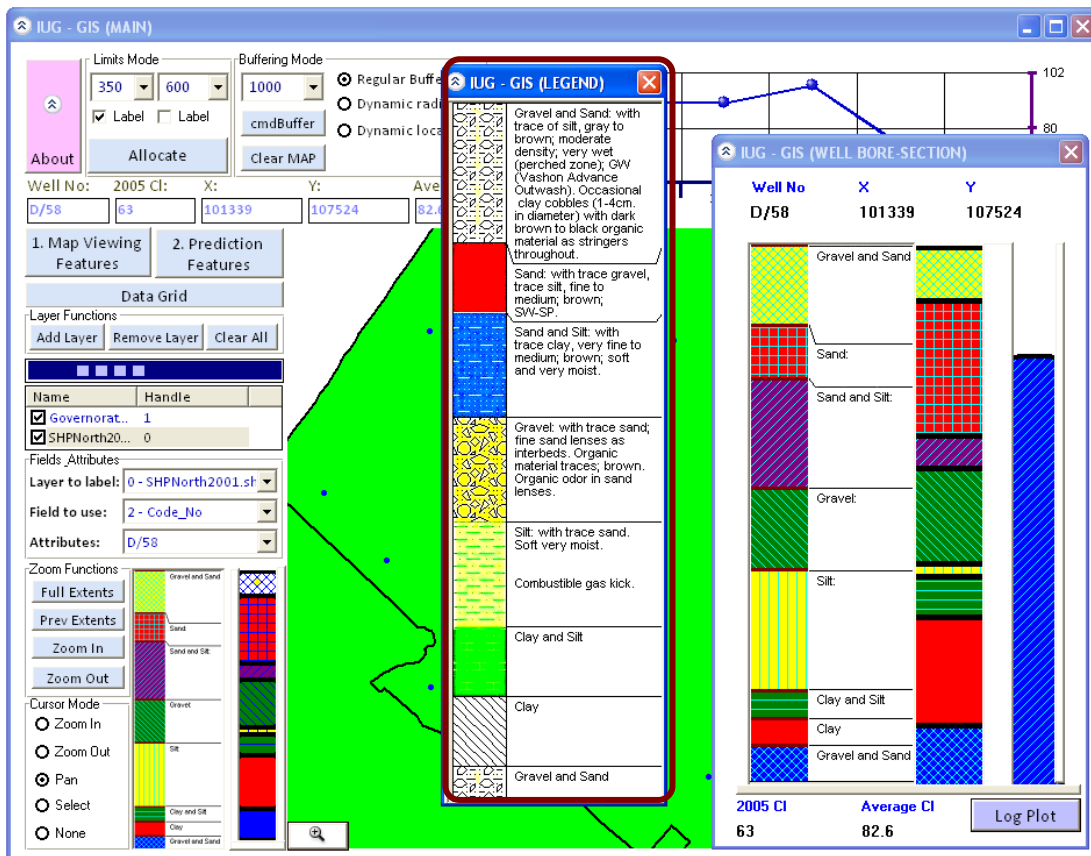
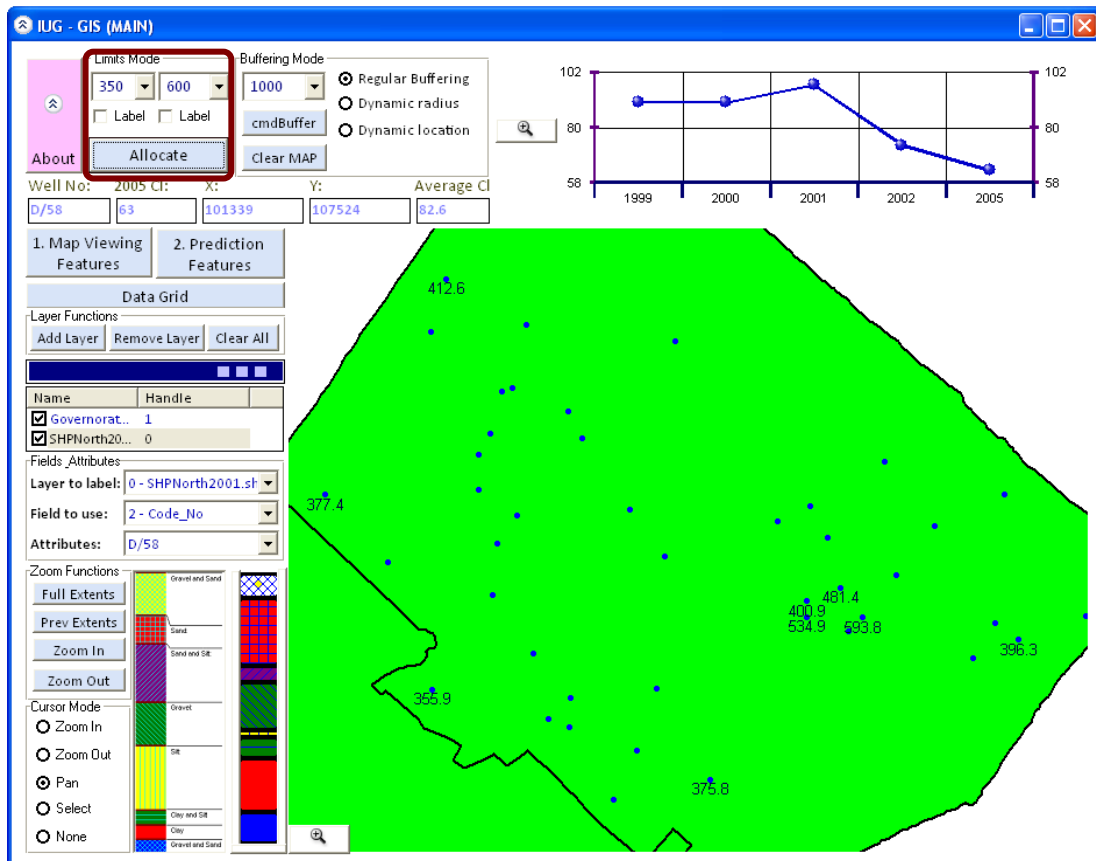


Figure 4-7. Bore-log and log legend and details.

In figure 4.8, water quality status is usually interpreted by comparing current concentrations of substances i.e. chloride, Nitrate, etc with those national/international MCLs of those substances.

This is made available for the chloride case Cl<sup>-</sup>, where user can identify an MCL to see how many water wells are not meeting that condition i.e. above it.

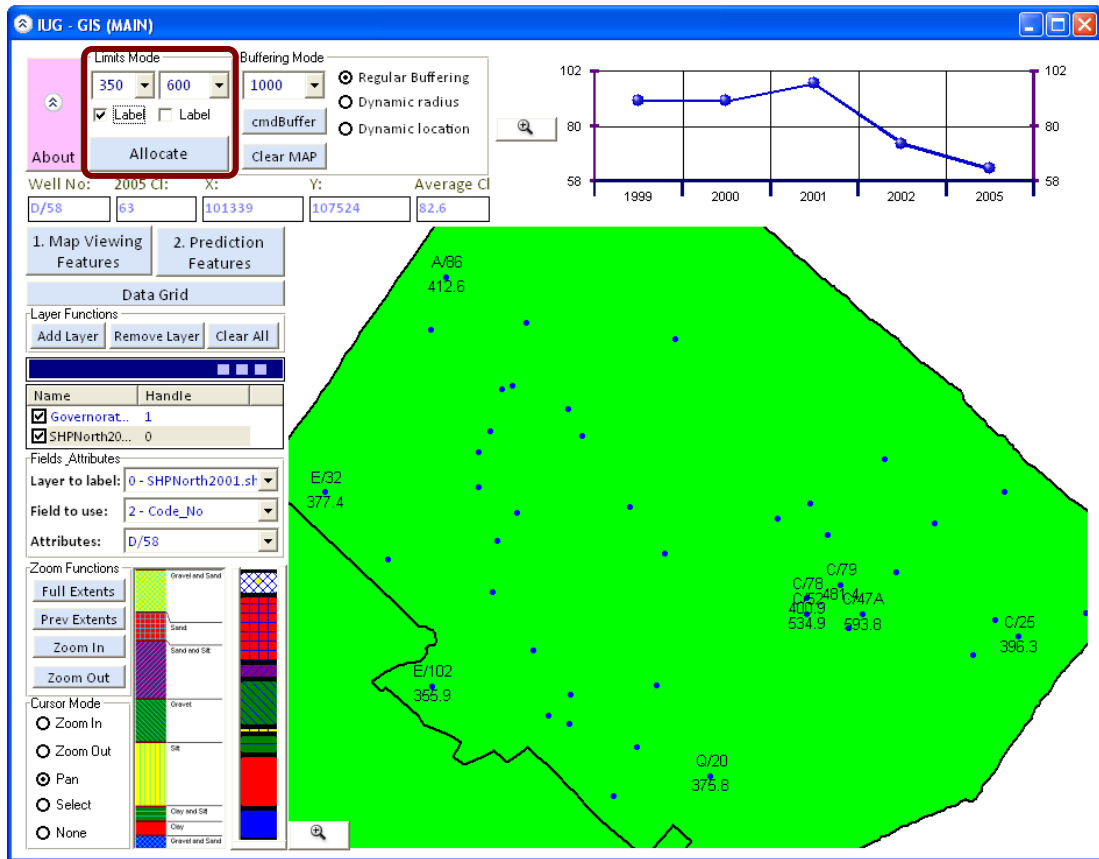
MCL is known to be a good interpreter of water quality, making this even more interactive using the spatial extent of such indicator will give the user ability to identify the extent of the problem if happened and could start using that in identifying possible reasons for that.



**Figure 4-8.** Local or international MCL, showing Wells with concentrations above

In figure 4.9, labeling identified wells above MCL upon user request enabling enough screen space to preview all map features without need to zoom in or out.

A utility that can let the user avoid congestion of elements on the map when no need to show all of them.



**Figure 4-9.** Labeling feature (only active) when user prompt for.

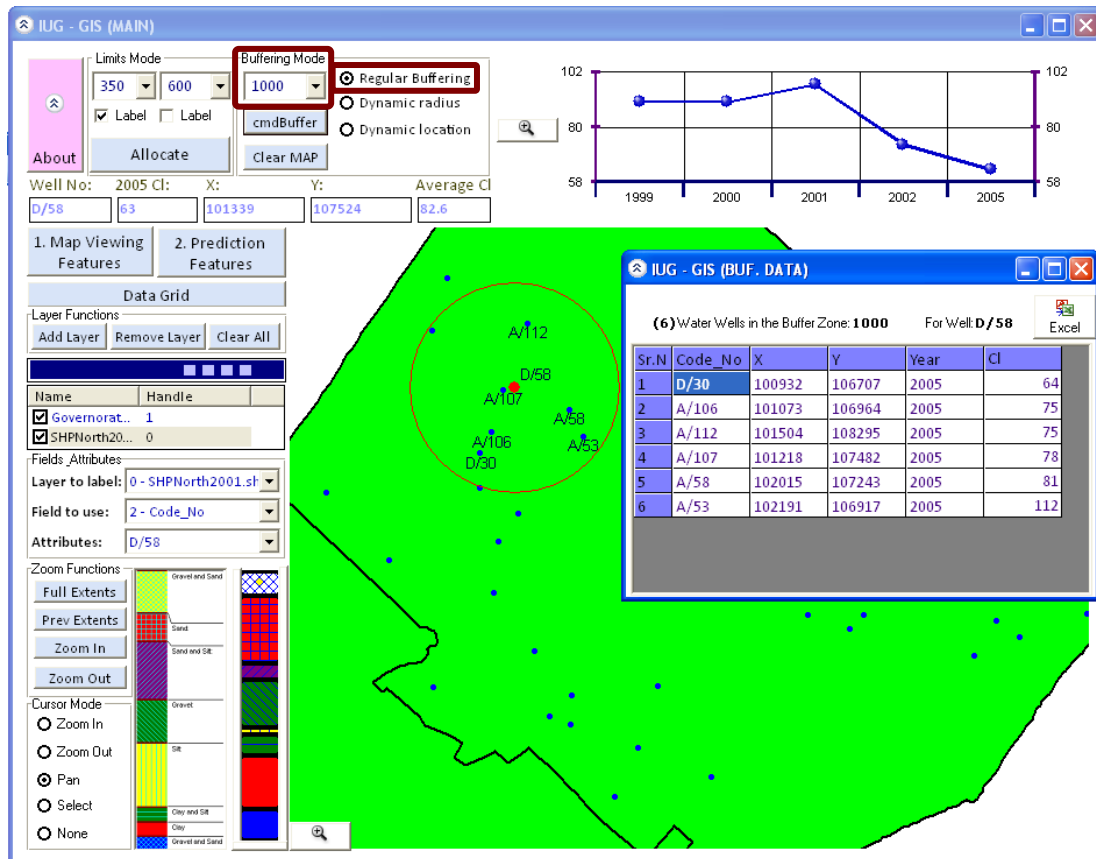
In figure 4.10, buffering Feature at level (1), enables the user to identify a radius for buffering and then query on the possible wells within that buffering zone.

Radius is being defined through independent combo box having regular incrementing radius sizes listed.

Once button clicked, a grid list is shown up indicating the wells in the perimeter defined with main relevant data; in addition to total of wells found.

Management at the filed could utilize this capability in daily queries, if a criterion is set up on digging new wells adjacent to other existing ones. This could help.

The criteria may take into consideration the pumping pattern, current quality indicators, etc....



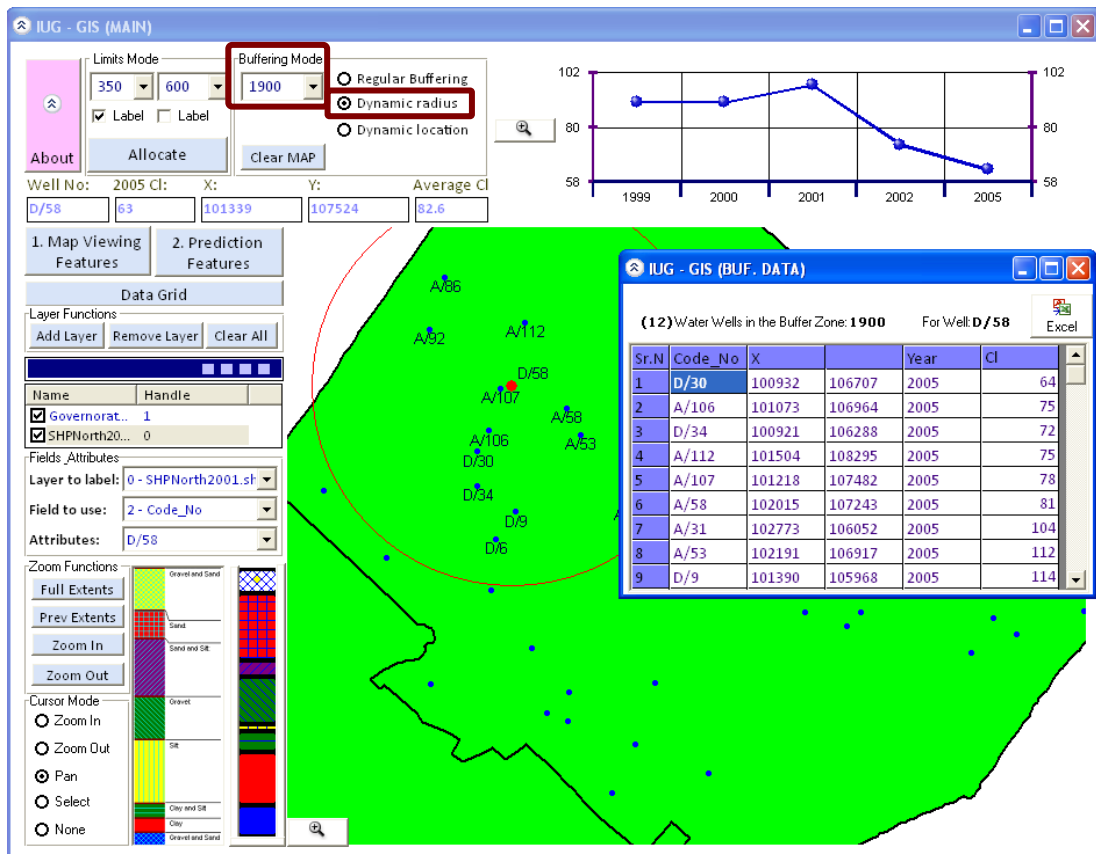
**Figure 4-10.** Buffering feature, Level 1: Buffering with specific radius.

In figure 4.11, buffering Feature at level (2), enable the user to identify different radiuses and buffering zones for one well, at that stage user would be able to preview different scenario results, if different radiuses and buffering zones are chosen.

Changes this time are taking place through combo box identifying the radius with mouse scrolling. Once done, a flex-grid list is shown up indicating the wells in the perimeter defined with main relevant data; the total number is also indicated.

Management at the field could utilize this capability in daily queries, identifying the most suiting buffering zone for any action before taken, i.e. opening new wells, identifying possible adjacent wells for use if this current well closed, permanently, or temporarily for maintenance.

If a criterion is set up on opening new wells adjacent to other existing ones or pumping pattern for those wells, user can be able to utilize this in solving such problems.



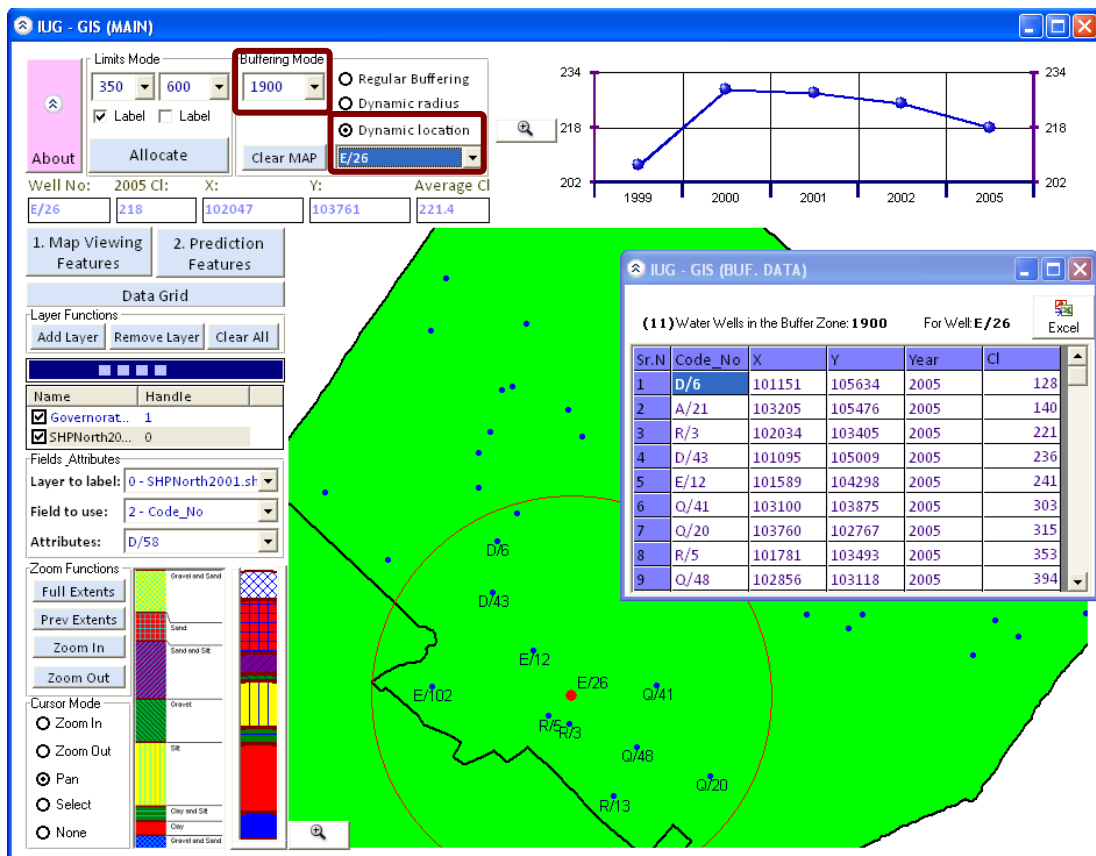
**Figure 4-11.** Buffering feature, Level 2: Buffering with dynamic radius, fixed well.

In figure 4.12, buffering Feature at level (3), enable the user to fix a radius and then buffering for multiple wells, at that stage user would be able to preview different scenario results for one buffering and see its impact on every well and what wells could be in the vicinity of the subject well.

Changes this time are taking place through the combo box identifying the wells with mouse scrolling.

Once button clicked, a grid list is shown up indicating the wells in the perimeter defined with main relevant data; the total number is also indicated.

Management at the filed could utilize this capability in daily queries, as some time constraint regarding buffering zone would result in switching between available wells and see where this could apply.



**Figure 4-12.** Buffering feature, Level 2: Buffering with dynamic Well location.

In figure 4.13, user will be always able to switch back between screens and modes by one click, at this stage button (1) was clicked to get us back to the map viewing features and start again from there.

A tool with easy-to-manipulate is usually a need whether during daily work, or when conducting training, easy and direct.

In figure 4.14, it has been made possible that user load other shapfiles, but they will not be linked to any database, user will be able to navigate through shapefiles loaded only.

Even if the system is purpose-specific, it is still a GIS based tool, that should be rich such any GIS tool, map viewing, zooming, etc..

At this stage, this GIS-based system is not developed to cope with different database or shapefile, it could be developed in a way that user is prompt to choose the shapefile and the database for the study need.

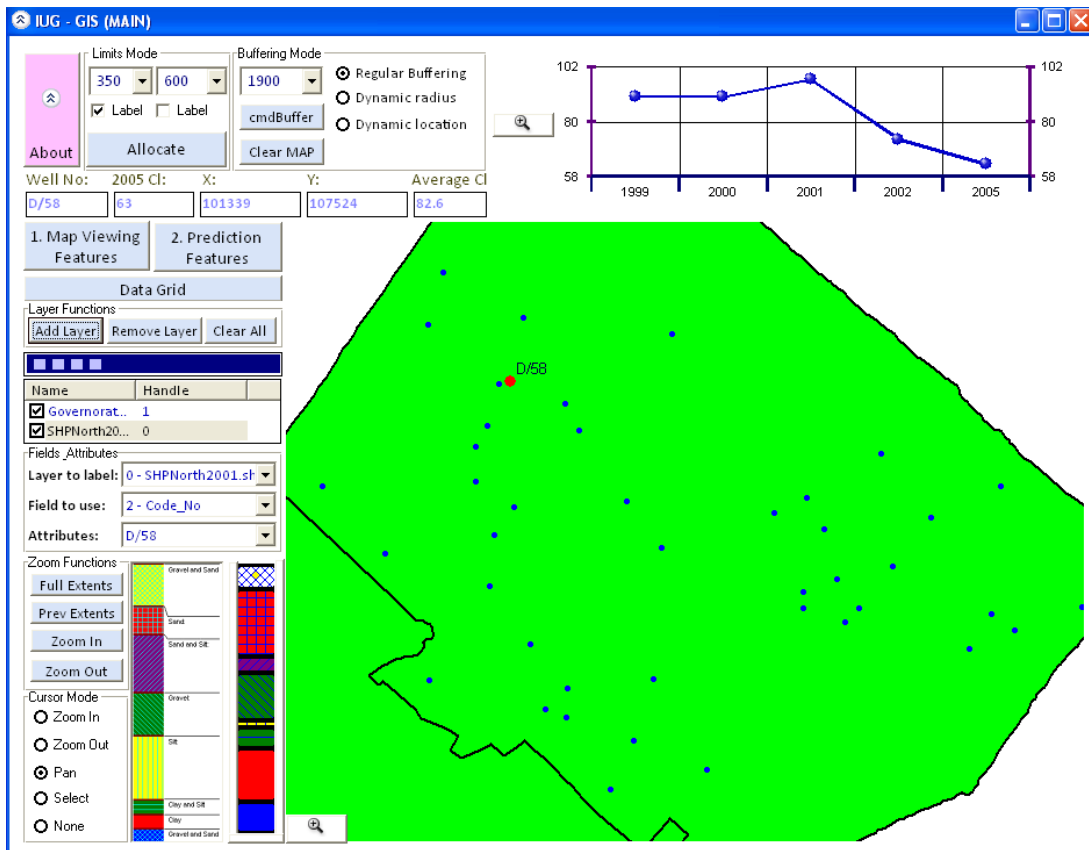


Figure 4-13. Switching between screens and modes (Map Viewing Features Mode).

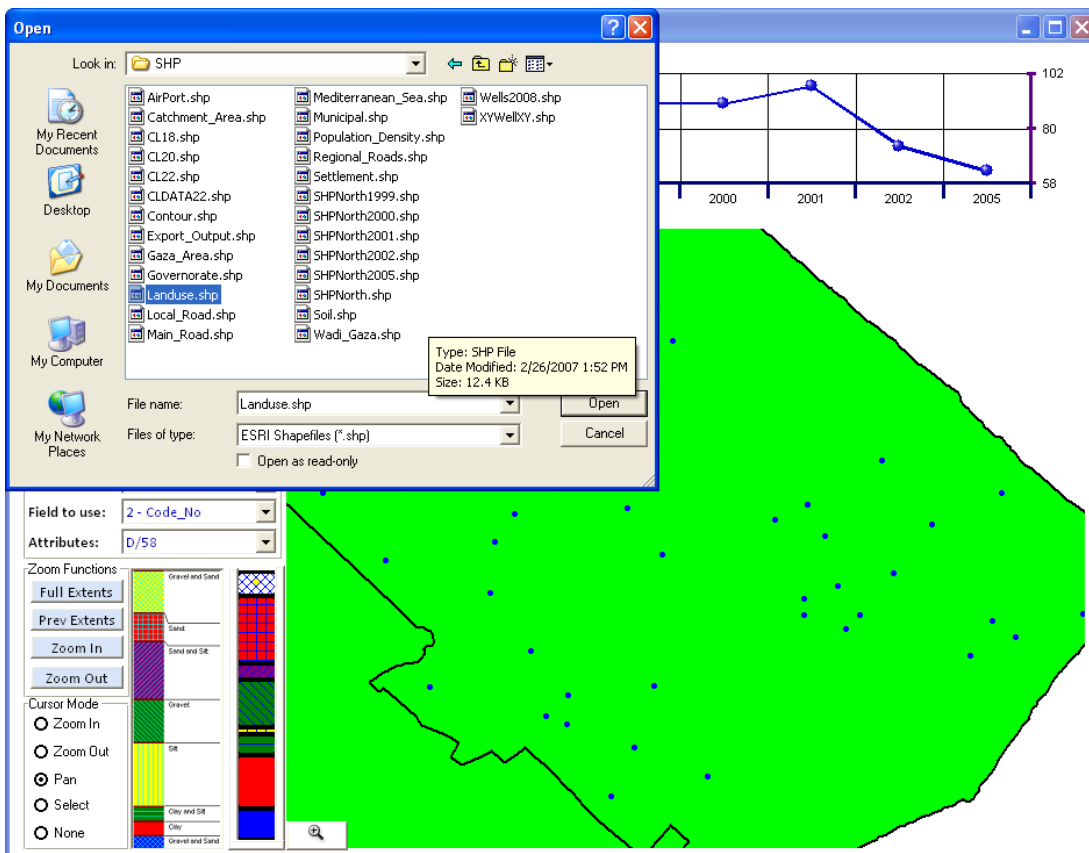
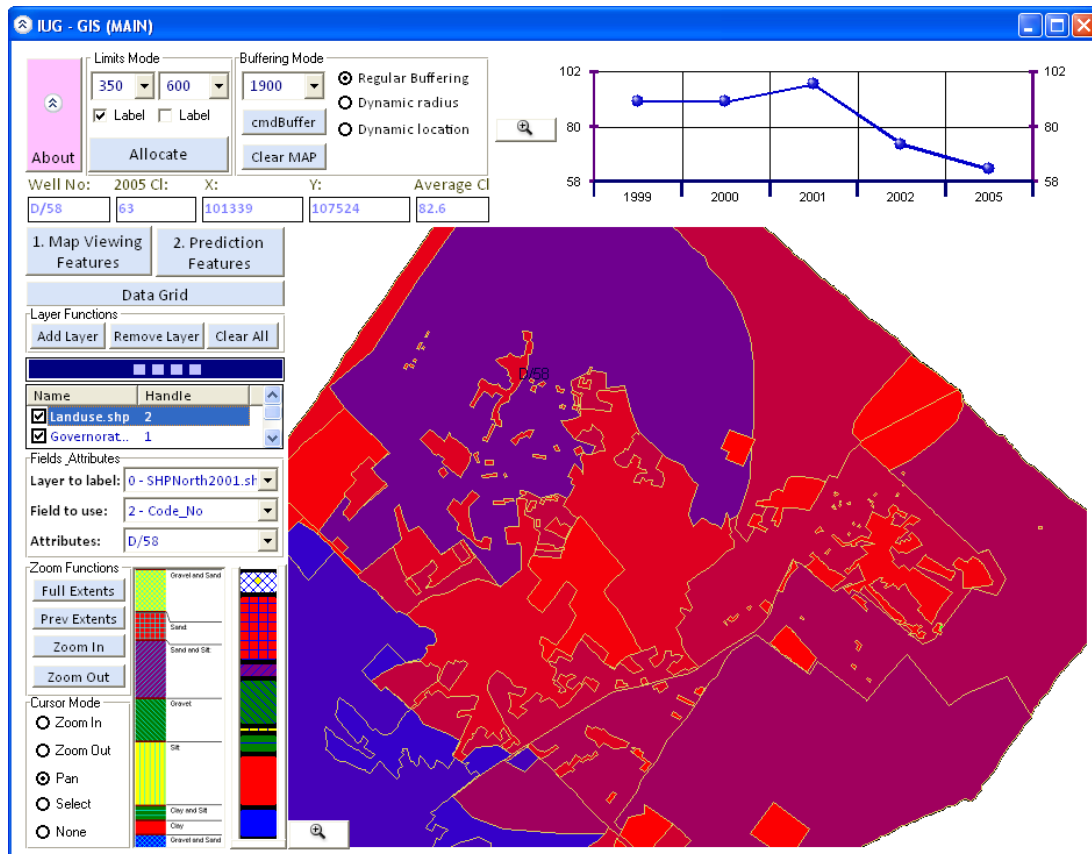


Figure 4-14. Loading other shapfiles

In figure 4.15, loaded shapefiles are automatically colored differentiating between different shapes, just upon clicking the shapefile.

Noted benefit to the user is enabling multiple functions in one click, coloring as legend.

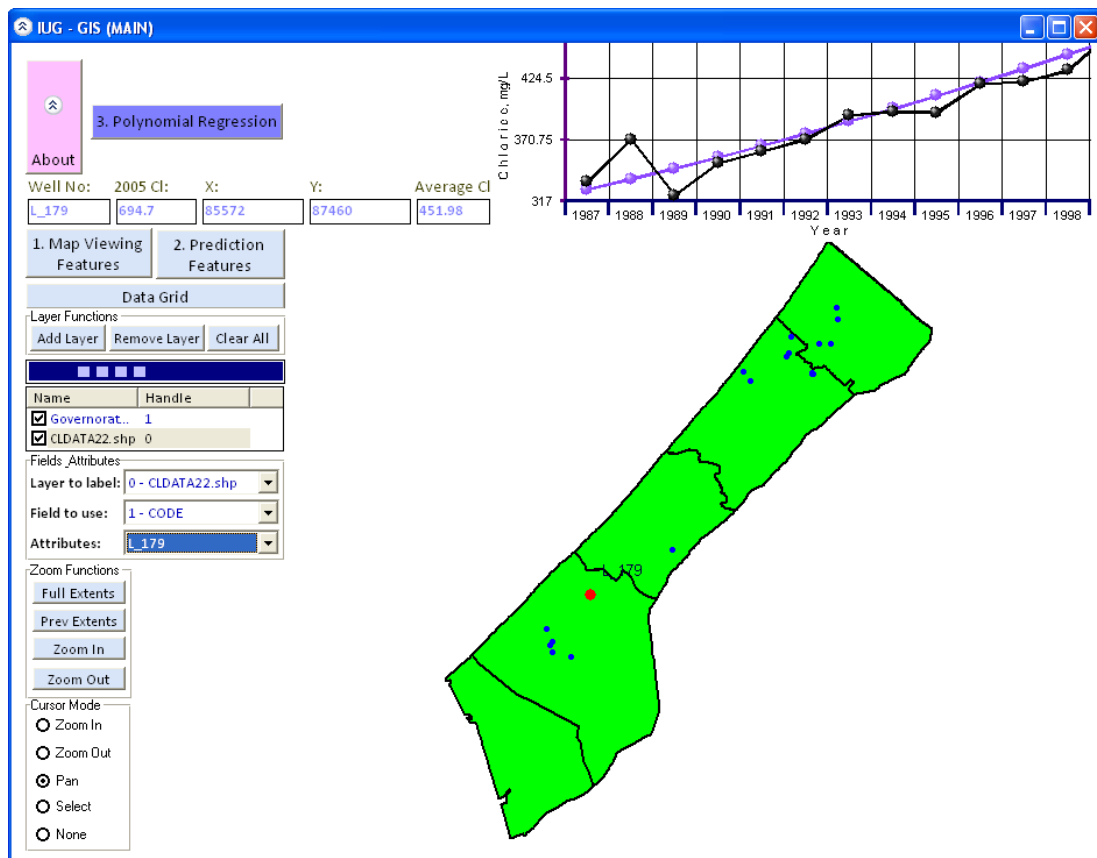


**Figure 4-15.** Shapefile Landuse loaded with automatic coloring system.

In figure 4.16, user will be always able to switch back between screens and modes by one click, at this stage button (2) was clicked to go to the prediction features mode.

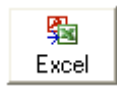
A tool with easy-to-manipulate is usually needed and has added value whether during daily work, or when conducting training, easy and direct.





**Figure 4-16.** Switching between screens and modes (Predication Features Mode).

In figure 4.17, exporting to MS Excel facility is available, through outlined button as



, which export lists to Excel.

This would enable the user to export any developed or extracted information to Excel, allowing for further manipulation or utilization of listed information.

Reporting, is to be developed in a way allowing for printing maps and figures, printing prepared lists directly from the application without the need to obtain other applications support such as MS Excel.

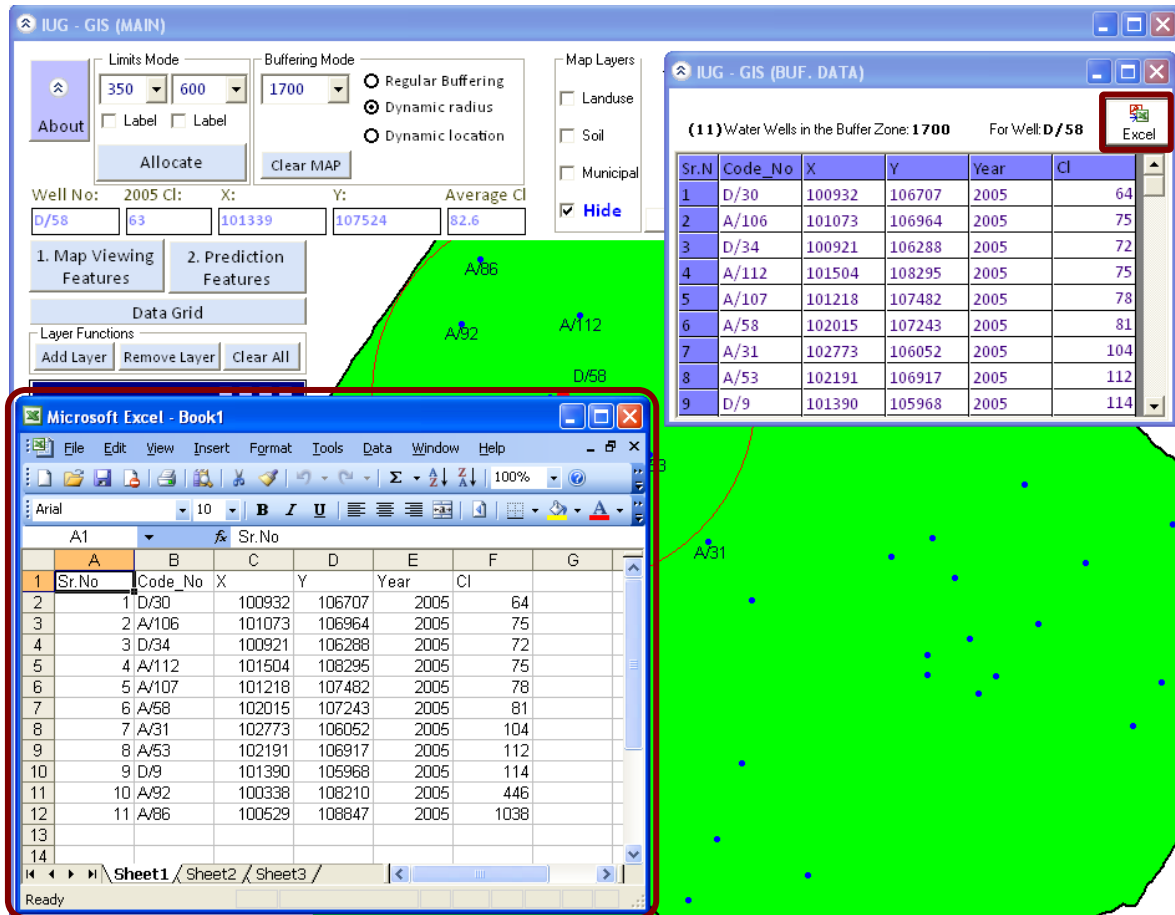


Figure 4-17. Exporting to MS Excel

### 4.3 Regression analysis

Regression analysis includes any techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps us understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables [28].

#### 4.3.1 Polynomial regression

Polynomial regression is a form of linear regression in which the relationship between the independent variable  $x$  and the dependent variable  $y$  is modeled as an  $n$ th order Polynomial. Polynomial regression fits a nonlinear relationship between the value of  $x$  and the corresponding conditional mean of  $y$ , denoted  $E(y|x)$ , and has been used to describe nonlinear phenomena such as the growth rate of tissues.

Polynomial regression models are usually fit using the method of least squares. The least-squares method minimizes the variance of the unbiased estimators of the coefficients, under the conditions of the Gauss–Markov theorem. Analyzing a Matrix for polynomial regression includes [29]:

The basis of polynomial regression is that a data set of  $n$  paired  $(x, y)$  members:

$$(x_1, y_1), (x_2, y_2), (x_3, y_3), \dots, (x_n, y_n) \dots \dots \dots (1)$$

Can be processed using a least-squares method to create a predictive polynomial equation of degree  $p$ :

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \dots a_px^p, p < n \dots \dots \dots (2)$$

The essence of the method is to reduce the residual  $R$  at each data point:

$$R_i = y_i - a_0 - a_1x_i - a_2x_i^2 \dots - a_px_i^p \dots \dots \dots (3)$$

This is accomplished by first expressing the system in matrix form (this example represents a polynomial of degree 4):

$$\begin{pmatrix} n & \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 \\ \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 \\ \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 & \sum x_i^8 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \\ \sum x_i^3 y_i \\ \sum x_i^4 y_i \end{pmatrix} \dots (4)$$

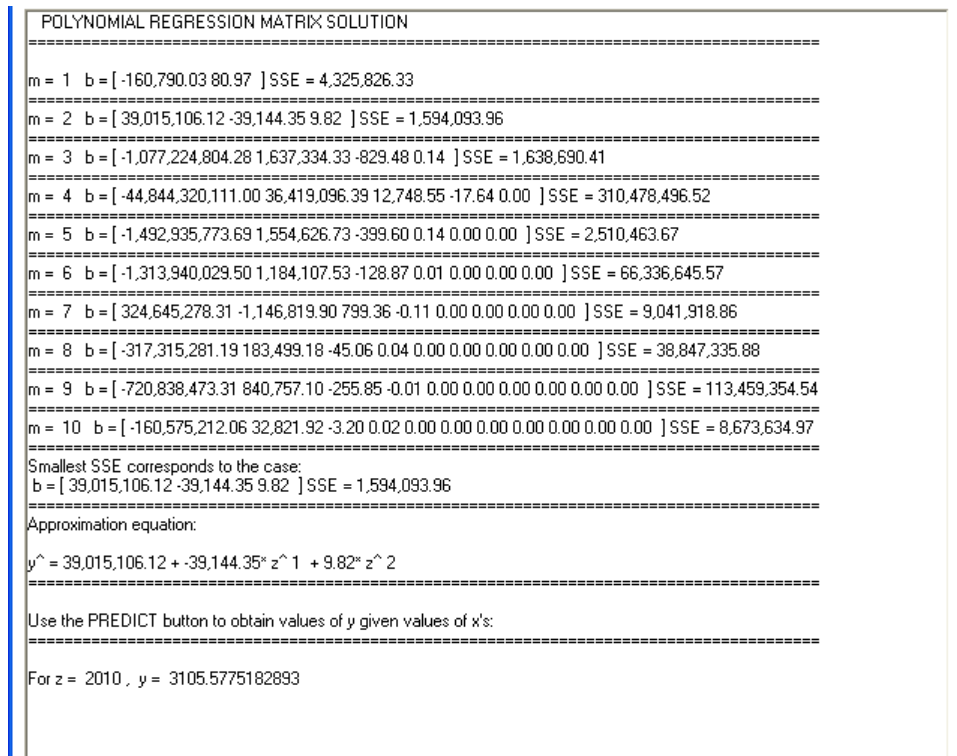
Then solving for the unknown middle column, (e.g.  $a_0, a_1, a_2 \dots$ ) by means of Gauss-Jordan elimination. The resulting values represent the polynomial coefficients for equation (2) above.

Example on one of the water well under this study will give the following:

Data for well No. R\_112:

Year	Cl <sup>-</sup> (mg/l)	Year	Cl <sup>-</sup> (mg/l)	Year	Cl <sup>-</sup> (mg/l)	Year	Cl <sup>-</sup> (mg/l)
1987	529	1993	328	1999	482	2005	2031
1988	455	1994	620	2000	392	2006	2353
1989	665	1995	693	2001	869	2007	2674
1990	726	1996	625	2002	787	2008	2144
1991	570	1997	780	2003	820		
1992	444	1998	581	2004	1430		

This if undergoes same steps as above example, gives as in figure 4.18 and 4.19:



**Figure 4-18.** Buffering feature, level 3: Level three: fixed radius, different locations



**Figure 4-19.** Polynomial regression analysis is conducted here through the least squared error

Where degree of equation is defined according to the minimum SSE.

$$\text{Error} = (y_{\text{observed}} - y_{\text{predicted}}) * 100$$

#### 4.3.2 Residues, Sum-of-Squares Error (SSE)

A residue is the difference between an observed and predicted value of a function. (A predicted value means a value given by some mathematical model.)

$$\text{Residue} = \text{Observed value} - \text{Predicted value}$$

The sum-of-squares error (SSE) when observed data are approximated by a function is given by: **SSE = Sum of squares of residues = Sum of  $(y_{\text{observed}} - y_{\text{predicted}})^2$**

The smaller SSE, the better the approximating function fits the data.

#### 4.3.3 Inflation of $R^2$ in least squares regression

The quantity  $r$ , called the linear correlation coefficient, measures the strength and the direction of a linear relationship between two variables. The linear correlation coefficient is sometimes referred to as the Pearson product moment correlation coefficient in honor of its developer Karl Pearson.

The mathematical formula for computing  $r$  is:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} \sqrt{n(\sum y^2) - (\sum y)^2}}$$

Where  $n$  is the number of pairs of data.

In least squares regression,  $R^2$  is weakly increasing in the number of regressors in the model. As such,  $R^2$  alone cannot be used as a meaningful comparison of models with different numbers of independent variables, figures 4.20 to 4.21.



**Figure 4-20.** Prediction for other years showing real and predicted values and error

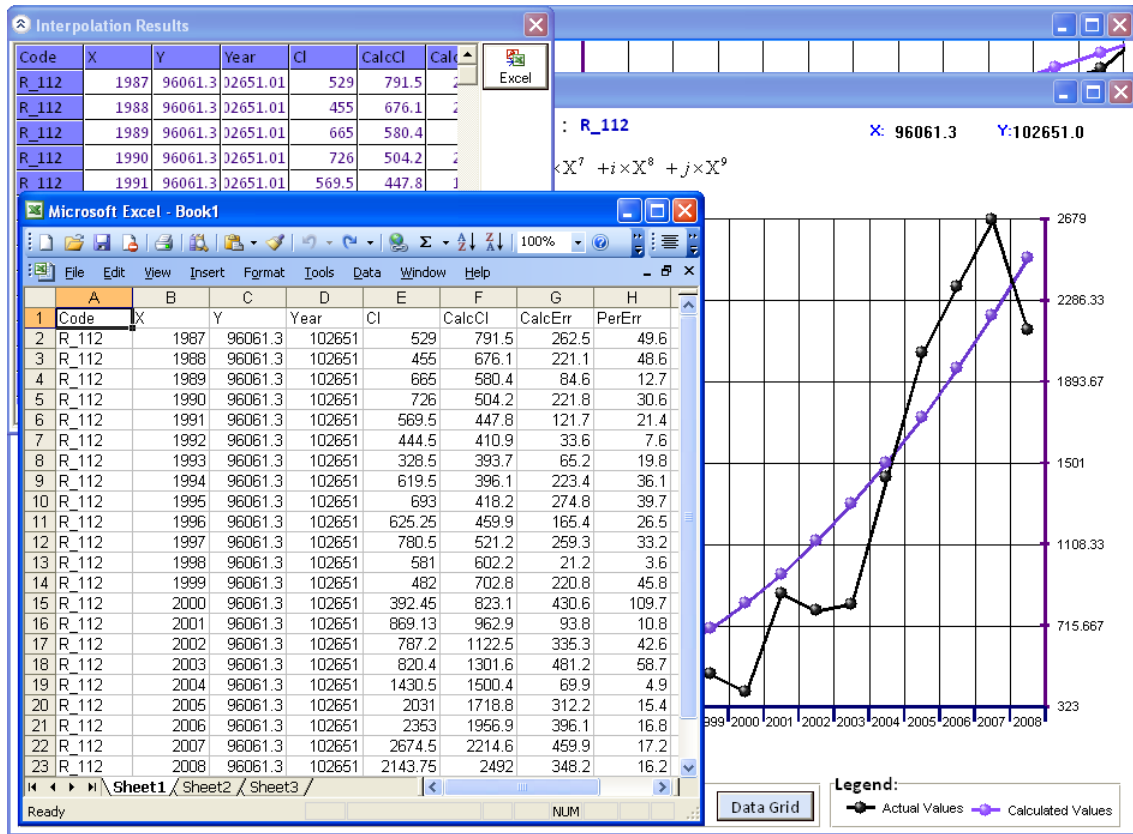


Figure 4-21. Preview of data recorded and developed and exporting it to MS Excel

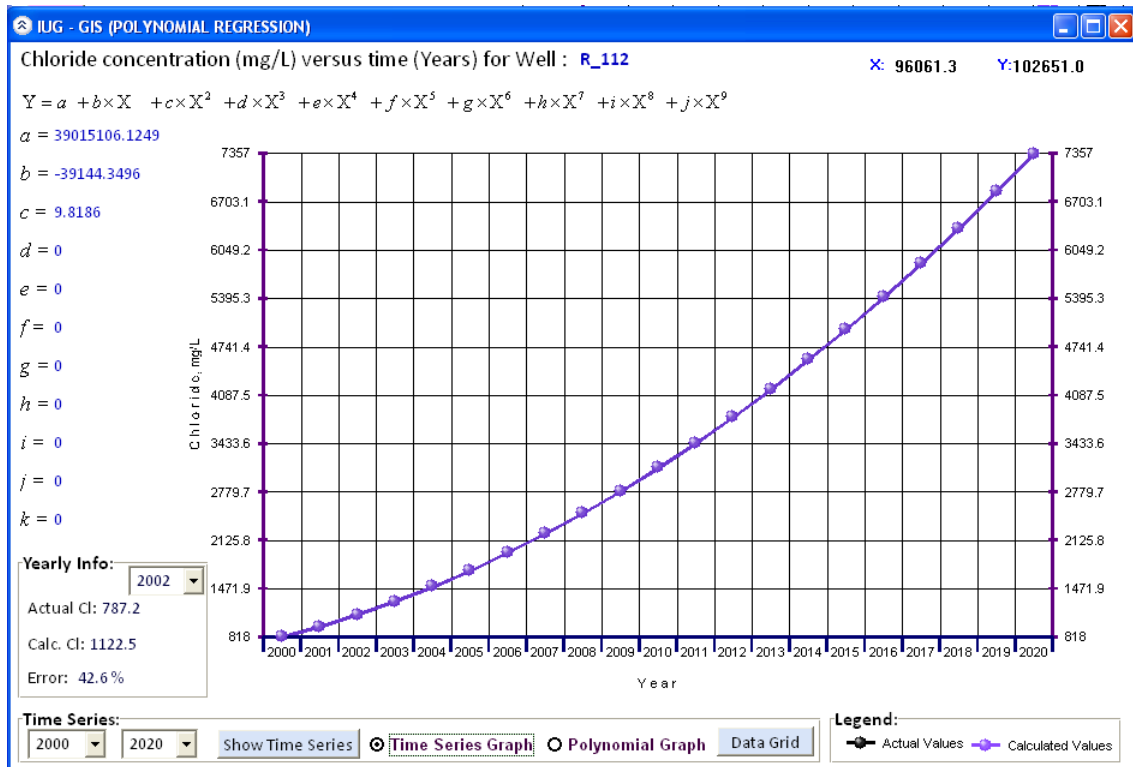
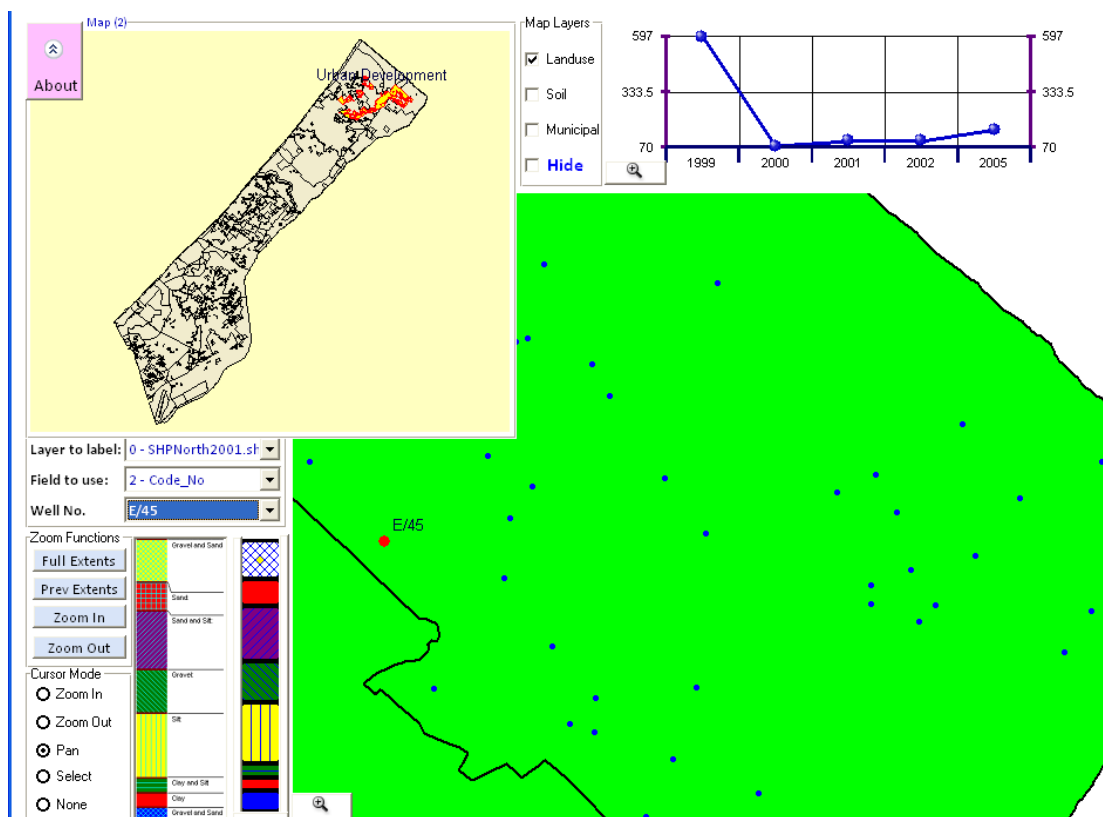


Figure 4-22. Time series calculation for set of years using the developed equation

#### 4.4 Map overlapping application

Throughout this developed system, user will be able to identify several related information at one time for a specific query i.e. Performing spatial queries on the data, and searching for features with specific attributes:

This is possible through selecting one additional map and hence information source in addition to existing information where location of subject water well is automatically identified and shows related information to that well from the other map. Below is illustration, figures 4.23 to 4.25:



**Figure 4-23.** Land use for selected well E/54



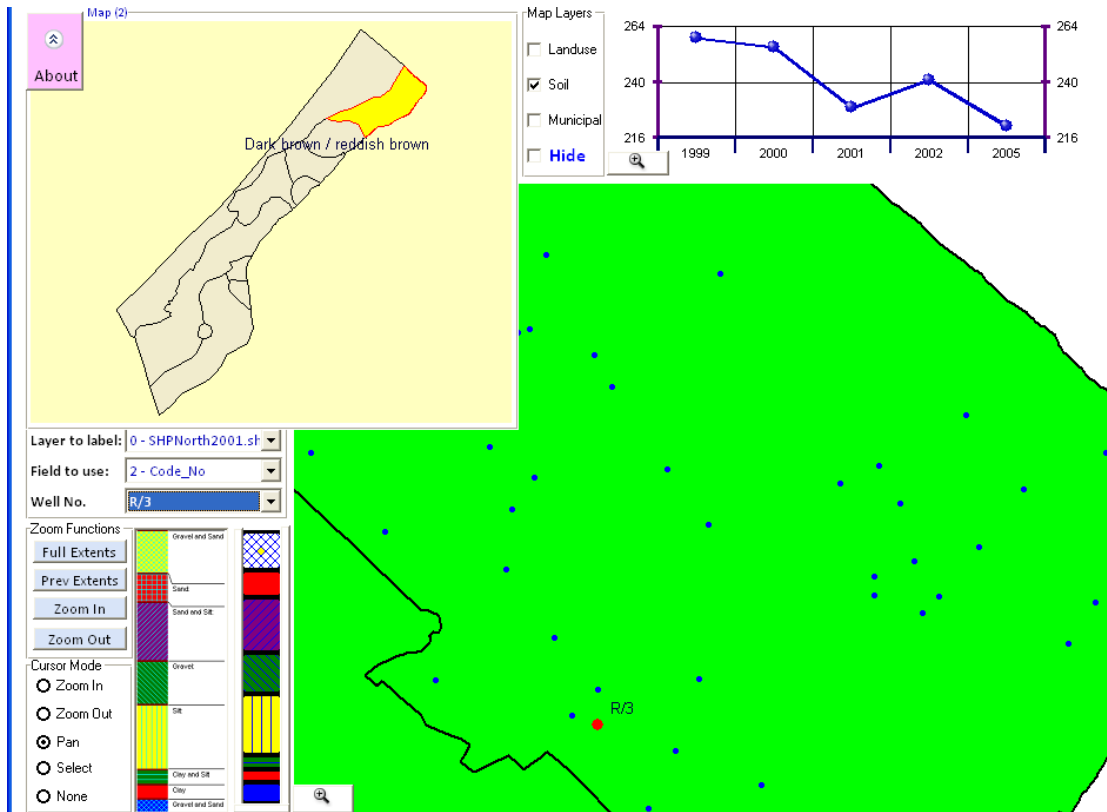


Figure 4-24. Soil type for selected well R/3

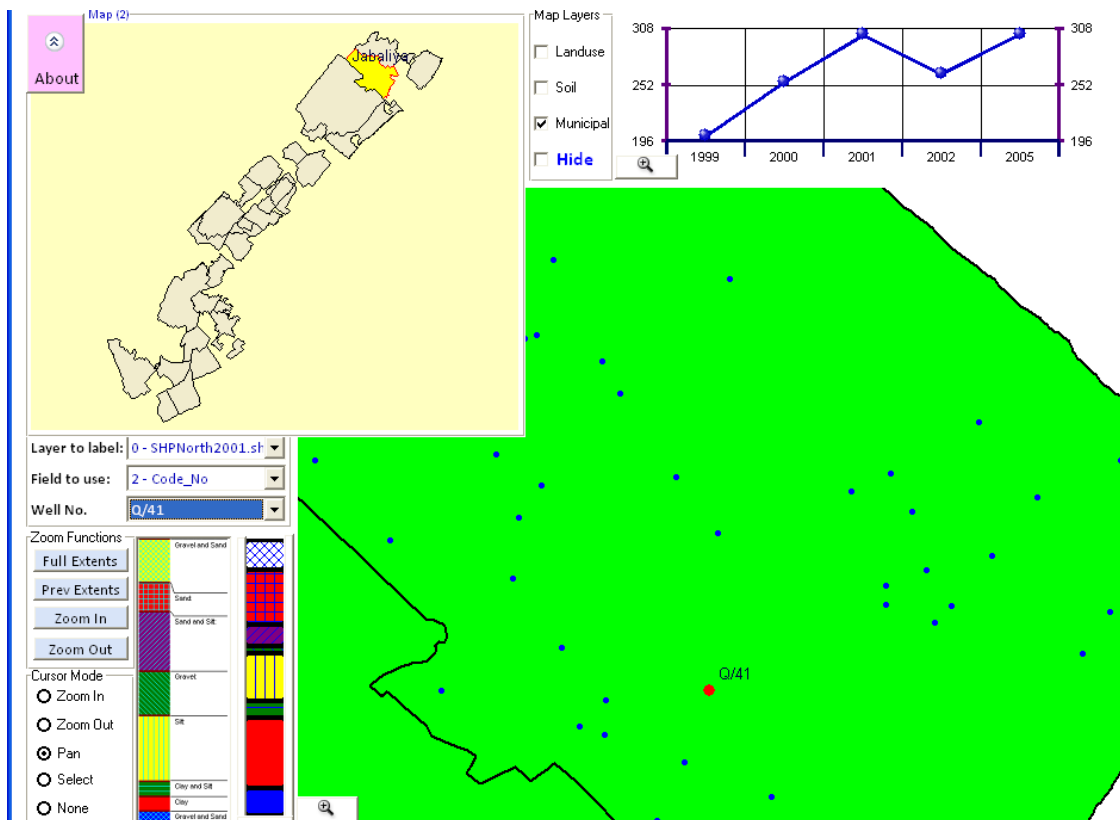
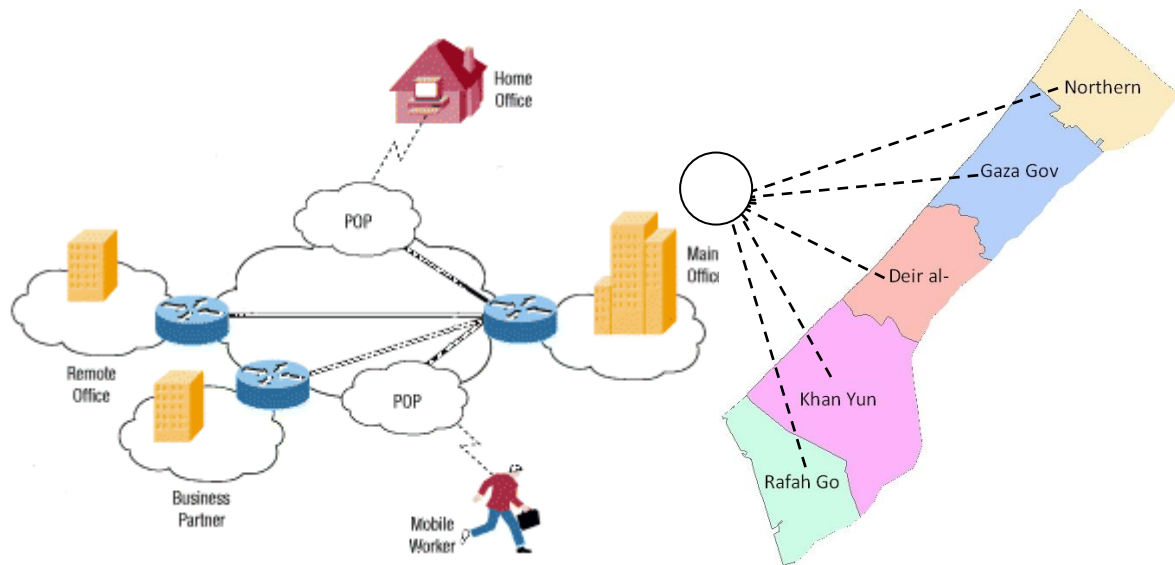


Figure 4-25. Municipality identifier for selected well Q/41

## 4.5 Extended system application

This developed tool in addition to being easy to use, it is easy to access, through advanced networking technologies, by localizing/centralizing the set of shapefiles and databases that will be used from within the organization through local networks or from out of it through virtual private networking (VPN) [40].

The concept here is to include the governorates (via municipalities), to share such tool and have it centralized in terms of management and data processing through i.e. CMWU in Gaza, figure 4.26.



**Figure 4-26.** Defined VPN through Gaza targeted areas

### 4.5.1 Virtual private network (VPN)

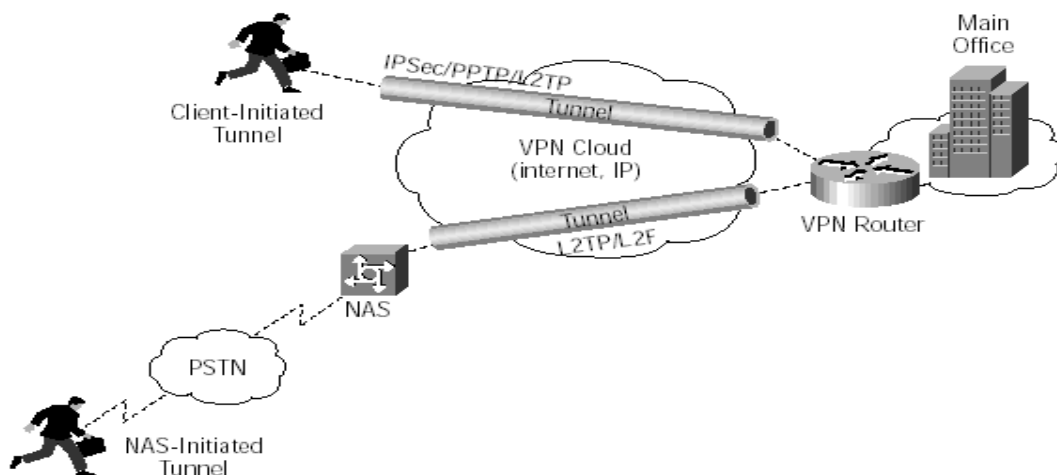
As the popularity of the Internet grew, businesses turned to it as a means of extending their own networks. First came intranets, which are password-protected sites designed for use only by company employees. Now, many companies are creating their own VPN to accommodate the needs of remote employees and distant offices.

Basically, a VPN is a private network that uses a public network (usually the Internet) to connect remote sites or users together. Instead of using a dedicated, real-world connection such as leased line, a VPN uses "virtual" connections routed through the Internet from the company's private network to the remote site or employee. Virtual private networks help distant colleagues work together, much like desktop sharing [40].

Remote-access, also called a virtual private dial-up network (VPDN), is a user-to-LAN (local area networks) connection used by a company that has employees who need to connect to the private network from various remote locations. Typically, a corporation that wishes to set up a large remote-access VPN will outsource to an enterprise service provider (ESP).

#### 4.5.2 Remote access VPNs

Remote access VPNs (see Figure 2), enables mobile users to establish a connection to an organization server by using the infrastructure provided by an ISP (Internet Services Provider). Remote access VPN allows users to connect to their corporate intranets or extranets wherever or whenever is needed. Users have access to all the resources on the organization's network as if they are physically located in organization.



**Figure 4-27.** Remote Access VPNs

#### 4.5.3 Productivity and Cost Benefit of VPNs

A well-designed VPN can greatly benefit a company. For example, it can:

- Extend geographic connectivity
- Improve security
- Reduce operational costs versus traditional wide area network (WAN)
- Reduce transit time and transportation costs for remote users
- Improve productivity
- Simplify network topology
- Provide global networking opportunities

- Provide telecommuter support
- Provide broadband networking compatibility
- Provide faster ROI (return on investment) than traditional WAN

In terms of productivity VPN's have come a long way, also VPN's Benefit an organization or in the following ways:

1. Extends Geographic Connectivity- a VPN connects remote workers to central resources, making it easier to set up global operations.
2. Boosts Employee Productivity- A VPN solution enables telecommuters to boost their productivity by 22% - 45% (Gallup Organization and Opinion Research) by eliminating time-consuming commutes and by creating uninterrupted time for focused work.
3. Improves Internet Security – An always-on broadband connection to the Internet makes a network vulnerable to hacker attacks. Many VPN solutions include additional security measures, such as firewalls and anti-virus checks to counteract the different types of network security threats.
4. Scales Easily – A VPN allows companies to utilize the remote access infrastructure within ISPs. Therefore, companies are able to add a virtually unlimited amount of capacity without adding significant infrastructure [40].

## **4.6 Conclusion**

Through the chapter, focus made on the outputs of the system developed through discussing main features such as the used prediction model and explaining other relevant measures introduced to ensure system integration and extendibility within the real application environment such as the VPN technology.

## **CHAPTER (5): CONCLUSION AND RECOMMENDATIONS**

### **5.1 Conclusion**

#### **5.1.1 Introduction**

The water resources management in the Gaza strip when it comes to GIS related technology relies on ordinary applications such as ESRI ArcMAP and Geomedia Professional, this result in the following:

- 1- Very high cost to adopt such platforms as each license should have a cost.
- 2- These applications are sophisticated in the general concept when it comes to non-technical users of the GIS.
- 3- Intensive training and up-to-date knowledge is required to keep tracking of the changes and updates on the versions of these products.
- 4- Portability is considered not possible as only the computer that have the application installed is the one to run that application, switching to another for the same licensing requires removing and re-installing.
- 5- It is not direct in its concept, as it serves a divers users over the world, this lets reaching some results time and effort consuming.

Trying to mitigate the effect of such complication, comes this research as a developing effort for a GIS-Based system for evaluating the water quality parameters / indicators and hence water quality in the Gaza strip, that tackles a very important issue for water resources management through availing the proper and easy tools to keep up-to-date tracking of data, which is a key element in the management cycle especially in water related issues and water wells more specifically.

The main contribution of this study is providing the water facilities and utilities with a daily to use tool if updated records preserved, that enable its users to have effective understanding of the water issues at their area through keeping track of quality indicators of water wells in that area.

This tool through application on water wells in Gaza is proving to give very needy results and outputs to water resources managers in the strip.

This new paradigm of GIS is moving to an open platform, where it is an equal component with other third party software, brings new avenues to water resources users, and application developers in this field.

### **5.1.2 Benefits of the research**

This research addresses the current situation of Gaza's water resources that are depleting by time and the need to utilize current affordable technologies in its management practices, additionally:

1. It introduces this concept practice into water utility association, as a supplementary tool for current GIS practices.
2. The GIS practice in Gaza is still in its very primitive levels, through but developing maps of different types including the interpolation and prediction maps. Thus, this GIS Based technology could provide other means of interpreting the information and data for water issues such as its quality, this is addition to providing a tool that can be used in the field i.e. at municipality level, while it is developed enough to assist even a broader management level with current and future indicators.
3. The introduction of this technology at its academic level through this research and then at the field level through its application at municipalities could enhance the decision making process of managers in this field by allowing extracting information on the time-history of a well with regard to chloride,  $\text{NO}_3^-$  etc..., buffering, threshold identifying, map overlaying, etc...
4. At the field, heavy installed applications that require specific high resources would not be an available options, research application is put on a very easy-to-use way, enabling GIS features with minimum system requirements.
5. At the field, with just one session of on the job training would easily enable non-technical users to benefit and utilize this application for their needs.

### **5.1.3 Compared to available applications**

A GIS development framework provides the necessary comprehensive spatial functionality for applications and allows the software developer to focus on building application specific logic. ESRI ArcGIS Engine is such a GIS framework, created in response to ESRI software users' requests that the rich technology of ArcGIS be productized to enable embedding of spatial functionality in new or existing applications. ArcGIS plug-ins can not be used without the proprietary ArcGIS software. This application does not require this proprietary,

but also, does not give ArcGIS Engine capabilities, but still acting as a component that is meeting variety of user GIS related needs in a very friendly user environment. Other issues that worth addressing:

1- the system guides the user through direct ways for obtaining information that could also be extracted using other popular applications such as ArcMAP, but this may require several steps from this application to obtain the same results obtained through this system with one step, such as buffering and results orientation.

2- layers overlaying, at instant this system allows the user to enquire and spatially preview information of same location (i.e. water well) on different maps, while to do that using other applications may require activating and deactivating and locating, etc...

3- The system enable the user to get to specific location, termed in the x and y at once, obtaining attribute value and using it if needed for other calculations, this could act as the Raster Calculator in ArcMAP, without the need to raster the shapfile into cells for specific value.

#### **5.1.4 Advantages of such development**

1. Minimum IT investment. The existing desktop environment: Windows and Microsoft Office package is sufficient.
2. A minimum GIS tool is made available, through screen navigation for visual output. No training is required.
3. No disruption of existing practice. The users may continue with their usual data entry and update with the standard office packages like Excel, or Access, or in simple relational database like Dbase as these components are embedded in the application.
4. Minimum developer's intervention.
5. The ease of information retrieval facilitates decision-making at all levels (field officers, management)

#### **5.1.5 Constraints encountered**

1. Lack of available updates and tracking of data records over time, renaming of wells and closing of others could present gap in flow of data of time.
2. No previous similar practice or research encountered in Gaza.

### **5.1.6 Shortcomings subject for further development**

1. Using polynomial regression for water quality in this case, was not encountering for seasonal variations i.e. average was taken per year this could result in data variation giving only short term predicting models i.e. for 2-3 coming years.
2. Management improvement was not reflected in Model inputs for the quality of water versus time, this could result in variation of input data and consequently the expected output information.
3. Limited capabilities when it comes to modeling, or deep data manipulation, where in such cases, referring back to GIS ordinary softwares/application would be the other option.
4. Scope of this study permitted tackling basics behind such system, still that several aspects of this application are prototyped and have larger extents for development.

## **5.2 Recommendations**

It is recommended that Gaza water institutions and facilities start considering the utilization of purpose-specific systems such as the GIS-Based system prototype developed out of this research, such facilities would be the CMWU, PWA, and the Municipalities that are usually governed by MoLG.

It is also recommended to enhance and improve this prototype system to broader levels beyond the scope of this study at both academic (professional) and commercial levels, as this would be a step forward towards upgrading the level of knowledge and then a strong base towards well developed institutions and utilities for the water component in the Gaza strip, the following points are recommended for further enhancement of the developed tool:

1. As future scenarios prediction is very important to decision makers, examining available data and covering any gaps will add to the value of obtaining reliable results, through out offering other models for the user (i.e. exponential, logarithmic, etc...), while giving the ability to eliminate or add any data value to the system, to enrich its capabilities. Simultaneously, seasonal variations could be accounted for if enough information and data recording through the years is made available.
2. Possibility of extending application capabilities to reach and extent of adding/editing shapefiles, editing (both map, and data) through customized menus / buttons e.g editing of fields while getting more deeper in its attributes, which gives more extendibility to the application making it extensive as any GIS application.



3. Extending the project to a larger scale and larger scope among water resources stakeholders in the Gaza strip.
4. Setting up an early warning and emergency response system that will enable to take appropriate actions to prevent or mitigate the impacts of large accidents on groundwater quality.
5. Enhancing the reporting system to include printing out useful and well arranged reports comprising of previewed maps and listed information.
6. Giving more interactivity to the system by allowing users to use the map directly for enquiring about the water wells rather enquiring through listed attributes.
7. Compatibility of the system should be extended for other database and shapefiles, to enrich the system capabilities of integrating much more information in it.

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## APPENDIXIES

### APPENDIX (A): Polynomial Regressions - Example

The basis of Polynomial Regressions - least square errors is that a data set of  $\mathbf{n}$  paired (x, y) members:

$$(x_1, y_1), (x_2, y_2), (x_3, y_3), \dots, (x_n, y_n) \dots \dots \dots (1)$$

Can be processed using a least-squares method to create a predictive polynomial equation of degree  $\mathbf{p}$ :

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \dots a_px^p, p < n \dots \dots \dots (2)$$

The essence of the method is to reduce the residual  $\mathbf{R}$  at each data point:

$$R_i = y_i - a_0 - a_1x_i - a_2x_i^2 \dots - a_px_i^p \dots \dots \dots (3)$$

This is accomplished by first expressing the system in matrix form (this example represents a polynomial of degree 4):

$$\begin{pmatrix} n & \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 \\ \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 \\ \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \sum x_i^7 & \sum x_i^8 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} \sum y_i \\ \sum x_i y_i \\ \sum x_i^2 y_i \\ \sum x_i^3 y_i \\ \sum x_i^4 y_i \end{pmatrix} \dots (4)$$

For implementing this method in computer code, the following is a detailed procedure with an example data set.

x	y	x	y	x	y	x	y
-1	-1	3	4	1	2.5	7	5
0	3	5	2	2	5	9	4

Creation of this particular data set for its pathological properties and its ability to show what sorts of things can go wrong during efforts to apply polynomial regressions to real-world data.

Referring now to equation (4) above and to the example data set, we can perform the operations required to produce this numerical matrix content:

$$\begin{pmatrix} 8 & 26 & 170 & 1232 & 9686 & 0 \\ 26 & 170 & 1232 & 9686 & 79256 & 0 \\ 170 & 1232 & 9686 & 79256 & 665510 & 0 \\ 1232 & 9686 & 79256 & 665510 & 5.68695e+06 & 0 \\ 9686 & 79256 & 665510 & 5.68695e+06 & 4.9209e+07 & 0 \end{pmatrix}$$

In evaluating the matrix shown in equation (4) above:

$\sum x_i^2 = \sum_{i=0}^{n-1} x_i^2$  and it means the *sum of the squares* of the  $x$  terms, not the square of the sum. Here is the matrix with the data added:

$$\begin{pmatrix} 8 & 26 & 170 & 1232 & 9686 & 24.5 \\ 26 & 170 & 1232 & 9686 & 79256 & 106.5 \\ 170 & 1232 & 9686 & 79256 & 665510 & 676.5 \\ 1232 & 9686 & 79256 & 665510 & 5.68695e+06 & 5032.5 \\ 9686 & 79256 & 665510 & 5.68695e+06 & 4.9209e+07 & 39904.5 \end{pmatrix}$$

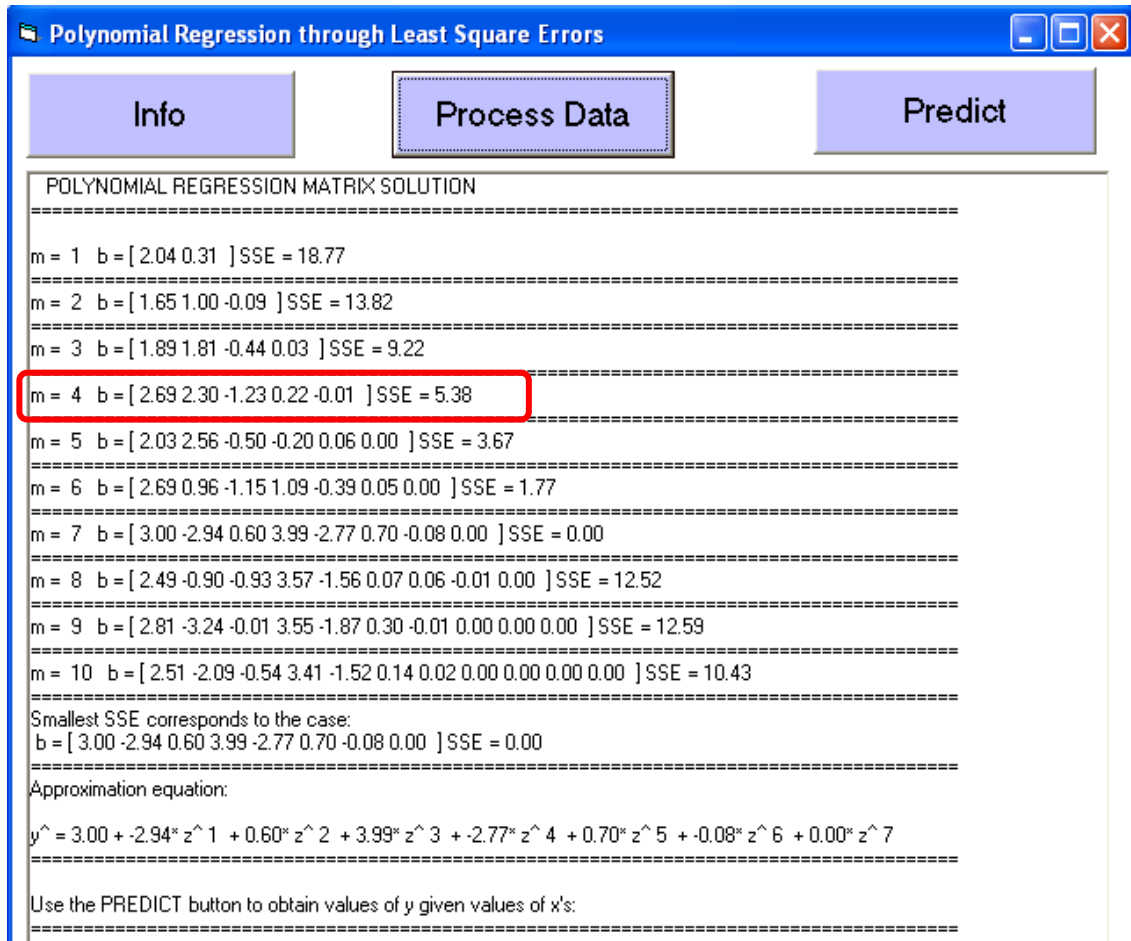
Next our matrix:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 2.68559 \\ 0 & 1 & 0 & 0 & 0 & 2.30146 \\ 0 & 0 & 1 & 0 & 0 & -1.23263 \\ 0 & 0 & 0 & 1 & 0 & 0.216892 \\ 0 & 0 & 0 & 0 & 1 & -0.0118197 \end{pmatrix}$$

Then, we can convert this result into a practical polynomial expression as shown in equation (2) above:

$$y = -0.01182x^4 + 0.2169x^3 - 1.233x^2 + 2.301x + 2.686 \dots (11)$$

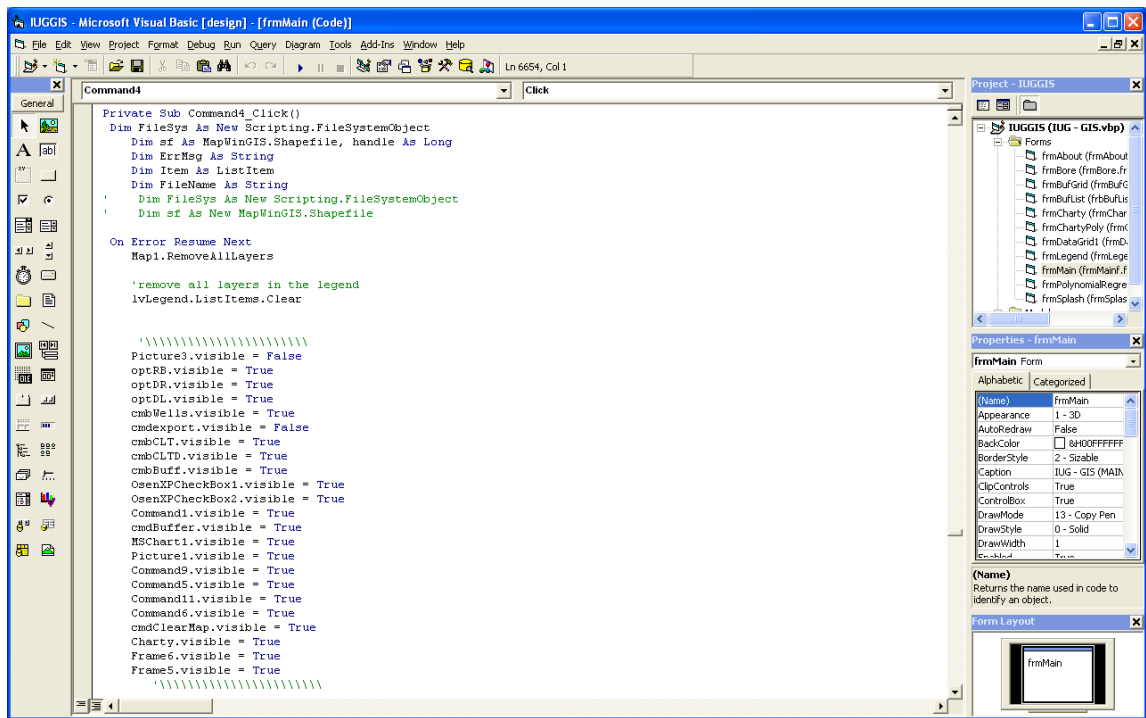
Application of above example through the developed model gives (this form is already embedded within the application):



**Figure App.-A-1.** Buffering feature, level 3: Level three: fixed radius, different locations

## APPENDIX (B): Map viewing Feature Code

The application code is extracted from Microsoft Visual Basic, more than 300 lines of code written for this application, following is the code in its window at Microsoft Visual Basic, (Figure App-B-1):



**Figure 0-1.** Buffering feature, level 3: Level three: fixed radius, different locations

Extracted Code:

```

Dim FileSys As New Scripting.FileSystemObject
Dim sf As MapWinGIS.Shapefile, handle As Long
Dim ErrMsg As String
Dim Item As ListItem
Dim FileName As String
' Dim FileSys As New Scripting.FileSystemObject
' Dim sf As New MapWinGIS.Shapefile
  
```

```

On Error Resume Next
Map1.RemoveAllLayers
  
```

```

'remove all layers in the legend
lvLegend.ListItems.Clear
  
```

```

'//////////
Picture3.visible = False
optRB.visible = True
optDR.visible = True
optDL.visible = True
cmbWells.visible = True
cmdexport.visible = False
cmbCLT.visible = True
cmbCLTD.visible = True
cmbBuff.visible = True
OsenXPCheckBox1.visible = True
  
```



```

OsenXPCheckBox2.visible = True
Command1.visible = True
cmdBuffer.visible = True
MSChart1.visible = True
Picture1.visible = True
Command9.visible = True
Command5.visible = True
Command11.visible = True
Command6.visible = True
cmdClearMap.visible = True
Charty.visible = True
Frame6.visible = True
Frame5.visible = True
optRB.Value = True

cdlOpen.CancelError = True

FileName = App.Path + "\GISWORK\SHP\SHPNorth2001.shp"
FileNameC = SHPNorth2001
txtFileNameC = "SHPNorth2001"

If LCase(Right(FileName, 3)) = "shp" Then
    Set sf = New MapWinGIS.Shapefile
    If sf.Open(FileName) = False Then
        ErrMsg = sf.ErrorMessage(sf.LastErrorCode)
        MsgBox "The file, " & FileName & " failed to open for the following reason:" & vbCrLf & ErrMsg, vbCritical
        Exit Sub
    Else
        handle = Map1.AddLayer(sf, True)

        If handle < 0 Then Exit Sub

        Map1.LayerName(handle) = FileSys.GetFileName(sf.FileName)

        Set Item = lvLegend.ListItems.Add(1, , Map1.LayerName(handle))
        Item.ListSubItems.Add , , handle
        Item.Tag = handle
        Item.Checked = True

        Map1.ShapeLayerFillColor(handle) = RGB((1 - 1) * Rnd, (1 - 1) * Rnd, (1 - 1) * Rnd)
        Map1.ShapeLayerLineColor(handle) = RGB(300, 399, 388)

        Map1.ShapeLayerPointSize(handle) = 10

        Map1.ShapeLayerPointType(handle) = ptCircle
        Map1.ShapeLayerPointSize(handle) = 5
        Map1.ShapeLayerPointColor(handle) = vbBlue

    End If
Else
    MsgBox "The file, " & FileName & " is not a shapefile."
End If

FileName = App.Path + "\GISWORK\SHP\Governorate.shp"

If LCase(Right(FileName, 3)) = "shp" Then
    Set sf = New MapWinGIS.Shapefile
    If sf.Open(FileName) = False Then
        ErrMsg = sf.ErrorMessage(sf.LastErrorCode)
        MsgBox "The file, " & FileName & " failed to open for the following reason:" & vbCrLf & ErrMsg, vbCritical
        Exit Sub
    Else
        handle = Map1.AddLayer(sf, True)

        If handle < 0 Then Exit Sub

        Map1.LayerName(handle) = FileSys.GetFileName(sf.FileName)

        Set Item = lvLegend.ListItems.Add(1, , Map1.LayerName(handle))
        Item.ListSubItems.Add , , handle

```

```

    Item.Tag = handle
    Item.Checked = True

    Map1.ShapeLayerFillColor(handle) = RGB(0, 255, 0) 'RGB((255 - 1) * Rnd, (255 - 1) * Rnd, (255 - 1) * Rnd)
    Map1.ShapeLayerLineColor(handle) = vbBlack
    Map1.ShapeLayerLineWidth(handle) = 2

    End If
Else
    MsgBox "The file, " & FileName & " is not a shapefile."
End If

Dim Name As String
Dim Index As Long
Dim retval As Boolean
Dim visible As Boolean

If (lvLegend.SelectedItem Is Nothing) Then Exit Sub

handle = lvLegend.SelectedItem.Tag
Index = lvLegend.SelectedItem.Index
Name = lvLegend.SelectedItem.text
visible = lvLegend.SelectedItem.Checked

Set Item = lvLegend.ListItems.Add(Index, , Name)
Item.ListSubItems.Add , , handle
Item.Tag = handle
Item.Checked = visible

    lvLegend.SelectedItem.Selected = True

retval = Map1.MoveLayerUp(Map1.LayerPosition(handle))
'move the selected layer up
If (Index > 1) Then

    lvLegend.ListItems.Remove Index

End If

cbLayerToLabel.Clear

For i = 0 To Map1.NumLayers - 1
    handle = Map1.LayerHandle(i)
    layerName = Map1.layerName(handle)
    cbLayerToLabel.AddItem (handle & " - " & layerName)
Next

cbLayerToLabel.ListIndex = 1

cbFieldToUse.Clear

If cbLayerToLabel.ListCount > 0 And cbLayerToLabel.text <> "" Then
    handle = Split(cbLayerToLabel.text, " - ")(0)

    Set sf = Map1.GetObject(handle)

    For i = 0 To sf.NumFields - 1
        cbFieldToUse.AddItem (i & " - " & sf.Field(i).Name)
    Next

End If

cbFieldToUse.ListIndex = 2

cbRowsToUse.Clear

Dim fieldIndex As Long
Dim text As String

```

---

```

If (cbLayerToLabel.text = "" Or cbFieldToUse = "") Then Exit Sub

On Error Resume Next

handle = Split(cbLayerToLabel, " - ")(0)

fieldIndex = Split(cbFieldToUse, " - ")(0)
cmbWells.Clear
Set sf = Map1.GetObject(handle)
For i = 0 To sf.NumShapes - 1
    text = sf.CellValue(fieldIndex, i)
    cbRowsToUse.AddItem (text)
    cmbWells.AddItem (text)
    Map1.AddLabel handle, text, cmdFontColor.BackColor, sf.Shape(i).extents.xMin, sf.Shape(i).extents.yMin, hjCenter
Next i

cbRowsToUse.ListIndex = 0
ycl = 200

For i = 1 To 25
    cmbCLT.AddItem (ycl)
    ycl = ycl + 50
Next i

cmbCLT.ListIndex = 3

ycl = 200

For i = 1 To 25
    cmbCLTD.AddItem (ycl)
    ycl = ycl + 25
Next i

ycl = 200

For i = 1 To 24
    cmbBuff.AddItem (ycl)
    ycl = ycl + 100
Next i

cmbBuff.ListIndex = 8
cbRowsToUse.SetFocus

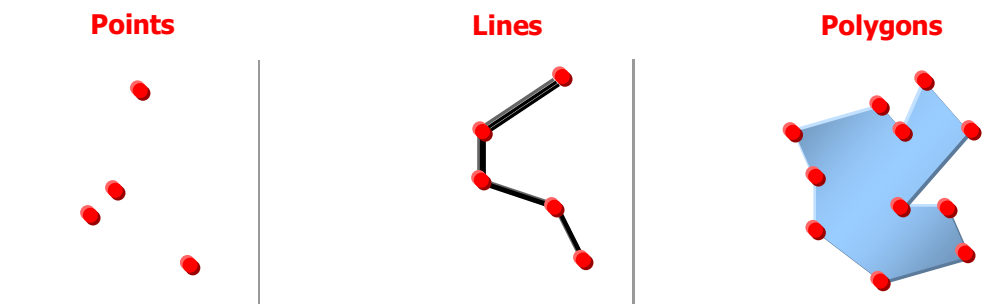
```

## ANNEXES

### ANNEX (A): The Geographic Information System

#### A.1 Introduction to Geographic Information System (GIS)

A Geographic Information System (GIS) can be defined as a system for entering, storing, manipulating, analyzing, and displaying geographic or spatial data. These data are represented by points, lines, and polygons (Figure A.1) along with their associated attributes (i.e., characteristics of the features which the points, lines, and polygons represent). For example, the points may represent hazardous waste site locations and their associated attributes may be the specific chemical dumped at the site, the owner, and the date the site was last used. Lines may represent roads, streams, pipelines, or other linear features while polygons may represent vegetation types or land use.

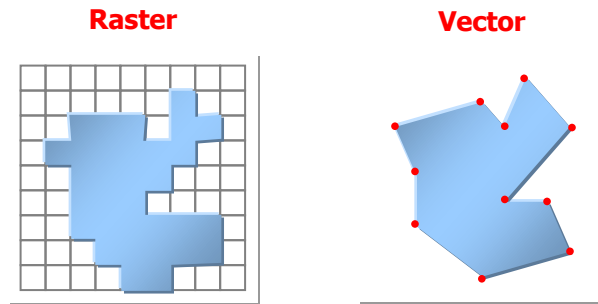


**Figure A.1:** The 3 elements of geographic data

In addition, geographic data can be represented in two data formats. The first of these formats is called raster or grid structure and is the older of the two data formats. Raster data are stored in a grid or pixel format which is referenced to some coordinate system (i.e., latitude and longitude). The size of the grid can vary and therefore the spatial resolution of the data is determined by the size of the grid. Raster data are computationally easier to manipulate but typically require larger amounts of storage. Digital remotely sensed data (i.e., satellite imagery) is a good example of raster or grid data.

Vector or polygon data are the second way geographic data may be represented. Vector data uses a series of points (i.e., x, y coordinates) to define the boundary of the object of interest. These types of data may require less storage and are preferred for display purposes

because a truer rendition of the shape of the object of interest is maintained. However, some computations are especially difficult and time consuming if performed on vector data. The example below shows what an object would look like in both raster and vector formats (Figure A.2). Note that the raster image has lost some of its true shape due to the ‘gridding’ process. (In this example, a large grid cell size was used to emphasize the differences between the two formats.)



**Figure A-2.** Depiction of the same polygon in raster & vector format

## 2 Data Acquisition & Registration

Spatial data are the “life blood” of any GIS. Somewhere between 80% and 90% of the effort and money required to run a GIS is used to acquire, input, update, and manipulate data. Therefore, it is critical that the GIS user have a thorough understanding of the many aspects of data acquisition and manipulation even before the system is turned on.

### 2.1 Map Projections & Coordinate Systems

A very important aspect of spatial data is ground registration. Registering spatial data to the ground requires transforming the original data which is recorded in digitizer inches to some ground-based coordinate system. (A digitizer is an instrument that permits the electronic transfer of x, y coordinates into a computer by manually tracing a map and sending the coordinate location to the computer.) A coordinate system is simply the two-dimensional (x, y) values that designate the position of a given point on the ground. Common coordinate systems include latitude-longitude, Universal Transverse Mercator (UTM), and state plane coordinates.

### 2.2 Sources of Spatial Data

As previously discussed, collecting, importing, verifying, and updating spatial data is the most expensive component of any GIS. Knowledge of how each data layer is obtained is critical to the ultimate economic success of the GIS.

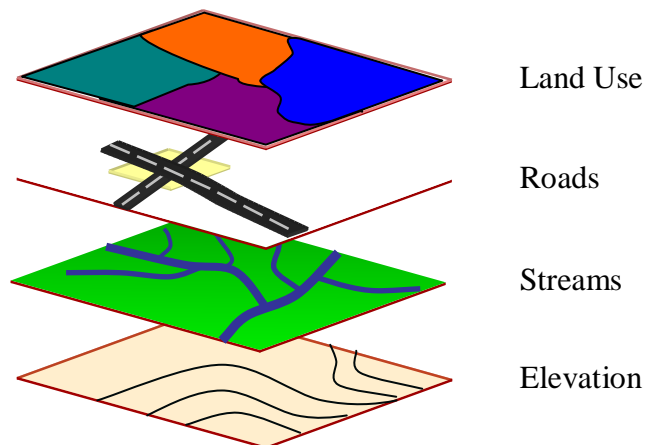
The most exciting development in the area of sources of spatial data is the ability to geocode and/or terrain process digital satellite data. Geocoding refers to a process by which the remotely sensed data is very accurately registered to a ground coordinate system.

### 3 Analysis Techniques

Once all the necessary existing and new data have been collected then it can all be registered to a common base map. As mentioned, the collection and registering of all these data from various sources can be an expensive, time consuming, and frustrating process. Once completed, however, the analysis can begin. Basic GIS analysis techniques include overlay analysis, modeling, buffering, and network analysis.

#### 3.1 Overlay Analysis

The concept of overlaying data layers to obtain certain information is not a new concept to GIS. Many of us have used tracing paper and colored pencils to produce transparent maps that could lay over the top of each other in order to derive some information; that could be considered a 'primitive' GIS. It is the ability of the system to create a new layer of information/data from two or more existing layers (Figure A.3)



**Figure A-3.** An example of overlaying various layers in a GIS

#### 3.2 Modeling

Primarily, GIS technologies can facilitate input of data sets to simulation models. This may take the form of one or multiple variable or GIS 'layer' inputs to models. However, we still need to develop or identify models in application areas that are already amenable to the entry of spatially distributed data. Models must be formulated in the future to receive spatial data directly from the GIS.

### **3.3 Buffering**

Buffering is a technique by which a boundary of known width is drawn around a point or linear feature. Some examples of point buffers may be a zone around a hazardous waste site or around a tree that is a nest for a particular endangered bird. Examples of linear buffers may be an area around a stream to prevent logging or an area around a utility pipeline to prevent digging. A related function is generally referred to as “proximity searches”. Proximity searches can be used to identify adjacencies between particular features or data classifications.

### **3.4 Network Analysis**

Network analysis is a technique by which a linear path is identified that represents the flow of some object through the area. Network analysis is especially useful in hydrology, water resources, transportation, and other disciplines that study the flow of an object. This flow is not limited to water but can also be used for vehicles, utility and communication lines, and animals.

## **4 Presentation Capabilities**

A particularly valuable use of a GIS is in project presentations. The managers or decision makers on any project appreciate the quantitative information derived from GIS analyses. Naturally, they also appreciate the high quality graphical products that support the project, and demonstrate the results of project analyses. Another valuable use is the public presentation of the results of project analyses using GIS. This is appropriate for public meetings and audiences beyond those of the immediate group. Current land and water planning efforts involve a wealth of information. GIS products can help to display the site conditions, and to show some of the variables that must be weighed to make a decision. The GIS displays can also help lead the audience through the same decision-making process, and help lend insight into the results of the planning study.

## **5 Error Analysis**

In order to effectively use any GIS, one must understand the errors associated with spatial information. Errors associated with spatial information can be divided into three groups: user errors, measurement/data errors, and processing errors. User errors are those errors which are probably most obvious and are more directly controlled by the user.

## **6 Hardware & Software**

The GIS software links the attribute data to the geographic features (represented by points, lines, and polygons and their topology), using a database management system. It also provides for the input, editing, and analysis functions previously discussed. The capabilities and costs of GIS software vary greatly from vendor to vendor and the selection of such software depends on the needs of the user. The following factors should be considered when choosing GIS software:

- Data input and editing functions
- Analysis functions
- Flexibility of the system (compatibility with other software/hardware)
- Risk associated with the vendor
- Cost to purchase, operate, and maintain the system
- Type of database management system

## **7 People**

An integral and yet largely forgotten and unnoticed component of a GIS is people. Geographic information systems need people in order to operate. Without well-trained people and an adequate staff, it is likely that an investment of thousands of dollars on state-of-the-art equipment and data will be wasted. Continued funding is critical to provide the necessary training and database maintenance. All in all, people are the most important resource; failure to make a strong commitment to the people operating the GIS dooms it to failure.



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