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Dissertation

Characterizing the Multi-criteria Parameters of Integrated Water Management Model in the Semi-arid Mediterranean Region: Application to Gaza Strip as a case study

by

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Abstract

Water is an essential and limited resource especially in the semi-arid Mediterranean region. Achieving sustainable water resources management is a common overall objective in this region. It requires a balance between the needs of the people and the protection of the natural resource base without undermining the integrity of the hydrological cycle or the ecological systems that depend on it, so that water resources can continue to provide benefits for improving people's livelihood and quality of life, reducing poverty and fostering economic growth. Sustainable water resources management in Gaza Strip (GS) as a case study is a complex challenge which requires a new approach if management should be based on sound scientific findings in order to optimize and conserve the available precious and scarce water resources. Increased water demand due to population and economic growth, environmental needs, land use change, urbanization, over abstraction of aquifer, deterioration of water quality, pollution from local and diffuse sources, water infrastructure hotspots and impacts on public health and ecosystems are all factors that will continue to create severe water shortage problems. During the recent years, water resources shortage and pollution have severely underpinned social and economic fabric of the Palestinian society which is characterized broadly as under-developed with widespread poverty. Considering the doubling of population of GS by the year 2020, the predicted water demand will increase to reach 260 $hm^3.y^{-1}$ which will definitely exceed by about three times the ecological limits and sustainable capacity of the GS coastal aquifer. The current water management challenge is to remediate and restore the coastal aquifer as part of nature conservation and to bridge the present and future water supply-demand gap based on provision of water with adequate quantities and qualities according to WHO standards.

In this research, a new conceptual water integrated model has been developed based on cause- effect relationship tackling the life cycle of water resources management. The Driver-Pressure-State-Impact-Response (DPSIR) was selected as a well established framework to develop the possible variables under five categories which are socio-economic, pollution pressures, water quality, impacts and management responses. The effective variables have been characterized and prioritized using multi criteria analysis with artificial neural networks (ANN), risk assessment techniques and expert opinion and judgment. The selected variables have been classified and organized using multivariate techniques which are cluster analysis, factor analysis and principal component and classification analysis.

It was concluded that no single measure will be able to solve the water problems in GS, but a combination of these measures is needed to ensure water availability, suitability, sustainability and security. Therefore, any future integrated strategy plan in GS should include: (1) policy and legal instruments for water pollution control (2) regulatory tools for controlling and auditing the use of water including metering, billing and revenue collection (3) monitoring networks and information management systems (4) actions that are purely technical including reuse of treated wastewater, storm water harvesting in urban and rural areas, seawater desalination, brackish water desalination, rehabilitation of water networks, regional water conveyance, water chemical treatment, clean-up and remediation of water hotspots and (5) socio-economic including pricing, access to water services, awareness on rational use of water and empowerment of the role of women in the water sector management. Within the integrated process for water resources management, it is recommended to adopt two significant approaches. The first is the preventive approach which is to move from restorative to protective management, while maintaining support for remediation of existing water hotspots, as the costs of preventing water pollution are rather small compared to remediation. The second is the ecosystem approach which aims to meet the human water requirements whilst maintaining the hydrological and ecological processes. Besides the existing project-focused Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA) procedure is recommended as an effective decision-making tool to strengthen the integrated approach and to mainstream the environmental sustainability considerations into water sector developmental policies, plans and programs. SEA ensures that the cumulative and large scale effects of certain water sector policies, plans and programs are identified and addressed at early stage and before their adoption.

Keywords: ANN; expert opinion and judgment; Gaza Strip; groundwater; integrated water management model; management and policy responses; pollution pressures; public health and ecological impacts; socio-economic driving forces; state of water quality.

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List of Symbols

AAF	Chemical-specific oral-water absorption adjustment factor (mg/mg)
Ab. E. Mean	Absolute Error of the Mean
Alkalinity	Alkalinity (mg.l^{-1})
ANN	Artificial Neural Network
BOD	Biological Oxygen Demand (mg.l^{-1})
ºC	Degrees centigrade
Ca	Calcium (mg.l^{-1})
CADD	Chronic Average Daily Dose (mg/kg-day)
Cave	Time-averaged contaminant concentration in surface water over the exposure duration (mg.l^{-1})
Cl	Chloride (mg.l^{-1})
Cmax	Maximum 7-year average contaminant concentration in surface water (mg.l^{-1})
CO^2	Carbon dioxide (ppm)
COD	Chemical Oxygen Demand (mg.l^{-1})
d	day
dunum	area; 1 dunum= 1000 square meters = 0.1 hectar
Error S.D.	Error Standard Deviation
ET	exposure time for surface water (hr^{-1})
Euro.m^{-3}	Euro per cubic meter- water tariff
Euro.y^{-1}	Euro per year
F	Fluoride (mg.l^{-1})
GRNN	General Regression Neural Networks
h	hecto, equals one million
hectar.y^{-1}	hectar per year
$hm^3.y^{-1}$	hecto (million) cubic meter per year
hr	hour
IR	Water ingestion rate (ml/l)
K	Potassium (mg.l^{-1})

km^2	square kilometers
LADD	Lifetime Average Daily Dose (mg/kg-day)
$l.cap^{-1}.d^{-1}$	liter per capita per day
Ln	Natural logarithm log(base e), where e= 2.718
m	meter
m^3	cubic meter
$m^3.d^{-1}$	cubic meter per day
Mg	Magnesium ($mg.l^{-1}$)
$mg.l^{-1}$	milligram per liter
MLP	Multilayer Perceptron
mm	millimeter
Na	Sodium ($mg.l^{-1}$)
ND	No Dose
NO_3	Nitrate ($mg.l^{-1}$)
P	The statistical significance "P" of a result is an estimated measure of the degree to which it is "true" (in the sense of "representative of the population").
PC	Chemical-specific skin permeability constant ($cm.hr^{-1}$)
PCCA	Principal Components and Classification Analysis
pH	Hydrogen Ion concentration
ppp	parts per million
R^2	Coefficient of determination
RBF	Radius Basis Function
RMSE	Root mean square error
s	second
S.D.	Standard Deviation
S.D. Ratio	The ratio of the prediction error standard deviation to the original output data standard deviation
SA	Total skin surface area exposed to surface water (cm^2)
SNN	Statistica Neural Networks
SO4	Sulfate ($mg.l^{-1}$)

t	ton; 1 ton= 1,000 kg
T-Coli:	Total Coliforms measured in numbers/100ml.
$t.d^{-1}$	tons per day
$t.y^{-1}$	tons per year
TDS	Total Dissolved Solids ($mg.l^{-1}$)
Te	Testing
Tr	Training
TSS	Total Suspended Solids ($mg.l^{-1}$)
Ve	Verification
yr	year
%	percentage

List of Abbreviations

AgWCon	Agriculture water consumption
ASTRAN	Accelerated Salt Transport method
BrWDes	Brackish water desalination
CAMP	Coastal aquifer Management Program
ChemFer	Chemical fertilizers
CSD	Commission for Sustainable Development
CWIMSAM	Conceptual water integrated model for semi-arid Mediterranean
DomSW	Domestic solid waste
DomWW	Generation of domestic wastewater
EEA	European Environmental Agency
EfInS	Efficiency of information system
EfRevCo	Efficiency in revenue collection
EfUWSN	Efficiency in urban water supply
EfWIrrig	Efficiency in water irrigation
EIA	Environmental Impact Assessment
EQA	Palestinian Environmental Quality Authority

EU	European Union
GEF	Global Environmental Facility
GenEmp	Gender empowerment
GS	Gaza Strip
GWP	Global Water Partnership
HazWas	Hazardous wastes
IAHS	International Association for hydrological Studies
IAIA	International Association for Impact Assessment
ImpW	Importation of water and regional conveyance
Inccap	Income per capita
IWRM	Integrated Water Resources Management
Lanuse	Land use measures the ratio of urban to agricultural areas
LosProd	Loss of productivity
LosWet	Loss of wetland
METAP	Mediterranean Environmental Technical Assistance Progam
MOPIC	Ministry of Planning and International Cooperation
Morbid	Morbidity
NGO	Non Governmental Organization
OECD	Organization for Economic Co-operation and Development, Paris
OrgFert	Organic fertilizers
PCBS	Palestinian Central Bureau of Statistics
Pesticid	Pesticides
PetrolS	Petrol stations
Populat	Population
PWA	Palestinian Water Authority
SEA	Strategic Environmental Assessment
StoWCov	Storm water system coverage
StoWHa	Storm water harvesting
SWD	Seawater desalination
SWInt	Seawater intrusion

Tourism	Number of guest days
TreatWW	Treated wastewater
UFW	Unaccounted for water
UNDP	United Nations Development Program
UNDPCSD	Commission on Sustainable development under United Nations Development Program
UNEP	United Nations Environmental Program
UNRWA	United Nations Relief and Work Agency
WAbstract	Water abstraction from coastal aquifer
WAwar	Water awareness and education
WCED	World Commission on Environment and Development
WcpCap	Water consumption per capita
WHO	World Health Organization
Wprice	Water price
WSSD	World Summit on Sustainable Development
Wsupply	Access to safe water supply
WWCov	Wastewater system coverage
WWTP	Wastewater Treatment Plant

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List of Articles submitted to International Journals

1. Jalala, S., Mania, J., 2004a. Artificial neural networks for coastal aquifer management in a semi-arid Mediterranean region. Submitted to Water Policy Journal in May 2004.
2. Jalala, S., Mania, J., 2004b. Characterizing the socio-economic driving forces of groundwater abstraction in the Middle East with artificial neural networks. Submitted to Hydro-informatics Journal in May 2004.
3. Jalala, S., Mania, J., 2004c. Artificial Neural Networks for Defining the Water Quality Determinants of Groundwater Abstraction in the Middle East. Submitted to Water Resources Management Journal in May 2004.
4. Jalala, S., Mania, J., 2004d. Defining the pollution pressures of groundwater quality in the Middle East region with artificial neural networks. Submitted to Water Research Journal in July 2004.

Chapter 1 General introduction

1.1 Background to water resources management in the semi-arid Mediterranean region (Application to Gaza Strip as a case study)

The Mediterranean Sea lies at the cross of three climatic zones. The climate is humid to the north and semi-arid to the south and east. Also, the Mediterranean sea is a North- South meeting point of physical environments since global warming is producing a South-North advancing front, causing drought and desertification.

The Mediterranean water resources especially in the southern and eastern countries are characterized by vulnerable, scarce, intensively exploited and threatened water resources. Water availability is about 100 m^3/inhabitant/yr (Margat and Vallee, 2000). There are severe water imbalances particularly in summer months due to low precipitation and uneven distribution and high temperature**.** Water resources are vulnerable to global change such as climate change and sensitive to drought. The consequences of droughts are severe on soils and sub-soils drying up, agriculture production, food security and socio-economic aspects where they lead to water deficit.

Water resources are also vulnerable to the fast growing demand of urban and rural populations, demand of economic sectors including agriculture, industry and tourism. The predicted water demand either exceeds or will exceed the sustainable supply within a short time since the water demand is high and on an upward trend.

Increasingly, water quality degradation from land use conflicts, destruction of wetlands and ecosystems and anthropogenic effects is undermining the sustainable management of water resources and threatening water resource base as part of nature. Anthropogenic effects are caused by local and diffuse sources. The pollution sources are: urban sewage, solid waste, hazardous waste, industrial waste, overuse of fertilizers and pesticides. In addition, over-exploitation of coastal aquifers has already led to many cases of irreversible saltwater intrusion (Blue Plan, 2003). If the pollution sources remain unrestrained, then it is likely to further exacerbate water scarcity in a region that has already a limited inheritance of water.

The current water scarcity in the semi-arid Mediterranean region has emerged strong trends in the water management including:

- Increasing water supplies from renewable and non-renewable natural resources remains the foremost priority in spite of the increase in the production costs and the incompatibility with environmental protection;
- Transfer of water between countries rich in water and those scarce in water supply;

- Use of non-conventional water resources such as treated wastewater, brackish & sea water desalination and water harvesting;
- Growth of water conflicts are spreading and worsening, particularly between urban and agricultural users and between upstream and downstream stakeholders;
- Need to give greater consideration to the concept of "environmental water demand" where the level of this demand can be added to socio-economic demand;
- Changes in water legislation responding to the new water management challenges with a tendency to give priority to regulatory measures besides the technical and engineering solutions in water management.

Gaza Strip (GS) is situated along the Mediterranean Sea between Israel and Egypt. It is bordered by Israel from north and east, Egypt from south, and the Mediterranean Sea from the west as shown in Figure 1.1. The length of GS from Rafah in the south to Beit Hannun in the north, measures 45 km. Its width ranges from 7 to 12 km. The total area of the GS is 365 km^2 . GS is divided into five main Governorates; North, Gaza, Deir El-Balah, Khan Younis and Rafah. GS contains 8 refugee camps and about 25 municipalities and village councils.

Figure 1.1 Geographical Projection of GS
(Source **UNEP, 2003**)

GS is currently facing an acute shortage of fresh water supply and water is seen as one of the most critically stressed resources. The water exploitation index for GS is the second highest index after Libya in the Mediterranean region (Figure 1.2). The population is expected to double by 2020 to reach 2.66 millions (PCBS, 2001). This will worsen the already precarious situation. Currently, about 145 million m3 (hm^3) of groundwater are withdrawn every year in addition to 6 hm^3 lost to natural recharge, compared to an annual natural recharge and return flow of about 120 hm^3 (CAMP, 2000) resulting in an annual over pumping gap of about 30 hm^3.

However, the current withdrawals are very far from meeting demand in terms of quantity

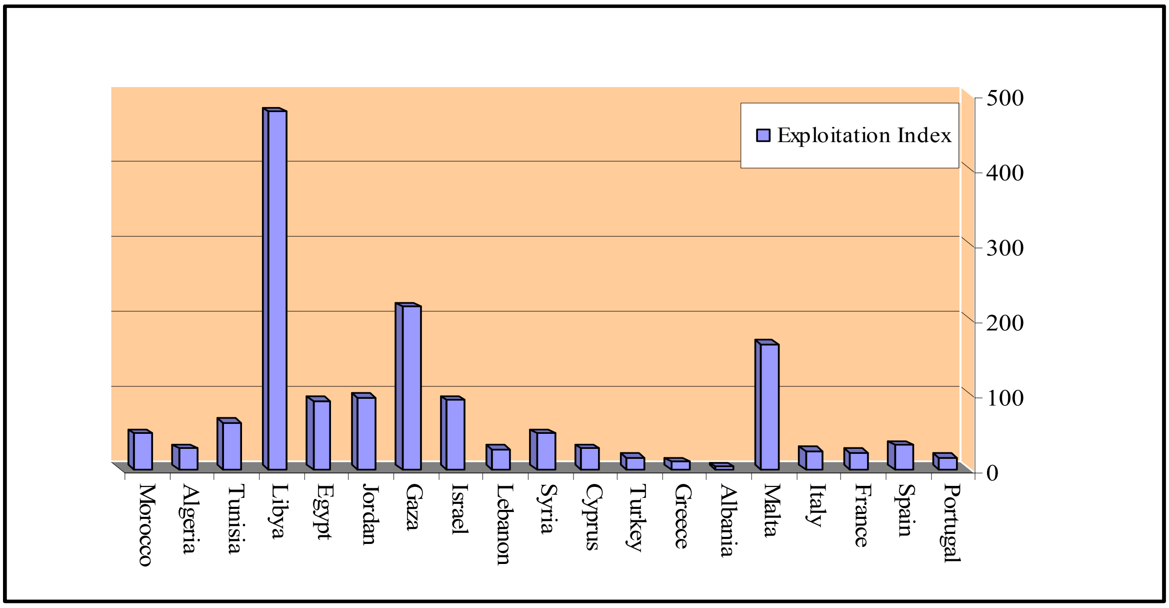


Figure 1.2 Current pressure on water resources in Mediterranean countries.
(Source **Blue Plan, 2000**)

and quality: domestic water supply is only 75 liters per capita per day ($l.c^{-1}.d^{-1}$), compared to 150 $l.c^{-1}.d^{-1}$ according to the World Health Organization (WHO) standards (World Health Organization, 2004). Over-exploitation of the aquifer has led to falling groundwater levels and deteriorated water quality due to seawater intrusion. Furthermore, groundwater quality is made worse through infiltration of sewage, polluted surface water, solid waste leachates, and agricultural chemicals. Chloride and Nitrate contents of the water are very high, exceeding maximum levels established by the WHO for drinking water at many locations. During recent years, water resource shortage and water pollution have severely hindered the socio-economic development in many parts of GS. Considering the potential doubling of population by year 2020, water demand will increase to reach 260 $hm^3.y^{-1}$ by that time. This projected value will definitely exceed the sustainable capacity of the aquifer.

1.2 Research problem statement

The current lack of comprehensiveness and efficiency in water resources management has become one of the problems facing semi-arid Mediterranean region in general and GS in particular. Sharma (1998) presented that the real problem in semi-arid Mediterranean region yet is not the lack of resources but the lack of an integrated water management policy to alleviate the current tragic conditions.

The concepts of water sustainability and integrated water resources management (IWRM) are poorly understood by water resources planners and managers. Besides, there are inadequate understanding and knowledge about the actual baseline conditions in terms water problems and geographical areas under water stresses. Accordingly, subjectivity is viewed as one of the weaknesses of the current water sector decision making.

Evidence exists that there is a relation between the existing degradation of water resources in GS and the poor policy and management interventions to balance the relationship between the natural and human systems. The natural system is of critical importance for water resource availability and quality whilst the human system determines the resource use, waste production and pollution of the resource.

Analysis of the present state of water resources in GS as a case study in the Mediterranean region has noted increased Nitrate levels from local and diffuse pollution sources and drawdown of water table due to over abstraction. This has led to loss of the wetlands and an increase in the water salinity caused by seawater intrusion. The high water salinity has resulted in a significant loss of the agriculture productivity.

Furthermore, there are human health risks associated with the water sector management originated mainly from the improper treatment and disposal of wastewater.

There is also a weakness in mainstreaming and integration of environmental sustainability into water sector policy making level due to lack of Strategic Environmental Assessment (SEA) procedure and methods. Besides, the existing Palestinian Environmental Impact Assessment (EIA) policy and procedure for water sector infrastructure has limitations to address the large scale and cumulative effects of several projects within the framework of water sector policies, plans and programs.

1.3 Research objectives

The main objectives of the research were to:

- Establish a new conceptual water integrated model to assist water managers to advance towards achieving sustainable water resources management;
- Characterize the effective variables of water sector management and define the geographical areas within GS under water stresses;
- Establish prediction relationships between the water abstraction from the coastal aquifer on one hand and socio-economic driving forces, water quality determinants

and policy interventions on the other hand. Besides that, a prediction relationship between the water quality and pollution pressures was established;

- Classify municipalities into clusters associated with their related water variables;
- Assess human health risk caused by Gaza wastewater treatment plant as a hotspot and the required clean up levels to remediate this contaminated site;
- Formulate recommendations for change including new concepts to sustain the natural water resources as sources of supply for both the present and future generations.

1.4 Need for holistic multidisciplinary integrated approach to water resources management

In semi-arid Mediterranean countries in general and GS in particular, water is not only an essential resource, but also a limited and scarce resource. The scarcity of water underpins the social and economic fabric of the southern and eastern Mediterranean societies which are characterized almost as underdeveloped with widespread poverty. The situation of water resources is described by supply oriented management, resources under pressure and exploited, environmental degradation and low coverage of water supply and sanitation facilities for both rural and urban areas.

One of the lessons learned over the years conclude that technical engineering solutions alone can not provide the increasing populations with adequate quantities to the required qualities and, in parallel, maintain the integrity of hydrological and ecosystems. It is certain that water management today can not be made with the methods and mentality of the past.

Hence, there is a need for careful and wise management of water resources. Accordingly transition from a water supply driven approach, where water resources development was the major focus, to an Integrated Water Resources Management (IWRM) is essential. A holistic multidisciplinary integrated approach is crucial as a feasible answer to the accumulated water problems and a way to avoid further water crises. It integrates socio-economic aspects, pollution pressures, natural surface water and groundwater system, public health and ecological considerations, and institutional mechanisms of its water resources and adopting the demand- driven approach which forms the basis for water sustainability.

The current main challenge for achieving sustainable management of limited water resources is the designing and implementation of IWRM and making it mandatory and legally binding through the enforcement of SEA to water sector policies, plans and programs.

1.5 Research methodology

In order to achieve the objectives of the research, the methodology was as follows:

- Literature review of international trends and agenda related to water resources management, water sustainability, IWRM, development of appropriate variables, Strategic Environmental Assessment (SEA).
- Development of a new conceptual water integrated model for water resources management in the semi-arid Mediterranean region including appropriate possible variables.
- Validation of the conceptual model and variables through expert opinion besides comparative analysis with case studies from Cyprus, Jordan and Netherlands;
- Application of the new conceptual water integrated model to GS and description of the variables.
- Field observations to evaluate the state of water sector in GS.
- Set up of data analysis plan consistent with the objectives of the research work.
- Compilation of the necessary real data about 25 municipalities and village councils in GS in terms of socio-economic driving forces, anthropogenic pressures, state water quality, public health and ecological impacts and institutional responses.
- Presentation of data for the 25 municipalities in GS using tabular format and GIS maps.
- Description of the analysis tools including artificial neural networks (ANN), expert opinion and judgment, basic statistics, multivariate techniques and health risk assessment.
- Establish prediction relationships between the water abstraction from the coastal aquifer on one hand and socio-economic driving forces, water quality determinants and policy interventions on the other hand. Besides, a prediction relationship between the water quality and pollution pressures was established.
- Characterization of the effective variables and the geographical areas under water stresses.
- Assessment of human health risk at the contaminated site of Gaza wastewater treatment plant as an environmental hotspot and the required clean up levels.
- Integration of the results into the conceptual water integrated model.

1.6 Document layout

The report is divided into seven main chapters (Figure 1.3). The first chapter gives an introduction highlighting background to water resources management in the Mediterranean region with application to GS as a case study, research problem statement, research objectives, need for holistic multidisciplinary integrated approach for water resources management and research methodology.

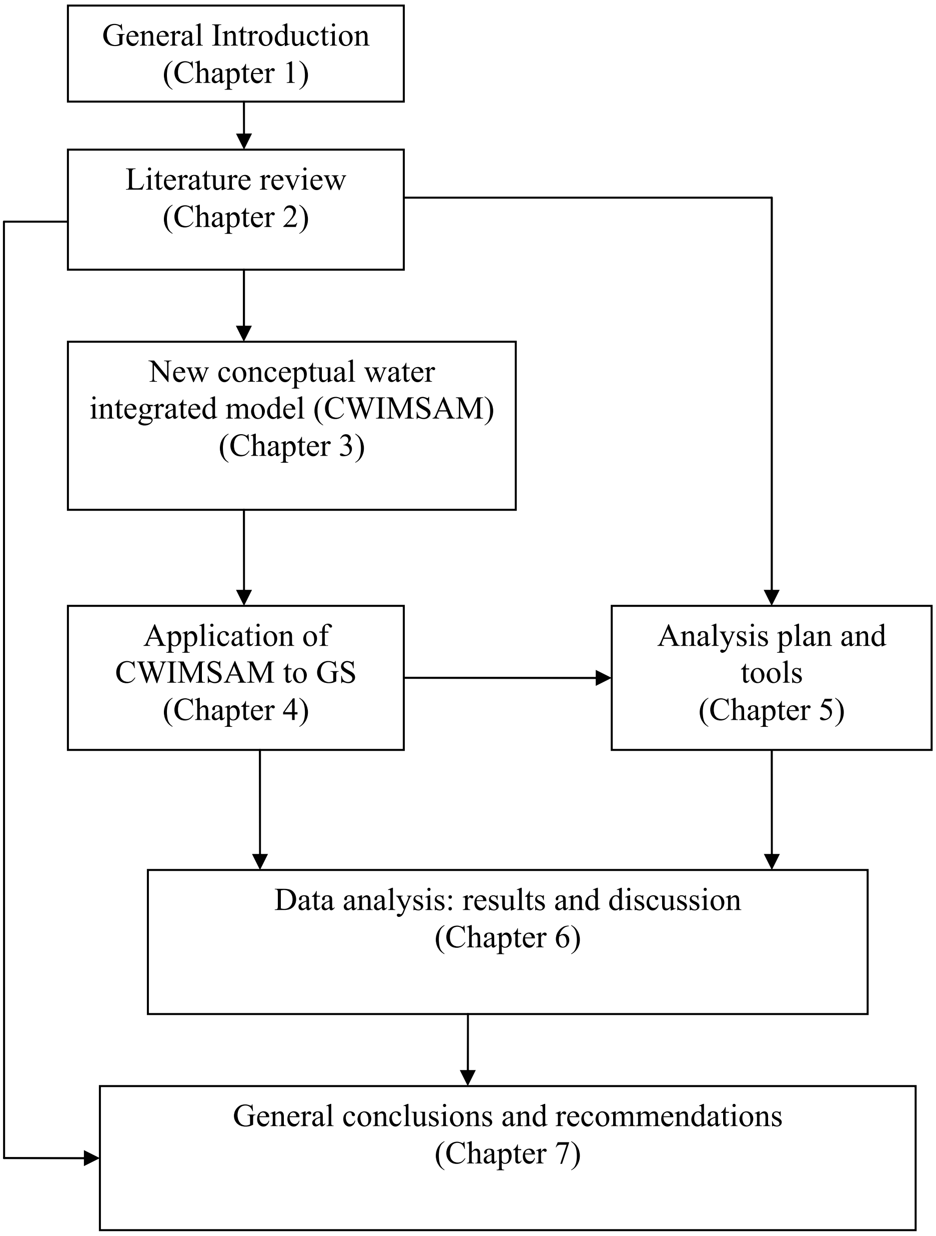


Figure 1.3 Thesis structure: interrelations of the chapters of thesis

The second chapter introduces the literature collection and review of international trends, orientations and agenda in water resources management. It embraces also literature review on sustainable development and water sustainability, IWRM, development and validation of conceptual models and water related indicators, and tools for environmental integration with emphasis on EIA and SEA. The third chapter presents the new appropriate conceptual framework model (CWIMSAM) for IWRM and its validation through expert judgment and review and comparison with actual used model. The fourth chapter explains the application of CWIMSAM to GS and, the data presentation and summary. The sixth chapter tackles the data analysis using various tools including statistical analysis, ANN and human health risk assessment. The last chapter deals with general conclusions and recommendations. It presents the principal features of analysis, significance and deliverables and limitations of research work, expected impacts of research work on water resources management in GS, recommendations for improvement and recommended areas for further research. The last chapter is followed by bibliography and annexes.

Chapter 2 Literature Review

2.1 International and regional trends, orientations and agenda in water resources management

There is an international and regional consensus on the sound water resources management. Emphasis by the International and regional organizations and forums are given to:

- The goal of the water sector is sustainable management of water resources that must incorporate the environmental, social and economic and institutional dimensions (WSSD, 2002; UNEP, 2003b; World Water Council, 2003).
- Sustainable water resources management includes two major related components which are in a dynamic conflict: (a) utilization and development of the water resources for the various human demands; and (b) protection and management of the water resources so that they can continue to be utilized for present and future generations (IAHS, 2003).
- Integrated approach for water resources planning and management to achieve water security and sustainability (European Commission, 2000; GEF, 2003; IAHS, 2003; UNEP, 2003b; World Water Council, 2003).
- Sufficient water quantity and quality is available to meet the basic human needs and the environmental flow requirements for the protection of ecosystems and their biodiversity due to their ecological and hydrological, social and economic benefits (WSSD, 2002).
- Protection of wetlands and river ecosystems (European Commission, 2000, World Bank, 1995).
- Water and sanitation services are basic requirements for human public health and poverty alleviation (WSSD, 2002; Millennium Assembly, 2003).
- Water pollution control from local and diffuse sources and water quality management (EU, 2000; UNEP, 2003b).
- Defining and mainstreaming of environmental sustainability in water resources management through environmental assessment tools including EIA and SEA (Athens declaration, 2002; METAP, 2003).
- Water conservation and demand management must be enhanced to improve water- use efficiencies (UNEP, 2003b).
- Stakeholders involvement should be encouraged (Solanes and Gonzalez-Villarreal, 1999; EU, 2000).

- Use of the approach understand- explore- suggest to formulate sound water policies, strategies and action plans (Blue Plan, 2003).

2.2 Sustainable development and water sustainability

Sustainable development is defined as development that meets the needs of current generations without compromising ability of the future generations to meet their needs and aspirations (WCED, 1987). It addresses the development and management of environmental resources to ensure the long term productive capacity of the resource base with the goal to improve the long-term societal well being (Schultink, 2000).

Sustainability ensures the attainment and continued satisfaction of human needs for present and future generations in environmentally sensitive, economically viable, institutionally robust and socially acceptable ways within the particular regional context" (RESCUE, 2002). It has four dimensions: the social, economic, environmental and institutional. Institution refers not only organizations, but as well to institutional mechanisms like procedures, legal norms and the system of rules governing the interaction of members of society. Institutions are considered as the fourth dimension of sustainable development (Spangenberg et al., 2002; Spangenberg, 2002).

Integration of the sustainability concepts in water sector management has become an overall objective for the Mediterranean countries in order to achieve sustainable water resources use and management. Hijri et al. (2002) defined water sustainability as the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it. Therefore, a balance should be found between the needs of the people and the protection of the natural resource base, so that water resources can continue to provide benefits for improving people's livelihoods and quality of life reducing poverty and fostering economic growth in the future. Jewitt (2002) defined water sustainability as development of a water resource should be regulated including the characteristics, resilience and integrity of the resource in question.

Concluding remarks

Obviously, there is a wide range of definitions given by experts and scholars for the terms water sustainability and sustainable development. Therefore, it is essential to establish a frame of reference for sustainability definition including scope and dimensions for the context of this research work tackling water resources management in the semi-arid Mediterranean region. Following is the proposed definition for water sustainability:

Water sustainability is maintaining the capital of natural water resource such that the rate at which the exploitation of renewable water resources does not exceed the rate at which the natural systems can replenish them and without undermining the integrity of the hydrological cycle or the ecological systems that depend on them. Besides, the natural water resources should be protected from all sources of pollution and restored, as necessary, at appropriate standards to sustain human health as well as ecosystems. It is intended to ensure the demands of human activities for present and future generations in environmentally friendly, socially acceptable, economically feasible and institutionally sound ways incorporated together in an integrated manner.

2.3 Integrated Water Resources Management (IWRM)

The definition adopted by Global Water Partnership (2003) is " IWRM is a process, which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable without compromising the sustainability of vital ecosystems" will be used as a reference to measure the status of research works and achievements made by scholars in relation to IWRM. The scientific papers which have the same focus and relevant to this research work, well known and widespread among scholars will be discussed. Besides that, the most related earlier research works will be tackled.

IAHS (2003) tackled the two decisive categories of IWRM: (1) the natural system, which is of critical significance for the water available quantities and qualities, and (2) the human system, which determines the use of water and the pollution of the resource. The integrated approach must balance consideration of both categories and their interdependencies. Accordingly, a balance will be established between society's demand for water and the restoration of waters as part of nature conservation. The integration concept links water quantity and quality, water supply and water conservation, atmospheric and surface water and groundwater, land use and water management, ecosystems, economic and social development, urban and rural users, poor and better-off users, technology application and capacity building, water governance and public participation.

Scoullos et al. (2002) defined IWRM as a systematic approach for decision making which recognizes the interdependence of the three main areas: environment, social stability and welfare and economic development and also, acknowledge the interrelationships among the sectors.

"IWRM approaches are based on the principles of economic efficiency, environmental sustainability and social equity to assist the water resources planners and managers (Hijri et al., 2002).

Ubbels (2001) presented that IWRM is not an end product but a dynamic process providing for a group of means, tools and methods with the objective of achieving water sustainability. IWRM relies on integrated decision making that recognizes different types of linkages: between land use and water; between socio-economic and environmental practices at the regional, national and local levels based on active and meaningful participation and involvement of all stakeholders.

Pollution prevention to preserve fresh water resources is an important element of the integrated model. Therefore, natural water resources management should be integrated with land use planning (Pretorius, 2001; Collin and Melloul, 2003).

Al Radif (1999) tackled several concepts of the integrated approach with the view of achieving sustainable water management. These concepts include health considerations, socio-economic aspects, environmental concerns and technological means in addition to stakeholders and local water users groups. He emphasized the need to strengthen human resources development in terms of awareness creation programs, training of water managers, development of new institutions and effective information management. The center of IWRM approach, which shapes the basis for water sustainable management, is the establishment of multi-disciplinary teams at various levels to communicate different views on water resources, building consensus on the conservation of water resources and safeguarding the ecosystem functioning.

Klohn and Appelgren (1998) emphasized the need for an integrated approach encompassing social, economic, and environmental policies. They discussed the linkages between the water scarcity and its driving forces, including population growth, environmental degradation and unequal access for water. The challenge is to take on a management approach based on critical social resource factors especially water scarcity can not be addressed by traditional technical and economic supply-oriented options. They emphasized the need to develop social and non-economic indicators that adequately reflect the societal capacity to water scarcity in order to avoid internal and external conflicts.

Bouwer (2000) emphasized that the integrated and holistic approaches are necessary to handle the emerging issues and challenges of water and to prevent catastrophies in developing countries. The challenges include population growth, higher living standards and uncertain climatic changes which will pose heavy demands for good quality water, and thus increasing sewage flows. Simultaneously, agriculture water demand will increase to meet the growing demand for food. In addition, more water will be required for environmental flows. He assumed that besides supply management, the integrated approach requires demand management (water conservation, transfer of water to uses with higher economic returns, water quality management, recycling and reuse of water, economics, conflict resolution, public involvement, public health, environmental and ecological aspects, water storage, conjunctive use of surface water and groundwater, water pollution control, regional approaches, weather modification).

Feng (2001) introduced the water sustainability as the water available for both society and nature uses that can be obtained from any natural water sources under the limitations of the combination of technological feasibility, economical effectiveness, environmental security and human acceptability. He described the required strategies for sustainable integrated water resources management in water scarce regions in developing countries especially those in arid and semi-arid areas.

Magnanga et al. (2002) pointed out fragmented planning and management, a lack of integrated approaches and conflicting sectoral policies in Tanzania have contributed to failure of water supply and sanitation systems to meet the needs of rural and urban populations. They stressed the significance of appropriate investment and operation and maintenance of water systems in addition to water pollution and stakeholders involvement in IWRM. Drawing upon case-study material from two major areas, they reviewed some of the practical steps to implement IWRM in Tanzania.

Durham et al. (2002) recognized that the IWRM in the Mediterranean countries is becoming as the only sustainable solution and must be supported by legislation. They focused on two technical solutions which are artificial aquifer recharge and reuse of treated wastewater due to their environmental, social and economic values. To overcome the current water shortage they promoted maximizing the efficiency of water management, import of water and desalination particularly where hybrid systems can provide a real benefit by taking advantage of the process synergy between power generation, desalination, reuse and aquifer recharge in one system to enable Mediterranean countries to move rapidly towards integrated water resources management. They also stressed the significance of the participatory approach involving users, planners, policy makers at all levels. Besides that, partnership between municipalities, NGO's and private sector is needed as one of the only workable responses to the serious water problems in the poor developing countries.

Al-Hadidi (1999) addressed the severity of water problems in Jordan with emphasis on supply management issues. He highlighted the need for the development of new water resources to remedy the water shortage. Amongst these resources, Al-Hadidi selected the brackish water desalination as a potential source for supply augmentation.

Ast (1999) explained the process of the development of the concept of water management in the Netherlands. He focused on the interactive water management. The water policy agencies are in a continuous interactive dialogue both with the water system in terms of ecological and environmental aspects and the society system including the involvement different actors in society. In IWRM, citizens are given the possibility to express their opinion, but in interactive water management, people think together with the water managers, about the most desired developments.

Haddad and Linder (2001) conducted a critical review for the water resources management in the Middle East with emphasis on Palestine, Jordan and Israel. It was concluded that (1) the least cost solution for short and medium water development is the water conservation through water demand management practices including technical, economic, financial, institutional, educational, and legal measures, (2) augmentation of water supply through treated wastewater reuse, weather modification, and rainwater harvesting, and (3) bringing additional non-conventional water either through land or sea transport, or through brackish and sea water desalination.

Schultz (2001) dealt with the IWRM in terms of the requirements of the European Union Water Framework Directive, the ecological risk caused by water projects in the environmental impact assessment and the implementation of sustainable development principle through making long-term forecasts for water development including water supply and demand such that future generations could agree to them.

LOE (2001) highlighted the potential role and capacity of the local governments to manage water resources in an integrated way. The local capacity is a function of technical, financial, institutional, political and social factors. He focused only on two elements: groundwater protection and flood plain management in Ontario in Canada.

Ubbels and Verhallen (2001) focused on the participatory approach in IWRM to support decision making. All interested parties and stakeholders can present their views, opinions and interests. They introduced the use of decision support tools to improve the dialogue between stakeholders, and between stakeholders and experts. It is intended to integrate the scientific technical knowledge into the process, together with the dialogue between stakeholders .with emphasis on citizens.

Gonzalez-Anton and Arias (2001) highlighted the principles of IWRM as adopted by EU. These principles include public participation as an essential part of IWRM, river basin management, river basin management planning, coordination of objectives and measures and the introduction of full recovery cost pricing. IWRM implies restructuring of the existing bodies and creation of new institutions. Similarly, Ast and Boot (2003) stressed the importance of public information and participation of various societal actors in the European water policy.

Chartzoulakis et al. (2001) presented the water resources management in the Island of Crete, Greece with emphasis on agriculture water use measures in semi-arid conditions. They emphasized that in order to secure water for the future of Crete, IWRM should include measures which that are purely technical (increase the use surface water, improvement of distribution systems and irrigation rescheduling, recycling, use of water saving irrigation systems, use of reclaimed and brackish waters) and socio-economic (pricing and cost recovery, rationalization, training and awareness). These measures are applicable to most of the Mediterranean countries. Also, Kijne (2001) introduced the demand-based water management in the irrigated agriculture sector in place of the existing supply-based water management to achieve IWRM as a step towards sustainable society. Furthermore, Sbeih (1995) presented the significance of wastewater treatment and reuse in agriculture irrigation as a potential water resource in Palestine. This should be associated with public education and awareness and capacity building for the management institutions.

Tapela (2002) explained the challenge of integration in the implementation of Zimbabwe's new water policy. She viewed the IWRM as facilitating the achievement of a balance between water resource use and resource protection, and the resolution of water-related conflicts. Ultimately, IWRM is seen as providing a framework towards ensuring broader security at the local, national, regional and global levels. The crucial issue in IWRM is the institutional arrangements and ability to address effective stakeholders participation and involvement in decision making and planning, equity in access to water, efficiency in water use and management, and protection of the ecosystem. Therefore, Tepela suggested addressing the founding principles of IWRM including good governance, democracy, stakeholder participation, gender empowerment, acceptable power relations and environmental sustainability and security .

Matondo (2002) recognized that multi-purpose water resources planning and management emerged to handle the increase in competing and conflicting water uses due to the rapid population and economic growth. He highlighted the institutional framework to coordinate water resources planning and management at all levels of government especially in developing countries. The institutional framework includes institutional setup, human resources, capacity building, coordination among ministries and other organizations.

Abufayed et al. (2002) tackled the need for environmentally and financially sustainable sea water desalination in IWRM in South Mediterranean countries. Sea water desalination is aimed to cover the deficit in water needs due to the growing gap between demands and supply.

Jonker (2002) defined IWRM as managing people's activities in a manner that promotes sustainable development through improving livelihoods without disrupting the water cycle. IWRM also, should address issues of access and equity, resource protection, efficient use, governance and land-use. He suggested a conceptual framework with people's practices at micro-level within the IWRM (meso-level) and the impacts on sustainable development (macro-level).

Jewitt (2002) highlighted that the ecosystem is a basic element in IWRM to ensure achieving sustainable use and management of water resources. Ecosystem also should be regarded as a user of water in competition with other users to maintain the hydrological and biological processes and to sustain the provision of goods and services. Analogous to Jewitt, Bergkamp et al. (2003) recognized the ecosystem approach as an optimization tool of the water resources management through maintaining the functioning of ecosystems as providers for services and goods. Also, Scphocleous (2000) presented the water sustainability issues from the hydrologic perspective. He recommended moving from the safe yield concept to sustainable yield and development of natural water resources so that adequate amounts of water are to be available to sustain the functioning of ecosystems.

Henocque and Andral (2003) tackled the French approach to managing water resources in the Mediterranean. It is a multi-sectoral approach strengthened by legislation that provided an institutional, regulatory, financial, and technical framework. Emphasis in this approach is given to institutional arrangements and consultations for stakeholders dialogue that involve representatives from sectors, technical committees, local governments and national water commissions and local communities. Besides, pollution prevention and control at source through the setting of environmental quality standards together with maintaining the ecosystem functions are significant element in water resources management. Long term effectiveness of water management is secured through a system of taxes and adopting the user pays and polluter pays principles. In addition, Piegay et al. (2002) introduced the water policy in France with emphasis on the environmental issues. This policy aims to be decentralized, consultative, collective, well balanced reconciling the different uses of water whilst protecting the ecosystems. The policy promotes the participative management through enlarging the numbers of actors involved in decision making, defining negotiated solutions to solve the problems, and allowing local consensus to be reached.

Concluding remarks

Still, semi-arid areas have a relatively large potential for water development, yet the real problem is not the lack of resources but the lack of an integrated water management policy to alleviate the current tragic conditions (Sharma, 1998). "Thirst, however, is not a problem of water scarcity; it is a problem of water management than of water availability" (Savenije, 2000).

Having discussed the achievements of the scholars in the area of IWRM, it is clear that none of the scholars presented and tackled the big picture of IWRM as defined by the GWP. Approximately, most of the scholars tackled fragmented concepts and explained how they can contribute to IWRM due to the financial constraints. Sometimes there is a difference among the scholars about the definition of IWRM "There is a long way to go to achieve a common understanding of IWRM and to develop and refine approaches for its successful implementation" (Jonker, 2002). It is recommended that more research needs to be done to make sure that management of water resources is based on concrete science (Bouwer, 2000). It is essential to develop an integrated scientific approach to support decision making in order to address the water scarcity problems and human factor in southern and eastern Mediterranean countries " it is argued that the time has come for scientists involved in management of scarce water and other natural resources to move towards multidisciplinary approaches that capture the most important social dimensions" (Appelgren and Klohn, 1998). Acknowledgement that people are a part of biogeochemical cycles and physical processes has necessitated a more integrated approach to natural resource management and research (Bowen and Riley, 2003).The science of integrated management is a great deal compared to the simple problem of engineering (Pretorius and Villiers, 2001), however "So far, science has not advanced a comprehensive framework to address these issues in an integrated manner" (Kamp et al., 2003).

2.4 Development and validation of indicators

2.4.1 Introduction

The inclusion of human factor into the natural web of interactions has called for new methodologies for studying the natural systems and for solving economic and health problems. The complexities of public health risk, economic sustainability and environmental quality are difficult to understand and are even challenging. These difficulties have contributed to promote the indicator-based approaches to management. Therefore in the last decade, the growth of indicators has become a commonly approach especially the human influence has been introduced as a new variable into scientific search for knowledge of the natural world. Without an integrated and sustained indicator-based system, it is difficult to establish linkages, generally accepted and acted upon (Bowen and Riley, 2003). Undoubtedly indicators are of growing relevance for international cooperation which enable a quantitative and qualitative environmental observation and give information about the success or failure of sustainability. Indicators really contribute to policy development what implicates that they are powerful enough to shape political goals (Piorr, 2003). Indicators are considered a requirement to the implementation of the sustainability concepts, and particularly its environmental factor (Hansen, 1996). By using indicators, the compliance of development processes with sustainable development on a national and international levels are tested. Another application of indicators is the future- oriented assessment of planned measures due to the fact that the entire system observed cannot be shown in the field of planning (Osinski, et al., 2003). As recommended in Chapter 40 of Agenda 21, the CSD has developed a set of sustainability indicators to assist assess the progress towards sustainability and to communicate the achievements (UNDPCSD, 1995). Different types of indicators have been developed to meet the growing demand of assessment instruments of environmental impacts. As any tool developed by research, indicators must be elaborated according to a scientific approach. One of the important steps of this elaboration is the validation (Bockstaller and Girardin, 2003).

2.4.2 Definition of indicator

Indicator is a variable which supplies information on other variables which are difficult to access and can be used as bench marker to take a decision "Alternative measures enable us to gain an understanding of a complex system so that effective management decisions can be taken that lead towards initial objectives" (Mitchel et al., 1995). Indicators may result from a set of measurements, from calculated indices, or they may be based on expert systems. At least two types of indicators may be distinguished: simple indicators resulting from the measurement or the estimation (i.e. by a model) of an indicative variable and composite indicators that are obtained by aggregation of several variables or simple indicators (Girardin et al., 1999). Many indicators are not aimed at being used to predict an actual impact but to supply information about a risk or a potential effect (Halberg, 1999). Indicators can also inform policy makers about the progress that is being made towards achieving a policy objective (Crabtree and brouwer, 1999; Vos et al., 2000; Manoliadis, 2002). Indicators are aimed at "raising the alarm", meaning they should give information on negative impacts prior to their incidence (Reus et al., 1999). In some cases, indicators are resulting from simulation models in order to make the output easier to understand and to" relay a complex message in a simplified manner" (Fisher, 1998). Indicators are not necessarily numbers; they might be informational signs or labels. We certainly trust them when taking certain decisions or for planning actions (Ronchi et al., 2002). The European Environment Agency (EEA) defined indicator as "observed value representative of a phenomenon to study". In general, indicators quantify information by aggregating different and multiple data. The resulting information is therefore synthesized. In short, indicators simplify information that can help to reveal complex phenomena" (European Commission, 2002). The Blue Plan explained indicators as means to consolidate and summarizes quantitative information; above all they are a preferred means to communicate and objectify situations and policies. The Blue Plan developed indicators to facilitate and illustrate the observation of the links between development and the environment. In this regard, two groups of indicators have been developed. The first group is the environmental performance indicators that seek to measure the gap between reality and the environmental goals as quantified and set by policies. The second group is the sustainable development indicators that intend to measure the progress towards achieving sustainable development in the Mediterranean countries. The general approach of Blue Plan for indicators is:

1. From problems to indicators: the problems are better analyzed using quantifiable indicators. This will help measure the performance of proposed alternative solutions in handling the gravity and scope of the problems
2. A preferred tool for dialogue: the selection and quantification of indicators constitutes an extraordinary tool for dialogue and public participation.
3. A procedure that evolves in time: the added value for indicators lies in their time-frame and their constant readjustment, taking account to the often rapid evolution of the issues involved and how they are perceived.

A more rigorous definition is given by the International Institute for sustainable development: "An indicator quantifies and simplifies phenomena and helps us understand complex realities. Indicators are aggregates of raw and processed data but they can be further aggregated to form complex indices." (IISD, 1995).

"Indicators are presentations of measurements. They are bits of information that summarize the characteristics of systems or highlight what is happening in a system. Indicators simplify complex phenomena, and make it possible to gauge the general status of a system." (Malta, 2000). RESCUE (2002) introduced indicators as measurable units that make statements about certain situations and reduce complexity in measuring developments, thus making situations and developments comparable and assessable with regard to time and space. Indicators are classified to single, additive, and systematic indicators. RESCUE also developed the following criteria for indicator selection:

- Measurable in qualitative and quantitative terms;
- Horizontally comparable between regions or nations and vertically compatible between national, regional and local levels over a certain period;
- Assess trends within the context of the four sustainability dimensions;
- Relevant for planning and political decisions;
- Selection and weighting of indicators is transparent;
- Simple, valid, comprehensive, specific, simple, reliable, communicable;
- Precautionary (early warning) and not reactive (RESCUE, 2002).

OECD (1998) has argued that a successful indicator should:

- Reduce the number of measures required for actual presentation of a situation; and
- Simplify the process communication to managers, stakeholders and communities.

In its work program, the United Nations Commission on sustainable Development (CSD) has listed the following criteria for the selection of indicators:

- Primarily national in scale or scope;
- Relevant to the main objective of assessing progress towards sustainability;
- Understandable: clear, simple and unambiguous;
- Achievable within the available resources including time, money, technical capacity, logistics and given the existing constraints;
- Conceptually well founded;
- Limited in number, remaining open ended and adaptable to future developments;
- Representative of an international consensus, to the extent possible; and

- Dependent on the data, that are readily available or available at reasonable cost to benefit ratio, are adequately documented, of known quality and updated at regular intervals (UNDPCSD, 1995).

Barrera-Roldan and Saldivar-Vales (2002) introduced the following criteria for the selection of the core, main and relevant indicators:

- Availability and reliability of the source of information data;
- The most current statistical data;
- Representatives in the analysis of the three systems: natural, social and economic;
- A holistic approach that included qualitative and quantitative terms.

Spangenberg et al. (2002) developed a number of criteria to determine the quality of selected indicators:

- Independent, each indicator must be meaningful in itself;
- Indicative, it must be truly representative of the phenomenon it is intended to characterize;
- General, not dependent on specific situation;
- Robust, directionally safe with no significant changes in the methodology or improvements in the data base;
- Sensitive, to changes in what they are monitoring.

Gilbert and Feenstra (1994) list four desirable characteristics of indicators including:

- The indicator must be representative for the chosen system and have a scientific basis;
- The indicator must be quantifiable;
- The indicator should clearly represent part of the cause effect chain;
- Indicators should offer implications of policy.

2.4.3 Methodologies used to develop indicators

☒ The Pressure-State-Response (PSR) model

The PSR model popularized by OECD considers that activities of human system exert " pressures" on the environment and affect the quality and quantity of natural resources "state", society responds to these changes through environmental, land use, awareness and sectorial policies "societal response". The PSR model highlights the cause- effect relationship. It helps decision makers and the public to observe the linkages between the human and the natural resources systems and to undertake the proper policy interventions. The PSR model provides a classification into indicators of environmental pressures, indicators of environmental conditions (state) and indicators of societal responses (OECD, 1993). Bowen and Riley explained that PSR model is a framework where environmental problems and solutions are represented and explained by variables that stress the cause and effect relationships between human activities that exert pressures on the environment, the condition of the environment, and the society's response to the condition (Figure 2.1). The PSR approach made explicit the need to focus on factors influencing environmental systems and associated consequences; both in terms of environmental conditions and regulatory change. However, it has significant conceptual limitations since it focuses on anthropogenic pressures and responses and ignores the natural causes into the pressure category. Hence, natural variability has no place in this model. This makes the model overly narrow in its scope (Bowen and Riley, 2003). "The Rio Principles on sustainable development clearly give three founding domains to sustainability in the environment, the economy and society. For the latter two, the PSR model is not effective" (Ronchi et al., 2002). Bayfield and Crabtree (1998) used the PSR model to develop sustainability indicators for mountain ecosystems in Scotland. They noted that the approach has some limitations when applied to sustainable development. It fails to incorporate the links between economic activity and environmental change and, with a concentration on state variables, is weak in handling the system fluxes essential for monitoring purposes.

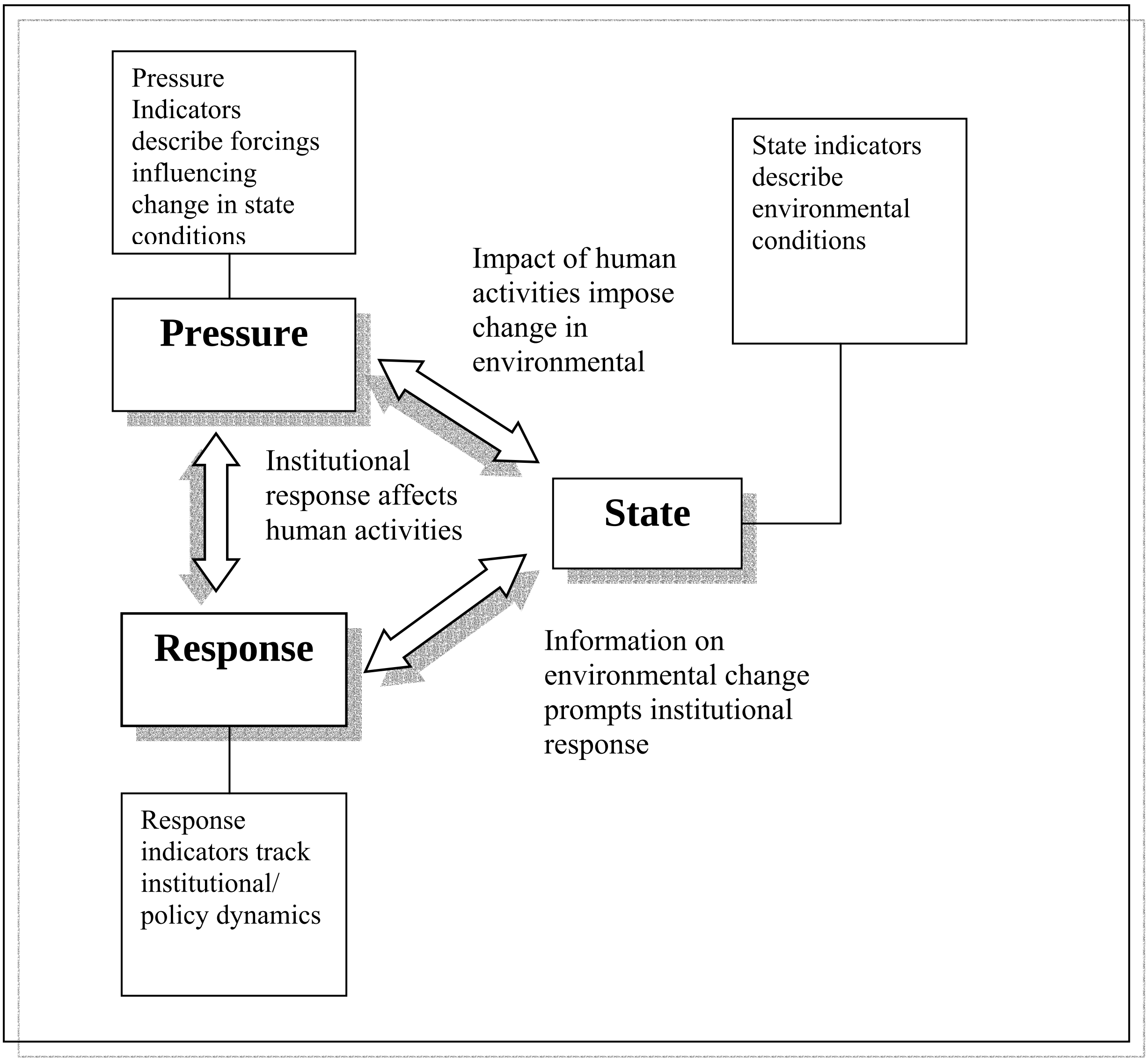


Figure 2.1 Pressure-State-Response model for indicator development
(Source **Riley C., Bowen R., 2003 and adapted from: OECD**)

☒ The Driving Force-State-Response (DSR) model

The constraints and limitations of the PSR model led the CSD to describe a Driving Force-State- Response model. A primary modification here was to expand the concept of " pressure" to incorporate social, economic, institutional and natural system driving forces. This enables grasp the root causes of the problems being addressed (UNEP, 2000). "Whereas the OECD indicators had been exclusively focused on the environment, the CSD had to take into account the other dimensions of sustainability. Hence, the economic and social dimensions were added to the framework, resulting in the need to extend the category of pressures to the more general driving forces. While the DSR scheme provides no suitable analytical basis for indicator development, it offers a convenient classification scheme for results derived otherwise" (Spangenberg et al., 2002). RESCUE (2002) mentioned that the PSR and DSR indicator frameworks tend to miss the complex interactions and interrelations between the different indicators and topics. The inadequacies of PSR and DSR, need to be considered as they can lead to oversimplification and to wrong policy recommendations. The DSR model is based on a logic and holistic framework of action-response relationships between society, economy and environment (Barrera-Roldan and Saldivar-Vales, 2002). Another element missing from the PSR model and still not tackled in the DSR model is the indicator system that measures the impacts to humans and ecosystem. The social and ecological impacts of environmental are essential factors in influencing the policy responses. An indicator system that considers the state but not the impact essentially assumes that every change in the pressure, state, and response should be given the same amount of resources and ignores the human factor which is at the center of development and should be considered a priority (Bowen and Riley, 2003).

☒ The Driving force-Pressure-State-Impact-Response (DPSIR) model

The challenges to the PSR and then to DSR models have contributed to the expanded model described as DPSIR developed by the European Environmental Agency (EEA) of the European Commission. The " Driving forces-Pressure-State-Impact-Response" model defines five indicator categories as explained in Figure 2.2 (European Commission, 2002) where:

D: Driving forces are underlying socio-economic and sectoral factors influencing a variety of relevant variables;

P: Pressure indicators describe the variables which directly cause environmental problems;

S: State indicators illustrate the existing conditions and the observable changes of the environment;

I: Impact indicators describe the ultimate effects of changes of state on the human and ecosystems; and

R: Response indicators present the efforts of the administration and policy making level (Decision makers, management) to intervene and solve the problems.

" The DPSIR approach more effectively represents the complexities of social/environmental interaction and highlights the need to understand and measure the nature and scale of that dynamic. The more effective integration of social condition, environmental dynamics and institutional response can only enrich the process of informed decision making on sustainable resource use and development practices" (Bowen and Riley, 2003). The risk assessment is highlighted as a tool to characterize the effective pollution indicators and calculate their carcinogenic risks on public health and ecology. Besides, clean-up levels of the pollution indicators can be calculated to support the management remediation responses.

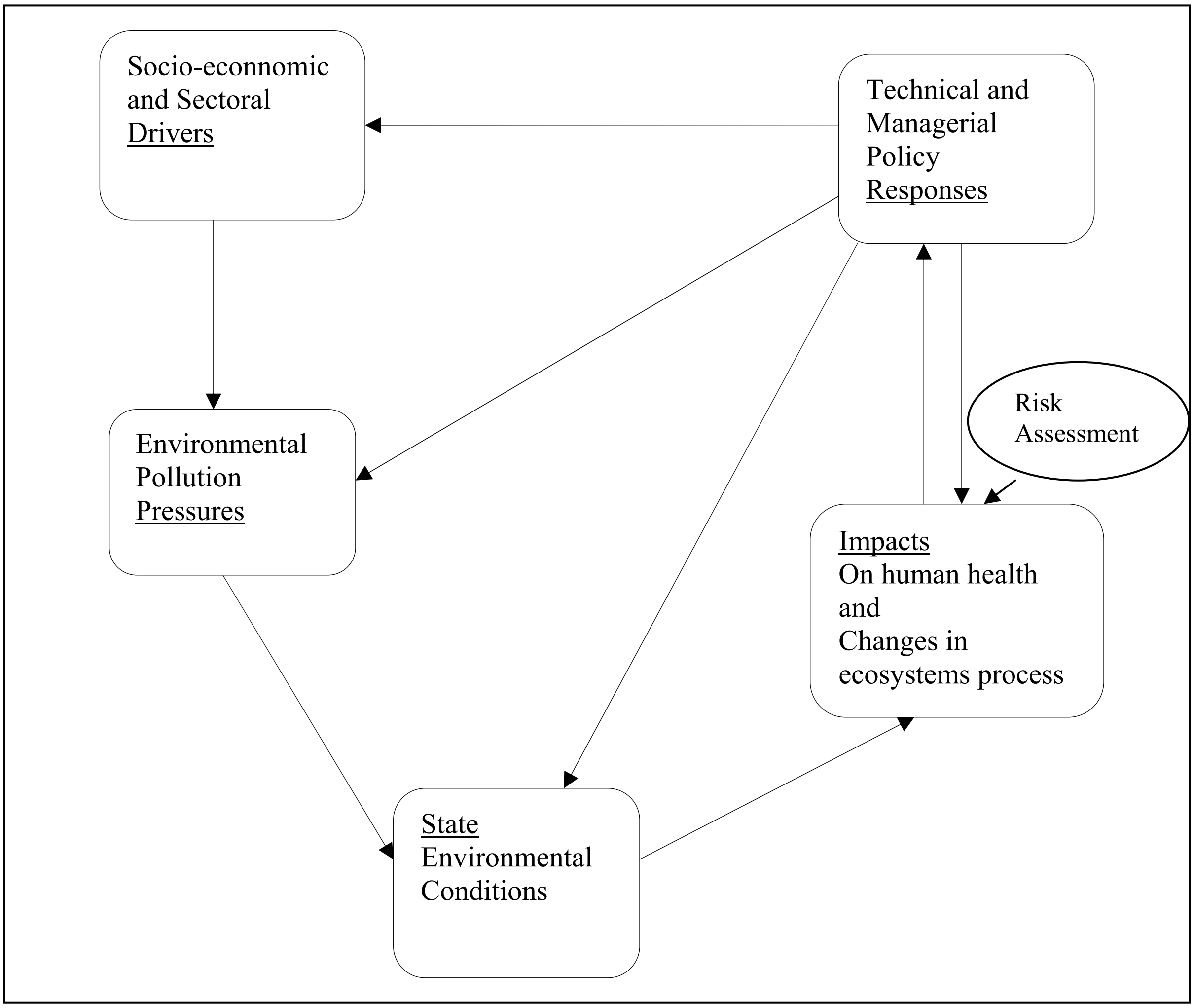


Figure 2.2 Driver-Pressure-State-Impact-Response Framework for indicator development (Source **European Environmental Agency, 1999**).

☒ **Development of indicators by public and community participation**

Yuan et al. (2003) focused on public participation as a means of identifying sustainability indicators as an opportunity to introduce a "bottom-up" approach. Community level indicators need to be connected to local people's understanding and knowledge of their local problems and their desires. Therefore, public participation is one of the most effective methods to these kinds of indicators. To develop indicators, a long list of possible indicators will be drawn up based on literature review of indicator systems. Then, a group of different local stakeholders including local governmental officers, beneficiaries and academics are asked to evaluate each of the proposed indicators. Also, a questionnaire will be administered to ask the participants to rank each indicator according to their judgment on the significance of each indicator to local sustainable development. Many people have participated in the formulation and development of sustainability indicators (Valentin and Spangenberg, 2000).

2.4.4 Validation of indicators

In any case, the methodology, underlying the elaboration and development of indicators should fit scientific standards, which implies a procedure of validation (Girardin et al., 1999). Some scholars mention the necessity for indicators to be scientifically valid (Mitchel et al., 1995; Crabetree and Brouwer, 1999; Smith et al., 2000; Vos et al., 2000) but those authors do not propose a procedure for validation. An indicator will be validated if it is well founded and scientifically designed, if the information it supplies is relevant, if it is useful and used by the end users (Bockstaller and Girardin, 2003). The validation of indicator design is very important (Reus et al., 1999). Experts' judgments and consensus for the choice of indicators among a panel of experts plays a major role in this kind of validation (Mayer and Butler, 1993; Van der Werf and Zimmer, 1998; Hess et al., 1999; Smith et al., 2000). To validate the quality of indicator, a usefulness test should be undertaken to get the end users opinions about the effectiveness of the indicator as diagnosis or decision support tool (Girardin et al., 1999).

2.4.5 Indicators for water resources management

The Driving force- Pressure- State- Impact- Response (DPSIR) framework has been selected to analyze all regional water catchments in the European research project, EUROCAT, which aims to achieve integrated catchment and coastal zone management. It will assist predict how future socio-economic changes in the water catchments might affect the water quality in order to formulate policy responses that will act to reduce the pressures created by certain drivers, and the impacts of certain pressures on water quality (Cave et al., 2003). Also, Jeunesse et al. (2003) introduced the DPSIR framework for environmental cause-effect relationship to develop indicators for integrated and operational decision support system for sustainable use of water resources at the catchment level. Manoliadis (2002) used a modified conceptual framework: Pressure-State- Impact- Response (PSIR) to develop ecological indicators for irrigation systems in Greece The pressure indicators tackled the water use, the state indicators explained the water quality and availability, the impact indicators presented the loss in food production and the response indicators concluded the measures for efficient water use. He et al. (2000) proposed a conceptual framework to develop and integrate a set of hydrological and biological indicators which describe the conditions and health of watersheds using remote sensing and GIS. These indicators are essential for sound policy and decision making in water resources management. Kodratyev et al. (2002) assessed the present state of water resources of Lake Ladoga in Russia and its drainage basin using sustainable development indicators as proposed by CSD. The Driving force-State-Response model is used to develop these indicators with the view of protecting the quality and supply of freshwater resources. Savenije (2000) stressed the need to develop water scarcity indicators that give a more reliable image of the water stress that is available in several parts of the world. Balkema et al. (2002) developed a multi-disciplinary set of indicators for the sustainability assessment of wastewater treatment systems. Sullivan (2002) presented ways to calculate water poverty index in which an interdisciplinary approach is followed to undertake an integrated assessment of water stress and scarcity, linking water availability with socio-economic indicators that reflect poverty. Feitelson and Cheoweth (2002) proposed a water poverty index to identify the degree to which countries are likely to face problems in addressing their water supply needs. The water poverty index will be based on three indicators including (a) cost of sustainable supply of potable water to all people at all times; (b) cost of sanitation and treatment; and (c) affordability. Malta (2002) developed freshwater, seawater quality and wastewater sustainability indicators using the DPSIR model. The criteria used for the selection of indicators are: scientific validity; easily understood; comparability and public sensitivity; measurable; capable of being updated regularly; and data availability.

Concluding remarks

It is clear that there are differences in views of scholars and international organizations regarding the definition, development frameworks, selection criteria and validation of indicators. Therefore, it is important to establish a reference framework for indicators for the context of water sustainability and based on integrated approach. The proposed indicator reference framework includes:

- The selected indicators reflect and translate the definition of water sustainability with emphasis on the four dimensions of sustainability; social, economic, environmental and institutional incorporated in an integrated manner.
- An indicator is defined as something that helps us to understand where we are, where we are going and how far from the goal. It is a parameter that provides information about a relationship between the DPSIR chain elements that summarize the characteristics of water resources system.
- DPSIR framework for environmental cause-effect relationship was adopted to develop indicators for integrated water resources management approach towards water sustainability in semi-arid Mediterranean region.

- Participatory indicator approach for the development and validation of the design and usefulness of indicators can be undertaken including experts representing the relevant water sector stakeholders from several Mediterranean Countries.
- The following criteria was used for the selection of indicators: (a) Relevant to the main objective of assessing progress towards sustainability; (b) Independent; (c)Understandable; (d) Measurable; (e) Achievable; (f) Scientifically sound and technically robust; (g) Indicative; and (h) General.
- GIS and remote sensing techniques were used to get the data and information about the environmental state indicators.

2.5 Development and validation of conceptual models

Conceptual models are graphical representation of the real world using the influence diagrams. Elements of these diagrams are represented by boxes and interactions between these elements by arrows indicating an influence of one element on another one both in horizontal and hierarchical levels. The conceptual models have to be translated into a list of indicators which are linked by parametrical processes (Brang et al., 2002).

The construction of a uniform, multidisciplinary conceptual framework model is extremely important in the accumulation of knowledge. Such a conceptual framework model would allow for a more theory-based choice of indicators and for the development of tools to evaluate the multidimensional aspects of an integrated trans-disciplinary and inter-sectoral approach. These tools are required to analyze the current situation and to assess the likely impacts of the proposed policy actions with respect to these dimensions. Ideally, this would enable a situation in which insights from different disciplines could be a source of mutual inspiration. Consensus about the core concepts and the basic assumptions behind them is a (first) pre-requisite for forming a multidisciplinary (uniform) framework (Kamp et al., 2003).

Several researchers claim that proper conceptual modeling is crucial since it helps to explain the problem to be worked out (McGregor and Korson, 1990; Bonfatti and Monari, 1994; Hoydalsvik and Sindre, 1993). McMenamin and Palmer (1984) and Jackson (1995) consider the two categories of conceptual models: (a) Current- state models, which express essential properties and functionalities of critical aspects of the existing system, and (b) Desired-state models, which define the requirements for the future system. Conceptual models play a central role during the problem analysis and their main characteristics are description and understanding. In concrete, conceptual models should support developers to understand the problem and its constraints before any solution is identified (Dieste et al., 2003), since they make possible to:

- Make real-world concepts and relations tangible (Motschnig-Pitrik, 1993);
- View a symbolic representations of mental maps that help to interpret ill-structured situations (Worren et al., 2000);
- Record parts of the reality that are important for performing the task in question and downgrade other elements that are insignificant (Borgida, 1991);
- Encourage the analyst to think and document in terms of the problem, as opposed to the solution (Davis, 1993);
- Support communication among the various stakeholders (Mylopoulos et al., 1997);
- Formally define aspects of the physical and social world around us for the purposes of understanding and communication (Loucopoulos and Karakostas, 1995).

The debate in academia is concerned with the scientific validity of theories and conceptual models, that is, the extent to which theories correspond to reality. In contrast, the practitioners who use the same theories are more interested with how helpful they are as conceptual tools in guiding them to attain specific objectives (Dieste et al., 2003).

Concluding remarks

In order to understand the problems of water resources management in the semi-arid Mediterranean region, it is essential to establish a conceptual water integrated model reflecting the life cycle of water resources management. Achieving water sustainability is the reference framework of identifying the gravity and scope of these problems.

To ensure the correctness and appropriateness of the intended conceptual water integrated model, it must be validated. Reviews are a common validation technique in which one or more stakeholders check the validity of a model (Haumer et al., 2000; cited from Freedman and Weinberg, 1982). Validation also can be done by comparison with well established and used models in other countries.

2.6 Tools for Environmental integration into water resources management

2.6.1 Environmental Impact Assessment (EIA)

Environmental Impact Assessment (EIA) is well established worldwide and has been widely practiced as planning tool that seeks to compare the various alternatives which are available for any project in terms of their possible impacts on the environment, where in this context 'environment' is taken to include all physical, biological and socio-economic aspects (Jalala, 1996). Nafti and George (2003) defined EIA as a process of scientific investigation, involving public participation, in which the necessary technical expertise is brought together to evaluate the likely impacts which a proposed development might have on the environment. According to the adopted Palestinian EIA Policy (2000b), EIA means a detailed assessment of the likely environmental impacts of a proposed project or activity according to approved terms of reference. The environment in this context means water, air, land, humans and other forms of life including domesticated and non-domesticated plants and animals, the inter-relationships among them and future generations.

Despite the adoption and practice of EIA, certain limitations are now being increasingly recognized with regard to achieving sustainable development and environmental quality has deteriorated in many parts of the world since the individual project EIA approach does not guarantee environmental quality (Briffett et al., 2003; Nierynck, 2000). Subjectivity is frequently viewed as one of the shortcomings of EIA. Politized evaluations are seen as problems in EIA (Wilkins, 2003). Recently, it has become obvious that while EIA may be a useful tool for incorporating environmental issues into the design of individual actions, it is not necessarily able to deal with cumulative impacts, indirect impacts, and large scale effects. As a result, EIA's contribution to sustainability is relatively limited (Annandale et al., 2001). Although EIA is extensively established as planning and decision-making tool, it is recognized that it is exhausted with a number of limitations and weaknesses, particularly the relatively late stage in the decision making process at which project EIA is applied, and the resultant lack of a choice of alternatives (Sadler and Verheem, 1996). The project-specific nature of current EIA practice is often seen as a constraint on accounting for sustainability which will only be realized if consideration is given to the environment at all significant decision points including policy, plan and program (PPP) levels (Noble, 2002). "But because of several inadequacies of limiting the assessment to projects only, a new environment assessment instrument has been designed, aimed at the strategic level of sectoral policies and programs that set the basic framework for project identification. This is referred to as Strategic Environmental Assessment (SEA)" (Kesseler and Dorp, 1998).

2.6.2 Strategic Environmental Assessment (SEA)

SEA is defined as a systematic ongoing process for evaluating the environmental consequences of policies, plans and programs that form the planning framework for projects at the earliest appropriate stage of decision making ensuring full integration of biophysical, economic, social and political considerations (Sadler and Verheem, 1996; Partidario, 1996; Arce and Gullon, 2000). Therivel (1992) have included in the core definition the methodology. SEA can be explained as ‘ the formalized, systematic and comprehensive process of evaluating the environmental impacts of a policy, plan or program and its alternatives, the preparation of a written report of the findings, and the use of the findings in publicly-accountable decision making’.

SEA is anticipated to ensure that environmental consequences of certain plans and programs are identified and assessed during their preparation and before their adoption. SEA will contribute to more transparent planning by involving the public and by integrating environmental considerations with a view to promoting sustainable development (EC, 2001). The SEA Directive will considerably assist to materialize the environmental integration towards achieving sustainable development since it is a valuable tool among the different approaches that are being tried out and developed for this purpose (Feldmann et al., 2001). The major purpose of SEA is to facilitate early and systematic consideration of potential environmental impacts in strategic decision making level (Therivel and Partidario, 1996; Partidario, 1996). SEA is mostly related to sustainability objectives so that decision makers can improve the design of more sustainable policies and strategies (Noble, 2002). It is very useful for sustainability assessment of infrastructure development and has been applied in several fields including water, waste, transport and energy (Arce and Gullon, 2000). SEA should be thought as a more integrated approach of trickling down sustainability principles from policies to plans and further to programs and after that to individual projects. Thus, ensuring that environmental and sustainability concerns are incorporated into the objective of policy plan or program (Annandale et al., 2001; Sebt, 1999). IAIA has established performance criteria for a good quality SEA process. The principles of the criteria are: integrated, interdisciplinary, sustainability-led, participative, iterative, adaptive, accountable, focused, rigorous, transparent, and systematic (Finnveden et al., 2003). A range of methods and techniques are used in SEA or are potentially available. Following some of the analytical methods and techniques needed for SEA are explained in Table 2.1.

Table 2.1 SEA methods

Step	***Examples of Methods***
Baseline Study:	• State of Environment Reports and similar reports • Points of reference
Screening/ Scoping:	• Formal/informal checklists • Survey, case comparison • Public or expert consultation
Defining Options:	• Environmental policy, standards, strategies • Regional/local plans • Public values and preferences
Impact Analysis:	• Scenario development • Risk assessment • Environmental indicators and criteria • Policy impact matrix • Predictive and simulation models • GIS capacity • Cost –benefit analysis (CBA) and other valuation techniques • Multi-criteria analysis
Documentation for Decision Making	• Cross-impact matrices • Consistency analysis • Sensitivity analysis • Decision 'trees'

Sources: FEARO, 1992; DHV Environment and Infrastructure, 1994

2.6.3 Relationship of SEA and EIA

The main difference between SEA and EIA is the type of decision to which they are linked. Sadar et al. (1996) defined EIA as project-specific only, and not applied to programs or policies which limit its usefulness and effectiveness. EIA examines alternative ways to carry out the project and proposes ways to avoid or mitigate predicted impacts. SEA, on the other hand, is associated with strategic decisions. At this level, SEA guarantees that environmental considerations and objectives are integrated into policy, plan and program development. SEA is advocated to transform traditional 'reactive" project level EIA into "proactive" "Strategic Environmental Assessment" which addresses policies, plans and programs (Arce and Gullon, 2000; Nierynck, 2000; Annandale et al., 2001). There is a strong connection between SEA and the already widely established EIA. They share broadly the same underlying objectives and principles and, correspondingly, their components are also broadly similar. SEA is to a large extent needed to complement and counteract the limitations of project EIA (Therivel and Partidario, 1996). There are often far more possible alternatives and mitigation measures to assess in SEA than in project EIA and the geographic area is normally much larger which makes the assessment process very complex (Therivel , 1992).

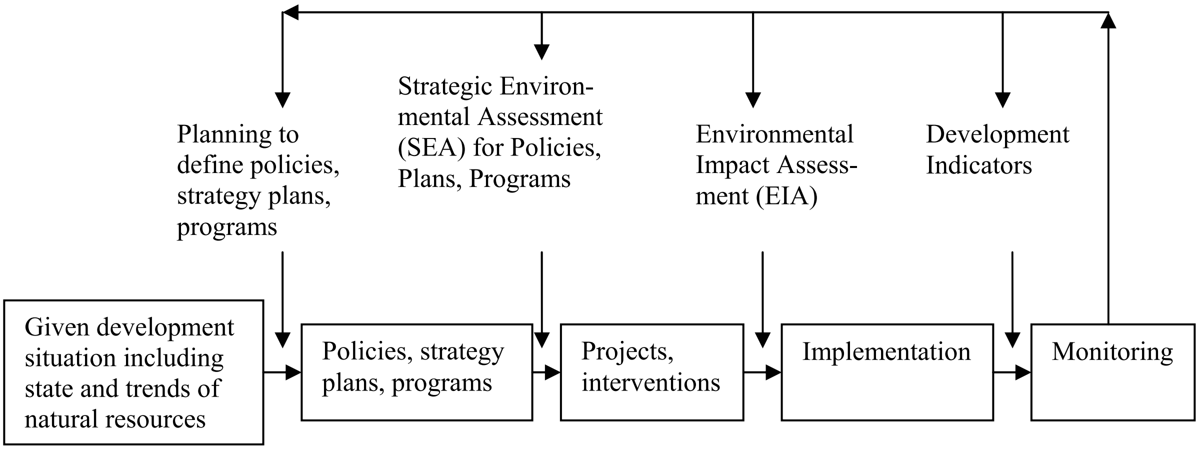


Figure 2.3 Relation between SEA and EIA in strategic planning process (Source **Kessler, 1997**).

A fully fledged SEA process, tiered to project level EIA (Figure 2.3) ensures that environmental implications, issues and impacts of development decision making can be addressed at the appropriate levels. To this end, SEA and EIA should be consistent with and reinforce each other such that SEA provides a frame of reference for EIA (Sadler and Verheem, 1996; Kessler, 1997; Nooteboom, 2000).

2.6.4 Application of SEA to water resources policies, plans and programs

☒ SEA of Jordan's water sector

The SEA study covers the water sector in Jordan addressing domestic, industrial, agricultural, and recreational and ecosystem use; covering water supply, wastewater disposal and reuse, and storm water drainage; and considering inter-basin transfers and desalination. The main objective of the study is to identify issues, in early stage that may require further actions or coordination for meeting the requirements of future projects related to possible environmental consequences. SEA will review proposed water sector investment programs in Jordan in a view to develop a strategic perspective of water related environmental issues and to identify policy, regulatory, technical, and institutional mitigation measures to ensure environmental protection of water resources and sustainable use and management (Jordan, 2002).

☒ SEA of Hydrological and irrigation plans in Castilla y Leon, Spain

The study demonstrates how SEA can promote sustainable water resources management plans through addressing the environmental, economic and social impacts of the combined proposed plans, using relevant indicators and objectives. The methodology designed for the SEA study includes the following:

- Defining the reference framework which provided a general overview of the current situation of the region including the most important socio-economic and environmental issues related to water management and, in particular, to the themes proposed in the plans. Besides, the reference framework analyses the government's commitment and institutional response regarding water management. Thus, the principles and constraints that should direct and coordinate water management and planning in the region were identified. In addition, the interactions between socio-economic and environmental elements on the one hand and between the various policies and institutional and legal principles on the other hand;
- Description of the plans with focus on their objectives and proposed lines of action;
- Selection of complete set of most relevant indicators that reflect the critical aspects including economic, ecological, and institutional;
- Impact prediction and evaluation of lines of actions based on the use of the selected indicators and checklists. This will assist predict which lines of actions are likely to have to have impacts on nature conservation and water quality, socio-economic, and environmental indicators;
- An initial proposal of strategic alternatives for water resources management to mitigate the impacts identified in the evaluation and to incorporate the sustainability patterns in integrated manner ;
- Monitoring plan for the implementation of the strategic alternatives to measure their performance in achieving the objectives based on the set of indicators (Hedo and Bina, 1999).

Concluding remarks

- The current project level EIA is insufficient to improve the water sector development significantly.
- SEA can be a supporting tool to IWRM towards achieving sustainable water resources management, and strengthening both the process of integrated decision making and the project level EIA. SEA facilitates the translation of sustainability concepts into water

resources policy making and requires developing indicators at strategic level. It also serves as an “early warning” system for anticipating and managing cumulative and large scale effects including global climate change.

- None of the scholars has connected between the Integrated Water Resources Management (IWRM) approach and the Strategic Environmental Assessment (SEA) which have the same context and objectives.
- IWRM approach can be incorporated in the SEA procedure and methods to be mandatory and legally binding. Thus, water policies, plans, programs shall undergo SEA. SEA supports IWRM approach through selecting sustainable scenarios that take account of the social, public health, economic, environmental (including pollution and the natural environment) and institutional factors based on participatory approach.
- Some of the SEA procedural steps and methods can be used in this research work.
- The SEA of Jordan's water sector lacks sound analysis for the baseline conditions which will identify the water sector crucial factors and the geographical areas under stress that demand urgent actions. Besides, there is no clear framework for developing the indicators supposed to be the reference for monitoring programs to measure the performance and contribution of the proposed alternative interventions. Furthermore, the analysis of proposed water interventions and their likely impacts using checklists is rather subjective since there is no clear weighting and ranking methodology.
- The SEA procedure followed in hydrological and irrigation plans of Spain lacks the analysis of baseline situation based on a set of indicators. Instead a reference framework is defined to give a general overview about the socio-economic and environmental issues of the region without indicators. Development of indicators was two steps after definition the reference framework which will weaken the monitoring program. The checklist method was used to analyze the likely impacts of the alternative which is rather subjective.

Chapter 3 New Conceptual Water Integrated Model for Semi-arid Mediterranean Region (CWIMSAM)

3.1 Introduction

Water resources management, in semi-arid Mediterranean countries with scarce water resources is a complex challenge. It requires new concepts and techniques if management should be based on sound scientific findings in order to optimize and conserve the precious water resources.

In regards to IWRM, no systematic and comprehensive multidisciplinary works have been developed so far and even they seem to have shortcomings. Therefore many scholars for instance Jonker (2002), Bouwer (2000), Appelgren and Klohn (1998), Kamp et al. (2003) explicitly have called for additional work to substantiate this aspect.

This research work was intended to contribute to those efforts through developing CWIMSAM. It has been the first experience that tackled the big picture of IWRM with emphasis on sustainability concepts and continuous interactions between the institutional system and the human and natural systems. The integrated, preventive and ecosystem approaches have been introduced in CWIMSAM. Besides, effective and useful sets of variables (indicators) were characterized for water sector analysis and monitoring. CWIMSAM supports water planners and managers to gain adequate knowledge and understanding of the actual water problems. It causes changes in the decision makers' subjective views and enables them to devise proper interventions with the objective of achieving sustainable use and management of Gaza aquifer as part of the nature conservation.

3.2 Reference framework

The reference framework has set the context and base for the new conceptual model. It aims to provide the general components and mechanisms of the water resources system that would be reflected by the new conceptual model. Important points in the reference framework are:

- The overall objective of the water sector is to achieve sustainable management of water resources. The definition of water sustainability is maintaining the capital of natural water resource such that the rate at which the exploitation of renewable water resources does not exceed the rate at which the natural systems can replenish them and without undermining the integrity of the hydrological cycle or the ecological systems that depend on them. Besides that, the natural water resources should be protected from all sources of pollution and restored, as necessary, at appropriate standards to sustain human health as well as ecosystems. It is intended to ensure the demands of human activities for present and future generations in environmentally friendly, socially acceptable, economically feasible and institutionally sound ways incorporated together in an integrated manner;

- Mainstreaming of environmental sustainability in water resources management through preventive and ecosystem approaches;
- IWRM is an effective approach to achieve water sustainability and security. It is not an end product but a dynamic balancing process. The integration concept links surface water and groundwater, water quantity and quality, pollution pressures and water quality, water supply and water conservation, social and economic development, urban and rural and users, institutional and capacity building. It incorporates also ecosystems and land use into water resources management;
- The Driver-Pressure-State-Impact-Response (DPSIR) was selected as a well established framework for cause-effect relationship to develop the possible variables;
- Experts opinion and judgment methods were undertaken for the development and validation of the design and usefulness of the conceptual model and variables;

3.3 Description of CWIMSAM

The most important elements and sciences related to water have been depicted in the form of a lence (Figure 3.1) as a new conceptual model. Figure 3.1 indicates that water resources development and management must be within the ecological sustaining limits of available natural water resources. The new conceptual model is based mainly on three decisive categories: (1) the natural system, which is of critical significance for the water available quantities and qualities, (2) the human system, which determines the use of water and the pollution of the resource, (3) the institutional and management system must balance consideration of the natural and human systems and their interdependencies. In Figure 3.1 and Figure 3.2, the three systems are divided into five categories based on cause-effect DPSIR framework for development of water related variables. The variables reflect and translate the water sustainability concepts, preventive and ecosystem approaches. The five categories are: socio-economic aspects, anthropogenic pollution pressures, state of water quality, public health and ecological impacts and the institutional responses. The human system is explained by the socio-economic, anthropogenic pressures and public health variables. The natural water system is presented by the state of water, and ecological impacts and the institutional system is reflected by the institutional responses.

Figure 3.1 shows a continuous interaction between the human system on one hand and the natural water system on the other hand. Besides, there is a dual relationship between the interacting human and natural water systems and the institutional system. Accordingly, a balance will be established between society's demand for water and the restoration of waters as part of nature conservation. Figure 3.2 highlights the involvement of water sector stakeholders and the experts opinion and judgment.

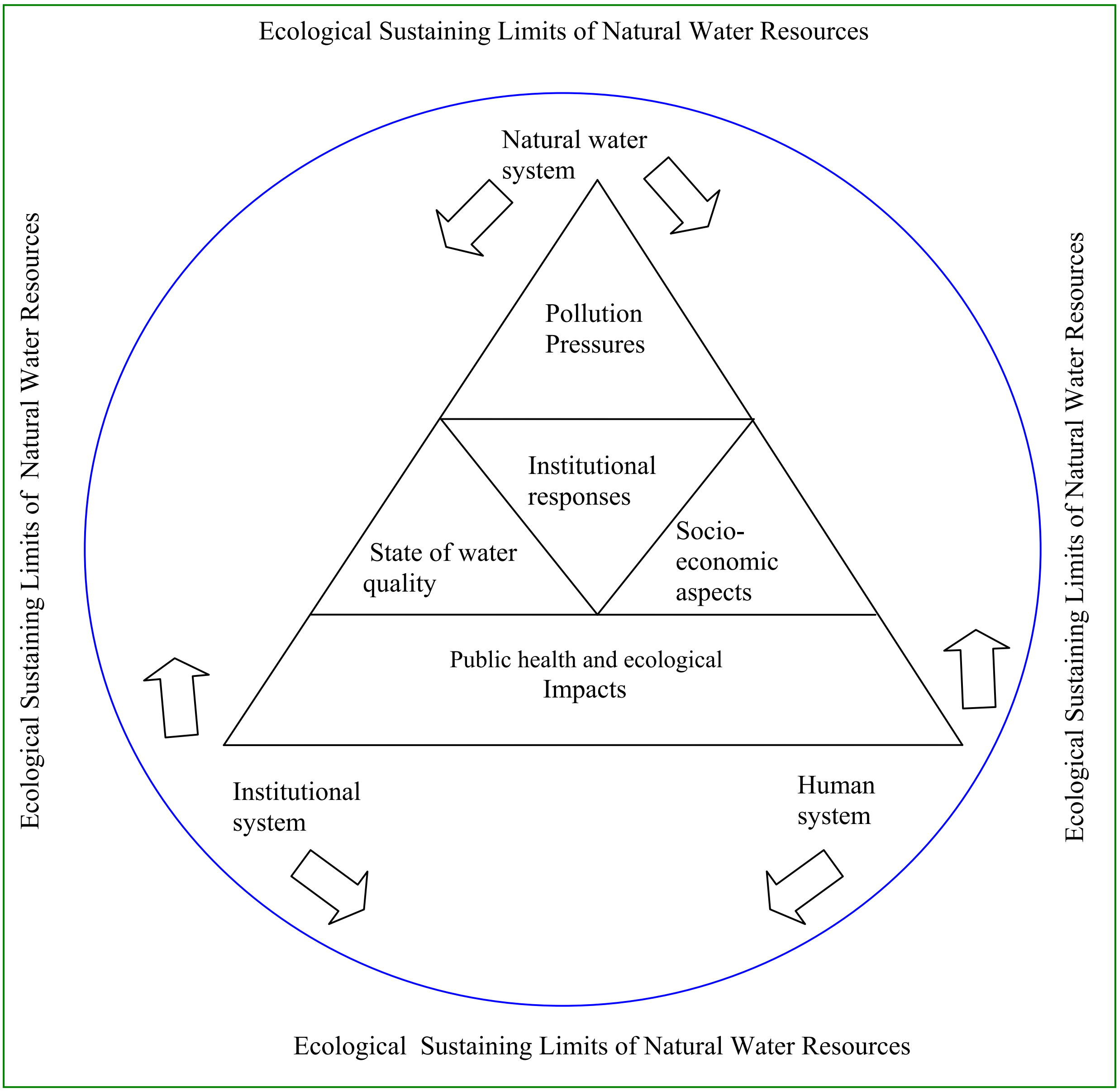


Figure 3.1 Lence of CWIMSAM

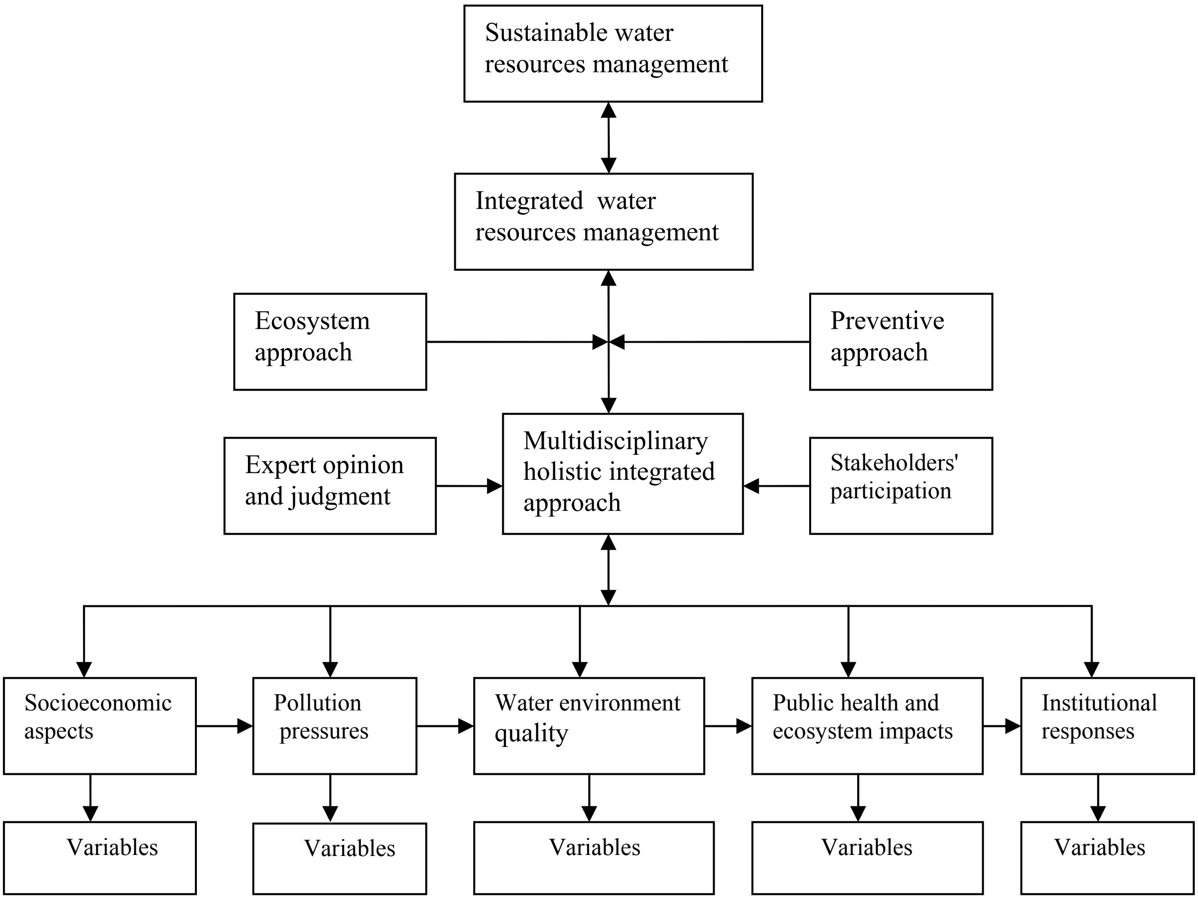


Figure 3.2 CWIMSAM Diagram

The five categories are segregated into a set of most relevant variables that reflect the critical aspects of water resources. Following are the categories and the selected possible variables:

1. Water abstraction from the aquifer
2. Total Dissolved Solids (TDS)

☒ **Category of socio-economic driving forces variables**

3. Population
4. Income per capita
5. Land use
6. Tourism
7. Access to safe water supply
8. Wastewater system coverage
9. Storm water system coverage
10. Water consumption per capita
11. Water price

12. Efficiency in revenue/taxation collection
13. Agricultural water consumption
14. Gender empowerment
15. Unaccounted for water

☒ **Category of pressure variables: pollution sources**

16. Hazardous wastes
17. Generation of domestic wastewater
18. Pesticides
19. Chemical fertilizers
20. Organic fertilizers
21. Petrol stations
22. Domestic solid waste
23. Industrial wastewater
24. Carbon dioxide (CO_2)
25. Seawater intrusion or upcoming reflecting Over-pumping

☒ **Category of state variables:**

- **Water quality**

26. Nitrate
27. Chloride
28. Sodium
29. Calcium
30. Magnesium
31. Potassium
32. Fluoride
33. Sulfate
34. Hydrogen Ion Concentration
35. Alkalinity
36. Total Coliform

☒ **Category: Impact variables**

- **Ecological**

37. Loss of productivity

38. Loss of wetland

- **Public health**

39. Morbidity

☒ **Category of response variables: management responses**

40. Brackish water desalination

41. Storm water harvesting

42. Importation of water and regional water conveyance

43. Treated/partially treated wastewater

44. Efficiency in water irrigation

45. Efficiency in urban water supply networks

46. Efficiency of water information system

47. Water awareness and education campaigns

48. Seawater desalination

3.4 Validation of the new conceptual model

3.4.1 Introduction

To ensure the correctness and appropriateness of the conceptual model proposed in this research work, it must be validated. Validation can be done through comparison with well established and used models in other countries. Reviews are also a common validation technique in which one or more stakeholders check the soundness of the model.

3.4.2 Validation through comparison with case studies

☒ **Case study from Cyprus**

Cyprus is an island with a semi-arid climate. It is situated in the northeastern corner of the Mediterranean Sea, having an area of 9,251 km^2 and population of 0.7 million. Cyprus being an island relies entirely on rainfall for its water needs. The average annual rainfall is about 500mm falling mostly in the months of October to April. Over one century, the temperature has been rising by 0.01 ºC.y^{-1} and annual rainfall has been falling by 1 mm.y^{-1}.

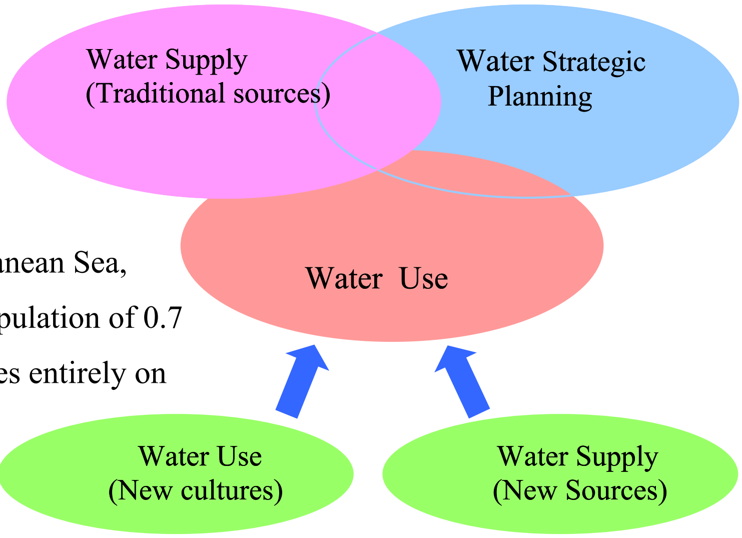


Figure 3.3 Multidisciplinary approach for an integrated water strategy in Cyprus (Source **Fessas, 2001**).

The total water resources are estimated around 790 hm^3, 510 hm^3 as surface and 280 hm^3 as groundwater (Tsiourtis, 2001).

In Cyprus, water is the most significant resource and a prerequisite for socio-economic progress. Cyprus is suffering from water scarcity with its water resources already intensely utilized which acted as a limiting constraint for the development of agriculture and for other economic activities such as tourism. The water balance of the island recognizes that there is already a deficit indicated by over-pumping of 40 hm^3.y^{-1} resulting in sea water intrusion into most of the coastal aquifers (Socratous, 2001). The deficit will increase since the concurrent increase of the demand for water couples with diminishing of the rainfall and the repeated droughts causing over-utilization of the natural water resources (surface and groundwater). This highlighted the need for a systematic and comprehensive approach for the proper and effective management of the water resources of Cyprus (Charalambous, 2001). As a result, an integrated multidisciplinary and multidimensional model has been developed (Figure 3.3) realizing that strategic groundwater reserves must be maintained and kept for the drought periods. A series of measures (Figure 3.4) have been considered for implementation to augment water availability, bridge the deficit between the definite conventional water resources and the water use and achieve water sustainability and security. These measures include: reduction in evapo-transpiration; loss reduction from surface and ground waters and developing new sources stressing on seawater desalination for domestic purposes, and reuse of treated wastewater for agriculture irrigation (Fessas, 2001).

Critical analysis: similarities and differences

Figure 3.3 embraces the three systems of integrated water resources management. These systems are: (1) the traditional water supply from the natural surface and groundwater resources; (2) the water use by different users including economic sectors, domestic and nature; (3) strategic planning carried out by the institutional system and based on the water policy to meet the growing gap between supply and demand of water. Cyprus model also focuses on two major areas to meet the water use requirements. First, the radical change in water use philosophy and culture must happen through awareness and education campaigns by teachers, journalists and mass communicators. Second, development of new sources including seawater desalination plants and wastewater treatment and reuse facilities.

Figure 3.4 represents the institutional responses focusing on policy and technical measures intended to: (1) Secure additional sources of water supply to augment the water availability, allocation, (4) Build up strategic reserves, (5) maintain and enhance the quality of water , (6) introduce new efficient management procedures.

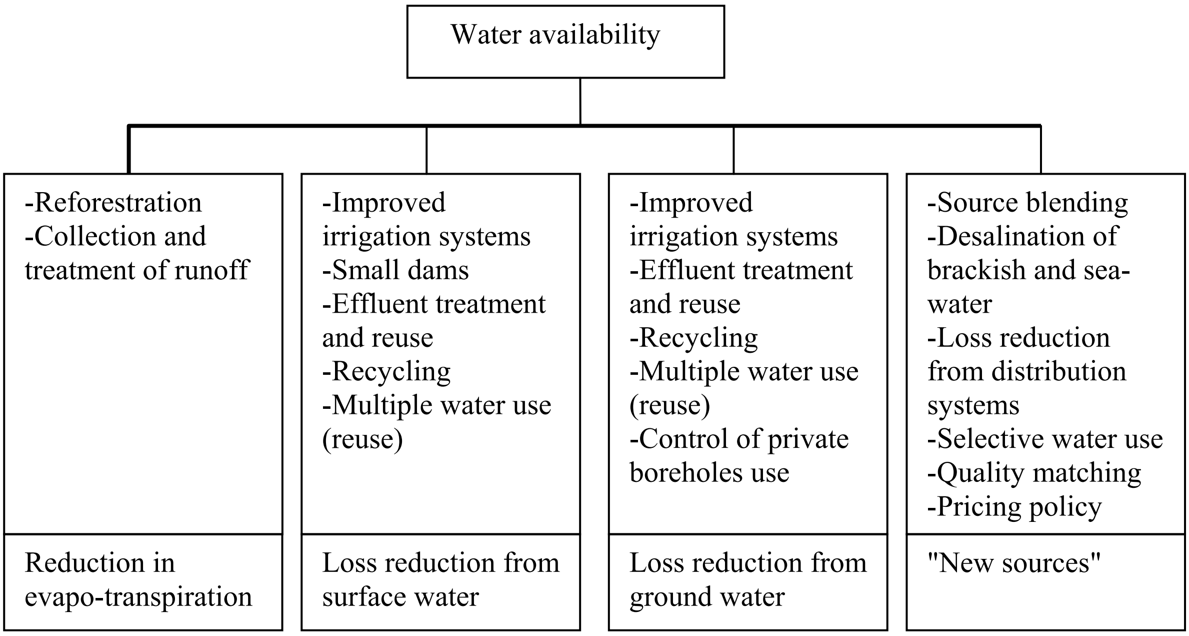


Figure 3.4 Measures for increasing water availability in Cyprus (Source **Fessas, 2001**).

The integrated water resources management model used by Cyprus has almost the same concepts and systems of the new conceptual model explained in Figure 3.1. The difference is that the level of details given in Cyprus model is small. The new conceptual model interprets the three systems through five categories including socio-economic aspects, pollution, state of water quality and the institutional responses in terms of institutional mechanisms (legislation, policy and planning), organizational structure of water sector and technical and regulatory measures. Besides, the five categories are divided into a number of appropriate variables covering all aspects of the integrated approach in a view to achieve sustainable water management.

The measures explained in Figure 3.4 for increasing water availability are narrow in scope since they have ignored the protection of water resources from local and diffuse pollution including solid waste, wastewater, fertilizers, pesticides and hazardous waste. Furthermore, the economic aspects and impacts of water quality on public health and ecosystems are missing.

☒ Case study from Jordan

Jordan is located in an arid to semi-arid region with an area of 92, 300 km^2 and population of 4.9 million in year 2000 expected to increase to 7.2 million in year 2015 at a growth rate of 2.5%. The weather conditions are severe; and variation in related hydrological parameters such as rainfall, runoff, and evaporation is wide. They vary from day to night, from summer to winter, and from one year to another. The principal water source in Jordan is rainfall, about 91.4% of Jordan receives an average annual rainfall less than 200mm. Total water use was about 950 hm^3.y^{-1} in 1997 of which 70% for agriculture, 24% for domestic, 1% for livestock and 5% for industrial uses. The calculated per capita domestic water use is only 80 Liter/capita/day. At the current rate of water use, there is a serious water shortage; the demand is exceeding the supply by 200 hm^3.y^{-1} even though all conventional sources have been developed including the non-renewable groundwater resources in the Disi and Shedia sandstone fossil aquifers in southeastern Jordan. The depletion of these aquifers has resulted in reducing their quality and yields, increasing of salinization as well as the dehydration of nearby wetlands. Water scarcity is becoming a significant constraint to development in Jordan and the complications inherent in water resources management exceeds the limits of traditional technical decision making. As a result, a comprehensive multidimensional and multi-objective integrated management approach for water resources has been developed taking account of economic efficiency, equity, environmental conditions, regional development, and water quality, management of uncertainty of supplies, depletion and reuse (Abu Taleb and Mareschal, 1995; Jaber and Mohsen, 2001). Figure 3.5 demonstrates a general layout of the problem tree of water resources sector in Jordan based on cause-effect relationship with emphasis on the core problem which is the scarcity of suitable water supply. The causes for the water scarcity in Jordan include the limited conventional water resources, shared international water resources, and the insufficient water quality due to water pollution from local and diffuse sources besides the water salinization from irrigation water return flow. Figure 3.6 presents the institutional responses to maximize water supply including: (1) management and optimization techniques, (2) development of non-conventional water resources; and (3) development of conventional groundwater and surface water resources (Al-Shemmeri et al., 2003).

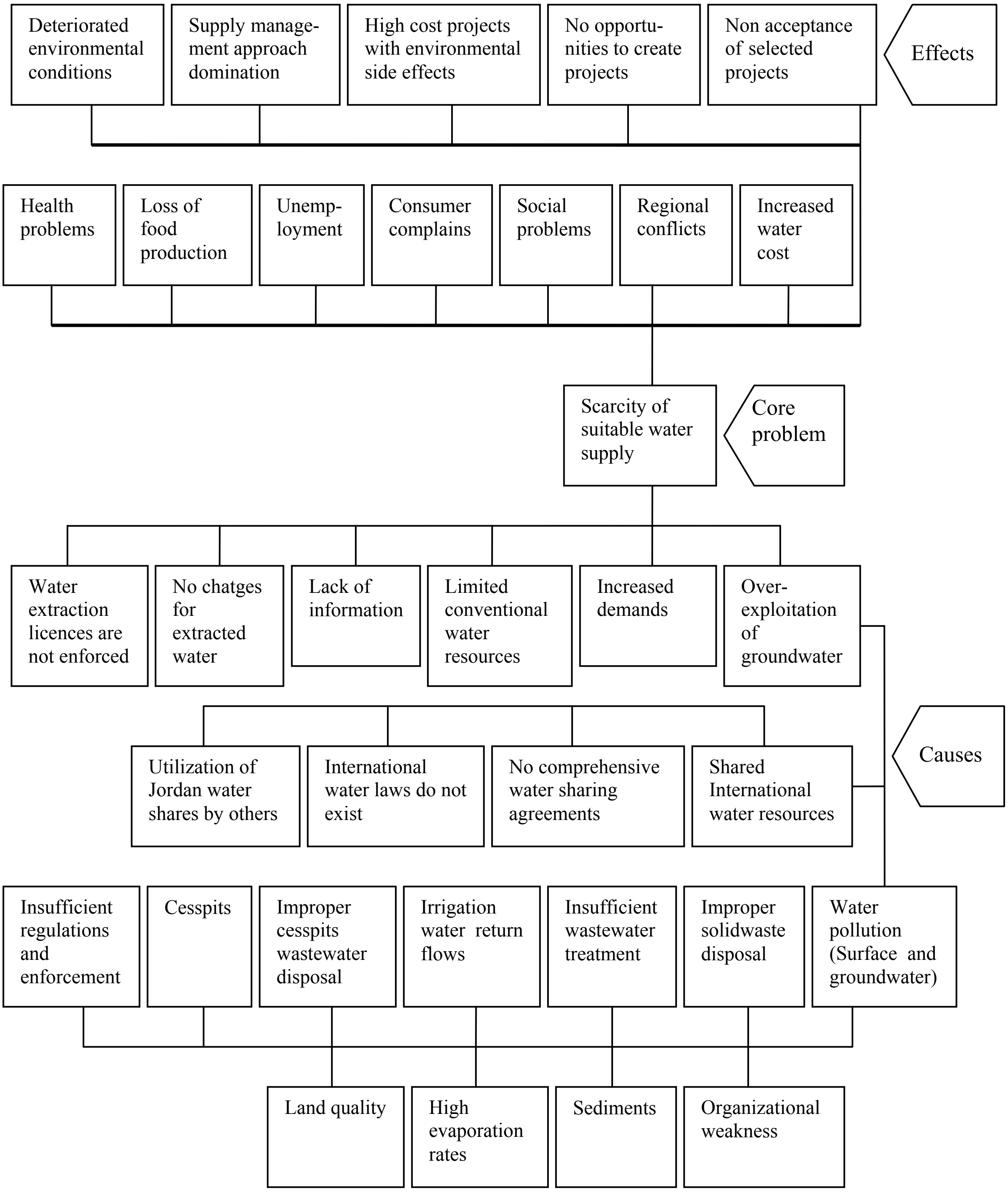


Figure 3.5 General Layout of water resources core problem, causes and effects in Jordan. (Source **Al-Shemmeri et al., 1997**).

Critical analysis: similarities and differences

The water management model of Jordan explained in Figure 3.5 and Figure 3.6 are very similar to the substance of the new conceptual model explained in Figure 3.1. The two models are based on cause- effect relationship and highlighting almost similar variables. However, there are small differences between the two models which are: (1) the new conceptual model in Figure 3.1 contains socio-economic driving forces, pollution pressures, state of water quality, public health and ecosystem impacts and institutional responses. Jordan's model consolidated the socio-economic driving forces and the pollution pressures under the causes category but the population growth, economic factors, and the water pollution from pesticides and fertilizers are missing, (2) the effect on ecosystems is missing. Ecosystems are significant for the optimization and sustainability of water resources management, (3) the institutional responses under management and optimization techniques include redistribution of population which is very tough measure and could not be adopted in the new conceptual model developed by the author due to its sensitivity and un-acceptance by the semi-arid Mediterranean countries.

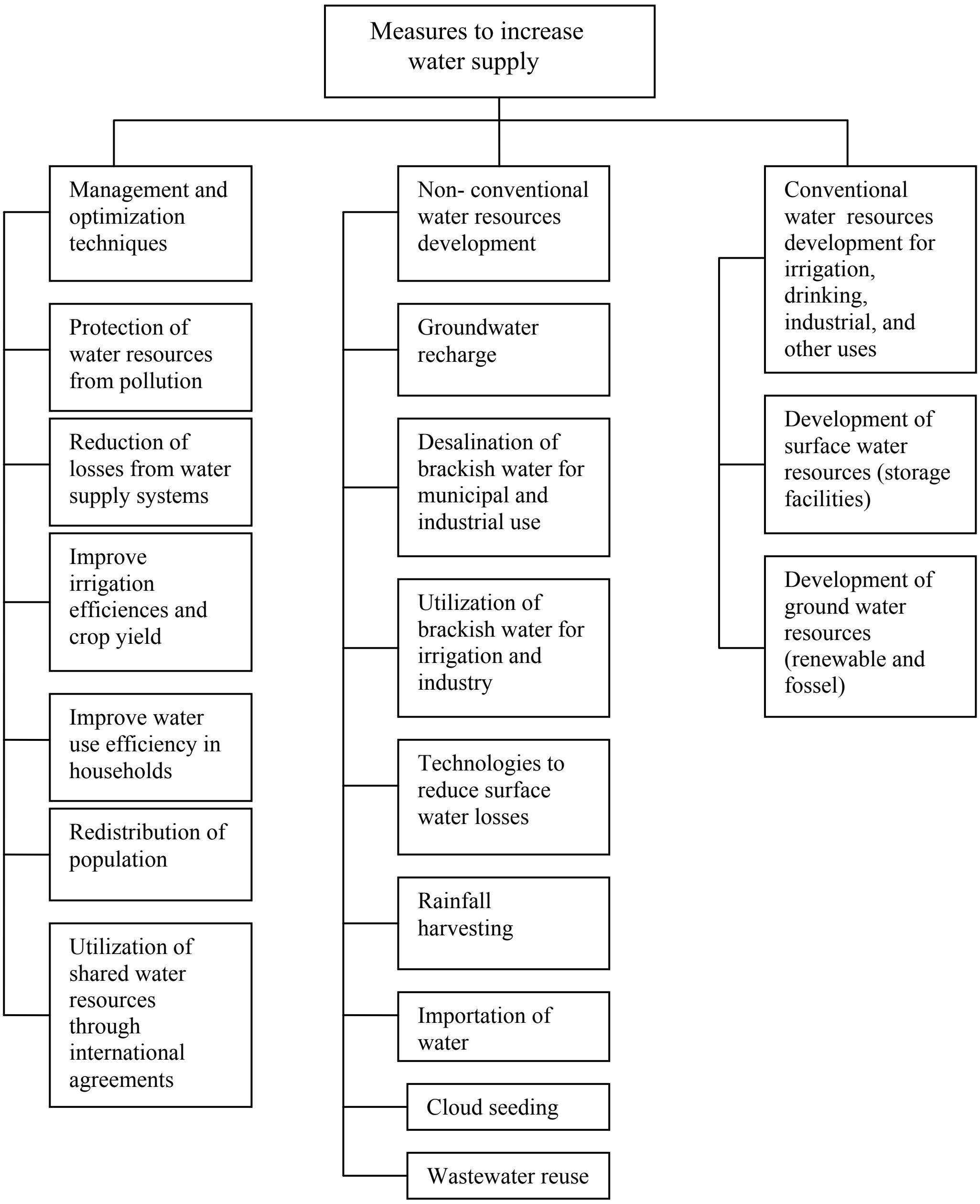


Figure 3.6 Layout of management measures to increase water resources supply in Jordan. (Source **Al-Shemmeri et al., 1997**)

☒ Case study from Netherlands

Netherlands is a flat and wet country situated on the North Sea in northwestern Europe within the estuarine basin of the rivers Rhine, Meuse, and Scheldt. It has an area of 41, 526 km^2 of which about 82% is land surface and population about 16 millions. Much of the western part is situated below the sea level with most of the land devoted to agriculture. The Netherlands shares the temperature maritime climate common to much of northern and western Europe with the average range -1 ºC to 5 ºC in January and 13 ºC to 22 ºC in July. The annual average range of annual precipitation is 690- 770 mm.

The scarcity of water, in general, in the Netherlands not a problem since there exists a precipitation surplus of about 250 mm a year, except in some regions in the summer time. Scarcity is mainly a problem of water quality since almost all the land in the Netherlands is in close contact with the phreatic groundwater level. It arose due to the rapid water pollution from non-point polluters such as traffic, shipping and agriculture practices including pesticides, continuous leaching of nutrients from manure, heavy metals and irrigation return flows (Van der Vlist, 1999). "Integrated" and "sustainable" were the key words for the new approach in the third national policy document on water management, which appeared in 1989. Figure 3.7 presents the conceptual model of comprehensive water management in

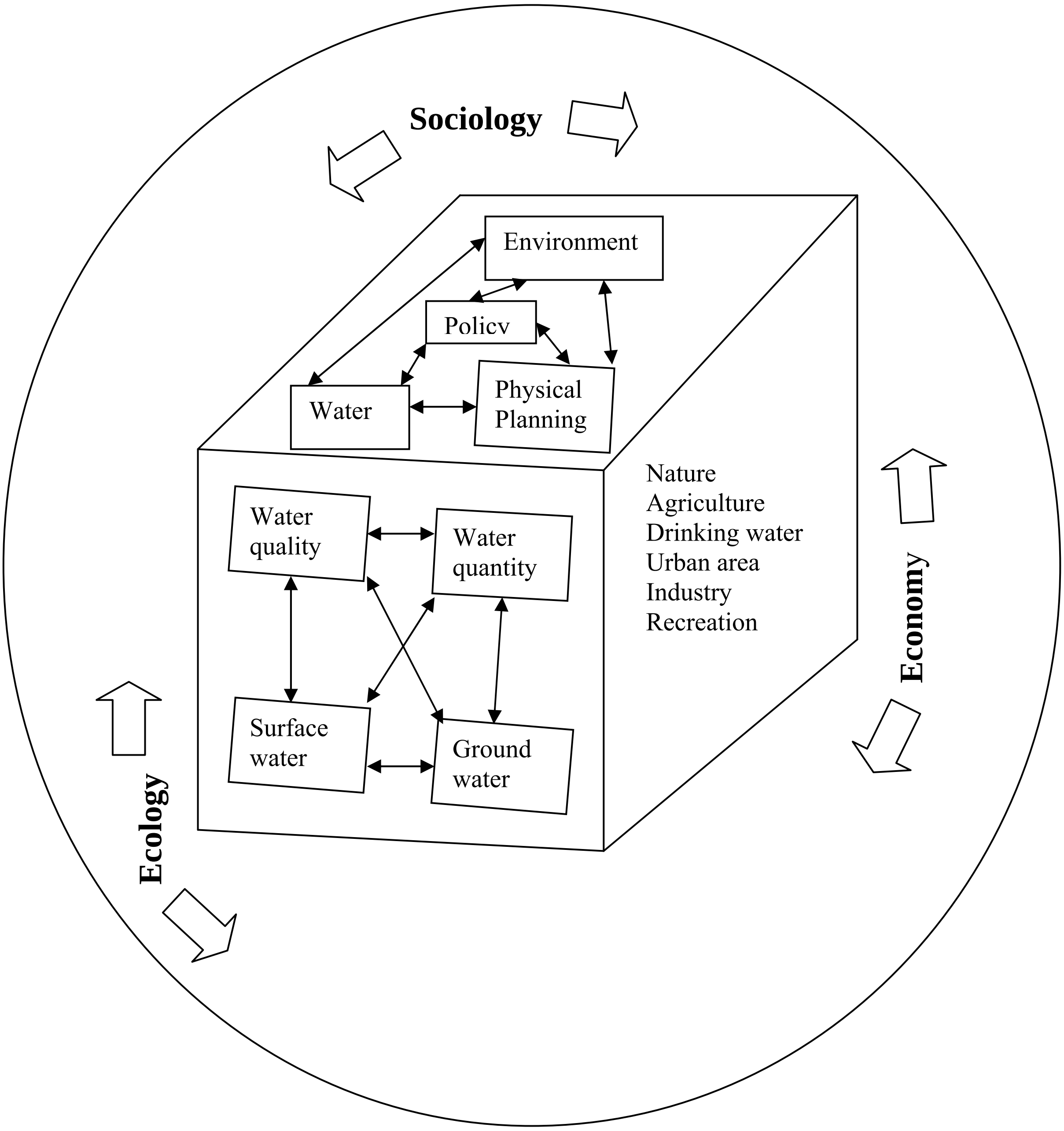


Figure 3.7 Comprehensive water management in Netherlands: Integrated Water Management set within an interactive framework of ecology, sociology and economy (Source **van Rooy and de Jong, 1995**).

Netherlands. This model is the fifth stage for development of water resources management responding to the growing realization that increasing water demands has led to a shortage of good quality water as well as causing serious damage to the environment. It involves adjusting water use, water management, and related policy areas to each other in an integrated manner. The water use reflects the demands for nature, agriculture, drinking, urban, industry, and recreation. The water management addresses the quantity and quality of surface and groundwater whilst the policy areas include land use planning, environment and water the integrated water resources management approach is set within an interactive framework with three factors: ecology, sociology, and economy. The model ensures the interaction between the three factors as well as a dual relationship between the water management and interacting social, economic and ecological factors. Thus, water resources management has become a part of society which encourages public participation and collaborative planning and thus ensures the success of undertaking responsive technical, managerial and regulatory measures (van Rooy and de Jong, 1995).

Critical analysis: similarities and differences

The comprehensive water management model of Netherlands explained in Figures 3.7 is analogous to the new conceptual model in Figure 3.1. It contains three comparable elements including: (1) natural system of water resources counting surface and groundwater quantity and quality (2) the water use by nature and economic sectors, and for drinking; (3) water related policies undertaken by the institutional system including land use and environment. Both models concentrate on the interaction between the water management and social, economic and ecological factors and the significance of public participation. The Netherlands comprehensive water resources management model is an empirical one since it has been developed based on facing the growing challenges and the learned lessons in the water sector. It also, focuses on the ecosystem approach through taking account of nature use of water. However, there are some differences between the two models which are: (1) The new conceptual model in Figure 3.1 gives more details than Netherlands model in Figure 3.7. It segregated the three elements based on the cause-effect chain into socio-economic driving forces, pollution pressures, state of water and environment quality, public health and ecosystem impacts and institutional responses, (2) Netherlands model does not include variables, (3) Netherlands model stresses on the water quality management since the quantity is not a problem whilst the new conceptual model focuses on both quantity and quality since the water availability is a major problem in semi-arid countries due to the low rainfall, high evaporation rates and the fast growing demands for water.

3.4.3 Validation through expert judgment and opinion

The author attended a workshop in Tunisia in the period 19-22 May, 2003 in the field of application of Strategic Environmental Assessment (SEA) for Water Sector under the Mediterranean Technical Assistance Action Program (METAP). The workshop was attended by experts representing different stakeholders from the Mediterranean countries. These countries are: Morocco, Tunisia, Algeria, Egypt, Palestine, Syria, Turkey and Croatia in addition to Netherlands. The author chaired a special session in which the experts from the Mediterranean region represented the various stakeholders including national water authorities, ministries of environment and agriculture, NGO's, local district authorities, urban areas and farmer organizations. The author introduced the suggested conceptual water integrated model and its reference framework in detail to the gathering of experts asking their opinions and objective judgments. The introduction included also explanation of the three major systems of the model, the five criteria, and the variables. They were reviewed by the experts and their remarks were fed back into the conceptual water model.

Another workshop was held in Jordan in the period 7-10 September, 2003 to discuss the water strategy and Strategic Environmental Assessment for water sector in Jordan prepared by the World Bank. A different group of experts from Jordan, Lebanon, Morrocco, Palestine, Syria, Turkey, Tunisia, Yemen attended the workshop. The author presented the modified conceptual water integrated model including the possible water related variables. The comments and suggestions of the experts were fed back into the model. Section 3.3 presents the concluded new conceptual water integrated model including the possible water variables.

3.5 Critical analysis of the Palestinian water management model

Water crises is the central challenge facing the Palestinian National Authority (PNA) especially there is a lack of control over the Palestinian water resources (Abu Zahra, 2001). The overall Palestinian water resources balance is estimated at 850 $hm^3.y^{-1}$. However, the Palestinians currently utilize only 20% of these resources. For recent years, water resource shortage and water pollution have been hindering the socio-economic development. It has been estimated that the economic losses due to water shortage and water pollution in the whole country would be equivalent to about 15% of GNP. In order to face the water problems and challenges of the water sector, the Palestinian Water Authority (PWA) developed water resources management model (Figure 3.8) within the National Water Plan (PWA, 2000b).

The reference framework for the model is achieving sustainable management of water resources. To this end, the model presents three major elements which are: facilitating environment, integrated management of water resources, and development of water resources. Under these elements, the model also mentions several actions.

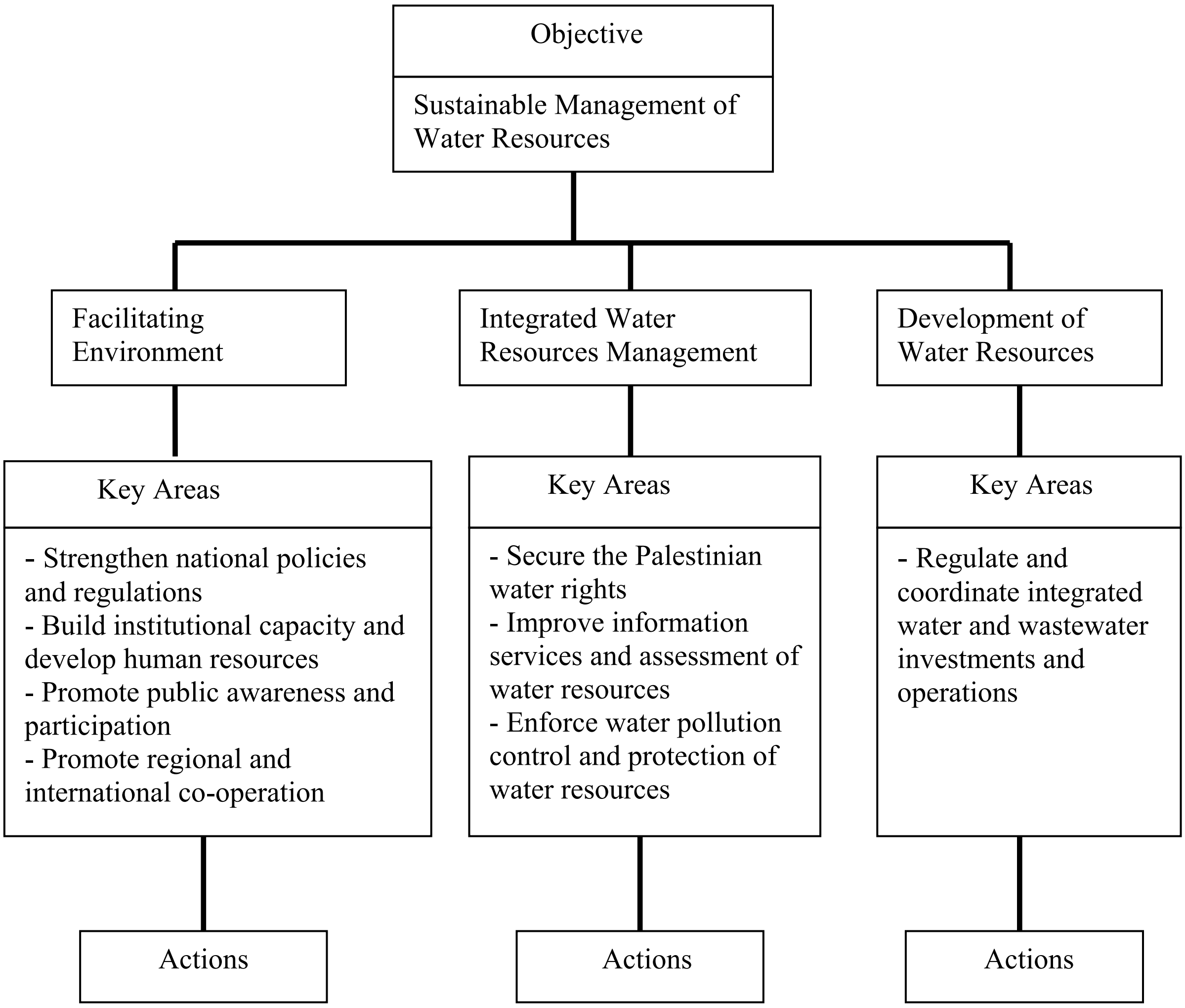


Figure 3.8 Conceptual model for water management in Palestine (Source **PWA, 2000**)

In light of the literature review, the new conceptual model and the presented case studies about Cyprus, Jordan, and Netherlands, critical analysis of the management model in Figure 3.8 concludes the following:

- The three elements in the model do not reflect the concepts of sustainability which are social, economic, environmental and institutional;

- The integrated water resources management (IWRM) should not be one out of three elements to achieve sustainable management of water resources. IWRM is an approach and a process that leads to sustainable development;
- The proposed actions in the National Water Plan do not meet the gravity and scope of water related problems;
- Water related variables have not been developed which makes the monitoring, follow up and the measure of the effectiveness of the plan difficult; and
- The water use for nature ecosystem is missing.

3.6 Concluding remarks

- CWIMSAM is an original research work that tackled the life cycle of water resources management in GS and based on cause- effect relationship. It has integrated socio-economic, pollution pressures, water quality, public health and ecological impacts and management responses together with the overall objective of achieving sustainable water resources management.
- DPSIR is an appropriate framework to develop water variables.
- CWIMSAM and the proposed possible variables have been validated through comparison with well established water management models and expert opinion and judgment.
- The current Palestinian water management model has to be elaborated to reflect and translate the overall objective of water sector which is sustainable water resources management.

Chapter 4 Application of CWIMSAM to GS

4.1 Introduction

The life cycle of water resources management in GS is represented by the schematic diagram (Figure 4.1). Water is pumped from the coastal aquifer, as the only available natural water resource, to meet the growing demands through municipality and agricultural wells. The service coverage of domestic water supply in GS is estimated to be 95% which means that most of the population are served by indoor tap. Each municipality has its own water sources and separate distribution system. Most of the municipalities use ground water without any treatment except for disinfection. In three municipalities (Gaza, Khan Younis and Deir El-Balah), brackish water desalination have been established and operated using reverse osmosis technology to desalinate the brackish groundwater. Two seawater desalination plants have been constructed and operated in the Northern and Middle governorates. The capacity of the two plants are 5000 $m^3.d^{-1}$ and 2400 $m^3.d^{-1}$ respectively. In the middle and the eastern part of Khan-Younis governorate, the municipalities depend mainly on water conveyance from the Regional water supply company (Mekorot). The urban water users include households, public institutions, schools, urban parks, commercial and industrial facilities. There are physical water losses from municipal water supply networks due to failures and deficiencies in the distribution facilities. The average physical losses for the year 2000 was 24%, which mainly represent the real leakage without being used. Besides, there are non-physical losses amounting to about 15% due to meter under-registration and illegal connections (LEKA, 1998). About 60% of the urban areas have connections to wastewater collection systems discharging into three main wastewater treatment plants. The effluent from these plants is partially reused in irrigation of agriculture pilot projects and stored in infiltration ponds with the purpose of recharging the aquifer. Large volume of the effluent is discharged to the Mediterranean Sea. The remaining 40% of the population are served by cesspits. As for the rural water use, water is pumped from agriculture wells to meet crop, livestock and rural population demands. There is a return flow from agriculture irrigation to the aquifer groundwater. Over-pumping in several municipal areas has resulted in lowering the water table which led to seawater intrusion or upcoming and hence increased water salinity. Socio-economic activities in urban areas have caused pollution from local sources including solid waste, cesspits, hazardous waste, industrial waste and petrol stations. In rural areas, water pollution has been resulted by point sources from wastewater treatment plants and solid waste dumpsites besides the diffuse sources from pesticides, organic and chemical fertilizers.

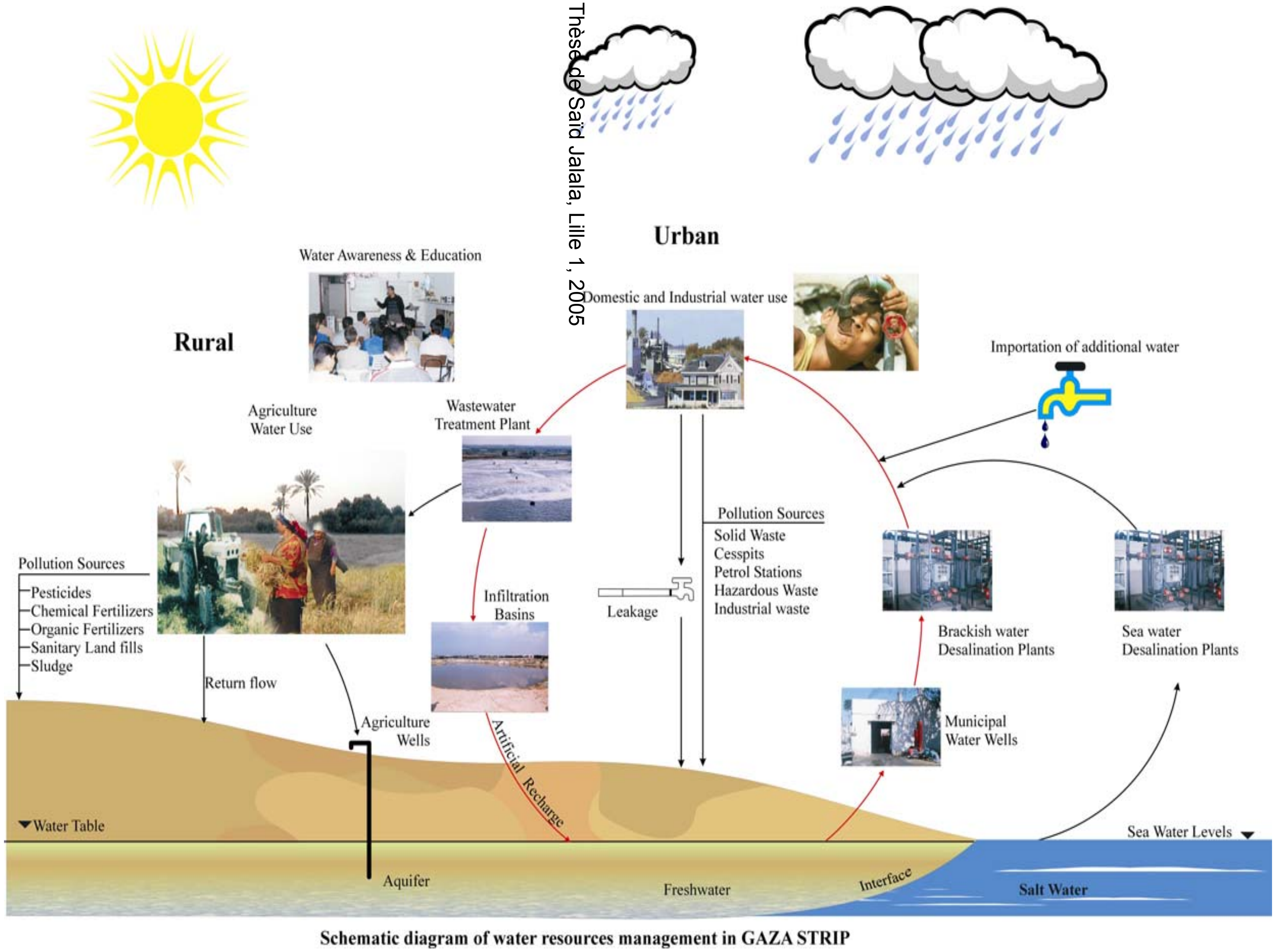


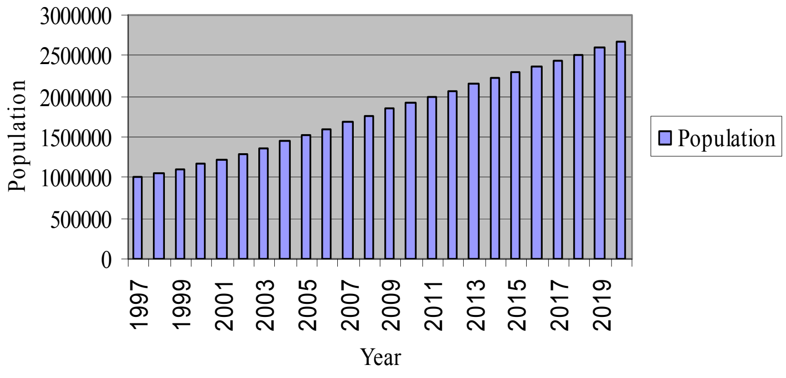
Figure 4.1 Life cycle of water resources management in Gaza Strip

4.2 General water related features of GS

4.2.1 Population

The total population of GS at the end of year 2000 has been estimated at 1,167,359 people of which 67% are refugees from 1948. The estimated growth rate is based on natural increase and net migration expressed as a percentage of the base population and ranges between 4.26- 5.35%. The proportion of population by locality is 28.50 in rural areas, 14.90 in refugee camps and 56.60 in urban areas and proportion of population under age 15 years is 49.90% (PCBS, 2001). Population projections are presented in Figure 4.2.

Figure 4.2 Population growth in Gaza Strip
(Source **PCBS, 2002**)



4.2.2 Water resources

- ☒ **Water availability**
- **Hydrogeology of the coastal aquifer**

The Gaza coastal aquifer is composed of Tertiary- Quaternary sands, calcareous sandstone and pebbles interbeded with impervious and semi-pervious clay. The aquifer extends from the coastal areas of Sinai in the South to Haifa in the North over some 120 km along the Mediterranean Coast (Figure 4.3). The width of the aquifer varies from 3-10 km in the north to about 20 km in the south. (WRAP 1994).

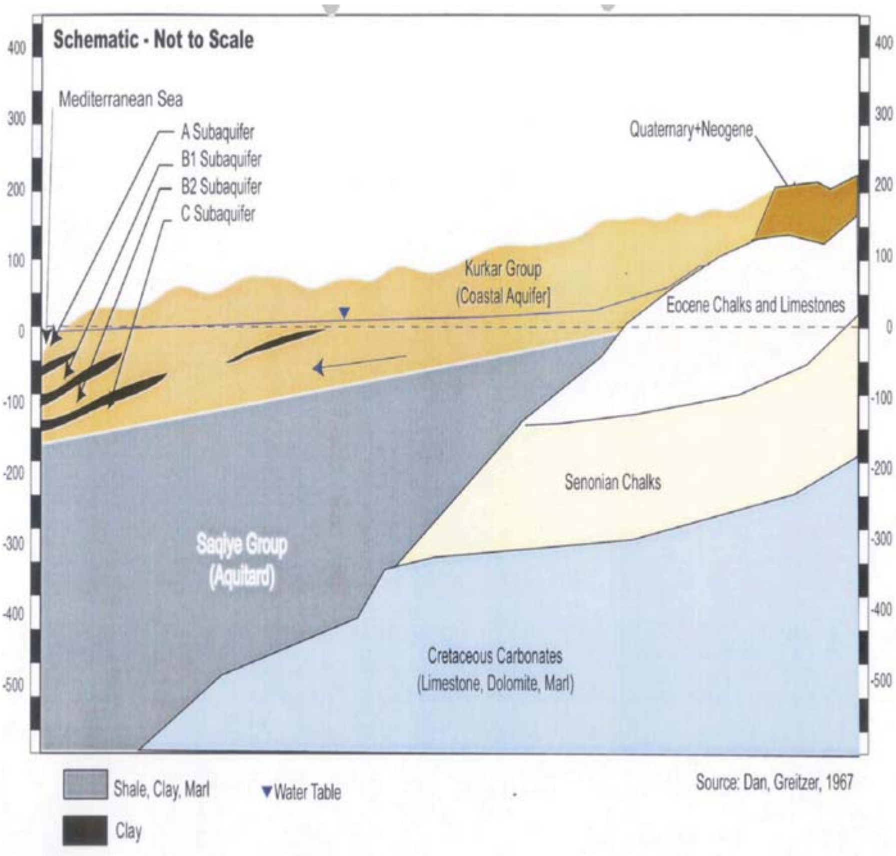
Geographic Projection
Compiled by: UNEP/GRID-Geneva
Date printed: December 2002
Source: UN Cartographic Section, DCW, Palestinian Environmental Quality Authority

The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the UNEP concerning the legal status of any country, territory, city or area of its authorities or concerning the delimitation of its frontiers or boundaries.

Figure 4.3 Mountain and Coastal Aquifers
Source (**Elmusa, S., 1997; UNEP, 2003a**)

The maximum thickness of the

bearing horizons occurs in the northwest along the coast (150 m) and decreasing gradually toward the east and southeast along the eastern border of GS to less than 10 m. Flow in the aquifer is in general from east to west. The Coastal aquifer is divided into four separate sub-aquifers near the coast (Figure 4.4).



Source: Dan, Greitzer, 1967

Figure 4.4 Section in Coastal Aquifer (Source **CAMP, 2000**)

Further east, the marine clays pinch out and the coastal aquifer can be regarded as one hydrological unit. Sub aquifer A is unconfined, whereas sub aquifers B1, B2, and C become increasingly confined towards the sea. Within Gaza, the base of the coastal aquifer is Saqiye formation from impermeable clay shade rocks of Neogene age with a thickness ranges between 500-1000 m. Approximately 10-15 km inland from the coast, the saqyie base pinches out (CAMP, 2000). The Coastal aquifer holds about 5.5x $(10)^9 m^3$ of groundwater of different qualities. Only 1.4x $(10)^9 m^3$ of this amount is “freshwater”, with Chloride content less than 500 $mg.l^{-1}$. In conclusion, approximately 70% of the aquifer is brackish or saline water leaving only 30% as acceptable water (Al-Jamal, Al-Yaqubi, 2000). Based upon the WHO standard for Chloride (250 $mg.l^{-1}$), only about 10% of the aquifer contains fresh water of 250 $mg.l^{-1}$ Chloride. The fresh groundwater typically occurs in the form of lenses that float on top of the brackish and saline ground (CAMP, 2000).

- **Hydrologic cycle**

The water sources in the GS originate from the rain during the winter season. Annual rainfall in the GS, although the area is small, varies from about 400 mm in the northern part and 300 mm in the middle area, to about 200 mm in the southern part, with an overall average 325 mm, totaling over the Strip’s area to 120 $hm^3.y^{-1}$. Of this amount, about 40-46 $hm^3.y^{-1}$ percolate to recharge the shallow aquifer. The remainder is either discharged to the Mediterranean through surface runoff or evaporated to the atmosphere. GS has a semi-arid Mediterranean climate. There are two well defined seasons: the winter season starting in October and extending through March, and the dry season from April to September with average mean daily temperature in Gaza ranges from 26 °C in summer to 12 °C in winter. Evapo-transpiration is high with a typical value of 1,900 mm.y^{-1}. The estimated amount lost by evapo-transpiration is estimated at 53 $hm^3.y^{-1}$ (WRAP, 1994).

- **Surface water**

The surface water system in the GS consists of wadis which only flow during winter season and for short periods. The major wadi is the Wadi Gaza which originates in Hebron southeast West Bank and reaches the Mediterranean Sea. Its catchment area is about 3500 km^2. The estimated average annual flow volume of the Wadi Gaza ranges between 20-30 $hm^3.y^{-1}$. Apart from the Wadi Gaza, there are two small and insignificant wadis in the GS: Wadi El Salqa in middle of GS with no outflow to the sea, and Wadi Beit Hannun in the North.

- **Ground water**

The groundwater balance of the Gaza coastal aquifer has been developed based on the estimates of all water inputs and outputs to the aquifer system. Table 4.1 shows that the present net aquifer balance in the GS is negative (-40.5 hm^3) which indicates that there is a water deficit. This results in lowering the levels of ground water table by about 7 cm and seawater intrusion with the same amount of the deficit and reduction in availability of fresh groundwater. The negative balance leads to decreasing the volume of freshwater in the aquifer and degradation of water quality (CAMP, 2000).

Table 4.1 Estimated Water Balance of the GS

Inflows ($hm^3.y^{-1}$)			Outflows ($hm^3.y^{-1}$)		
	MIN	MAX		MIN	MAX
Rainfall Recharge (1)	42.0	45.0	Municipal Abstraction	54.50	54.50
Lateral inflow from Israel	18.0	30.0	Agricult. Abstraction	95. 0	100.0
Lateral Inflow from Egypt	2.0	5.0	Discharge to the Sea	10.0	15.0
Saltwater Intrusion-Shallow	10.0	15.0			
Water System Leaks	10.9	15.0			
Wastewater Return Flows	10.5	10.5			
Other Recharge	3.5	3.5			
Irrigation Return Flows	20.0	25.0			
Loss of Aquifer Storage	2.1	3.2			
Totals	119.0	152.2		159.5	169.5
Net Balance	-40.5	-17.3			

Source: compiled from CAMP, 2000 and PWA, 2000a

☒ Water quality

The water supply environment in GS is sensitive and fragile as the aquifer is highly vulnerable to various sources of pollution. The water quality is a problem of great concern nowadays since it is currently undergoing a slow but a continual process of degradation. The gradual increase of the groundwater salinity in terms of Chloride (Cl) in the coastal area is attributed to the combined effect of several factors, including surface salinization from irrigation with brackish water, up coning of deep brine groundwater, infiltration of saline water from the east and the intrusion of seawater due to many years of over-pumping. Furthermore, the discharge of sewage with high content of Chloride into the open environment may also contribute significantly to the elevated Chloride concentrations recorded in groundwater. The salinity of water in GS varies both in vertical and lateral direction. In general, it increases from the upper to the lower sub-aquifers and from the west to the east within the same sub-aquifers, with an exception in the central part of GS where the salinity is high even near the coast with a Chloride content of 700-1000 $mg.l^{-1}$ because of the sea water intrusion (Figure 4.5). So the upper aquifer in its western northern and southern parts (that is where the sand dunes are wider) has the best water quality with the least salinity of 50-200 $mg.l^{-1}$ Cl.

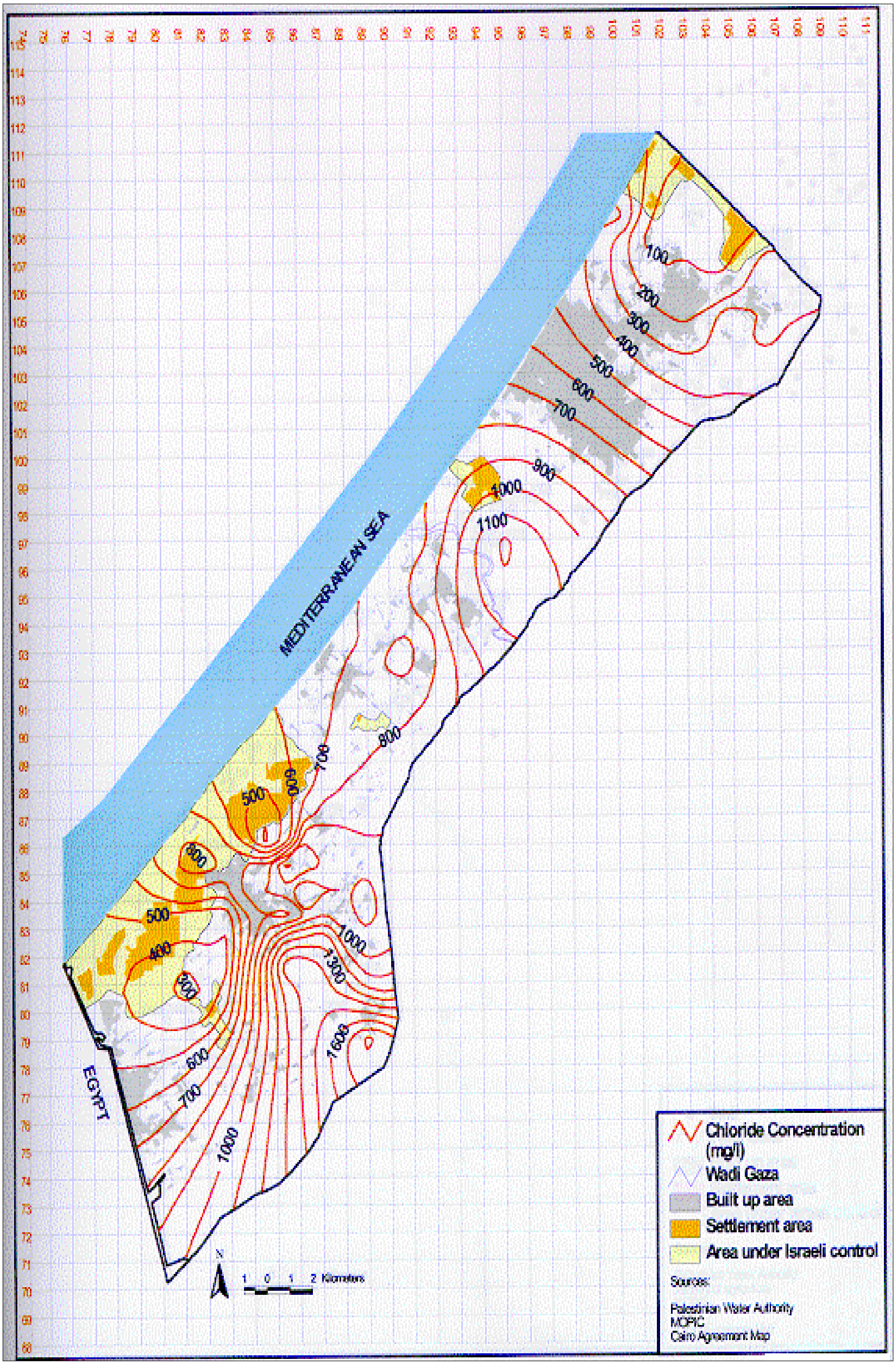


Figure 4.5 Chloride Concentration in GS
(Source **CAMP, 1999**)

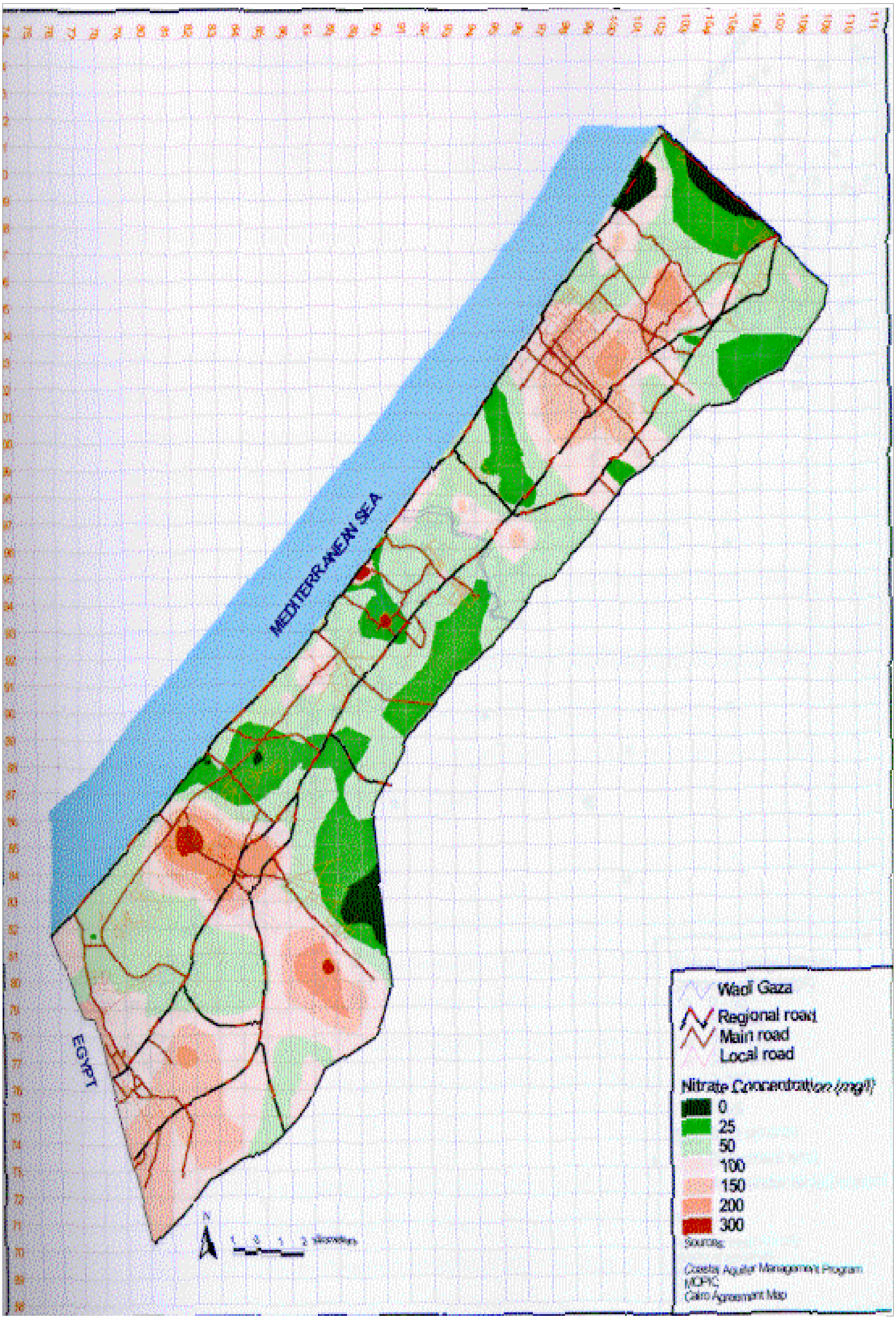


Figure 4.6 Nitrate Concentration in GS
(Source **CAMP, 1999**)

Besides, the Nitrate (NO_3) is a major ground water contaminant throughout GS. It is expanding due to pollution from agricultural fertilizers and pesticides, industrial wastes, leachates from uncontrolled dumping of solid wastes, direct discharges of raw and partially treated wastewater to wadis and soil and the pressure of urbanization. The Nitrate concentration in GS is high especially inside the refugee camps due to the additional pollution resulting from domestic wastewater cesspits (Figure 4.6). According to the standards of WHO, the maximum allowable concentrations for drinking water are: 250 $mg.l^{-1}$ Cl, 45 $mg.l^{-1}$ NO_3. Figure 4.7 presents Chloride content for municipal drinking wells in GS. Fifty percent of these wells exceed the WHO maximum allowable concentrations for Chloride. The domestic water is becoming more saline every year and average Chloride concentrations of 500 $mg.l^{-1}$ or more is no longer an exception. Figure 4.8 explains the Nitrate concentrations in GS municipal drinking wells. Eighty percent of the GS municipal drinking wells exceed the

Figure 4.7 Chloride content for drinking wells in GS

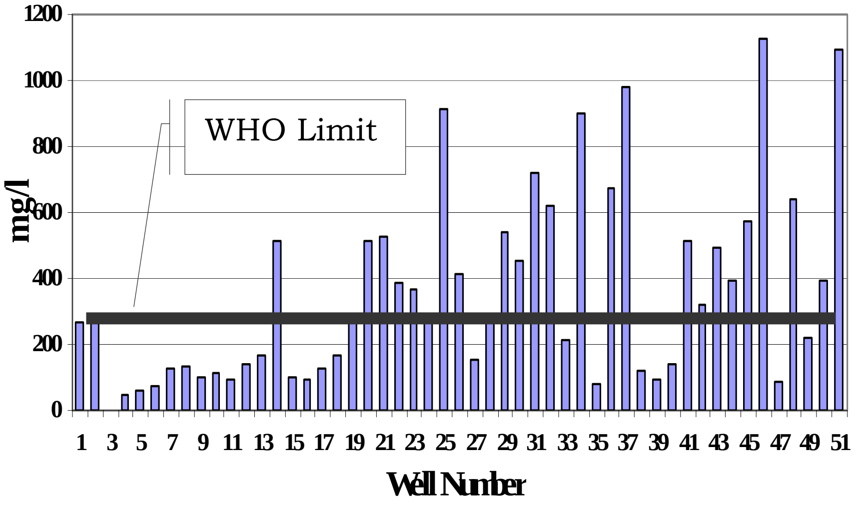
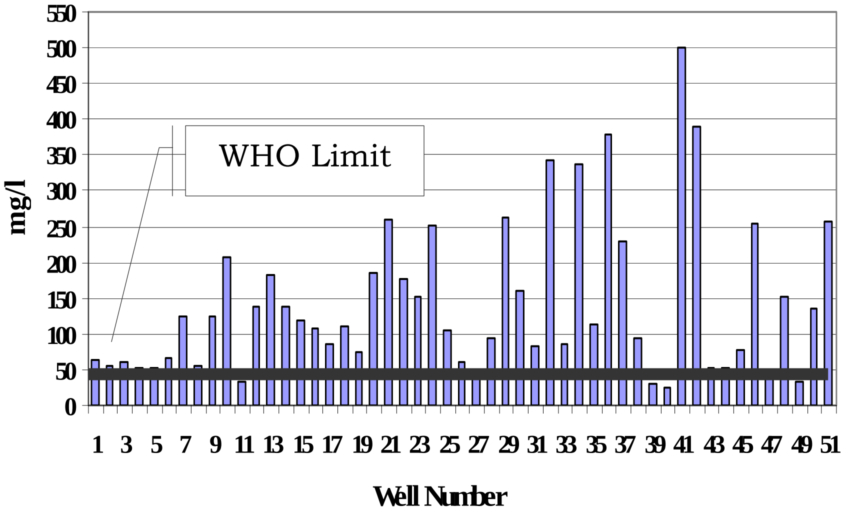


Figure 4.8 Nitrate concentration in drinking wells in GS



WHO maximum allowable concentrations for Nitrate. For a number of wells, the permissible limits of WHO for Nitrate are exceeded by a factor of 8 times. Accordingly, most of the public water supply wells don't comply with the drinking water quality standards since the Chloride and Nitrate concentrations of the water exceeds the WHO standards. So, water has become unfit for drinking and even for agriculture in many areas. For the above mentioned reasons, the depletion of water resources and the deterioration of water quality in GS have been given the highest priorities for action in the Palestinian Environmental Strategy (UNEP, 2003a; CAMP, 2000; Al-Yaqubi, 2001; EQA, 2001; MEnA, 2000a).

4.2.3 State of existing water infrastructure facility (contaminated site)

- **Gaza Wastewater Treatment Plant and Reuse Scheme**

The existing wastewater treatment plant (WWTP) is located to the southwest of Gaza City (Figure 4.9). The original system consists of grit removal, two sedimentation ponds, two aeration ponds, and an effluent pump station with a pressure main to the sea and another emergency gravity overflow to Wadi Gaza. The long term plan included an agriculture reuse system and a ground water recharge system via soil infiltration. The reservoir (5000 m^3) was constructed, the infiltration beds (0.5 ha) were constructed, the pump station and the main delivery line to the irrigation reuse area were constructed. The line connecting the treatment plant to the irrigation reservoir was never constructed. The treatment plant has recently been rehabilitated with an influent flow rate of 42,000 m^3 per day (equivalent to what is normally a population of 300,000). Nevertheless, the plant is still receiving 52,000 m^3 which is more than it has capacity to treat. Consequently, the efficiency of the existing plant is very low, where the effluent quality is not suitable for any kind of reuse (Table 4.2). Therefore, most of the effluent is discharged to the Mediterranean Sea and to Wadi Gaza. Chemicals contained in wastewater (Table 4.3) are released into marine water and are transmitted to population living in the surrounding areas. This has led to potential public health effects and become a major public concern. To assess the impact of wastewater disposal on the morbidity of people in GS, human health risk assessment was carried out in section 6.4.

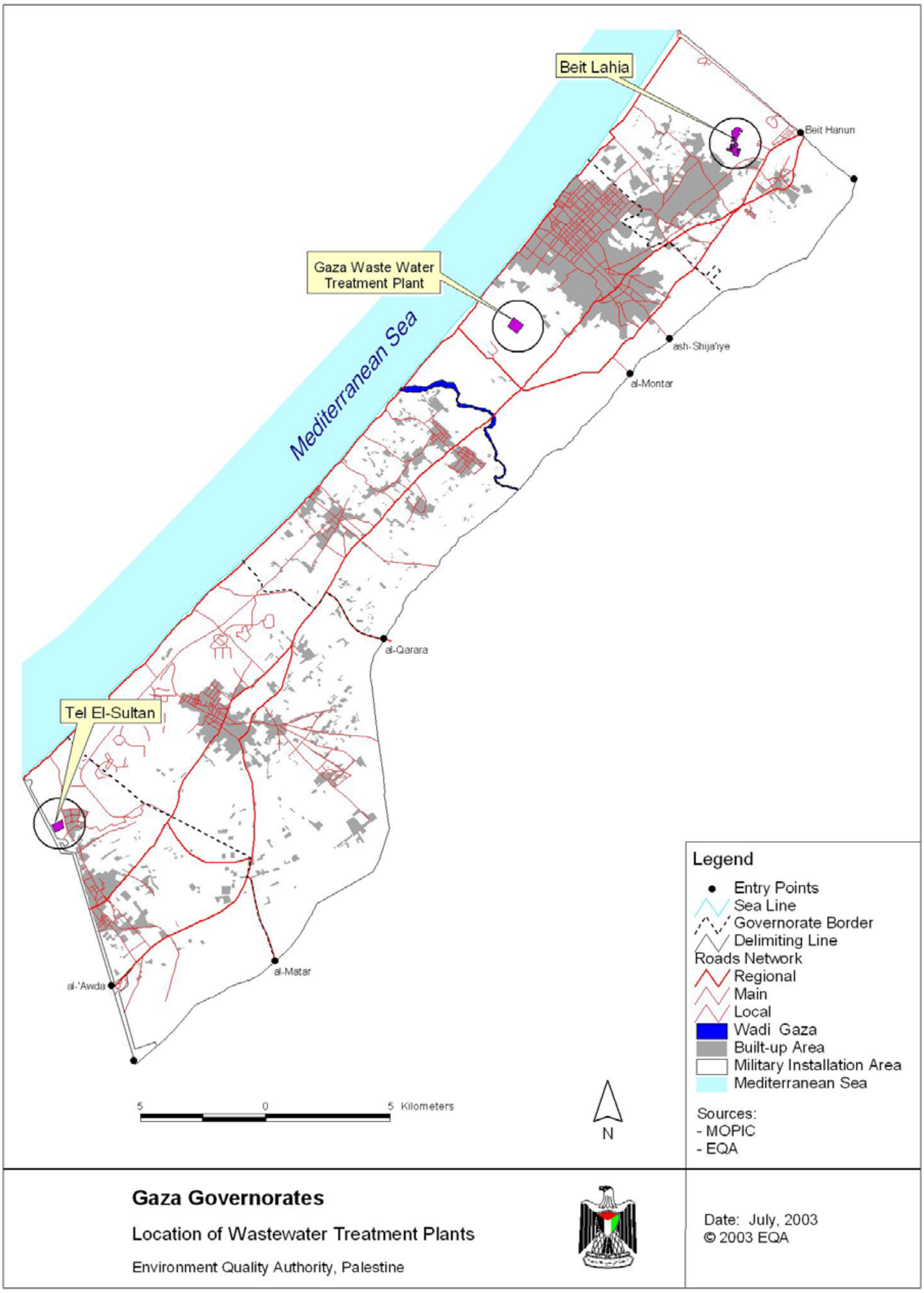


Figure 4.9 Location of wastewater treatment plants

Table 4.2 Wastewater characteristics (Gaza WWTP)

Parameter	Influent	Effluent
PH	7.51	7.68
BOD ($mg.l^{-1}$)	667	33
COD ($mg.l^{-1}$)	1306	106
Temperature (°C)	17.3	17.9
TSS ($mg.l^{-1}$)	617	34
TDS ($mg.l^{-1}$)	989	983
Daily influent ($m^3.d^{-1}$)	50,000	

Source: PCBS, 2003

Table 4.3 Heavy metals concentration in bathing sea water polluted by wastewater disposal

Pollution Parameter	Concentration ($mg.l^{-1}$)
Arsenic (As)	0.1
Cadmium (Cd)	0.01
Chromium (Cr)	0.5
Copper (Cu)	0.2
Cyanide (CN)	0.1
Lead (Pb)	0.1
Mercury (Hg)	0.001
Nickel (Ni)	0.2
Phenol	1
Selenium	0.02
Vanadium (V)	0.1
Zinc (Zn)	5

Source: compiled from Afifi, 2003 and UNEP, 2004

4.2.4 Industry

- Industrial water use is about 7%.
- There is one industrial estate, but most of the industries are scattered in the residential areas. The number of different industries over GS are explained in Table 4.4.

Table 4.4 Industries in GS

Description of Industry	Number
Food	244
Plastic	72
Chemical	29
Metal	495
Wood	440
Textile & Textile print	24
Textile Dyeing	4
Paper	11
Mechanical Work-shop	446
Garment	1093
Print-shop	51
Glass	5
Leather Manufacturing	48
Jeans Wash	5
Tile	56
Block	249
Asphalt	3
Concrete	20
Petrol Stations	134
Refrigerators/Air Condit.	31
Marble	107

Source: Jalala and Safi, 2002

4.2.5 Agriculture

- Cultivated agriculture land is 183,170 dunums including: vegetables 52,188 dunums, fruit trees 75,307 dunums, field crops 55,575 dunums;
- Production: vegetables 232,947 tons, fruit trees 110,288 tons, field crops 64,248 tons;
- Livestock: Cows 4,863, Sheep 45,294, Goats 14,925, Beehives 16,077, Chicken 1,7351,000.
- Water use 95 million m^3 which is about 61.5% of the total use.

4.2.6 Tourism

- Number of hotels is 16.
- Number of guest nights 7,478.
- Annual number of diaspora Palestinians visiting GS is 5,000 . The average period of the summer visit is 20 days.

4.3 Description of variables

Year 2000 was selected as a reference year for data compilation and analysis. The water abstraction from the aquifer will be the dependent variable for socio-economic, state, impact and response independent variables. The Total Dissolved Solids (TDS) will be the dependent variable for the pollution pressure independent variables.

1. Water abstraction from the aquifer (WAbtrac)

This represents the amounts of water pumped by municipal wells in addition to the agricultural wells. It is measured by million cubic meters per year ($hm^3. y^{-1}$).

2. Total Dissolved Solids (TDS)

TDS reflect the salinity of freshwater and originate from natural sources, sewage, urban, runoff, industrial wastewater and chemicals. TDS consist mainly of inorganic salts (principally Calcium, Magnesium, Potassium, Sodium, carbonates, bicarbonates, Chlorides, Sulfates, phosphates) and some small amounts of organic matter that are dissolved in water. TDS are measured in milligram per liter ($mg.l^{-1}$).

☒ **Category of socio-economic and natural driving forces variables**

3. Population (Populat)

This refers to population living within the boundaries of municipalities in the year 2000. It is measured in numbers.

4. Income per capita (Inccap)

Income refers to the average gross national income. It is measured by Euro/Year.

5. Land use (Landuse)

Land use represents the ratio of urban to agricultural areas within the boundaries of the municipalities. Urban areas include public buildings, residential and housing plots, parksand gardens. They include also commercial and industrial facilities.

6. Tourism

This refers to the international, regional tourists and business people visited GS in 2000. Furthermore, it includes the Palestinian living diaspora who come to visit their families during the summer holidays. It is measured by number of guest days.

7. Access to safe water supply (WSuppl)

This represents the proportion of the population who have connection to the municipal water supply network.

8. Wastewater system coverage (WWCov)

This item represents the proportion of population connected to the conventional wastewater conveyance system. It is measured by percentage (%).

9. Storm water system coverage (StorWCov)

This represents the proportion of urban areas served by storm water systems. Storm water systems include pipelines, culverts and storage ponds. It is measured by percentage (%).

10. Water consumption per capita (WCpCap)

This refers to the per capita average daily municipal water use within the boundaries of municipal councils. The main sources of the municipal water are municipal wells pumping from the coastal aquifer besides the imported water from Mekeroth Israeli Water Company. It is measured by cubic meters per year ($l.cap^{-1}.d^{-1}$).

11. Water price (WPrice)

Water prices represents the billed price of water supply to the users. It is defined by $Euro.m^{-3}$.

12. Efficiency in revenue/taxation collection (EfRevCo)

This represents the proportion of the collected revenues to the billed taxation of water services. Water services include water supply and wastewater collection.

13. Agricultural water consumption (AgWCon)

This refers to the amounts of water pumped by agriculture wells and used for agricultural purposes. It is measured by million cubic meters per year ($hm^3. y^{-1}$).

14. Gender empowerment (GendEmp)

This refers to the proportion of employee females in water resources management departments in GS municipalities. It is measured in percentage (%).

15. Unaccounted For Water (UFW)

The unaccounted for water represents the water loss calculated as the difference between the quantity of water fed into a distribution system and the quantity of water put to legitimate use, which has been metered or can be estimated. There are two types of UFW, the first is called physical losses and the second is called non-physical losses. Physical losses are the amount of losses, which are lost without being used, due to failures and deficiencies in the distribution facilities, and they mainly represent the real leakage. Non-physical losses include meter under-registration and illegal connection. It is measured in percentage (%).

- ☒ **Category of pressure indicators: pollution sources**

16. Hazardous wastes (HazWas)

Hazardous wastes refers to generation of domestic, industrial, medical and agricultural hazardous wastes. They are measured in tons per day ($ton.d^{-1}$).

17. Generation of domestic wastewater (DomWW)

Domestic wastewater represents the liquid waste generated by households, public institutions, schools, hospitals and public places. It is approximately 80% of the water use. It is measured by million cubic meters per year ($hm^3. y^{-1}$).

18. Pesticides (Pesticid)

Pesticides represents all substances used to kill pests, whether the pests are animals or plants. They include insecticides, herbicides, and fungicides. They are measured in metric $tons.y^{-1}$.

19. Chemical fertilizers (ChemFer)

Chemical fertilizers refers to the amounts of chemical fertilizers used in agriculture to promote the plant growth. They include Urea, Ammonium, Nitrate and Sulphate, Ammonia, Phosphatic fertilizers. They are measured in $tons.y^{-1}$.

20. Organic fertilizers (OrgFert)

Organic fertilizers represents the amounts of organic nitrogen input released by micro-organisms in the soil for plants use and growth. They are derived from animal manures and vegetable by-products, composted organic matter and sludges. and measured in tons per year ($ton.y^{-1}$).

21. Petrol stations (PetrolS)

This refers to the number of fuel stations that provides the vehicles with fuel. These station have underground storages which are considered as source for the hydrocarbon contamination.

22. Domestic solid waste (DomSW)

This refers to all garbage, rubbish, refuse, or other discarded material generated from domestic, commercial and construction operations ($tons.d^{-1}$).

23. Industrial wastewater (IndWW)

This means the volume of liquid waste produced by the industrial facilities both existing in the residential areas and industrial states. It is measured by million cubic meters per year ($hm^3. y^{-1}$).

24. CO_2

This means the CO_2 content in the air due to the emissions from transport, energy station, fuels, industrial processes and waste. It is measured in parts per million (ppm).

25. Seawater intrusion or upcoming reflecting Over-pumping (SWInt)

This refers to the amounts of water pumped from aquifer above the rate of inflow. It indicates water deficit and reflects salinization from sea water intrusion and upcoming due to water table lowering. It is measured by million cubic meters per year ($hm^3. y^{-1}$).

☒ **Category of state variables:**

- **Water quality**

26. Nitrate (NO_3)

Nitrate represents an intermediate oxidation state of nitrogen in the biochemical oxidation of ammonia to Nitrate. Excessive levels of Nitrate in groundwater have been caused by diffuse pollution sources including wastewater , solid waste, hazardous waste and the use of organic and chemical nitrogenous fertilizers and pesticides in agriculture. The guideline value of WHO for Nitrate is 45 $mg.l^{-1}$. Water supplies contain higher levels are considered as health risks especially for infants and pregnant women in terms of methaemoglobinaemia.

27. Chloride (Cl)

Chlorides refers to the compounds of chlorine with another element especially with Sodium and, to a lesser extent, with Calcium and Magnesium. The availability of Chloride in groundwater is attributed to industrial wastewater, return flow from irrigation, seawater intrusion or upcoming and the seepage of saline water across the eastern border of GS**.** The WHO standard for Chloride is 250 $mg.l^{-1}$.

28. Sodium (Na)

This refers to the Sodium salts soluble in groundwater. High levels of Sodium in groundwater are caused by the Sodium mineral deposits and seawater intrusion or up-coning. In general Sodium salts are not acutely toxic, but excessive salt intake seriously aggravates chronic congestive heart failure, hypertension and other ill effects. The effects of Sodium on infants are more serious from those in adults because of the immaturity of infant kidneys. Sodium may also affect the taste of drinking water at levels above 200 $mg.l^{-1}$.

29. Calcium (Ca)

This represents the Calcium content in groundwater which depends on the type of rock that water pass through. It is available as carbonate or bicarbonate and Sulfate or as Chloride in groundwater of high salinity. Calcium contributes to the hardness of water. The WHO guideline value is 100 $mg.l^{-1}$.

30. Magnesium (Mg)

Magnesium forms highly soluble salts. It contributes to both carbonate and non-carbonate hardness in water. Excessive concentration of Magnesium is undesirable in drinking water due to the health side effects especially when associated with Sulfates.

It is measured by $mg.l^{-1}$.

31. Potassium (K)

This refers to the concentration of Potassium in groundwater. Potassium is originated usually from the use of chemical fertilizers in agriculture. The WHO guideline value is 5 $mg.l^{-1}$. High content of Potassium affects the taste of drinking water.

32. Fluoride (F)

Fluoride is fairly common element that does not occur in the elemental state in nature because of its high reactivity. It exists in a number of minerals, of which fluorspar, cryolite, fluorapatite are the most common. The natural Fluoride content in groundwater varies with the type of rock that the water flows through. The WHO guideline value of 1.5 $mg.l^{-1}$ of Fluoride content in water supplies is accepted. Concentrations above this value carry an increasing risk of dental flourosis, and much higher concentrations lead to skeletal flourosis.

33. Sulfate (SO_4)

Sulfate in groundwater is derived from the evaporate minerals gypsum ($CaSO_4.2H_2O$).

Sulfate is one of the least toxic anions. The major physiological effects resulting from concentration of Sulfate higher than 600 $mg.l^{-1}$ are catharsis and dehydration. The high concentration of Sulfate in drinking water can also result in a noticeable taste. One of the sources for Sulfate is the chemical fertilizers.

34. Hydrogen Ion Concentration (pH)

The pH of a solution is equal to the logarithm of the inverse of the hydrogen ion activity

$$pH = Log\frac{1}{H}$$

The pH of water is a measure of the acid- base equilibrium. In natural waters, pH is controlled by Carbon dioxide-bicarbonate-carbonate equilibrium system. An increased Carbon dioxide concentration will lower pH. Whereas a decrease will cause it to rise. A pH less than 7 indicates an acid solution, whereas a pH greater than 7 indicates an alkaline solution.

35. Alkalinity

Alkalinity refers to the natural carbonates, bicarbonates, and hydroxide ions associated with Calcium, Magnesium and Potassium available in groundwater. It is measured by $mg.l^{-1}$.

36. Total Coliforms (T-Coli)

Total coliforms (Coliform organisms) present a suitable microbial quality indicator of public water supply. They are heterogeneous and include lactose-fermenting bacteria which can be found in both faeces and the environment. Higher values indicate that water supply contains relatively high levels of nutrients. Total coliforms are measured in Number/100 ml.

☒ Category: Impact Variables

- **Ecological**

37. Loss of productivity (LosProd)

Loss in productivity means the reduction in the yield of agriculture land measured in tons.

38. Loss of wetland (LosWet)

This refers to the area of wetland already dried as a result of the drawdown of water table. It is measured by hectar.

- **Public health**

39. Morbidity (Morbid)

Morbidity refers to the number of people affected by water borne diseases. The predominant diseases in GS that spread through wastewater-contaminated drinking water supplies, use of raw or partially treated wastewater for edible crop irrigation, health hazards to farmers using the untreated wastewater and spread of insects include diarrhea diseases, dysentery, infectious hepatitis and typhoid fever. In addition, Giardiasis is a very common infection among the population in GS which are caused by waterborne and other sources like: food, venereal transmission, and direct fecal-oral transmission.

☒ Category of response variables: management responses

40. Brackish water desalination (BrWDes)

This represents the amounts of water produced by Reverse Osmosis desalination plants established on municipal wells. It is measured by million cubic meters ($hm^{-3}.y^{-1}$).

41. Storm water harvesting (StoWHa)

Storm water harvesting represents collection of rainfall using check dams in wadis, storage and infiltration bonds for recharging and aquifer replenishment. Also, it includes cisterns in urban and rural areas for household and livestock use. It is measured by million cubic meters per year ($hm^{-3}.y^{-1}$);

42. Importation of water and regional water conveyance (Import)

This represents the amounts of water provided by the Regional Water Company (Mekeroth) for municipalities that have water of high Chloride content. It is measured by million cubic meters ($hm^{-3}.y^{-1}$).

43. Treated/partially treated wastewater (TreatWW)

Treated wastewater represents the amounts of effluent at the outlet of the existing wastewater treatment plants. The quality of the effluents varies according to inflow amounts and the efficiency of the plant. It is represented by million cubic meters ($hm^{-3}.y^{-1}$).

44. Efficiency in water irrigation (EfWIrrig)

It refers to the actual agricultural water consumption based on the crop water requirements as a percentage of the water production by agricultural wells.

45. Efficiency in urban water supply networks (EfUWSN)

This refers to the municipal water consumption as a proportion of the water production from the municipal water wells.

Efficiency= consumption/production

46. Efficiency of water information system (EfInS)

This refers to the level of existing information system including human resources, equipment, software as a ratio to the required water information system to better manage the water resources sector.

47. Water awareness and education Campaigns (WAwar)

Awareness represents the number of people participated in the educational campaigns on rational use of water. These campaigns were arranged by the Palestinian Water Authority (PWA), Non Governmental Organizations (NGOs) and municipalities.

48. Sea Water Desalination (SWD)

This indicates the amounts of desalinated seawater used by the population. There is only one operational desalination plant based in Deir Al-Balah Governorate and using the technology of Reverse Osmosis (RO). It is measured in million cubic meters ($hm^{-3}.y^{-1}$).

4.4 Presentation of Data

GS is divided into five main governorates; North, Gaza, Deir El-Balah, Khan Younis and Rafah. GS contains twenty five municipalities and village councils including Beit Hannun (BHan), Beit Lahia (Blah), Jabalia (Jaba), Um Alnasser (UmNa), Gaza , Al-Zahra' (Zahra), Al-Mograga (Mogr), Wadi Gaza (WaGa), Nusseirat (Nuse), Magazi (Maga), El Bureij (Bure), Zawaida (Zawa), Deir El-Balah (DBala), Wadi Salga (WaSa), Al-Musadar (Musa), Khan Younis (KYou), Qarara (Qara), Bani Suhaila (BSuh), Khuza'a (Khuz), Abassan Kubra (AbKu), Abassan Jadida (AbJa), Al-Fukhari (Fukh), Rafah (Rafa), Al-Shoka (Shok), Al-Bayuk (Bayu).(Figure 4.10).

The raw data used were real data compiled by the author from the twenty five municipalities, Ministry of Agriculture, Ministry of Industry, Ministry of Local Government, Water Authority, Environment Quality Authority and the Palestinian Central Bureau of Statistics as independent data sets (each case is independent) for the reference year 2000. The raw data are presented in Annex A2 (Tables A2.1.1, A2.1.2, A2.1.3, A2.1.4, A2.1.5, A2.1.6, A2.1.7).

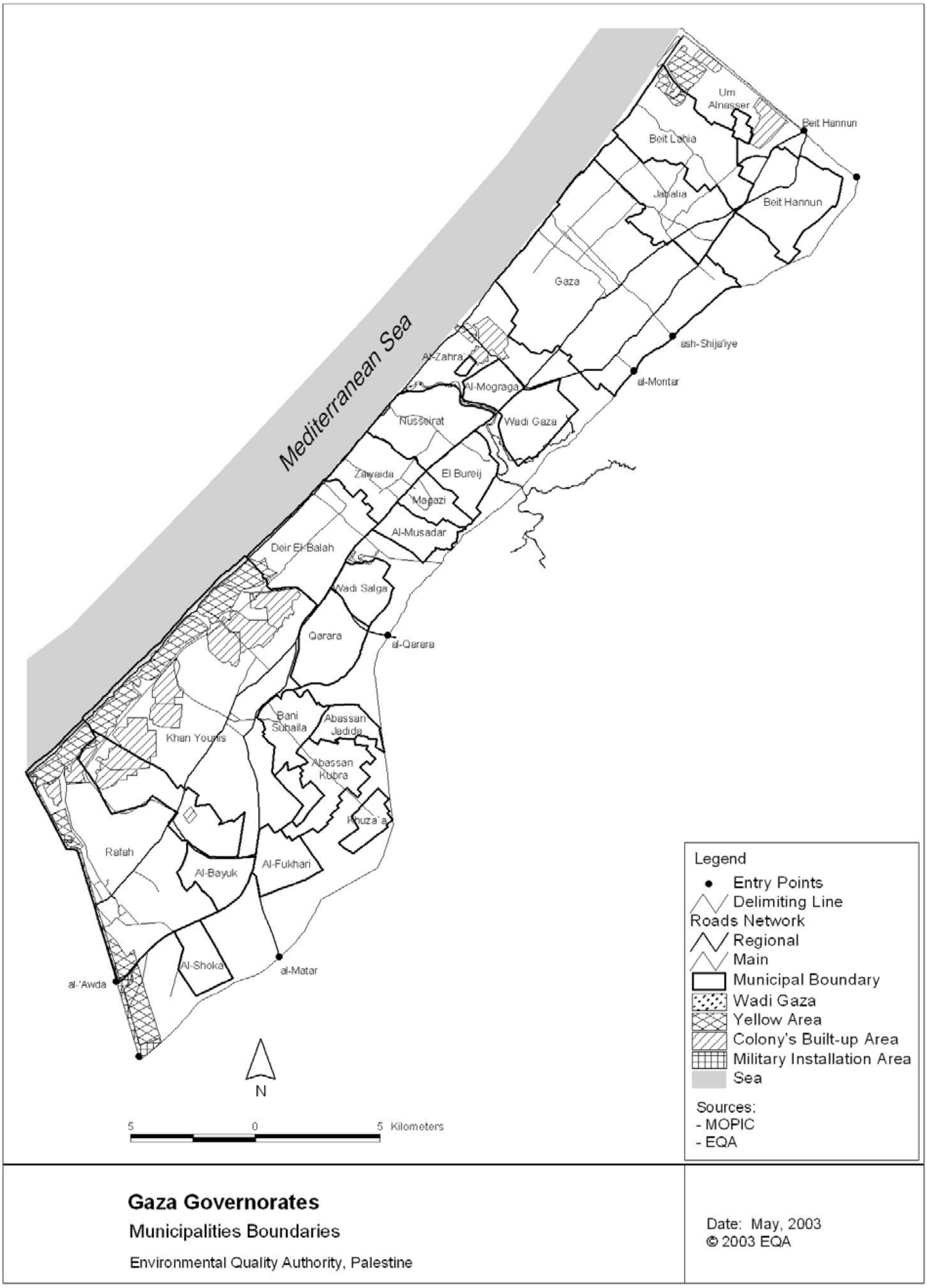


Figure 4.10 Map of Gaza Strip
(Source **EQA, 2001**)

4.5 Summarizing data

The selection of appropriate data analysis procedures requires describing and summarizing those data in forms which indicate their characteristics. Characteristics often described include mean, median, standard deviation, skewness and lower and upper quartiles (see Annex A2- A2.2). Summary descriptive statistics was calculated for the categories of socio-economic, pollution pressure, state of water quality, impact and management responses variables. The variables water abstraction and TDS were discussed in detail since they represent two different cases of non-normal and normal distribution of data. The data summary of the remaining variables were discussed briefly.

- **Water abstraction and TDS variables**

There are 23 observations of water abstraction variable (92% of the data) located within the two standard deviations range (Figure 4.11). This proportion of data is greater than the designated proportion (68.3%) for the normally distributed data. There are only two observations (8% of the data) located in one direction outside the four standard deviations range as outliers. Figure 4.12 indicates that all data of TDS variable are located within the four standard deviations range. Table 4.5 explains that both water abstraction and TDS have positive skewness but with different values (right skewed). Right skewed indicates long right tail and the data mean is greater than the data median since outliers are only in one direction. The data mean of water abstraction is greater than the data median and even greater than upper quartile which indicates considerable skewness whilst TDS has very small skewness. Accordingly, the data of water abstraction variable reflect non-normal distribution (Figure 4.13) whilst TDS has reasonably normally distributed (Figure 4.14). Outliers in the water abstraction data can not be discarded since they represent actual data for very important municipalities which are Gaza and Khan Younis. Hence, transformation using logarithms may produce quite symmetrical data in order to use analysis procedures requiring symmetry or normality. The natural *logarithm* log (base e) is selected (Ln), where e = 2.718.

Table 4.5 Summary descriptive statistics for water abstraction and TDS variables

	Mean	Median	Lower quartile	Upper quartile	Standard deviation	Skewness
WAbstrac	4.55	1.69	1.210	4.48	7.21	3.00976
TDS	1587.720	1512.000	1078.000	1890.000	699.4322	0.775615

Figure 4.11 Box plot for water abstraction variable

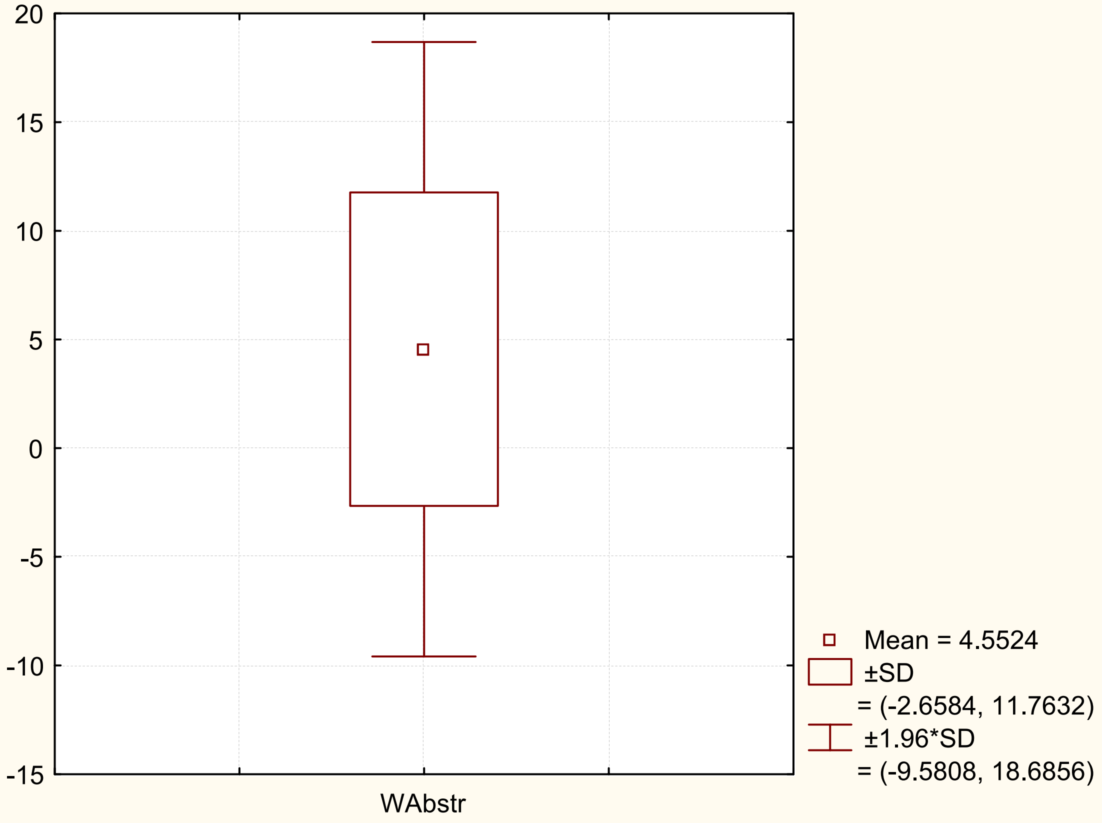


Figure 4.12 Box plot for TDS

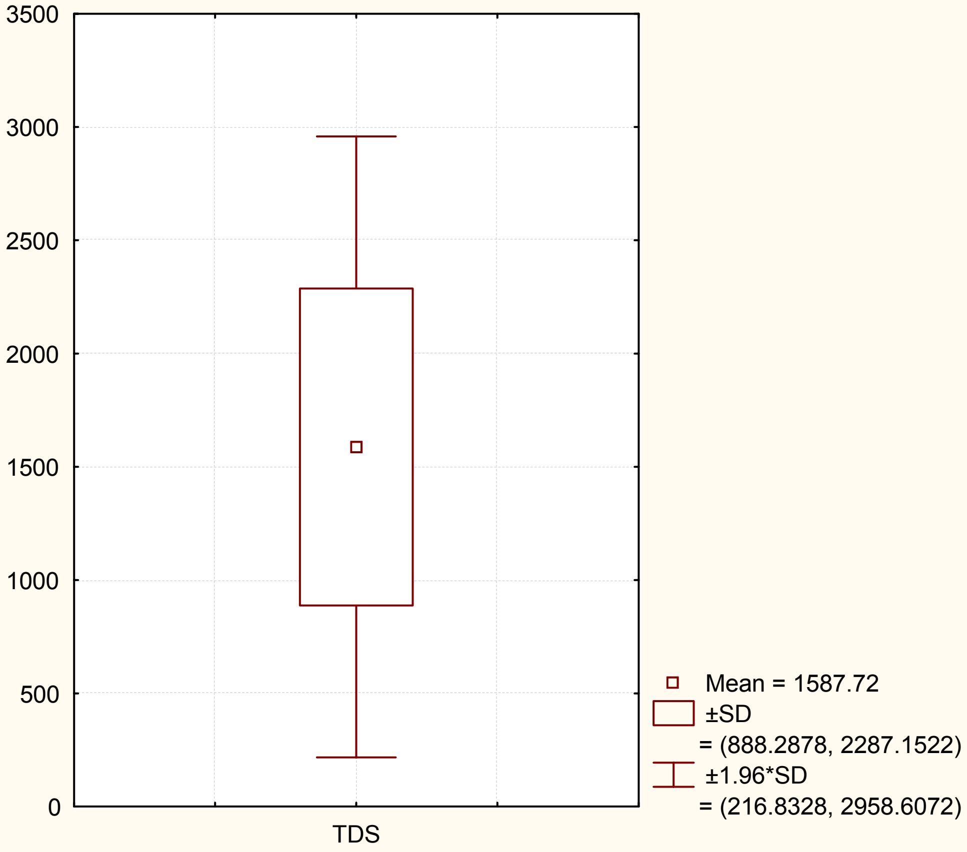


Figure 4.13 Histogram of water abstraction

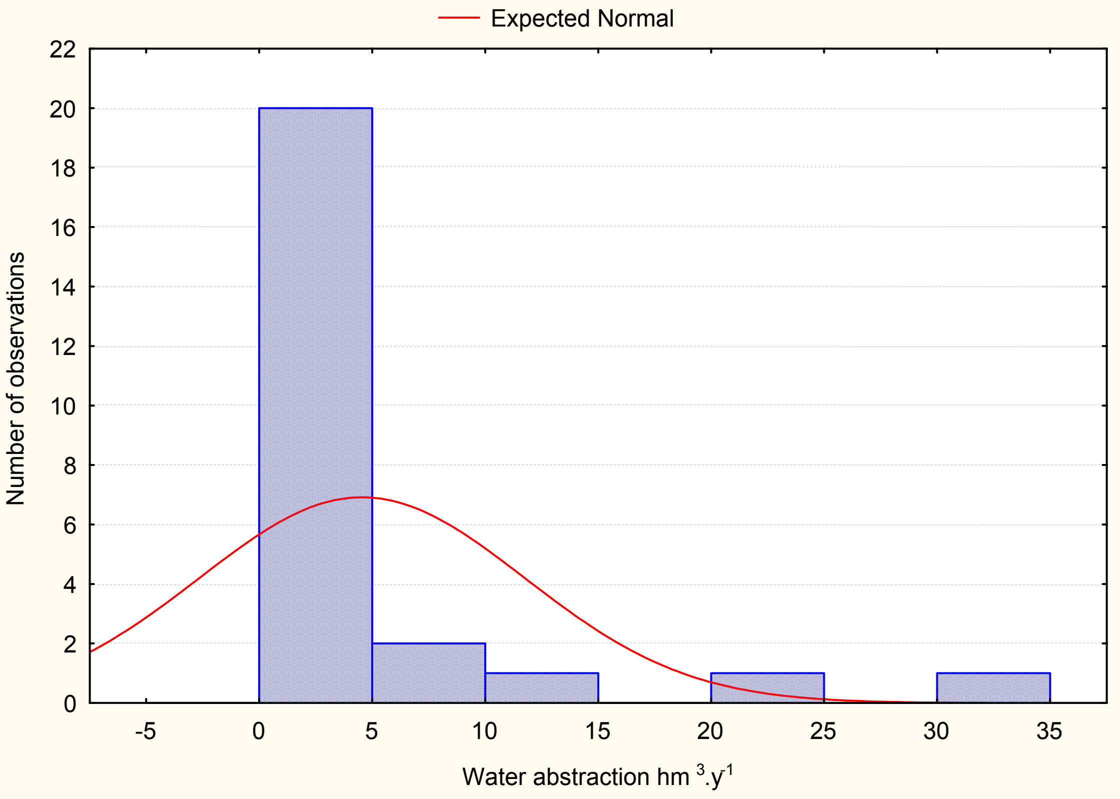
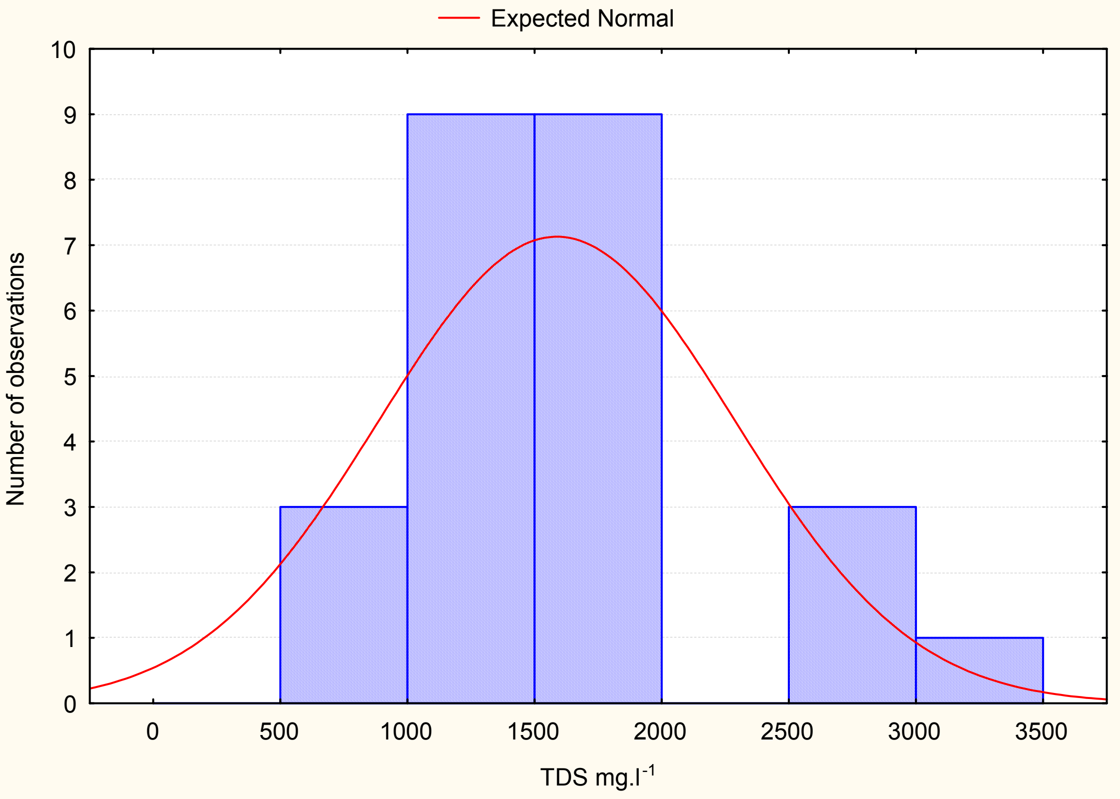


Figure 4.14 Histogram Of TDS



- **Socio-economic driving forces variables**

Table 4.6 presents that all socio-economic variables have positive skewness with different values (right skewed) except water supply has negative skewness (left skewed). Population, land use, tourism, wastewater system coverage, storm water system coverage, agriculture water consumption, gender empowerment and unaccounted for water have substantial skewness, small spread and non-normal data distribution. The variables income per capita, access to safe water supply, water consumption per capita, water price and efficiency of revenue collection have reasonably normal distribution of data.

Table 4.6 Summary descriptive statistics- socio-economic variables

	Mean	Median	Lower quartile	Upper quartile	Standard deviation	Skewness
Populat	46626.72	19496.00	5295.000	35123.00	85834.05	3.49417
Inccap	1345.56	1339.00	1335.000	1347.00	20.66	2.57643
Lanuse	2.00	1.09	0.743	2.24	2.02	2.02582
Tourism	4284.81	1368.00	458.000	3758.00	8615.16	3.82064
WSupply	0.95	1.00	0.980	1.00	0.11	-2.26299
WWCov	0.38	0.20	0.100	0.65	0.32	0.62641
StoWCov	0.15	0.13	0.120	0.15	0.06	2.43439
WCpCap	79.16	70.00	62.000	90.00	26.61	1.22204
Wprice	0.29	0.31	0.227	0.34	0.07	0.31182
EfRevCo	0.79	0.79	0.740	0.82	0.08	-0.24799
AgWCon	2.62	1.67	1.020	2.65	3.35	2.67833
GendEmp	0.02	0.00	0.000	0.00	0.05	4.03639
UFW	0.25	0.23	0.129	0.38	0.14	0.44508

- **Pollution pressure variables**

The variable seawater intrusion and CO_2 have reasonably normal distribution of data. Hazardous wastes, domestic wastewater, pesticides, chemical fertilizers, organic fertilizers, petrol stations, domestic solid waste and industrial wastewater have big skewness, small spread and non-normal data distribution (Table 4.7).

Table 4.7 Summary descriptive statistics- pollution variables

	Mean	Median	Lower quartile	Upper quartile	Standard deviation	Skewness
HazWas	0.477	0.168	0.050	0.569	0.8180	3.479927
DomWW	1.367	0.330	0.074	1.170	3.1532	4.326789
Pesticide	18.715	11.560	8.520	19.020	24.8215	3.662902
ChemFert	83.443	58.580	40.510	86.143	116.2180	3.801257
OrgFert	197.960	142.000	100.000	184.000	275.1939	3.568080
PetrolSt	4.800	2.000	2.000	4.000	7.1414	3.262396
DomSW	43.080	9.000	5.000	26.000	109.6492	4.465423
IndWW	0.072	0.016	0.004	0.055	0.1812	4.466564
CO_2	298.800	298.000	295.000	300.000	5.7446	1.091426
SWIntr	7.630	0.000	0.000	10.630	14.7483	2.309836

- **State of water quality variables**

Table 4.8 explains that NO3 and Total Coliforms have considerable positive skewness, small variability and non-normal distribution of data. Chloride, Sodium, Calcium, Magnesium, Potassium, floride, Sulfate, hydrogen ion concentration and Alkalinity have slight skewness, large spread and reasonably normal data distribution.

Table 4.8 Summary descriptive statistics- state of water quality variables

	Mean	Median	Lower	Upper quartile	Standard deviation	Skewness
NO3	74.2180	52.5000	36.0000	107.5000	49.2664	1.125659
CL	583.3164	528.4000	238.6700	870.0000	340.0546	0.188175
Na	424.1616	382.0000	157.0000	738.0000	293.8355	0.348689
Ca	56.2080	62.0000	35.0000	78.0000	25.1290	0.164832
Mg	28.6488	28.0000	14.0000	38.0900	13.7408	0.079695
K	4.7924	3.0700	2.5300	6.6000	3.1714	0.970223
F	1.4830	1.6000	0.6200	2.1500	0.7756	-0.274885
SO4	293.1800	158.0000	58.0000	594.0000	275.8514	0.577172
pH	7.5883	7.6180	7.4000	7.7000	0.2582	-0.429916
Alkalinity	207.7016	220.0000	162.5000	245.5000	62.3617	-0.721328
T-Coli	30.4800	15.0000	8.0000	39.0000	46.7468	4.030956

- **Ecological and public health impact variables**

The variables morbidity and loss in agriculture productivity have positive significant skewness, data mean is greater than data median, minor spread and non-normal data distribution. Loss of wetlands has appropriate spread and reasonably normal distribution of data (Table 4.9).

Table 4.9 Summary descriptive statistics- impact variables

	Mean	Median	Lower quartile	Upper quartile	Standard deviation	Skewness
LosProd	327.2800	190.0000	156.0000	342.0000	455.1444	3.723694
LosWet	3.9160	0.0000	0.0000	4.7800	7.3280	2.245427
Morbid	422.3600	153.0000	62.0000	314.0000	707.1055	2.466454

- **Management response variables**

Table 4.10 refers that the variables efficiency of information system, importation of water and regional water conveyance and seawater desalination have reasonable normal distribution of data. The variables storm water harvesting, brackish water desalination, treated wastewater, efficiency in water irrigation, efficiency in urban water supply networks and water awareness and education have considerable positive skewness, data mean is grater than data median, small variety and non-normal distribution data.

Table 4.10 Summary descriptive statistics- management response variables

	Mean	Median	Lower quartile	Upper quartile	Standard deviation	Skewness
WAbstrac	4.552	1.690	1.2100	4.480	7.21	3.009755
BrWDes	0.051	0.000	0.0000	0.000	0.19	4.470569
StoWHa	0.123	0.048	0.0300	0.115	0.20	2.843418
Import	0.165	0.000	0.0000	0.222	0.35	2.918695
TreatWW	0.993	0.000	0.0000	0.000	3.71	4.563476
EfWIrrig	0.768	0.720	0.7160	0.850	0.07	0.501955
EfUWSN	0.754	0.768	0.6230	0.871	0.14	-0.445080
EfInS	0.388	0.500	0.0000	0.600	0.31	-0.399757
WAwar	8258.400	1890.000	940.0000	6000.000	16954.96	3.760430
SWD	24.000	0.000	0.0000	13.000	50.11	2.081551

4.6 Concluding remarks

- Population growth is high and population are expected to double at the year 2015.
- There is a negative net aquifer water balance in GS indicating a water deficit.
- There are significant environmental impacts of existing wastewater treatment plants as they are located on top of the fresh groundwater aquifers and very close to the urban areas without proper mitigation measures. The characteristics of the effluent indicates that these plants are mis-planned, over loaded and poorly operated.
- The average income per capita is quite low. The low income results in lowering the affordability of people to pay for the water sector services.
- The water consumption per capita ranges between 43 -140 l.cap^{-1}.day^{-1}. It indicates imbalances in water allocation.
- The average water supply services coverage is high whilst the average wastewater services coverage is low. This implies that large quantities of raw wastewater are disposed into the open environment.
- Gender empowerment is very weak. In 18 municipalities, there are no women employed in water management departments whilst in the remaining 6 municipalities, employment opportunities given to women are very small.
- The total losses from the water supply network including leakage and illegal connections range between 0.1-0.39. This indicates high losses in most of the municipalities.
- The quantities of seawater intrusion in the coastal aquifer is quite high which explains the high Chloride concentration in groundwater in most of the municipal wells.

- The range of CO_2 concentration in the air is 290-314 ppm. The variation of CO_2 concentration is resulted by the sites of industrial facilities in addition to the differences in the number of cars and the associated consumption of fossil fuel.
- Groundwater quality is undergoing a continual process of degradation. The concentration of Nitrate and flouride in groundwater exceeds the WHO standards in about one half and one third of the municipal wells respectively. Chloride and Sodium concentrations exceed the WHO standards in about two thirds of the municipalities whilst Potassium and Sulfate concentrations exceed the WHO standards in one third of the municipalities. Calcium concentration in groundwater is below the WHO in all municipalities.
- Total Dissolved Solids in the groundwater produced in about 90% of the municipalities exceeds 1000 $mg.l^{-1}$. Drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 $mg.l^{-1}$ (World Health Organization, 2004).
- The range of Total Coliforms is 3-240 in ml samples. The variations in the numbers of Total Coliforms are due to the differences in the availability of wastewater collection and treatment systems in municipalities. The presence of coliform bacteria in a water supply shows possible pollution that may contain disease causing organisms. The Total Coliforms is high in Deir El-Balah due extensive use of cesspits for domestic wastewater disposal in an area of high water table.
- The concentrations of Arsenic, Cadmium, Chromium, Cyanide, Lead, Nickel and Selenium in bathing marine areas are higher than the WHO standards.
- Wetlands were available in one third of the municipalities. One of the impacts of water sector management in GS is the dry up of these wetlands.
- The impacts on public health and agriculture productivity are significant in all municipalities.
- Information management systems are not available in about one third of the municipalities. The range of the efficiency of the information management systems in the remaining municipalities is 0.50-0.80. The low efficiency of information systems has resulted in weakening the management of water resources sector.
- The range in efficiency of the irrigation systems is 0.71-0.87. The variation is due to various irrigation techniques used. These techniques are subsurface irrigation, drip irrigation, sprinkler irrigation and open canals system.
- Seawater desalination is concentrated only in the middle area of GS.

- Brackish water is concentrated in three large cities to meet the drinking water demands of some neighborhoods.
- About one fourth of the municipalities receive water from regional water companies. These municipalities are located in the Middle and Khan Younis governorates.
- There are storm water harvesting activities in all the municipalities.
- The treated wastewater has been reused only in three municipalities due to the lack of treatment and reuse facilities in the remaining municipalities. This has resulted in wasting large quantities of potential water that can be reused in agriculture, recreation, industry and artificial recharging.
- The raw data are characterized with presence of outliers on the high side, considerable skewness, non-normal distribution of data in approximately 50% of the variables. Therefore, transformation is needed to produce quite symmetrical data in order to use analysis tools requiring normality.

Chapter 5 Analysis plan and tools

5.1 Analysis plan

The objectives of the analysis plan were to:

- characterize and prioritize the effective variables among the possible baseline variables under the five categories of validated CWIMSAM model. The selected variables together with the associated municipalities (observations) were classified and organized so that the municipalities under water stresses have been well identified; and
- model prediction relationships between the groundwater abstraction on one hand and socio-economic driving forces, water quality determinants and policy interventions on the other hand. The prediction relationship between the water quality and pollution pressures has been also established.

The tools chosen for this research work were ANN, expert opinion and judgment, health risk assessment, basic statistics and multivariate techniques. The software selected were **STATISTICA** package version 6.0, STATITICA Neural Networks (SNN) Release 4.0 E and RISC WorkBench. The steps adopted to carry out data analysis are shown in Figure 5.1. Step (1) expresses the creation of ANN model, the characterization and prioritization of the effective variables and the establishment of the modeling prediction relationships. Step (2) indicates the analysis of the questionnaire undertaken (see Annex A1) to explore the expert opinion and judgment of various stakeholders using descriptive statistics (A2.2). The results of Step (2) was compared with the results of ANN in Step (1) to examine the understanding and knowledge of the local experts about the actual baseline conditions of water sector. Transformation of non-normal data distribution variables and correlation matrix were carried out in Step (3) for the selected variables from Step (1). Three various multivariate analysis techniques were undertaken in Step (4) for the selected variables to classify them with the relevant municipalities. Step (5) explains the health risk assessment of Gaza WWTP as a contaminated hotspot. It assessed the health risks associated with the current disposal of wastewater on the sea shore close to the bathing areas. The identified chemicals with carcinogenic risks were fed back into CWIMSAM model

The results of Steps (1) and (4) were also fed back to complement the CWIMSAM model with the selected priority variables and geographical areas under water stresses. The whole results will be a basis and an input to evaluate the national water plan (PWA, 2000) through Strategic Environmental Assessment study which is beyond the scope of this research work.

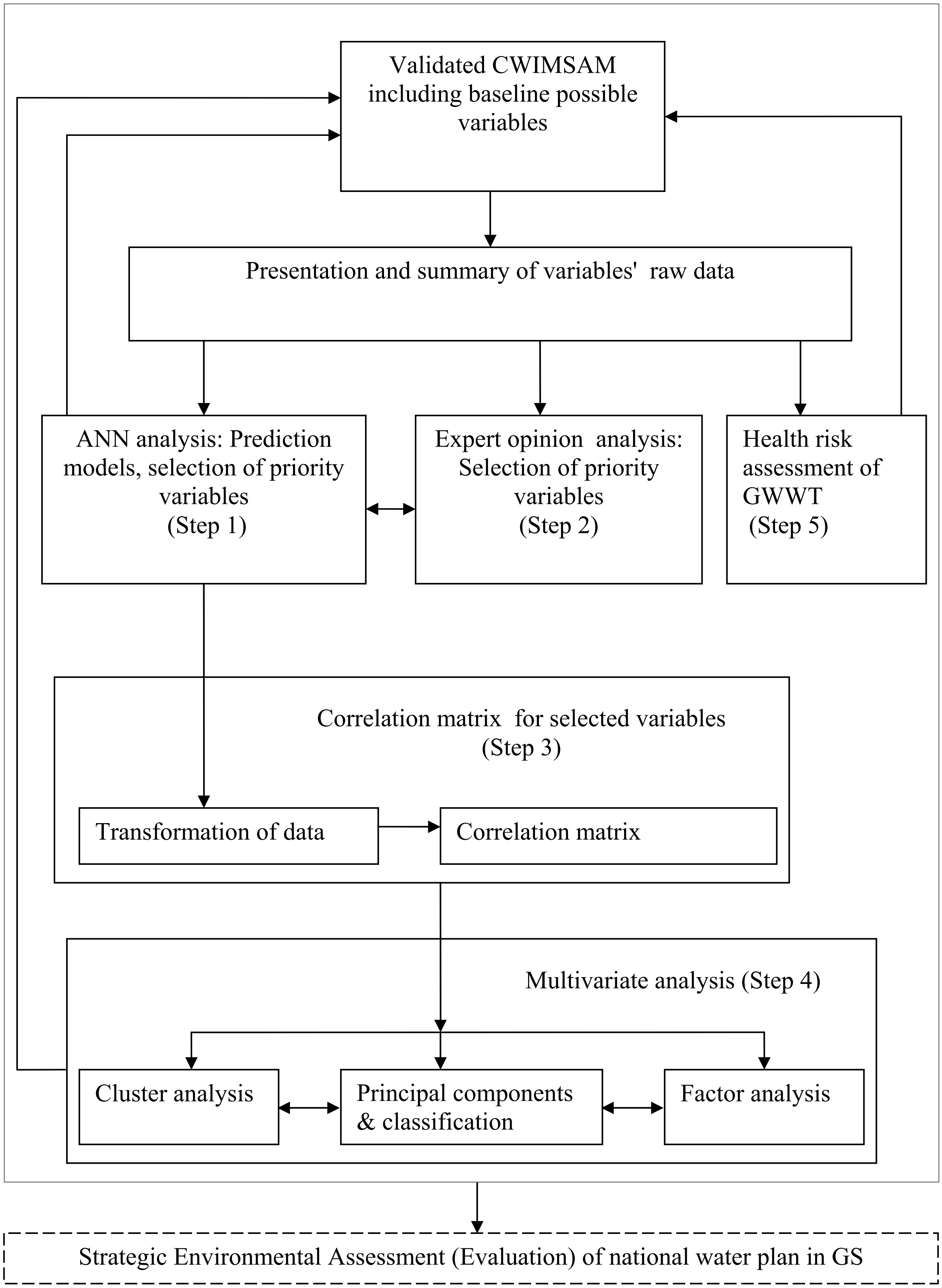


Figure 5.1 Steps of data analysis

5.2 Analysis tools

The analysis tools used in this research work arre: ANN, basic statistics and multivariate techniques. Basic statistics includes descriptive statistics and correlation matrix analysis. Multivariate techniques include cluster analysis, factor analysis and principal components & classification analysis.

5.2.1 Artificial Neural Networks (ANN)

☒ Introduction

ANN models are mathematical tools, capable of modeling extremely complex functions and wide spectrum of challenging problems (Najjar et al., 1997). ANN models are biologically inspired computational systems that rely on the collective number of processing elements called neurons (nodes) which are arranged in an input layer, one or more hidden layers, an output layer and connection weights (Liu et al., 2003; Riad et al., 2004; Jalala and Mania, 2004a,b,c,d). Important issue in Multi-Layer Perceptron (MLP) design includes specification of the number of hidden layers and the number of nodes in these layers (Haykin, 1994; Bishop, 1995).

In recent years, ANN models have been successfully applied across an extraordinary range of problem domains of science and engineering (Lallahem and Mania, 2003). In water resources context, ANN has been used for water quality parameters (Maier and Dandy, 1996), forecasting of water demand (Liu et al., 2003), stream flow forecasting (Change et al., 2003), prediction of rainfall-runoff relationship (Rajurkar et al., 2004; Riad et al., 2004), and coastal aquifer management (Jalala and Mania, 2004a), socio-economic driving forces of groundwater abstraction (Jalala and Mania, 2004b), water quality determinants of water abstraction (Jalala and Mania, 2004c) and pollution pressures of water quality (Jalala and Mania, 2004d). A review of ANN modeling issues and applications in water resources can be found in Maier and Dandy (2000).

A back-propagation feed-forward MLP with sigmoidal-type transfer functions is the most popular neural network architecture in use due to its high performance compared to the other networks (Lippmann, 1987; Riad et al., 2004). Other common types of ANN models include Radial Basis Function (RBF), General Regression Neural Networks (GRNN) and Linear. Details about these ANN types can be found in the literature (see Bishop, 1995; Broomhead and lowe, 1998; Haykin, 1994; Moody and Darkin 1989; Patterson 1996; Speckt, 1991).

A typical schematic diagram of ANN network is given in Fig. 5.2. It shows a typical feed-forward structure with signals flow from input nodes, forward through hidden nodes, eventually reaching the output node. The input layer is not really neural at all: these nodes simply serve to introduce the standardized values of the input variables to the neighboring hidden layer without any transformation. The hidden and output layer nodes are each connected to all of the nodes in the preceding layer. However, the nodes in each layer are not connected to each other. A numeric weight is associated with each of the inter- node connections. Weight of W_{ij} represents the strength of connections of nodes between input and hidden layer while W_{jk} represents the strength of connections of nodes between hidden and output layers.

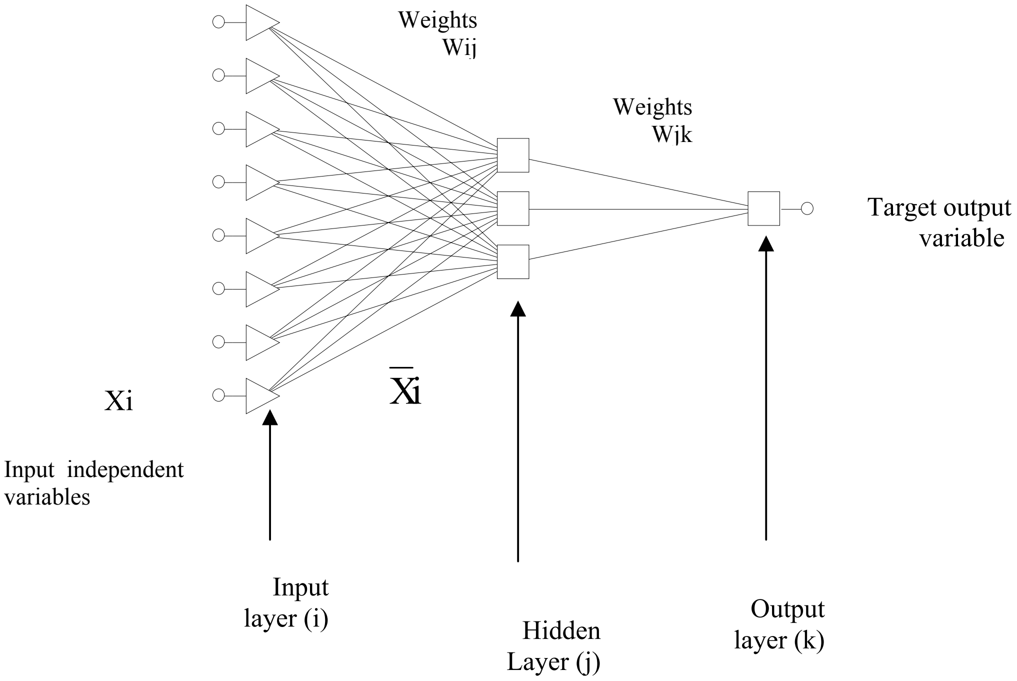


Figure 5.2 MLP Network (three layers)

Each hidden node (j) receives signals from every input node (i) which carries scaled values ($\overline{X}i$) of an input variable where various input variables have different measurement units and span different ranges. $\overline{X}i$ is expressed as:

$$\overline{X}_i = \frac{X_i - X_{\min(i)}}{X_{\max(i)} - X_{\min(i)}} \qquad (1)$$

Each signal comes via a connection that has a weight (W_{ij}). The net integral incoming signals to a receiving hidden node (Net_j) is the weighted sum of the entering signals, $\overline{X}_i$, and the corresponding weights, W_{ij} plus a constant reflecting the node threshold value (TH_j):

$$Net_j = \sum_{i=1}^{n} \overline{X}_i W_{ij} + TH_j \qquad (2)$$

The net incoming signals of a hidden node (Net_j) is transformed to an output (O_j) from the hidden node by using a non-linear transfer function (*f*) of sigmoid type, given by the following equation form:

$$Oj = f(Netj) = \frac{1}{1+e^{-Netj}} \qquad (3)$$

Qj passes as a signal to the output node (k). The net entering signals of an output node (Net_k)

$$Net_k = \sum_{i=1}^{n} O_j W_{jk} + TH_k \qquad (4)$$

The net incoming signals of an output node (Netk) is transformed using the sigmoid type function to a standardized or scaled output ($\overline{O}_k$) that is:

$$\overline{O}_k = f(Net_k) = \frac{1}{1+e^{-Netk}} \qquad (5)$$

Then, $\overline{O}_k$ is de-scaled to produce the target output:

$$O_k = \overline{O}_k(O_{max(k)} - O_{min(k)}) + O_{min(k)} \qquad (6)$$

Riad et al. (2004) explained that the sigmoid function should be continuous, differentiable and bounded from above and below in the range [0, 1]. The graph of sigmoid function is shown in Figure 5.3.

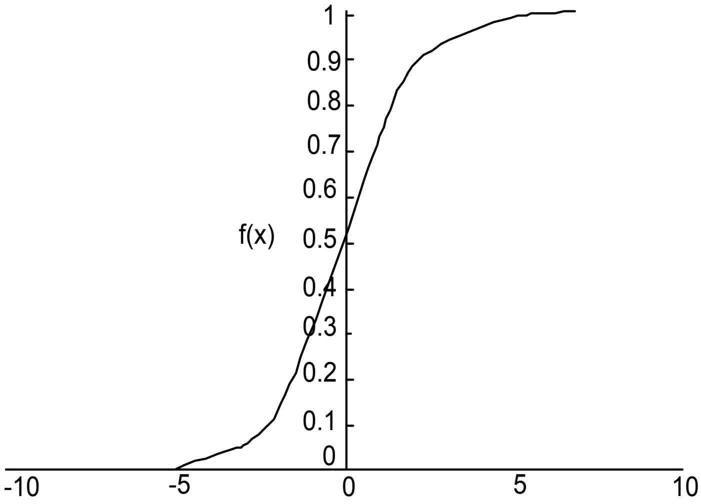


Figure 5.3 Sigmoid transfer function

The calculated error between the observed actual value and the predicted value of the dependent variable is back-propagated through the network and the weights are adjusted. The cyclic process of feed forward and error backpropogation are repeated until the verification error is minimal (Liu et al., 2003).

☒ Calibration and verification of the model

In case that limited data sets are available, cross verification can be used as a stopping criteria to determine the optimal number of hidden layer nodes (Braddock, Kremmer and Sanzogni, 1997) whilst avoiding the risk of over training (Xiao and Chandrasekar, 1997). Cross verification is a technique used commonly in ANN models and has a significant impact on the division of data (Bruden, Brereton and Walsh, 1997). It aims to train the network using one set of data, and to check performance against a verification set not used in training. This examines the ability of the network to generalize properly by observing whether the verification error is reasonably low. The training will be stopped when the verification error starts to increase (Lallahem and Mania, 2003).

☒ Selection of the performance criteria

Building the ANN model requires a clear definition of the criteria by which the performance of the model will be judged, as they can have a significant impact on the model architecture and weight optimization techniques selected (Maier and Dandy, 2000). The root mean square error (RMSE) and the coefficient of determination R^2 can be selected as numerical indicators to define the optimal MLP network (Lallahem and Mania, 2003; Riad et al., 2003; Najjar et al., 1996). Besides that, the RMSE can be used to compare the performance of MLP with other common types of ANN including RBF, GRNN and Linear.

$$\mathrm{RMSE} = \sqrt{\sum_{\iota=1}^{N} \frac{(Q_\iota - \hat{Q}_\iota)^2}{N}} \tag{7}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (Qi - \hat{Q}i)^2}{\sum_{i=1}^{N} (Qi - \overline{Q}i)^2} \tag{8}$$

where Qi - is the observed TDS value; $\hat{Q}i$ - is the predicted TDS value; $\overline{Q}i$ - is the mean value of Qi values; N- is the total number of data sets. The RMSE gives a quantitative indication for the network error. It measures the deviation of the predicted values from the corresponding observed values of target output which refers to the prediction accuracy. R^2 value is an indicator of how well the network fits the data and accounts for the variability with the variables specified in the network. Values of R^2 above 90% refers to a very satisfactory model performance. Values range between 80-90% indicates a fairly good model whilst values in the range 60-80% indicates unsatisfactory model (Lallahem and Mania, 2003). The ideal value for RMSE is zero and for R^2 is unity.

- ☒ **Determination of model inputs**

ANN models have the ability to determine which inputs are critical. They are useful mainly for complex problems where the number of potential inputs is large and where a priori knowledge is not available to determine appropriate inputs (Lachtermacher and Fuller, 1994). A sensitivity analysis can be carried out to identify the importance of the input variables. This indicates which variables are considered to be most useful to be retained by the ANN model. The ANN models removes the input variables with low sensitivity. The sensitivity is presented by the Error, Ratio and Rank. The basic sensitivity figure is the Error. This indicates the performance of the network if that variable is "unavailable." Important variables have a high error, indicating that the network performance deteriorates badly if they are not present. The Ratio reports the ratio between the Error and the Baseline Error (i.e. the error of the network if all variables are "available"). The Rank simply lists the variables in the order of their importance.

- ☒ **Software**

The software package of SNN, Release 4.0 E was used in this research work. to characterize the effective variables and to establish prediction relationships between the target output variable and the related independent input variables. SNN is a comprehensive, state–of-the-art, powerful, and extremely fast neural network data analysis package featuring:

- Integrated pre- and post-processing, including data selection, nominal-value encoding, scaling, normalization, and missing value substitution, with interpretation for classification, regression, and time series problems.
- Exceptional ease of use coupled with unsurpassed analytic power; for example, a unique wizard-style Intelligent Problem Solver can guide step by step through the procedure of creating a variety of different networks and choosing the network with the best performance.
- Powerful exploratory and analytic techniques, including Input Feature Selection algorithms (choosing the right input variables in exploratory data analysis, which is a typical application of neural networks, is often a time-consuming process; SNN can also do this.
- State-of-the-art, highly optimized training algorithms full control over all aspects that influence the network performance such as activation and error functions, or network complexity.
- Support for combinations of networks and network architectures of practically unlimited sizes organized in Network Sets; selective training of network segments; merging, saving of network sets in separate files.
- Comprehensive graphical and statistical feedback that facilitates interactive exploratory analyses; and
- Selecting a Neural Network Model: SNN supports the most important classes of neural networks including MLP, RBS, GRNN and Linear for real world problem solving.

5.2.2 Correlation matrix

Correlation matrix is a table showing inter-correlation among all variables analyzed. It calculates the direction and strength of the relationship between any two variables in the data set. Direction is indicated by positive or negative. Strength is indicated by how close the value of the correlation is to +1 (perfect) in a direct relationship (if one increases then the other increases), and -1 in an inverse relationship (if one increases then the other decreases). The most commonly-used measure of correlation is Pearson's r. It is called the linear correlation coefficient because r measures the linear association between two variables. Pearson's r assumes that the data follow bivariate normal distribution (Helsel and Hirsch, 1992. pp. 218).

5.2.3 Multivariate Exploratory Techniques

☒ Cluster Analysis

The cluster analysis actually encompasses a number of different classification algorithms. It aims to organize observations to clusters so each cluster is more-or-less homogeneous and distinct from other clusters. In this classification, the higher the level of aggregation the less similar are the members in the respective cluster. Hierarchical techniques are the most widely applied clustering techniques (Davis, 1986). Hierarchical clustering joins the most similar observations, then successively connects the next most similar observations.

First n x n matrix of similarities between all pairs of observations is calculated. Those pairs having the highest similarities are then merged, and the matrix recomputed. This is done by averaging the similarities that combined observations have with the other observations. The process iterates until the similarity matrix is reduced to 2 x 2. The levels of similarity at which observations are merged is used to construct a dendogram.

The similarity between every pair of observations in a standardized n x m raw data matrix is calculated using a standardized m-space Euclidian distance, d_{ij}. The distance coefficient is computed by:

$$d_{ij} = \sqrt{\frac{\sum_{k=1}^{m}(X_{ik} - X_{jk})^2}{m}}$$

where

X_{ik} denotes the k_{th} variable measured on observation i.

X_{jk} denotes the k_{th} variable measured on observation j.

d_{ij} is the distance between observation i and observation j.

A low distance indicates that the two observations are similar whereas a large distance indicates dissimilarity.

The general categories of cluster analysis methods are: Joining (Tree Clustering), Two-way Joining (Block Clustering), and K-means Clustering.

☒ Principal Components & Classification Analysis (PCCA)

The PCCA module aims at the reduction in the number of variables to a smaller number of, ‘representative’ and ‘uncorrelated’ factors and the classification of variables and cases. Two types of analyses are available, depending upon whether the data needs to be standardized or centered. In the former case the analysis is carried out via the correlation matrix, while in the latter the analysis is carried out via the covariance matrix. The basic method, however, consists of diagonalizing the symmetric matrix: correlation or covariance. The special feature of this module is the graphics that provide visual aid for the classification of variables and cases.

Another unique feature of this module is that active and supplementary variables and cases can be specified. Active variables and cases are used in the derivation of the principal components; the supplementary variables and cases can then be projected onto the factor space computed from the active variables and cases. These facilities make the PCCA module a powerful tool for classification and data mining.

The PCCA module produces results in two forms: spreadsheets and graphs. While the spreadsheets can be used for interpreting the results, the associated graphs provide visual aid for the classification of variables and cases. It also produces a wide range of results, such as factor coordinates of variables and cases, loadings of variables, factor scores, factor score coefficients, eigenvalues, and descriptive statistics.

Eigenvalue is defined as the sum of squares of the loadings in a column in the factor matrix. Eigenvalues are referred to as latent roots and represent the amount of variance accounted for by a factor.

The maximum number of components (factors) to extract can be defined by Kaiser criterion (Kaiser, 1960) and Cattell's scree test (Cattell, 1966). The criterion proposes that factors with an eigenvalue greater than 1 can be retained. The scree test suggests that the point where the continuous drop in eigenvalues levels off suggests the cutoff, where only random "noise" is being extracted by additional factors.

Factor loadings are the correlation coefficients between the variables and factors. There is a single significant loading for each variable on only one factor. The factor loading magnitude and sign represent the correlation or linear association between a variable and the latent factor. The larger the absolute size of the factor loading for a variable, the more important the variable in interpreting the factor.

The factor score is the actual value of an individual case (observations) on the newly identified factors. It is a linear combination of all of the original variables that were relevant in making the new factor.

The main aim in the PCCA is to recover a vector space of lower dimension onto which the original points (variables or cases) can be projected, so that the underlying structure of the data could be detected. In order to facilitate this, 2D plots of the factor coordinates can be produced in this module. This option is available both for variables and cases. The module also plots the eigenvalues of the correlation or covariance matrix of the active variables, i.e., the Scree plot.

☒ Factor Analysis

Factor analysis is a generic term for statistical techniques concerned with the reduction of a set of observable variables into a small number of latent factors and the detection of the structure in the relationships between variables, that is to classify variables. This structure is expressed in the pattern of variances and covariances between variables and similarities between observations. The underlying assumption of factor analysis is that there exists a number of unobserved latent factors that account for the correlations within a set of multivariate observations. Factor analysis operates by extracting the eigenvalues and eigenvectors from a square matrix $[R]$ which is m x m, produced by multiplying a standardized data matrix $[X]$ by its transpose $[X]'$.

$$[R] = [X]'[X]$$

the elements of R consists of the correlation coefficients which are the raw sums of squares and cross-products of the m variables. That is,

$$r_{jk} = \sum_{i=1}^{n} X_{ij} X_{ik}$$

where the j and k are two columns of the data matrix.

Rotating the factor solution is essential to yield a factor structure that is simplest to interpret. Rotation maximizes the variance of factors on the new axes. The most standard computational method of rotation to re-orient or clean up the loadings obtained in a principal component analysis and bring about simple structure is the *varimax* rotation (Kaiser, 1958).

Varimax rotation is an orthogonal rotation of factors that redistributes the variance accounted within the pattern of factor loadings. The total variance accounted for is the same before and after rotation.

PCCA analysis versus factor analysis:

The methods used in PCCA analysis are similar to those offered in the factor analysis , but they differ in the following ways:

- PCCA does not use any iterative methods to extract factors.
- PCCA allows to consider some variables and/or cases as supplementary. These variables and cases can be mapped onto the same factor space as derived from the analysis (active) variables and cases.
- PCCA allows to analyze the data collected on variables that are heterogeneous with respect to their means or with respect to both their means and standard deviations, by providing an option to analyze covariance matrices as well as correlation matrices.

☒ Software

STATISTICA software package version 6.0 was used in this research for basic statistical analysis methods and multivariate exploratory techniques. STATISTICA is a comprehensive, integrated data analysis, graphics, database management, and custom application development system featuring a wide selection of basic and advanced analytic procedures for data mining, science, and engineering applications. . *STATISTICA*'s input and output data files and graphs can be of practically unlimited size, comprising hierarchies of documents of various types. The output can be directed to a multitude of output channels such as high performance workbooks, reports, the Internet, etc.

Some of the features of the *STATISTICA* line of software include:

- The breadth of selection and comprehensiveness of implementation of analytical procedures.
- The unparalleled selection, quality, and customizability of graphics integrated seamlessly with every computational procedure.

- The efficient and user-friendly user interface.
- The fully integrated *STATISTICA* Visual Basic.
- A wide selection of advanced software technologies that is responsible for *STATISTICA*'s practically unlimited capacity, performance (speed, responsiveness), and application customization options.

5.2.4 Human health risk assessment and risk-based clean-up levels for contaminated sites

☒ Introduction

Spence and Waldon (2001) defined human health risk assessment as the characterization of the potential adverse effects on human life or health. They explained that risk assessment process is aimed to:

- Provide an analysis of the baseline risks and help determine the need for action at sites.
- Provide a basis for determining levels of chemicals that can remain onsite and still be adequately protective of public health.
- Provide a basis for comparing potential health impacts of various remedial alternatives.
- Provide a consistent process for evaluating and documenting public health threats at sites.

Karademir (2004) used the term multimedia risk assessment to predict the health risk of human receptors from exposure to pollution sources.

European Commission (2002) integrated the role of risk assessment in DPSIR framework for development of impact indicators and organizing information about the life cycle of water resources management (Figure 2.2).

In recent years, health risk assessment has been applied across a range of pollution problem domains. It has been used for urban air pollution (Hrelia, Maffei, Angelini and Forti, 2004) , drinking water microbial contamination (Ashbolt, 2004), uranium in groundwater (Kim, Park, Cho, Sung and Shin, 2004), land farming operation of oily sludge in arid region (Hejazi, Husain and Khan, 2003) and the study of the short-term health effect levels of Arsenic exposure in young children with age range of 0-6 years and adults (Tsuji, Benson, Schoof and Hook, 2004). Sigh, Mohan, Sinha and Dalwani (2004) studied the impact of wastewater toxicants on human health. They assessed the extent of the metals exposure through different media to the population in the area receiving the wastewater. The approach was based on evaluation of the risk quotient for each individual toxicant by first computing the total daily intake of each one through the major exposure routes and then comparing with respective acceptable daily intake.

☒ **Software (RISC WorkBench)**

RISC WorkBench is a software package designed to (1) assess human health risk from exposure to contaminated sites, (2) estimate site-specific clean-up levels, (3) perform fate and transport modeling and (5) evaluate potential ecological impacts to surface water and sediment. A unique feature of RISC is its ability to perform a backward risk calculation as well as the conventional forward risk calculation. The backward risk calculation refers to calculating a cleanup level for an input value of risk. Fate and transport models are available to estimate receptor point concentrations in groundwater and indoor and outdoor air. RISC can be used to estimate the potential for adverse human health carcinogenic and non-carcinogenic impacts.

Risk Integrated Software for Cleanups (RISC) is designed to be run in six main steps (Spence and Waldon, 2001):

Step 1: Choose Chemicals of Concern

The main purpose of Step 1 is to choose the chemicals of concern for the risk assessment. The chemicals in Gaza wastewater are: Arsenic, Cadmium, Chromium, Copper, Cyanide, Lead, Mercury, Nickel, Phenols, Selenium, Vanadium and Zinc.

Step 2: Exposure Pathways

The wastewater from Gaza treatment plant is disposed into Wadi Gaza which ends into the sea or disposed directly into the sea through the emergency overflow. Therefore, the exposure routes that can be evaluated are:

1. Ingestion while swimming.
2. Dermal intake while swimming.

Step 3: Determine Receptor Point Concentrations

Receptor point concentrations are concentrations of chemicals of concern at seawater where the receptor might contact the media.

Step 4: Describe the Receptors

Receptor types of wastewater are:

1. Adult resident: refers to adults living permanently in GS and use the bathing areas close to the sewage outlets.
2. Child resident: represents the children living permanently in GS and use the bathing areas close to the sewage outlets.

Step 5: Calculate Risk

In this step the carcinogenic risk and hazard index will be calculated using the information entered. If the Calculate Clean-up Levels option was chosen, concentrations in the various sources will be calculated such that the target risk and hazard is not exceeded.

The first step in the risk calculation is to estimate the intake rate for each chemical of concern from each exposure rate. The intake rate, or dose, is expressed in milligrams per day of chemical taken into the body per unit body weight (mg/kg-d). Intake in surface water by ingestion while swimming is estimated as follows:

$$CADD = \frac{C_{ave}.IR_{sw}.ET.AFF.EF}{BW.365\frac{d}{yr}} x10^{-3}\frac{1}{ml} \qquad (9)$$

$$LADD = \frac{C_{ave}.IR_{sw}.ET.AFF.PC.EF.ED}{LT.BW.365\frac{d}{yr}} .10^{-3}\frac{1}{ml} \qquad (10)$$

where

C_{max} = maximum 7-year average contaminant concentration in surface water ($mg.l^{-1}$)

C_{ave} = time-averaged contaminant concentration in surface water over the exposure duration ($mg.l^{-1}$)

IR = water ingestion rate ($ml.l^{-1}$)

ET = exposure time for surface water ($hr.d^{-1}$)

AAF = chemical-specific oral-water absorption adjustment factor ($mg.mg^{-1}$)

Intake in surface water by dermal contact is estimated as follows:

$$CADD = \frac{C_{\max}.SA.AAF.Pc.ET.EF}{BW.365\frac{d}{yr}}.10^{-3}\frac{1}{cm^{3}} \qquad (11)$$

$$LADD = \frac{C_{ave}.SA.AFF.ET.PC.EF.ED}{LT.BW.365\frac{d}{yr}}.10^{-3}\frac{1}{cm^{3}} \qquad (12)$$

where

C_{max} = maximum 7-year average contaminant concentration in surface water ($mg.l^{-1}$)

C_{ave} = time-averaged contaminant concentration in surface water over the exposure duration ($mg.l^{-1}$)

SA = total skin surface area exposed to surface water (cm^2)

PC = chemical-specific skin permeability constant (cm/hr)

ET = exposure time for surface water (hr/day)

AAF = dermal-water chemical-specific absorption adjustment factor (mg/mg)

Step 6: View Results

This is the last step in RISC. It allows to view summary tables and charts of the overall risk and hazard index. The hazard index is estimated by adding the hazard quotients across all chemicals and routes. Hazard quotient is the ratio of exposure to toxicity for an individual pathway and chemical.

When calculating clean-up levels, Step 6 displays the table containing the concentrations for each media.

Chapter 6 Data Analysis: results and discussion

6.1 Analysis with ANN and comparison with expert opinion and judgment

The ANN models (see section 5.2.1) were used to characterize and prioritize the effective variables of the various categories. Linearity and normality of data are not pre-requisites for using ANN models. Hence, there is no need for transformation of data.

The expert opinion and judgment (Section 2.4.3) was undertaken for comparison purposes to examine the level of understanding and knowledge of the selected group about the actual baseline conditions of water sector. The formation of the group judgment was facilitated by means of a questionnaire (see Annex A1) interspersed with controlled opinion feedback. Knowledge about the ranking of variables in the five categories were collected from 30 experts based in GS (Tables A1.2.1, A1.2.2, A1.2.3, A1.2.4, A1.2.5). The group included the minister of environment, senior staff from the water, environment, industrial and agricultural authorities, managers of water services in municipalities, academia, senior staff of the World Bank in Gaza, specialized staff from non-governmental organizations representing the civil society and a Dutch expert in water issues.

The ANN and expert opinion results were compared for the categories of socio-economic, pollution pressure, state of water quality, impact and management responses variables.

6.1.1 Socio-economic driving forces variables

The data of groundwater abstraction (Table A2.1.1) and socio-economic driving forces (Table A2.1.3) were applied to create the ANN model. The socio-economic driving forces (Section 4.3) were: population (Populat), income per capita (Inccap), landuse (Lanuse), tourism (Tourism), access to safe water supply (Wsupply), wastewater system coverage (WWCov), storm water system coverage (StoWCov), water consumption per capita (WcpCap), water price (Wprice) , efficiency in revenue collection (EfRevCo), agriculture water consumption (AgWCon), gender empowerment (GenEmp**),** water awareness and education (WAwEd) and unaccounted for water (UFW).

The variables representing The socio-economic driving forces were considered as the possible input variables whilst the target output variable was the water abstraction (WAbstract). The MLP network can be represented by the following compact form:

{WAbstrac} = ANN [Populat, Inccap, Lanuse, Tourismt, WSupply, WWCov, StoWCov, WCpCap, Wprice, EfRevCo, AgWCon, GendEmp, WAwEd, UFW] (1)

A schematic diagram of this network is given in Figure 6.1.

Results and discussion:

The types of networks considered are: MLP (3 and 4 layers), RBF, GRNN, and Linear. During the analysis, 678 networks were tested. The best optimal ANN model found is MLP (3 layers) with 7 hidden nodes (Figure 6. 2) and a minimal error of 0.08809 compared with the other types of ANN networks (Table 6.1). The model has very good performance in verification with regression ratio (S.D. ratio) of 0.045 and the RMS errors for training, verification and testing are small and close which indicates that the data sub-sets are from the same population (Table 6.2). In addition, the correlation coefficient is higher than 99% for training, verification and testing which shows an excellent agreement between the actual observed and predicted water abstraction (Figure 6.3). The model training error for the independent cases is shown in Figure 6.4. It graphs the RMS error of the network against epochs during iterative training of the back propagation training algorithms. In addition, it plots separate lines for the RMS error on the training and verification sub-sets of the independent cases at the end of the last iterative training run. The graph indicates that the range of RMS error of independent cases for both training and verification is very small.

Table 6.1 RMS Error in various neural networks- socio-economic variables

Network	RMS Error
RBF	0.654313
GRNN	0.510853
Linear	0.481441
MLP (4 layers)	0.203141
MLP (3 layers)	0.08809

Table 6.2 Regression statistical parameters for the target output (WAbstrac) - socio-economic variables

	Tr. WAbstrac	Ve. Wabstrac	Te. Wabstrac
Data Mean	3.990667	2.83	7.96
Data S.D.	5.563164	2.152708	13.40202
Error Mean	0.03561	-0.01592	-0.2827
Error S.D.	0.2494362	0.09687	0.5936371
Abs E. Mean	0.1883892	0.07994	0.3848977
RMS Error	0.2436	0.08809	0.6015
S.D. Ratio	0.04484	0.045	0.04429
Correlation	0.998997	0.9997398	0.9990293

Legend: Tr: Training, Ve: Verification, Te: Testing

Table 6.3 Sensitivity analysis of independent input variables- socio-economic variables

	Populat	Inccap	Lanuse	Tourism	WSupply	WWCov	StoWCov	WCpCap	Wprice	AgWCon	GendEmp	UFW
Rank	6	2	5	1	3	8	7	11	10	4	12	9
Error	0.837	1.2166	1.1024	1.7644	1.152	0.5103	0.76445	0.3512	0.3805	1.11521	0.3365	0.4361
Ratio	3.435	4.9945	4.5257	7.2434	4.7293	2.095	3.13822	1.4417	1.5619	4.57814	1.3814	1.7904
Rank	5	1	12	2	7	8	10	4	9	3	6	11
Error	0.466	0.5538	0.0507	0.5534	0.2289	0.2253	0.10564	0.5273	0.1191	0.54281	0.4118	0.0619
Ratio	5.293	6.2871	0.5749	6.2816	2.5985	2.5577	1.19921	5.986	1.3516	6.16197	4.6751	0.703

Table 6.4 Ranking of input variables via expert opinion and judgment- socio-economic variables

	Populat	Inccap	Lanuse	Tourism	WSupply	WWCov	StoWCov	WCpCap	Wprice	EfRevCo	AgWCon	GendEmp	UFW
Rank	1	6	8	12	7	5	11	3	4	9	2	13	10

The ANN sensitivity analysis of socio-economic variables in verification phase (Table 6.3) indicates that income per capita is the most important socio-economic driving force followed by Tourism. The remaining effective socio-economic driving forces according to their rank in the verification phase are: agricultural water consumption, water consumption per capita, population, gender empowerment, water supply, wastewater coverage, water price, storm water coverage, unaccounted for water and land use. The ANN model removed one input variable due to its low sensitivity which is efficiency in revenue collection. The results of the ANN model and expert opinion (Table 6.4) are similar only in ranking the fifth variable which is water supply whilst they differ in ranking the remaining variables.

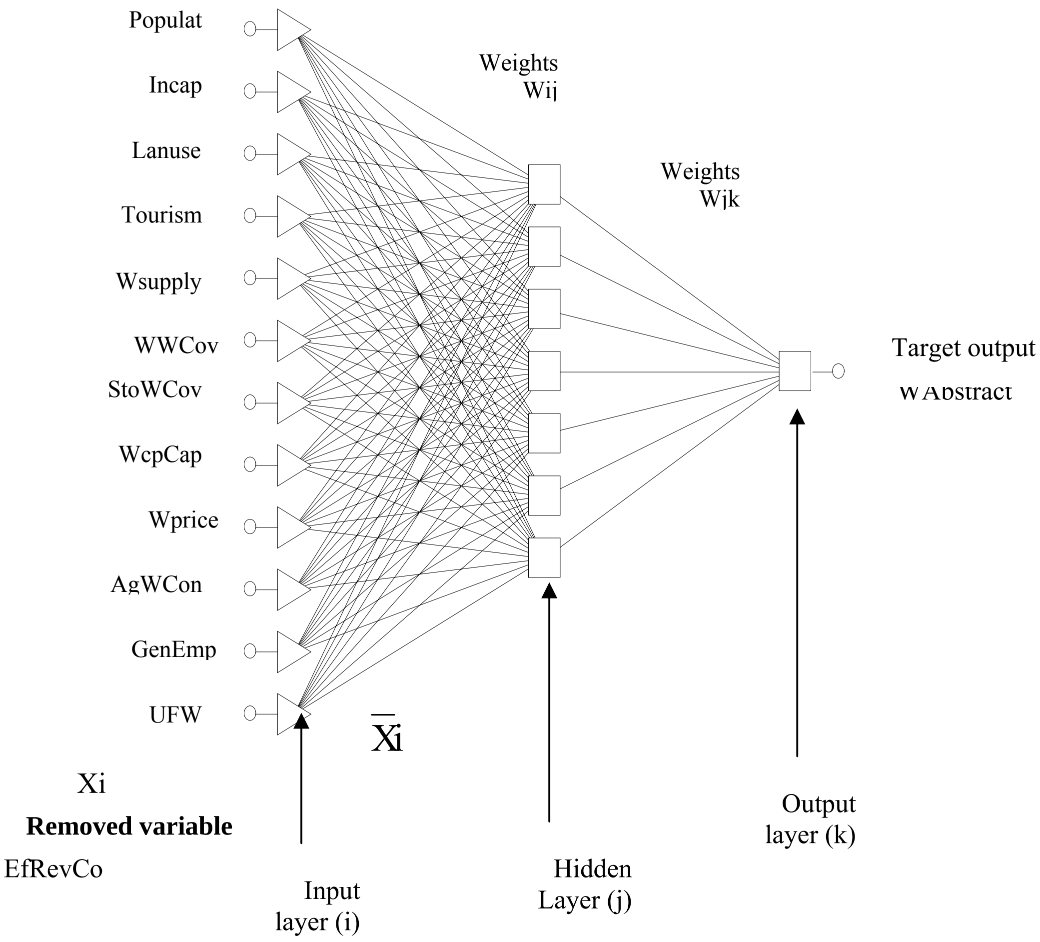


Figure 6.1 MLP Network (three layers), socio-economic variables

Legend:

WAbstract: Water abstraction from coastal aquifer measured in hm^3.y^{-1}
Populat: Population measured in numbers
Inccap: Income per capita measured in Euro.y^{-1}
Lanuse: Landuse measures the ratio of urban to agricultural areas
Tourism: Tourism measured by number of guest days
Wsupply: Access to safe water supply measured in percentage
WWCov: Wastewater system coverage measured in percentage
StoWCov: Storm water system coverage measured in percentage
WcpCap: Water consumption per capita measured in l.cap^{-1}.d^{-1}
Wprice: Water price measured in Euro.m^{-3}
EfRevCo: Efficiency in revenue collection measured in percentage
AgWCon: Agriculture water consumption measured in hm^3.y^{-1}
GenEmp: Gender empowerment measured in percentage
UFW: Unaccounted for water measured in percentage

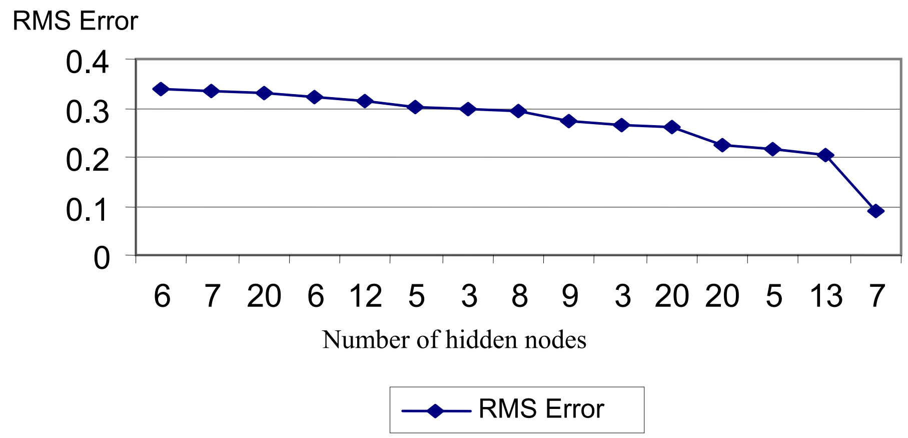


Figure 6.2 RMS Error versus number of hidden nodes-
socio-economic variables

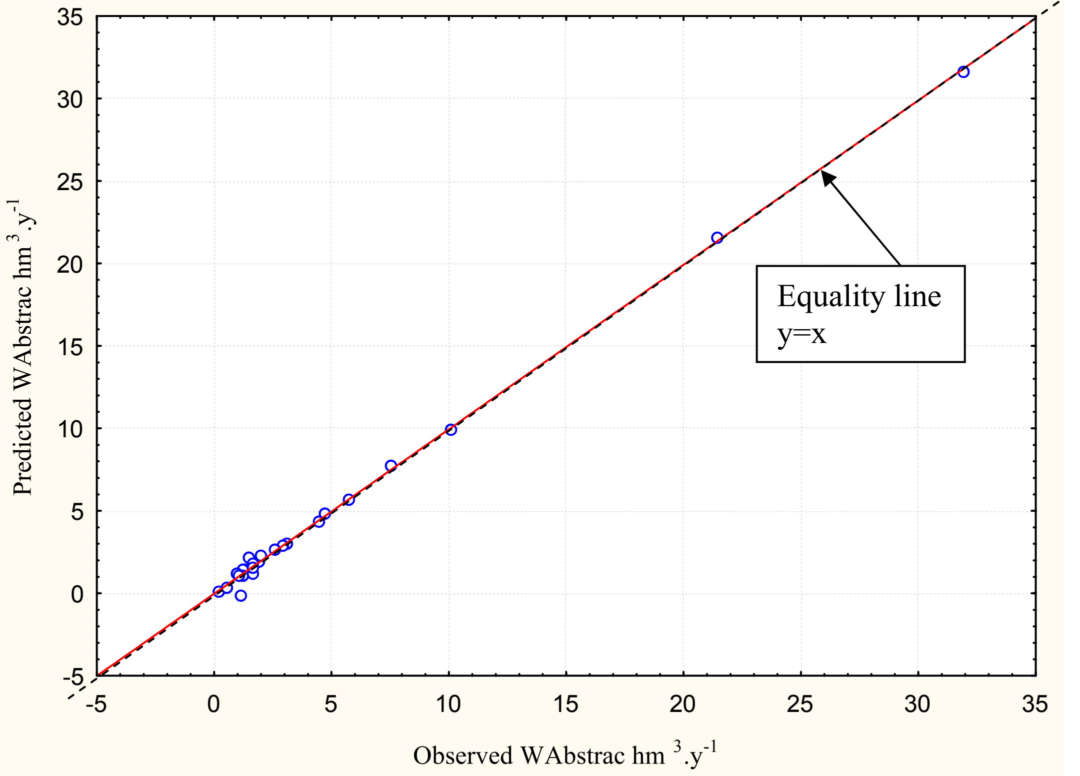
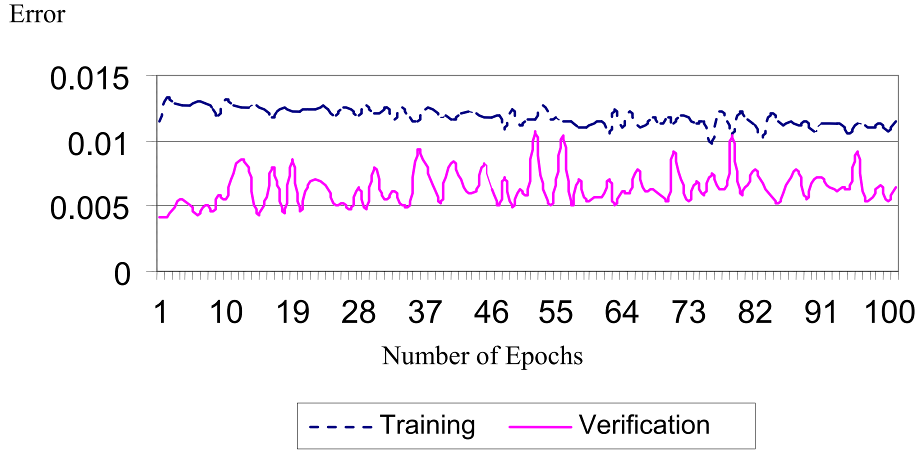


Figure 6.3 Predicted WAbstrac versus Observed WAbstrac -
socio-economic variables, y = -0.0251+0.9971*x

Figure 6.4 Training- Verification Error graph for cases- socio-economic variables



6.1.2 Pollution pressure variables

The Total Dissolved Solids data (Table A2.1.2) and pollution pressure data (Table A2.1.4) were used to create the ANN model . The point and non-point pollution pressures (Section 4.3) were: hazardous wastes (HazWas), generation of domestic wastewater (DomWW), pesticides (Pesticid), chemical ferrtilizers (ChemFer), organic fertilizers (OrgFert), petrol stations (PetrolS), domestic solidwaste (DomSW), industrial wastewater (IndWW), Carbon dioxide (CO_2), seawater intrusion (SWInt). The pollution variables were considered as the possible input variables whilst the target output variable was the groundwater quality represented by TDS. The MLP network can be represented by the following compact form:

{TDS} = ANN [HazWas, DomWW, Pesticid, ChemFer, OrgFert, PetrolS, DomSW, IndWW, CO_2, SWInt] (2)

A schematic diagram of this network is given in Figure 6.5.

Results and discussion:

The types of networks considered are: MLP (3 and 4 layers), RBF, GRNN, and Linear. The best optimal ANN model found is MLP (3 layers) with 3 hidden nodes (Figure 6.6). The error in this model of 2.465 which was the least compared with the other types of ANN networks (Table 6.5). The model had excellent performance in verification with regression ratio (S.D. ratio) of 0.004697 and the RMS errors for training, verification and testing are relatively small and close which indicates that the data sub-sets are from the same population (Table 6.6). In addition, the correlation coefficient was higher than 99% for training, verification and testing which indicated an excellent agreement between the actual observed and predicted TDS (Figure 6.7).

The model training error for the independent cases (Figure 6.8) graphed the RMS error of the network against epochs during iterative training of the back propagation training algorithms. The graph explains that the range of RMSE of independent cases for both training and verification is small.

The ANN sensitivity analysis of pollution variables in verification phase (Table 6.7) indicates that domestic wastewater is the most pressing pollution source followed by domestic solid waste. The remaining pollution variables according to their ranking in the verification phase are: Carbon dioxide, hazardous waste, seawater intrusion, chemical fertilizers, organic fertilizers and industrial wastewater. The ANN model removed two input variables due to their low sensitivity which are pesticides and petrol stations. The results of the ANN model and expert opinion (Table 6.8) are similar only in ranking the industrial wastewater (IndWW) variable whilst they differ in ranking the remaining variables.

Table 6.5 RMSE in various neural networks - pollution variables

ANN Network type	RMSE	R^2
RBF	444.5	0.6113619
GRNN	296.5	0.7269483
Linear	30.2	0.9979
MLP (4 layers)	12.63	0.99967
MLP (3 layers)	2.465	0.999997

Table 6.6 Regression statistical parameters for the output (TDS) - pollution variables

	Tr. TDS	Ve. TDS	Te. TDS
Data Mean	1529	1212	2139.6
Data S.D.	706.3431	444.0524	649.405
Error Mean	1.044467	1.611686	1.286557
Error S.D.	2.765549	2.085743	2.51634
Abs E. Mean	2.125859	1.631181	1.85367
RMS Error	2.869	2.465	2.592
S.D. Ratio	0.003915	0.004697	0.003875
Correlation	0.999993	0.999997	0.999993

Legend: Tr: Training, Ve: Verification, Te: Testing

Table 6.7 Sensitivity analysis of independent input variables- pollution variables

	HAZWAS	DOMWW	CHEMFERT	ORGFERT	DOMSW	INDWW	CO_2	SWINT
Rank	4	1	6	7	2	8	3	5
Error	288.3788	652.232	36.34392	30.83359	614.7751	25.67261	583.4891	78.28383
Ratio	116.9743	264.5631	14.74209	12.50695	249.3696	10.41351	236.6791	31.75406

Table 6.8 Ranking of input variables via expert opinion and judgment- pollution variables

	HazWas	DomWW	Pesticid	ChemFer	OrgFert	PetrolS	DomSW	IndWW	CO_2	SWInt
Rank	5	2	9	3	6	7	4	8	10	1

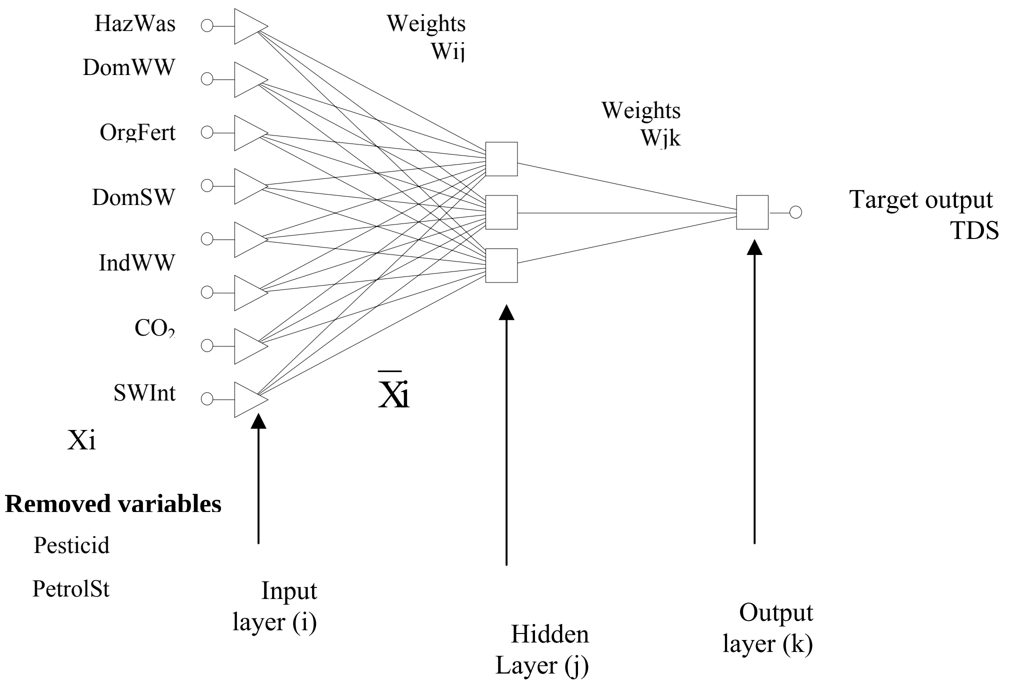


Fig. 6.5 MLP Network (three layers)- pollution variables

Legend:
TDS: Total Dissolved Solids measured in milligram per liter ($mg.l^{-1}$)
HazWas: Hazardous wastes measured in tons per day ($t.d^{-1}$)
DomWW: Generation of domestic wastewater measured in million cubic meters per year ($hm^3.y^{-1}$)
Pesticid: Pesticides measured in metric tons per year ($t.y^{-1}$)
ChemFer: Chemical fertilizers measured in tons per year ($t.y^{-1}$)
OrgFert: Organic fertilizers measured in tons per year ($t.y^{-1}$)
PetrolS: Petrol stations measured in numbers
DomSW: Domestic solid waste measured in tons per day ($t.d^{-1}$)
IndWW: Industrial Wastewater measured in million cubic meters per year ($hm^3.y^{-1}$)
CO_2: Carbon dioxide measured in parts per million (ppm)
SWInt: Seawater intrusion measured in million cubic meters per year ($hm^3.y^{-1}$)

Figure 6.6 RMSE versus number of hidden node -pollution variables

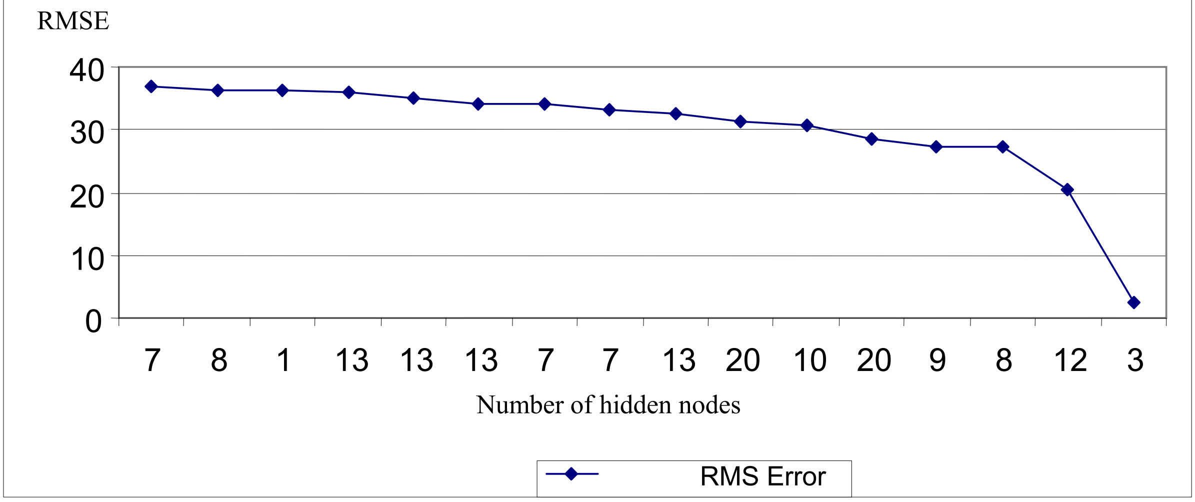


Figure 6.7 Predicted TDS versus Observed TDS- pollution varaibles, y = 1.0915+1.0001*x

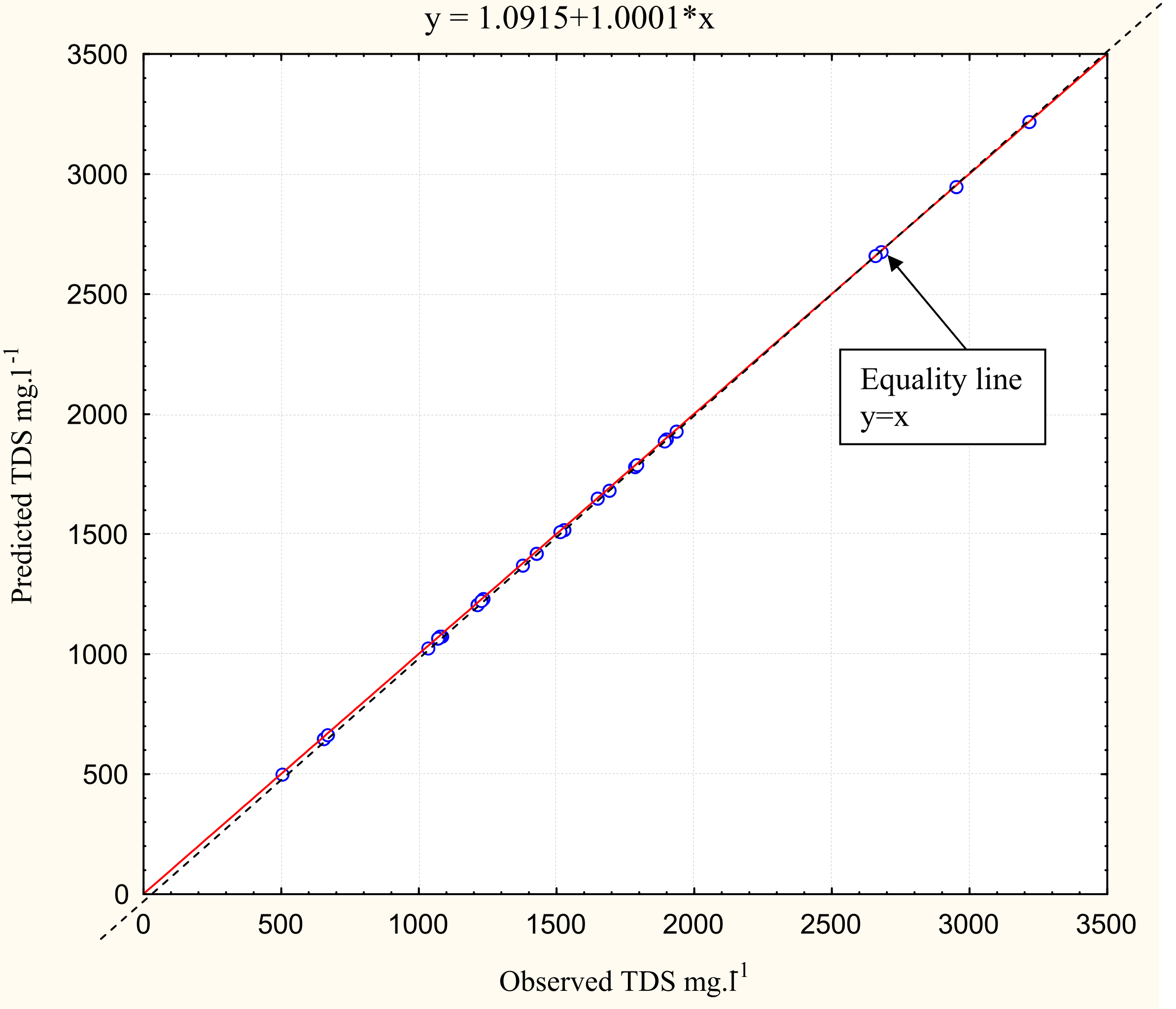
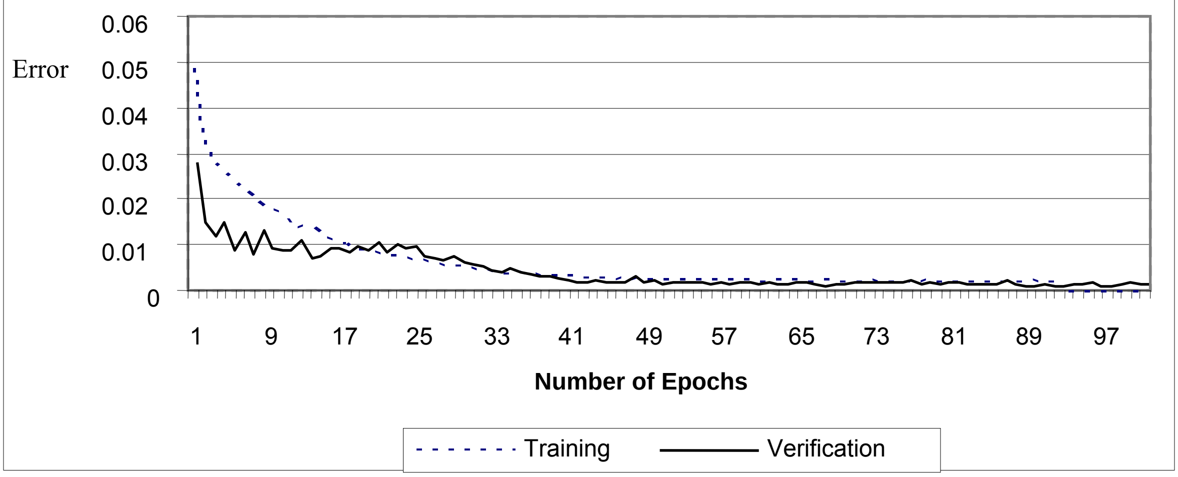


Figure 6.8 Training- Verification Error graph for cases-pollution variables



6.1.3 State of water quality variables

Groundwater abstraction data (Table A2.1.1) and water quality parameters (Table A2.1.5) were applied to create the ANN model. The water quality parameters (Section 4.3) were: Nitrate (NO_3), Chloride (Cl), Sodium (Na), Calcium (Ca), Magnesium (Mg), Potassium (K), floride (F), Sulfate (SO_4), hydrogen ion concentration (pH) , Alkalinity (Alkalinity), and total coliforms (T-Coli).

The water quality variables were considered as the possible input variables whilst the target output variable was the water abstraction (WAbstrac).

The ANN network can be represented by the following compact form:

{WAbstrac}= ANN [NO_3, Cl, Na, Ca, Mg, K, F, SO_4, pH, Alkalinity, T-Coli] (3)

A schematic diagram of this network is given in Figure 6.9.

Results and discussion:

The types of networks considered are: MLP (3 and 4 layers), RBF, GRNN, and Linear. During the analysis, 697 networks were tested. The best optimal ANN model found is MLP (3 layers) with 6 hidden nodes (Figure 6.10) and a minimal error of 0.3125517 compared with the other types of ANN networks (Table 6.9). The model has very good performance in verification with regression ratio (S.D. ratio) of 0.0468047 and the correlation coefficient is higher than 96% for training, verification and testing (Table 6.10) which shows an excellent agreement between the actual observed and predicted water abstraction (Figure 6.11). The model training error for the independent cases is shown in Figure 6.12. The graph presents that the range of RMS error of independent cases for both training and verification is small.

The ANN sensitivity analysis of water quality variables in both training and verification phases (Table 6.11) indicates that Chloride and Nitrate are the most important and effective factors influencing the attractiveness of groundwater users. The ANN model removed nine input variables due to their low sensitivity which are Sodium, Calcium, Magnesium, Potassium, Fluoride, Sulfate, hydrogen ion concentration, Alkalinity, and Total Coliforms. The results of the ANN model and expert opinion (Table 6.12) are similar only in ranking the first and second priority variables which are Nitrate and Chloride.

Table 6.9 RMS Error in various neural networks – state variables

Network Type	RMS Error
GRNN	3.312591
RBF	3.085885
Linear	2.149379
MLP (4 layers)	1.169872
MLP (3 layers)	0.3125517

Table 6.10 Regression statistical parameters for the target output (WAbstrac) – state variables

	Tr. WAbstrac	Ve. WAbstrac	Te. WAbstrac
Data Mean	5.244667	4.202	2.826
Data S.D.	9.045404	3.544146	2.7149
Error Mean	0.2928929	-0.2751	1.15001
Error S.D.	2.420605	0.1658827	4.240479
Abs E. Mean	1.453928	0.2750907	2.327411
RMSE	2.357	0.3125517	3.963
S.D. Ratio	0.2676061	0.0468047	1.561929
Correlation	0.9637625	0.9989866	0.9841797

Legend: Tr: Training, Ve: Verification, Te: Testing, WAbstrac: Water Abstraction

Table 6.11 Sensitivity analysis of independent input variables– state variables

Phase	Result	NO3	CL
Training	Rank	2	1
	Error	8.077049	9.226894
	Ratio	3.427129	3.915013
Verification	Rank	1	2
	Error	6.713201	2.549773
	Ratio	21.47869	8.157926

Table 6.12 Ranking of input variables via expert opinion and judgment– state variables

	NO_3	Cl	Na	Ca	Mg	K	F	SO4	pH	Alkalinity	T-Coli
Rank	1	2	5	6	10	11	3	9	7	8	4

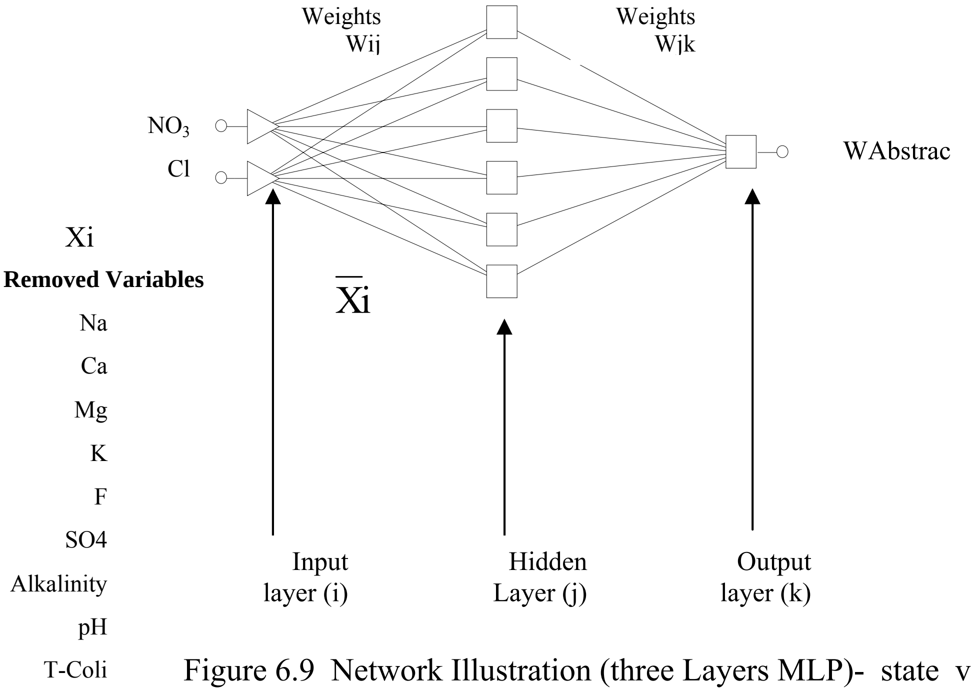


Figure 6.9 Network Illustration (three Layers MLP)- state variables

Legend:

WAbstrac:	Groundwater Abstraction measured in $hm^3.y^{-1}$
NO_3:	Nitrate measured in milligrams per liter ($mg.l^{-1}$)
Cl:	Chloride measured in milligrams per liter ($mg.l^{-1}$)
Na:	Sodium measured in milligrams per liter ($mg.l^{-1}$)
Ca:	Calcium measured in milligrams per liter ($mg.l^{-1}$)
Mg:	Magnesium measured in milligrams per liter ($mg.l^{-1}$)
K:	Potassium measured in milligrams per liter ($mg.l^{-1}$)
F :	Floride measured in milligrams per liter ($mg.l^{-1}$)
SO4:	Sulfate measured in milligrams per liter ($mg.l^{-1}$)
pH:	Hydrogen Ion concentration. It is measured by logarithmic scale
Alkalinity:	Alkalinity measured in milligrams per liter ($mg.l^{-1}$)
T-Coli:	Total Coliforms measured in numbers/100ml.

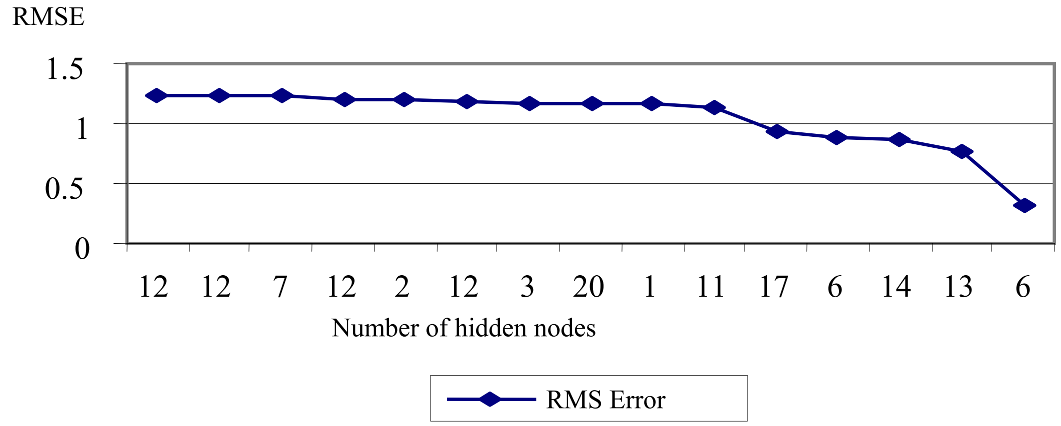


Figure 6.10 RMS Error versus number of hidden nodes- state variables

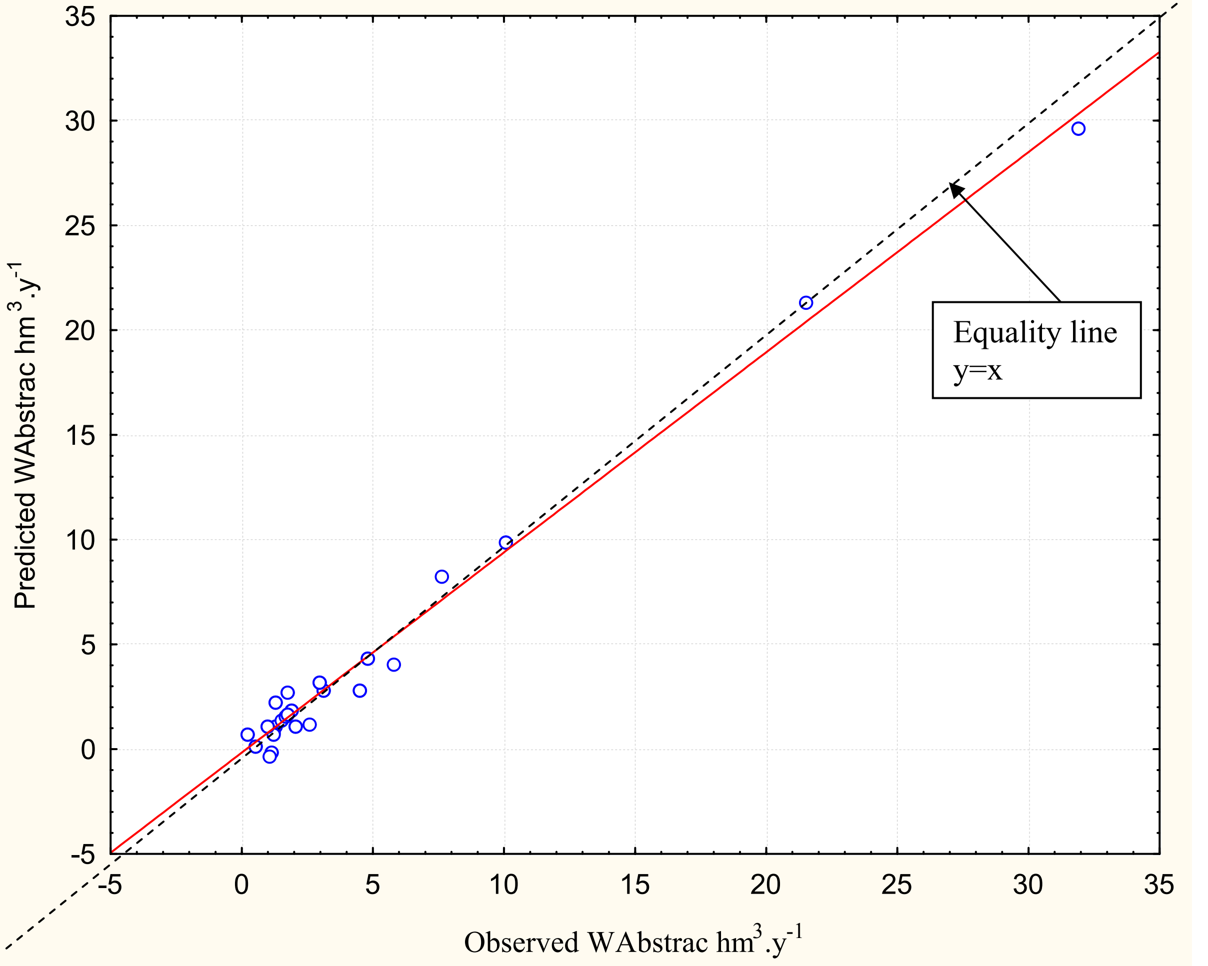
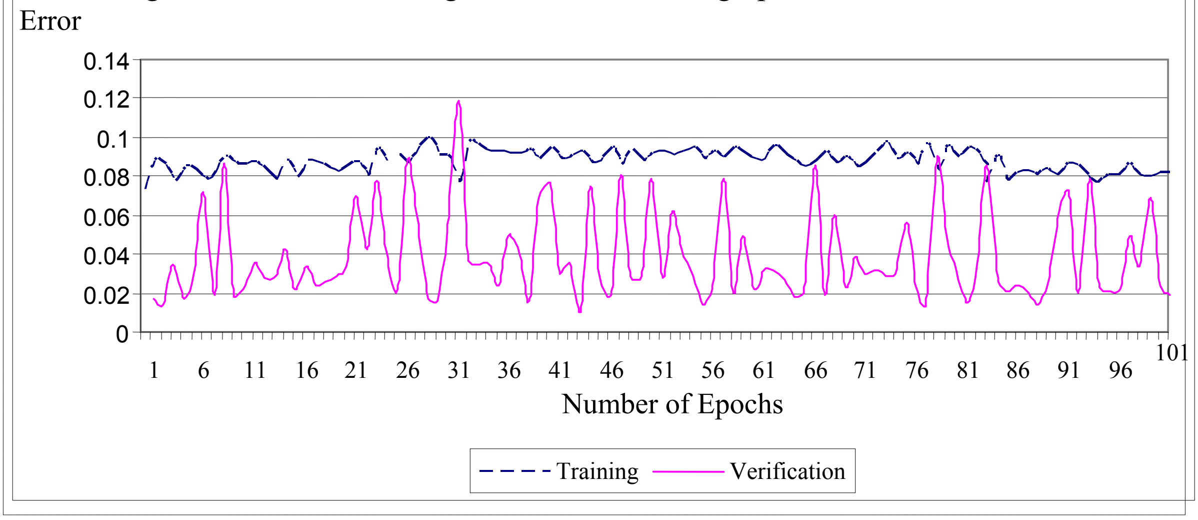


Figure 6.11 Predicted WAbstrac versus Observed WAbstrac- state variables

$y= 0.5941+0.9465*x$

Figure 6.12 RMS Training- Verification Error graph for cases- state variables



6.1.4 Ecological and public health impact variables

Water abstraction data (Table A2.1.1) from the coastal aquifer and ecological and public health impacts (Table A2.1.6) were employed to create the ANN model. The impacts (Section 4.3) were: loss of productivity (LosProd), loss of wetlands (LosWet), morbidity (Morbid). The variables representing these impacts were considered as the possible input variables whilst the target output variable was the water abstraction (Wabstrac) from the coastal aquifer.

The ANN network can be represented by the following compact form

{WAbstrac} = ANN [LosProd, LosWet, Morbid] (1)

A schematic diagram of this network is given in Figure 6.13

Results and discussion:

The types of networks considered are: MLP (3 and 4 layers), RBF, GRNN, and Linear. During the analysis, 716 networks were tested. The best optimal ANN model found is MLP (3 layers) with 6 hidden nodes (Figure 6.14) and a minimal error of error 0.2219 compared with the other types of ANN networks (Table 6.13). The model has very good performance in verification with regression ratio (S.D. ratio) of 0.0823 and the correlation coefficient is higher than 97% for training, verification and testing (Table 6.14) which shows an excellent agreement between the actual observed and predicted water abstraction (Figure 6.15). The model training error for the independent cases is shown in Figure 6.16. The graph explains that the range of RMS error of independent cases for both training and verification is small.

The ANN sensitivity analysis of impact variables in both training and verification phases Table 6.15 presents that Morbidity is the most important and effective factors influencing the attractiveness of groundwater users. The results of the ANN model and expert opinion (Table 6.16) are similar in ranking the three impact variables.

Table 6.13 RMS Error in various neural networks – impact variables

Network Type	RMS Error
GRNN	2.522
Linear	1.13
RBF	0.5685
MLP (4 layers)	0.2247
MLP (3 layers)	0.2219

Table 6.14 Regression statistical parameters for the target output (WAbstrac) – impact variables

	Tr. WABSTR	Ve. WABSTR	Te. WABSTR
Data Mean	4.790667	2.398	5.992
Data S.D.	7.890342	2.950114	8.761611
Error Mean	0.09094	-0.1185	-0.8032
Error S.D.	1.882434	0.2427953	1.3246
Abs E. Mean	1.164754	0.1906085	0.8085548
RMSE	1.676	0.2219	1.387
S.D. Ratio	0.2385744	0.0823	0.1511823
Correlation	0.9735649	0.9966807	0.9996463

*Legend**:** Tr: Training, Ve: Verification, Te: Testing, WAbstrac: Water Abstraction*

Table 6.15 Sensitivity analysis of independent input variables– impact variables

	LOSPROD	LOSWET	MORBID
Rank	3	2	1
Error	2.235163	2.533221	6.675943
Ratio	1.227521	1.39121	3.666336
Rank	2	3	1
Error	0.7240716	0.1968992	3.165742
Ratio	2.92706	0.7959652	12.79751

Table 6.16 Ranking of input variables via expert opinion and judgment– impact variables

	LosProd	LosWet	Morbid
Rank	2	3	1

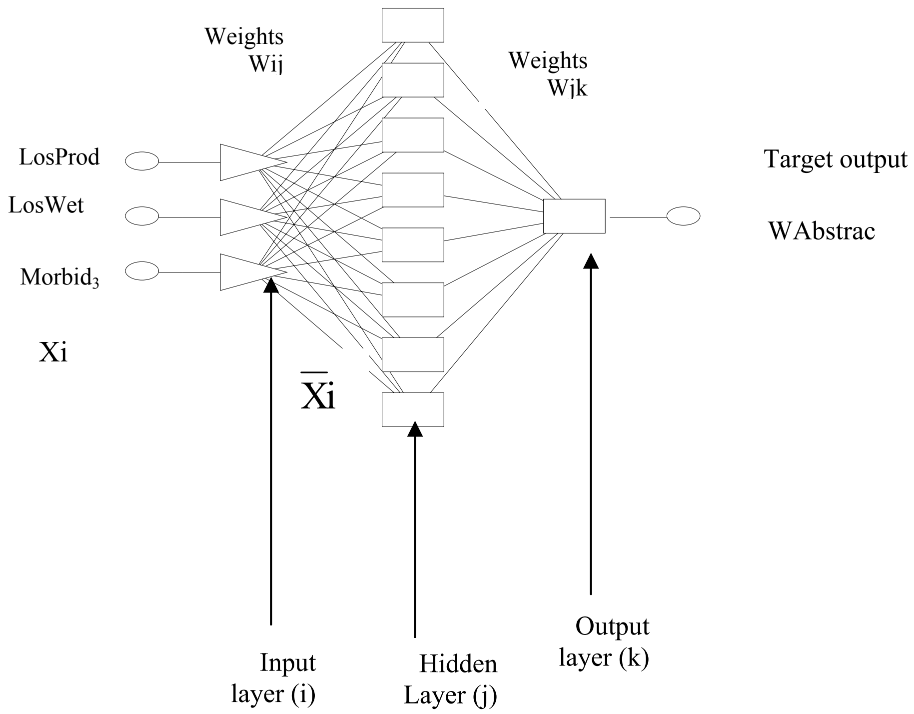


Figure 6.13 Network Illustration (three Layers MLP)- impact variables

Legend:

WAbstrac:	Groundwater Abstraction measured in $hm^3.y^{-1}$
LosProd	Loss of productivity measured in tons per year ($t.y^{-1}$)
LosWet:	Loss of wetland measured in hectars per year ($hectar.y^{-1-}$)
Morbid:	Morbidity measured by number

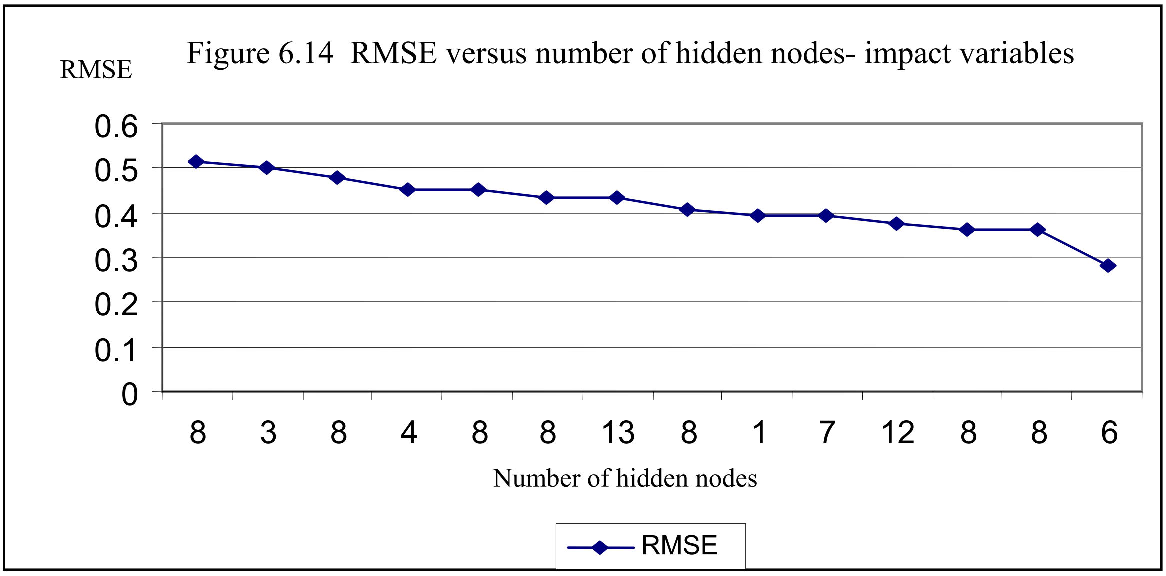


Figure 6.14 RMSE versus number of hidden nodes- impact variables

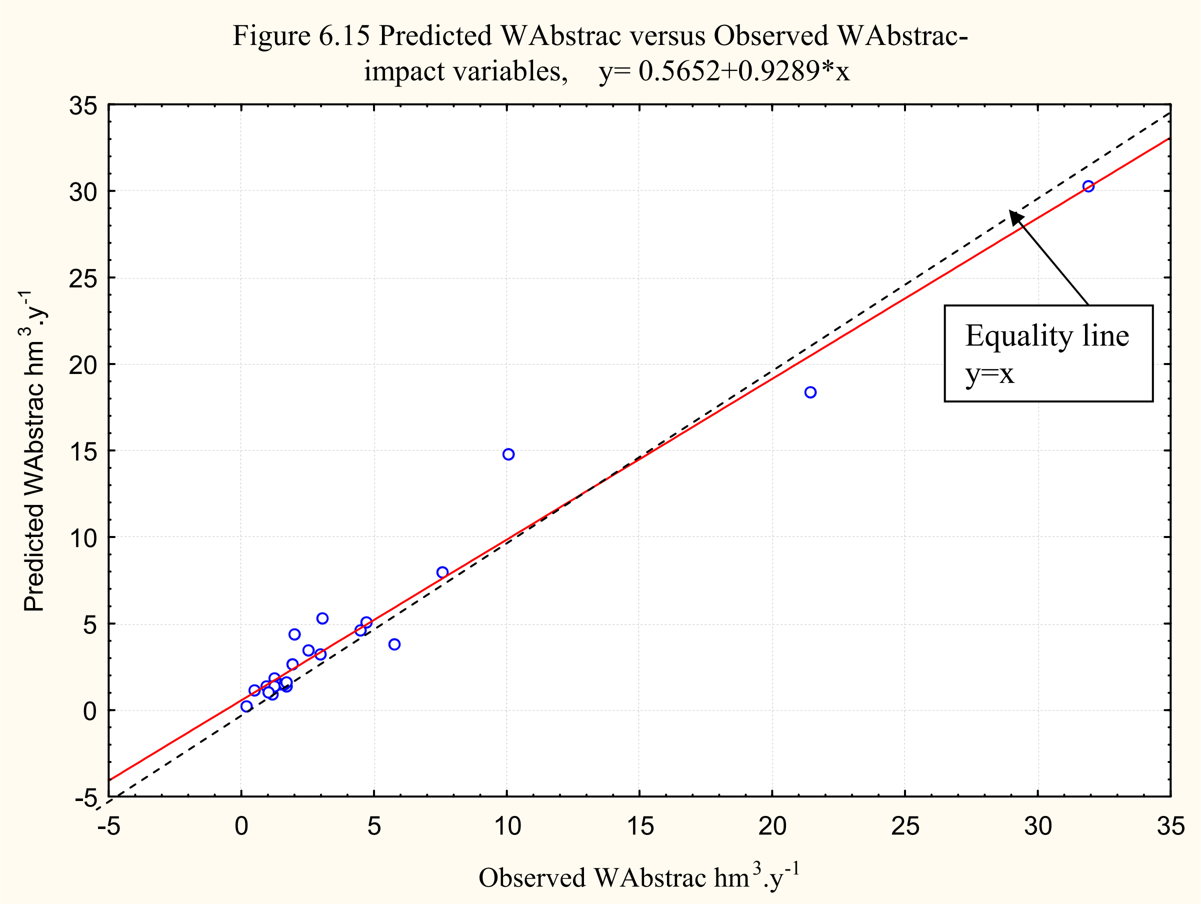
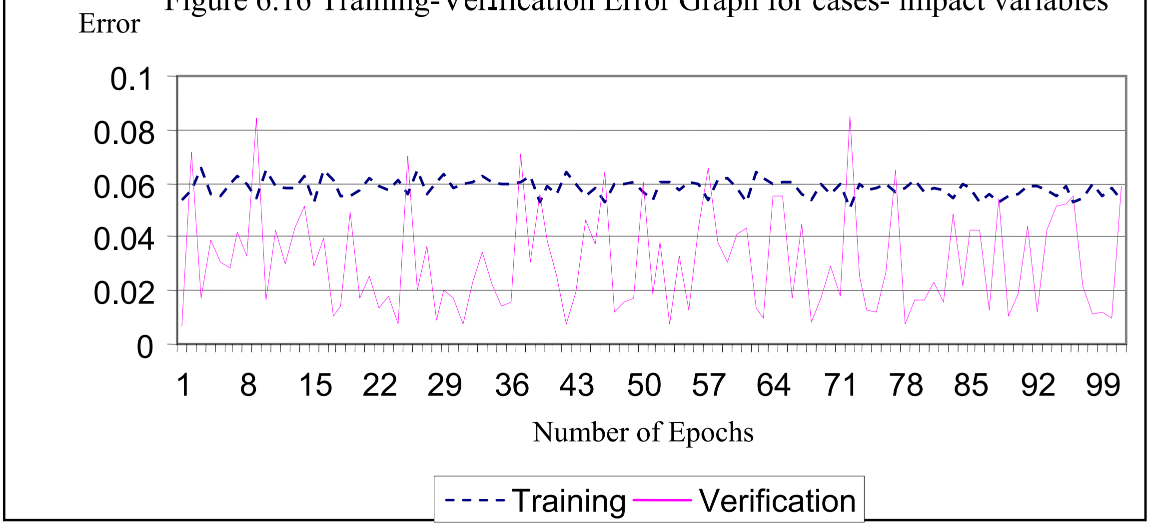


Figure 6.15 Predicted WAbstrac versus Observed WAbstrac- impact variables, y= 0.5652+0.9289*x

Figure 6.16 Training-Verification Error Graph for cases- impact variables



6.1.5 Management response variables

The data of water abstraction (Table A2.1.1) and water management interventions were applied (Table A2.1.7) to create the ANN model. The management interventions undertaken by the water administrations (Section 4.3) included: brackish water desalination (BrWDes), storm water harvesting (StoWHa), importation of water and regional conveyance (ImpW), treated wastewater (TreatWW), efficiency in water irrigation (EfWIrrig), efficiency in urban water supply (EfUWSN), efficiency of information system (EfInS), water awareness and education (WAwar) and seawater desalination (SWD). The variables representing these management interventions were considered as the possible input variables whilst the target output variable was the water abstraction (Wabstrac) from the coastal aquifer.

The ANN network can be represented by the following compact form:

{WAbstrac} = ANN [BrWDes, StoWHa, ImpW, TreatWW, EfWIrrig, EfUWSN, EfInS, WAwar, SWD] (1)

A schematic diagram of this network is given in Figure 6.17

Results and discussion:

The types of networks considered are: MLP (3 and 4 layers), RBF, GRNN and Linear. During the analysis, 698 networks were tested. The best optimal network found is MLP (3 layers) with 5 hidden nodes (Figure 6.18) and a minimal error of 0.2561 compared with the other types of ANN networks (Table 6.17). The selected model has good performance in verification with regression ratio (S.D. ratio) of 0.2263636. The correlation coefficient is higher than 97% for training, verification and testing (Table 6.18) which indicates an excellent agreement between the observed and predicted water abstraction (Figure 6.19).

The network training error for the independent cases is shown in Figure 6.20. The graph shows that the range of RMS error of independent cases for both training and verification is small and has approximately a stable trend which is not anyhow increasing.

Table 6.17 RMS Error in various neural networks - management variables

Network	RMS Error
RBF	1.682691
Linear	0.968414
GRNN	0.547683
MLP (4 layers)	0.518656
MLP (3 layers)	0.2561

Table 6.18 Regression statistical parameters for the target output (WAbstrac) - management variables

	Tr. WABSTRAC	Ve. WABSTRAC	Te. WABSTRAC
Data Mean	5.64	2.756	3.086
Data S.D.	9.004928	1.263756	3.925599
Error Mean	0.1790797	-0.01157	0.2890466
Error S.D.	1.270074	0.2860685	1.936971
Abs E. Mean	0.7870616	0.1910796	1.527902
RMS Error	1.24	0.2561	1.756
S.D. Ratio	0.1410421	0.2263636	0.4934206
Correlation	0.9900086	0.9943014	0.9707078

Legend: Tr: Training, Ve: Verification, Te: Testing

Table 6.19 Sensitivity analysis of independent input variables- management variables

	BRWDES	STOWHA	IMPORT	TREATWW	EFWIRRIG	EFUWSN	EFINS	WAWAR	SWD
Rank	2	4	9	1	6	5	7	8	3
Error	4.158889	1.547513	1.267242	5.725366	1.441349	1.462439	1.330914	1.28698	1.674237
Ratio	3.353923	1.247987	1.021963	4.617204	1.162372	1.17938	1.073312	1.037881	1.350183
Rank	2	5	8	1	7	4	6	9	3
Error	1.327138	0.589662	0.32748	1.439469	0.376946	0.818565	0.534952	0.281463	1.177033
Ratio	5.181523	2.302209	1.278575	5.620096	1.471703	3.195911	2.088605	1.098912	4.595471

Table 6.20 Ranking of input variables via expert opinion and judgment- management variables

	BRWDES	STOWHA	IMPORT	TREATWW	EFWIRRIG	EFUWSN	EFINS	WAWAR	SWD
Rank	4	5	6	2	1	3	8	7	9

The ANN sensitivity analysis of water management variables in both training and verification phases (Table 6.19) indicates that reuse of treated wastewater is the most important intervention followed by desalination of brackish and sea waters. The remaining policy interventions according to their order in the verification phase are: efficiency of urban water supply, storm water harvesting, efficiency of information systems, efficiency in water irrigation, importation or regional conveyance of water and then water awareness and education. The results of the ANN model and expert opinion (Table 6.20) are similar only in ranking the fifth intervention which is storm water harvesting whilst they differ in ranking the remaining interventions.

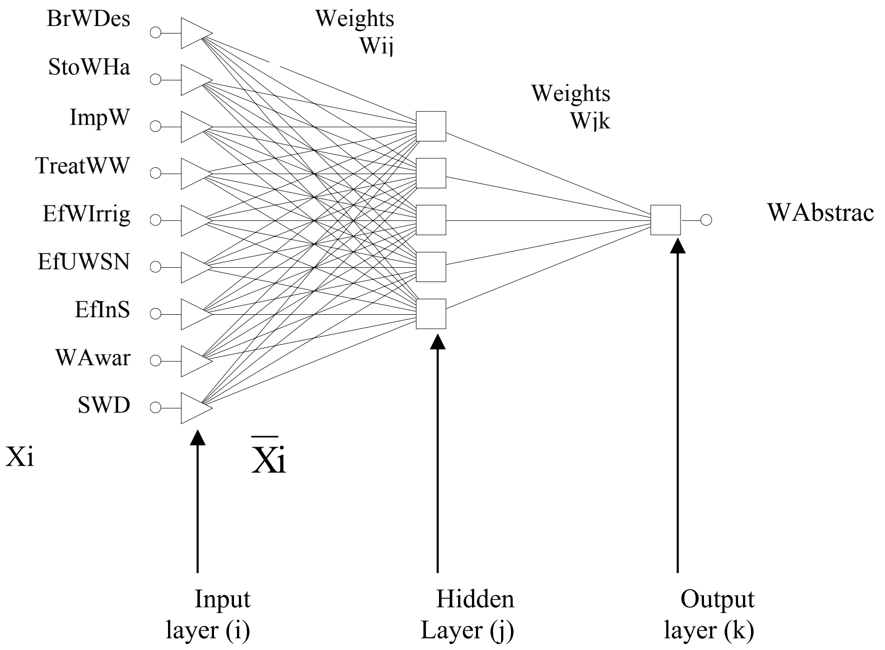


Figure 6.17 Network Illustration (three Layers) MLP)- management variables

Legend:

BrWDes:	Brackish water desalination measured in hm^3.y^{-1}
StoWHa	Storwater harvesting measured in hm^3.y^{-1}
ImpW:	Importation of water and regional conveyance measured in hm^3.y^{-1}
EfWIrrig:	Efficiency in water irrigation measured in percentage.
EfUWSN:	Efficiency in urban water supply measured in percentage.
EfInS:	Efficiency of information system measured in percentage.
WAwar :	Water awareness and education measured in number of people.
SWD:	Seawater desalination measured in hm^3.y^{-1}

Figure 6.18 RMSE versus number of hidden nodes- management variables

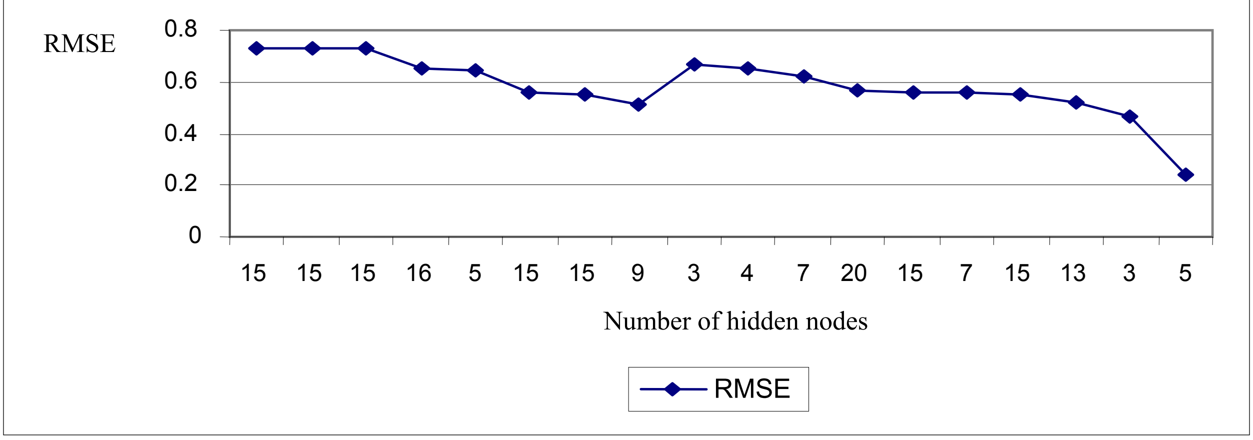
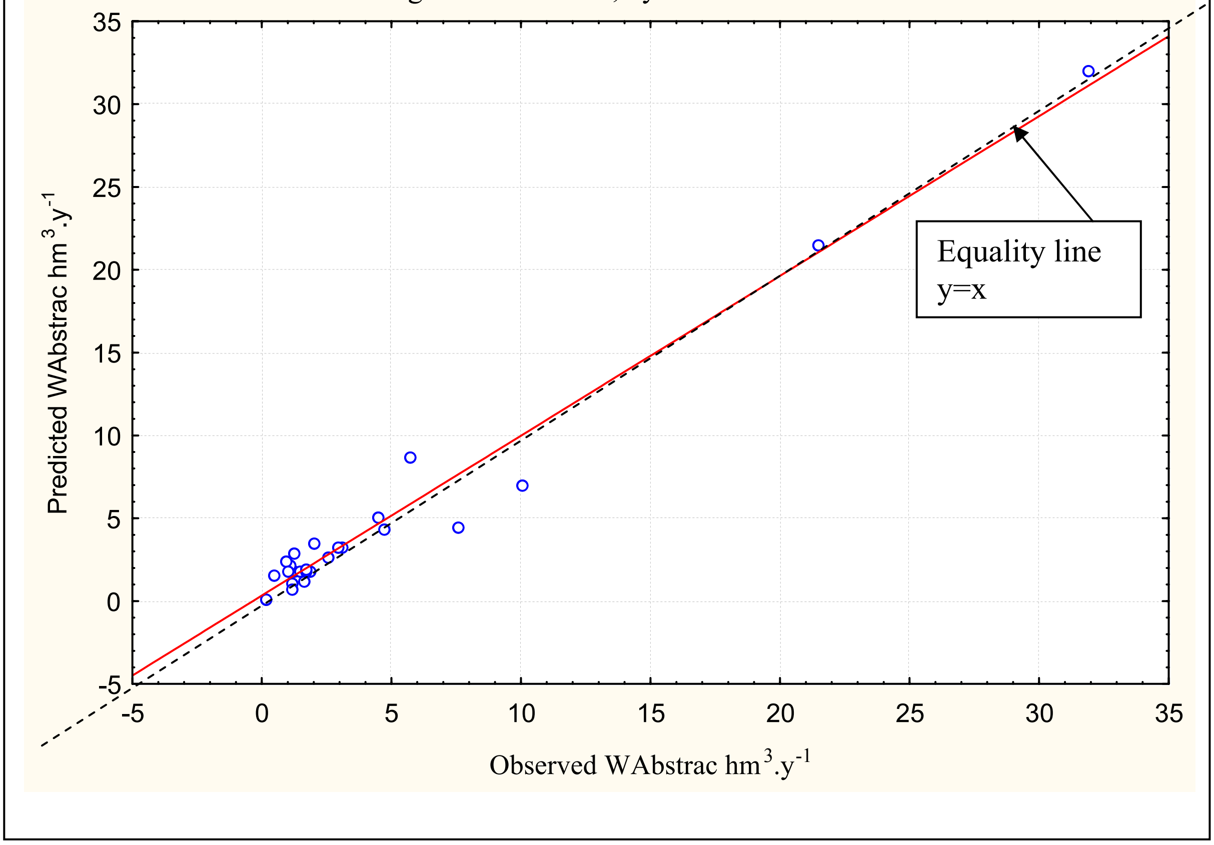


Figure 6.19 Predicted WAbstrac versus Observed WAbstrac- management variables, y = 0.3361+0.9646*x



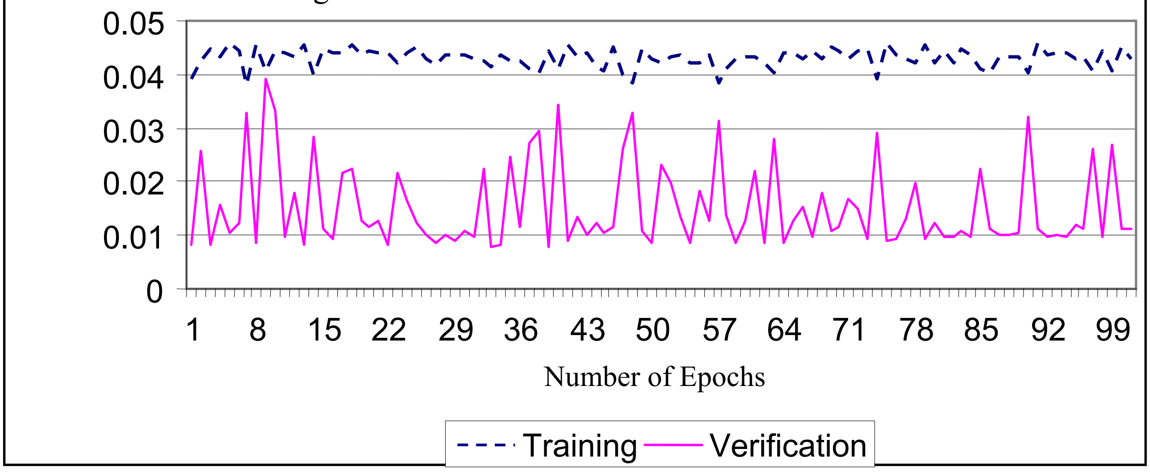
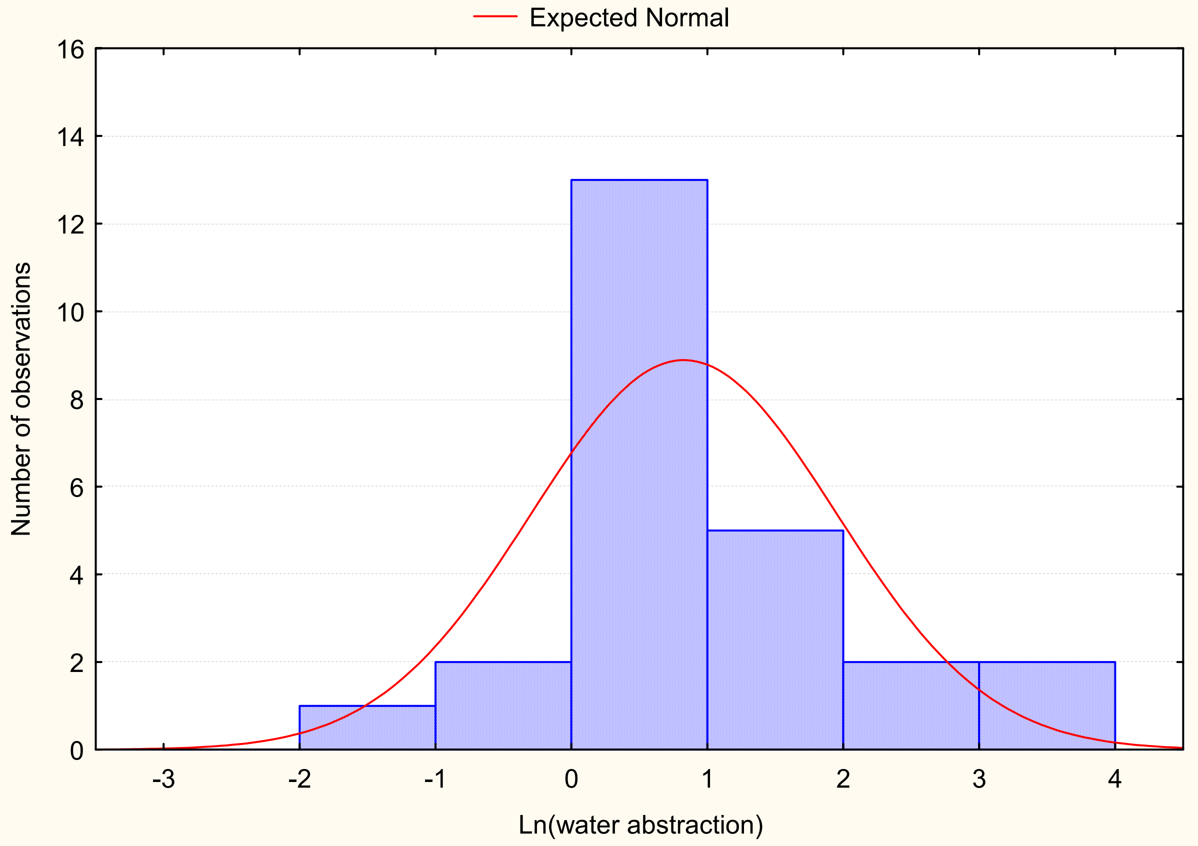


Figure 6.20 Training- Verification Error Graph for cases-management variables

6.2 Correlation Matrix

Correlation matrix analysis (Section 5.2.2) was undertaken to explore the direction, strength and significance of relationship between any two variables in the same category of data set. It is a pre-requisite to transform the specified variables with non-normal distribution in section 4.5. Transformation using the natural *logarithm* log (base e), where e = 2.718) is reasonably well for all intended variables. As an example the water abstraction variable shown in Figure 4.13 is transformed to ln (water abstraction) presenting normal distribution (Figure 6.21).

Figure 6.21 Histogram of water abstraction



Correlation matrix analysis was carried out for the categories of socio-economic, pollution , state of water quality, impact and management responses variables.

- **Socio-economic variables**

The socio-economic variables analyzed in the correlation matrix are: population, income per capita, land use, tourism, access to safe water supply, wastewater system coverage, storm water system coverage, water consumption per capita, water price, agriculture water consumption, gender empowerment and unaccounted for water.

Analysis and discussion:

Table 6.21 shows that ln(water abstraction) has significant and positive linear relationships with ln(storm water coverage), income per capita, ln(agriculture water consumption), ln(population), ln(unaccounted for water) and ln(tourism). The strength of positive correlation is the highest between water abstraction and storm water coverage and the lowest with tourism. Increase in income per capita, intensification of agriculture water consumption, growth of population, rise in the number of tourists are important factors influencing the water demand and abstraction of groundwater as the only available resource. The water abstraction increases in case that the unaccounted for water heightens due to the losses resulted from deficiencies and failures in the water system. The water abstraction increases with the rise in storm water coverage due to the water quality improvement resulted from aquifer recharge. This will attract various water users to pump more water to meet their requirements. Ln(water abstraction) has also a negative linear relationship with safe access to water supply. If water abstraction increases then the salinity increases resulting in less opportunities for users to access acceptable water quality.

There are positive linear relationships between ln(population) and, ln(tourism), ln(storm water coverage), income per capita, ln(unaccounted for water) and ln(land use). The Palestinian society is encouraged to increase its population if the income per capita increases, more employment opportunities are created due to the rise in the number of tourists, better storm water infrastructure, more urban areas designated for housing, and if water services are for free.

The income per capita has positive linear relationships with ln(storm water coverage), ln(tourism), ln(agriculture water consumption) and ln(unaccounted for water). Income of the people is associated with the increase of storm water coverage due to the improvement in water quality which promotes its utilization for domestic, agriculture and industrial uses. This will result in enhancing the public health and income. Increase in tourism and agriculture activities will increase the income per capita. The rise in unaccounted for water particularly the illegal connections lessens the expenditures of agriculture and industrial activities and results in increase in the income per capita.

Ln(land use) has significant and positive linear relationships with ln(wastewater coverage)and ln(tourism), and a negative linear relationship with ln(agriculture water consumption). The expansion of urban areas grows rapidly where sanitation infrastructure services are built, thus encouraging more tourists to visit GS. Agriculture water consumption decreases if urban areas encroach agriculture lands.

Ln(tourism) has positive linear relationships with ln(storm water coverage), ln(unaccounted for water) and ln(wastewater coverage). The number of visitors to GS will increase if the infrastructure services improve (i.e. increase in storm water and wastewater system coverage. The unaccounted for water will increase if the number of visitors increases due to the high losses from the growing water demand.

Access to safe water supply has a negative linear relationship with ln(unaccounted for water). If the leakage from water networks and illegal connections are high, this will limit the expansion of safe water supplies to un-served locations due to the current scarcity of water.

Ln(storm water system coverage) has positive linear relationships with ln(agriculture water consumption) and ln(unaccounted for water). The expansion of storm water infrastructure including collection and storage in reservoirs either for direct use in agriculture or for aquifer recharge has made additional good quality water available for use in agriculture. This has promoted farmers to utilize more agriculture lands resulting in digging more illegal wells and thus increase the agriculture water consumption. Water consumption per capita has a negative correlation with water price. If water tarrif increases then the domestic water consumption per capita decreases.

Ln(agriculture water consumption) has a positive linear relationship with ln(unaccounted for water). Agriculture water consumption increases due to weakness of control on meter registration and illegal connections.

Table 6.21 Correlation matrix - socio-economic variables

	ln (WAbstrac)	ln (Populat0	Inccap	ln (Lanuse)	ln (Tourism)	WSupply	ln (WWCov)	ln (StoWCov)	WCpCap	Wprice	ln (AgWCon)	GendEmp	ln (UFW)
ln(WAbstrac)	1.00												
ln(Populat)	0.77	1.00											
Inccap	0.86	0.77	1.00										
ln(Lanuse)	-0.03	0.48	0.10	1.00									
ln(Tourism)	0.66	0.86	0.66	0.44	1.00								
(WSupply)	-0.40	-0.33	-0.23	-0.08	-0.31	1.00							
ln(WWCov)	0.17	0.51	0.24	0.49	0.46	0.07	1.00						
ln(StoWCov)	0.89	0.81	0.92	0.20	0.65	-0.3[illegible]	0.28	1.00					
WCpCap	0.19	0.15	0.15	-0.01	0.18	-0.08	0.42	0.19	1.00				
Wprice	-0.03	-0.02	-0.14	-0.10	0.06	0.13	-0.15	-0.14	-0.64	1.00			
ln(AgWCon)	0.82	0.35	0.61	-0.42	0.24	-0.19	-0.05	0.62	0.08	0.12	1.00		
(GendEmp)	0.06	0.17	-0.03	0.14	0.15	0.02	0.34	0.01	-0.01	0.14	0.10	1.00	
ln(UFW)	0.69	0.63	0.54	0.11	0.58	-0.49	0.31	0.55	0.20	-0.15	0.50	0.15	1.00

Legend: Marked and underlined correlations are significant at p < .05000

- **Pollution variables**

The pollution pressure variables analyzed in the correlation matrix are: hazardous wastes, generation of domestic wastewater, chemical fertilizers, organic fertilizers, domestic solid wastes, industrial wastewater, CO_2 and seawater intrusion.

Results and discussion

Table 6.22 shows a significant and positive linear relationship between Carbon dioxide and Total Dissolved Solids. Carbon dioxide in the air will be built-up in rain water as carbonic acid which will break up in ground water to carbonates, thus increasing the TDS content.

There are significant positive linear relationships between ln(hazardous waste) and, ln(domestic wastewater), ln(domestic solid waste) and ln(industrial wastewater). The increase of domestic solid waste, wastewater and industrial wastewater increases the production of hazardous waste. Also, ln(hazardous waste) has linear positive relationship with seawater intrusion. The seawater is highly polluted from land-based pollution sources. When seawater intrusion increases, highly polluted seawater penetrates the interface with freshwater zone causing pollution of groundwater used later for domestic and industrial purposes. Thus, generating domestic and industrial wastewater and eventually makes hazardous waste as a by-product in treatment plants.

Ln(Domestic wastewater) has significant and positive linear relationships with ln(domestic solid waste), ln(industrial wastewater), and ln(seawater intrusion). Increase in domestic solid waste is associated with the increase in wastewater generation since the garbage produced at the screens in the treatment facilities are transferred to the solid waste sanitary landfills. Domestic wastewater increases with the increase in the industrial wastewater generation since the industrial facilities are connected to the urban wastewater systems immediately after pretreatment. The increase in the domestic wastewater generation indicates rise in groundwater abstraction and thus increase in seawater intrusion. The rise in the domestic wastewater production yields more sludge at the treatment facilities which may be used as organic fertilizer.

Ln(chemical fertilizers) has significant and positive linear relationships with ln(organic fertilizers), ln(solid waste), ln(industrial wastewater) and seawater intrusion. The use of chemical fertilizers is always associated with organic fertilizers since they are applied for the same agriculture land but with different proportions. If the chemical fertilizers are applied to plants, they demand additional irrigation water which implies more water abstraction, lowering water table and seawater intrusion. The production and use of chemical fertilizers generates solid and liquid waste.

There is a positive linear relationship between ln(organic fertilizers) and, ln(seawater intrusion), In(solid waste) and In (industrial wastewater). The application of organic fertilizers to agriculture land is associated with more water abstraction resulting in lowering the water table and seawater intrusion. Both solid waste and industrial wastewater produce organic fertilizers as by- products from the treatment process.

Ln(domestic solid waste) has positive linear relationships with ln(industrial wastewater) and ln(seawater intrusion). If industrial wastewater generation increases, then more garbage generates at the screens of treatment facilities to be transferred to sanitary landfills. Increase in domestic solid waste generation implies increase of groundwater use for the cleaning and maintenance of equipment and facilities. This results in lowering the water table and promotes seawater intrusion.

Ln(industrial wastewater) has a positive linear relationship with seawater intrusion. Increase of industrial wastewater generation is caused by more use of groundwater which results in lowering the water table and seawater intrusion.

Table 6.22 Correlation matrix - pollution variables

	TDS	in (HazWas)	ln (DomWW)	ln (ChemFert)	ln (OrgFert)	ln (DomSW)	ln (IndWW)	CO$_2$	SWIntr
TDS	1.00								
ln(HazWas)	-0.23	1.00							
ln(DomWW)	-0.22	0.96	1.00						
ln(ChemFert)	-0.02	0.30	0.32	1.00					
ln(OrgFert)	-0.14	0.34	0.35	0.96	1.00				
ln(DomSW)	-0.29	0.93	0.95	0.44	0.48	1.00			
ln(IndWW)	-0.25	0.86	0.91	0.60	0.63	0.92	1.00		
CO$_2$	0.99	-0.23	-0.22	-0.01	-0.14	-0.28	-0.24	1.00	
SWIntr	-0.20	0.75	0.71	0.54	0.62	0.77	0.73	-0.23	1.00

Legend: Marked and underlined correlations are significant at p < .05000

- **State of water quality variables**

The water quality variables analyzed in the correlation matrix are: Nitrate and Chloride.

Results and discussion

Table 6.23 shows a positive linear relationship between ln(water abstraction) and ln(Nitrate). The attractiveness of the farmers to use groundwater for agricultural activities increases if the water is more rich with Nitrate due to its high value for agriculture productivity. The association between water abstraction and Chloride is not significant but negative. The attractiveness of farmers to use groundwater is lessened due to the increase in Chloride concentration but they moved to grow more tolerant plants to salinity.

Table 6.23 Correlation matrix- state variables

	ln (WAbstrac)	ln (NO3)	CL
ln(WAbstrac)	1.00		
ln(NO3)	0.50	1.00	
CL	-0.17	0.26	1.00

Legend: Marked and underlined correlations are significant at p < .05000

- **Ecological and public health impact variables**

The ecological and public health impact variables analyzed in the correlation matrix are: loss in agriculture productivity, loss of wetlands and morbidity.

Results and discussion:

Table 6.24 presents significant and positive linear relationships between ln(water abstraction) on one hand, and ln(loss in agriculture productivity) and ln(morbidity) on the other hand. Increase in the loss of agriculture productivity is associated with increase of water abstraction due to growing salinization of soil resulted from the high Chloride concentration in groundwater. The water borne diseases grow in case of excessive water abstraction for various uses due to deteriorated water quality.

There is also a positive linear relationship between ln(loss in agriculture productivity) and ln(morbidity). The increase in the loss of agriculture productivity is associated with increase in morbidity due to the shortage of available food and malnutrition.

Table 6.24 Correlation matrix - impact variables

	ln (WAbstr)	ln (LosProd)	LosWet	ln (Morbid)
ln(WAbstr)	1.00	0.84	0.34	0.81
ln(LosProd)	0.84	1.00	0.23	0.48
LosWet	0.34	0.23	1.00	0.21
ln(Morbid)	0.81	0.48	0.21	1.00

Legend: Marked and underlined correlations are significant at p < .05000

- **Management response variables**

The management response variables analyzed in the correlation matrix are: brackish water desalination, storm water harvesting, importation of water and regional water conveyance, treated wastewater, efficiency in water irrigation, efficiency in urban water supply networks, efficiency of information system, water awareness and education and seawater desalination.

Results and discussion:

Table 6.25 reflects significant and positive linear relationships between ln(water abstraction) and, ln(storm water harvesting), efficiency of information system, treated wastewater and brackish water desalination. The strength of correlation is the highest between water abstraction and storm\water harvesting. The increase in storm water harvesting will improve the groundwater quality and attract water users to increase the water abstraction specially for agriculture purposes. Enhancing the efficiency of information system gives a better understanding and knowledge about the hydrogeology of the coastal aquifer. This supports decisions in the field of freshwater utilization and protection. Generation of treated wastewater increases with the increase in domestic water use extracted from municipal wells. Increase in desalination of brackish water will result in increase of groundwater abstraction due the loss of about 30 % as brine water. There is also a significant and negative relationship between ln(water abstraction) and ln(efficiency of urban water supply network). The decrease in the efficiency of water supply networks due to the high water losses requires more water abstraction to meet the requirements of various users.

Ln(brackish water desalination) has a negative linear relationship with ln(efficiency of urban water supply network). Lessening the physical losses and enhancing the water supply efficiency will result in lower production of brackish water to meet the demand of urban users.

Ln(storm water harvesting) has a negative linear relationship with ln(efficiency of urban water supply networks) and a positive linear relationship with ln(efficiency of information systems). The decrease in the efficiency of urban water supply forced people to construct cisterns in their houses to harvest rainfall water , thus increasing storm water harvesting. Improving the efficiency of information system identifies the best techniques for storm water harvesting and conservation.

Importation of water and regional water conveyance has a positive relationship with sea water desalination. A combination of policy measures including storm water harvesting, importation of water, efficiency of information systems, brackish water desalination and seawater desalination are required to bridge the current water gap (see Table 4.1) and to meet the growing demands.

Table 6.25 Correlation matrix- management variables

	ln (WAbstrac)	BrWDes	ln (StoWHa)	ImpW	TreatWW	ln (EfWIrrig)	ln (EfUWSN)	EfInS	ln (WAwEd)	SWD
ln(WAbstrac)	1.00									
BrWDes	0.51	1.00								
ln(StoWHa)	0.81	0.39	1.00							
ImpW	-0.03	-0.13	0.28	1.00						
TreatWW	0.56	0.08	0.35	-0.13	1.00					
ln(EfWIrrig)	0.07	0.18	-0.11	-0.13	-0.16	1.00				
ln(EfUWSN)	-0.73	-0.62	-0.54	0.08	-0.23	-0.05	1.00			
EfInS	0.71	0.29	0.52	0.30	0.35	0.07	-0.70	1.00		
ln(WAwEd)	-0.24	-0.12	-0.21	-0.03	0.08	-0.18	0.16	-0.21	1.00	
SWD	0.03	0.02	0.33	0.69	-0.13	-0.35	-0.20	0.32	-0.09	1.00

Legend: Marked and underlined correlations are significant at p < .05000

6.3 Multivariate Exploratory Techniques

6.3.1 Cluster Analysis

The cluster analysis (Section 5.2.3) was selected to organize observations and variables in the same category of data set, to a more meaningful groups so each group is more-or-less homogeneous (share properties in common) and distinct from other clusters. It was carried out for the categories of socio-economic, pollution, state of water quality, impact and management responses variables. Transformed variables were standardized, complete linkage of tree clustering was selected so that Euclidean distance between two clusters is determined by the distance of the furthest cases of these two clusters.

- **Socio-economic variables**

The socio-economic variables organized by the cluster analysis are: population, income per capita, land use, tourism, access to safe water supply, wastewater system coverage, storm water system coverage, water consumption per capita, water price, agriculture water consumption, gender empowerment and unaccounted for water.

Results and discussion

Figures 6.22 shows two distinct groups of variables. The first group of variables contains income per capita, storm water coverage, water abstraction, population, tourism, unaccounted for water, agriculture water consumption and water consumption per capita. It can be labeled as water abstraction. The second group of variables has land use, wastewater coverage, gender empowerment, access to safe water supply and water price. It can be labeled as land use.

Figure 6.23 indicates two dissimilar clusters of municipalities. The first cluster (right) consists of Beit Hannun, Beit Lahia, Nusseirat, Deir El-Balah, Rafah, Magazi, Zawaida, Abassan Kubra, El Bureij, Um Alnasser, Al-Zahra', Al-Mograga, Wadi Gaza, Al-Fukhari, Wadi Salga, Al-Musadar, Al-Bayuk, Khuza'a, Al-Shoka, Qarara, Abassan Jadida and Bani Suhaila. The second cluster of municipalities contains Jabalia, Khan Younis and Gaza.

Based on the magnitudes of the linkage distances in Figure 6.17 and Figure 6.18, the first cluster of municipalities is associated with the second group of variables whilst the second cluster of municipalities is associated with the first group of variables. Therefore, the first cluster of municipalities can be identified as "land use" cluster whilst the second cluster of municipalities is labeled as "water abstraction" cluster.

Figure 6.22 Tree diagram for variables- Socio-economic driving forces
Complete Linkage
Euclidean distances

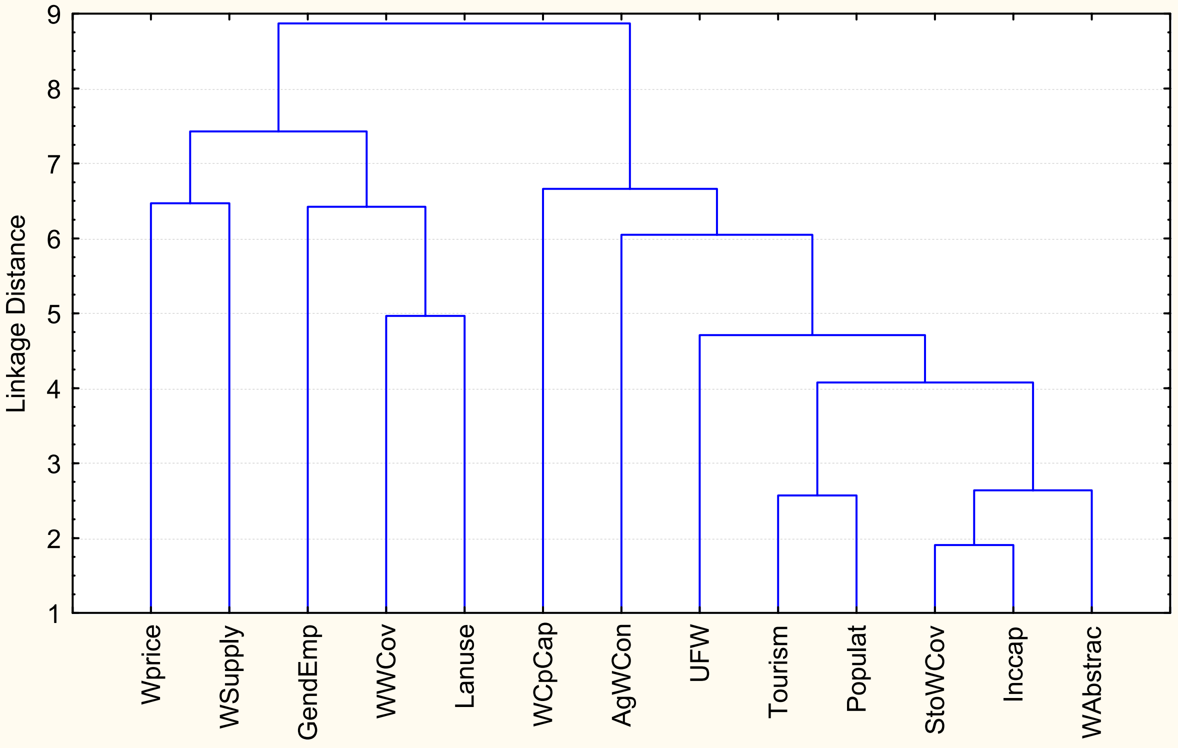
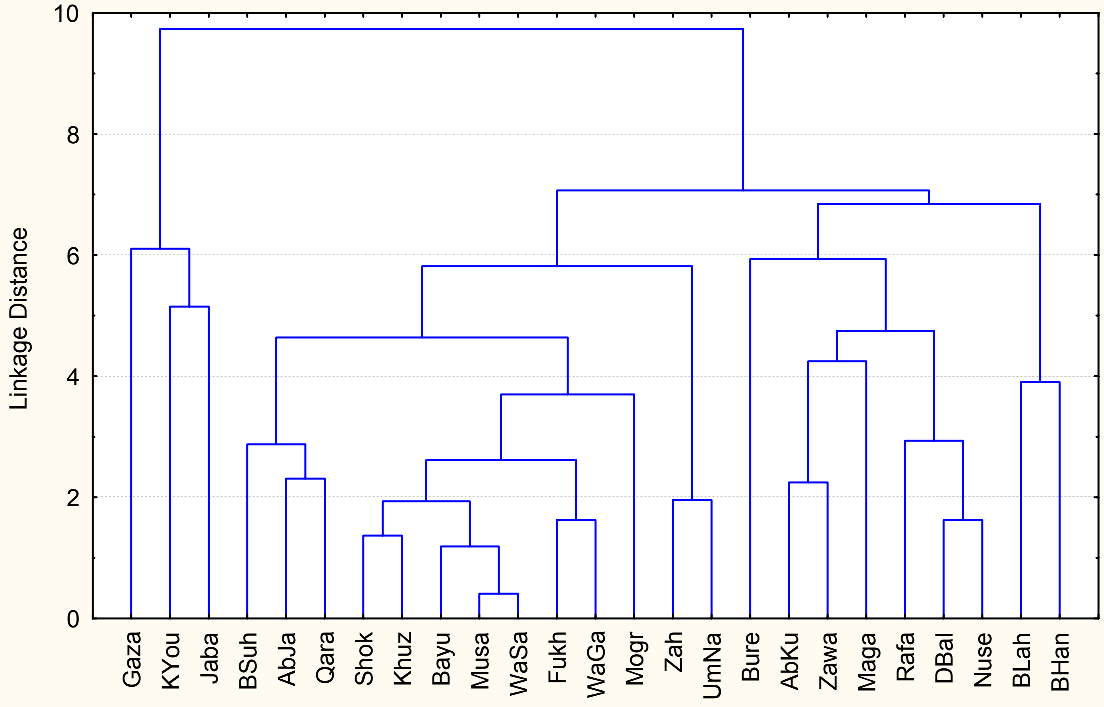


Figure 6.23 Tree diagram for cases- Socio-economic driving forces
Complete Linkage
Euclidean distances



- **Pollution variables**

The pollution pressure variables classified in the cluster analysis are: hazardous wastes, generation of domestic wastewater, chemical fertilizers, organic fertilizers, domestic solid wastes, industrial wastewater, CO_2 and seawater intrusion.

Results and discussion

Figures 6.24 presents two dissimilar groups of variables. The first group is formed by TDS and CO_2. It can be labeled as water quality. The second group has hazardous waste, domestic wastewater, domestic solid waster, industrial wastewater, seawater intrusion and chemical and organic fertilizers. It can be labeled as anthropogenic pollution.

Figure 6.25 indicates two dissimilar clusters of municipalities. The first cluster consists of municipalities contains Beit Hannun, Deir El-Balah, El Bureij, Zawaida, Abassan Kubra, Qarara, Beit Lahia, Rafah, Jabalia, Gaza and Khan Younis. The second cluster of municipalities includes Um Alnasser, Al-Zahra', Magazi, Al-Mograga, Al-Musadar, Al-Bayuk, Al-Fukhari, Wadi Gaza, Wadi Salga, Al-Shoka, Nusseirat, Bani Suhaila, Khuza'a, and Abassan Jadida.

Based on the magnitudes of the linkage distances, the first cluster of municipalities can be identified as "anthropogenic pollution" cluster whilst the second cluster of municipalities can be labeled as "water quality" cluster.

Figure 6.24 Tree diagram for variables- Pollution pressure
Complete Linkage
Euclidean distances

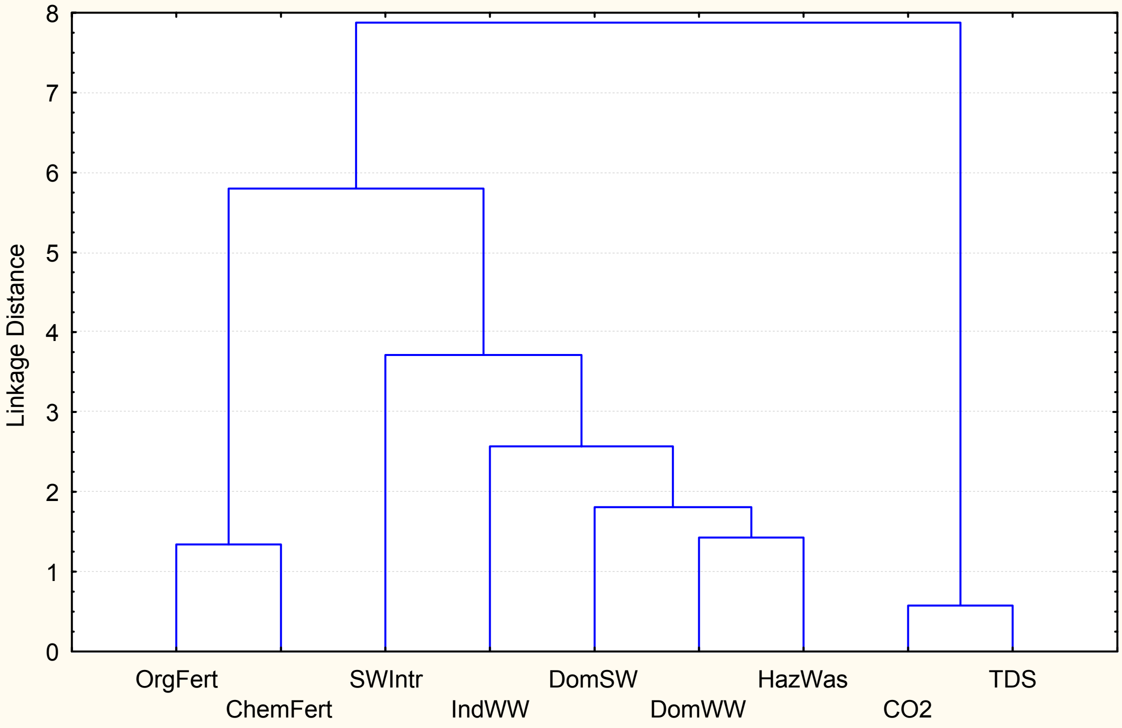
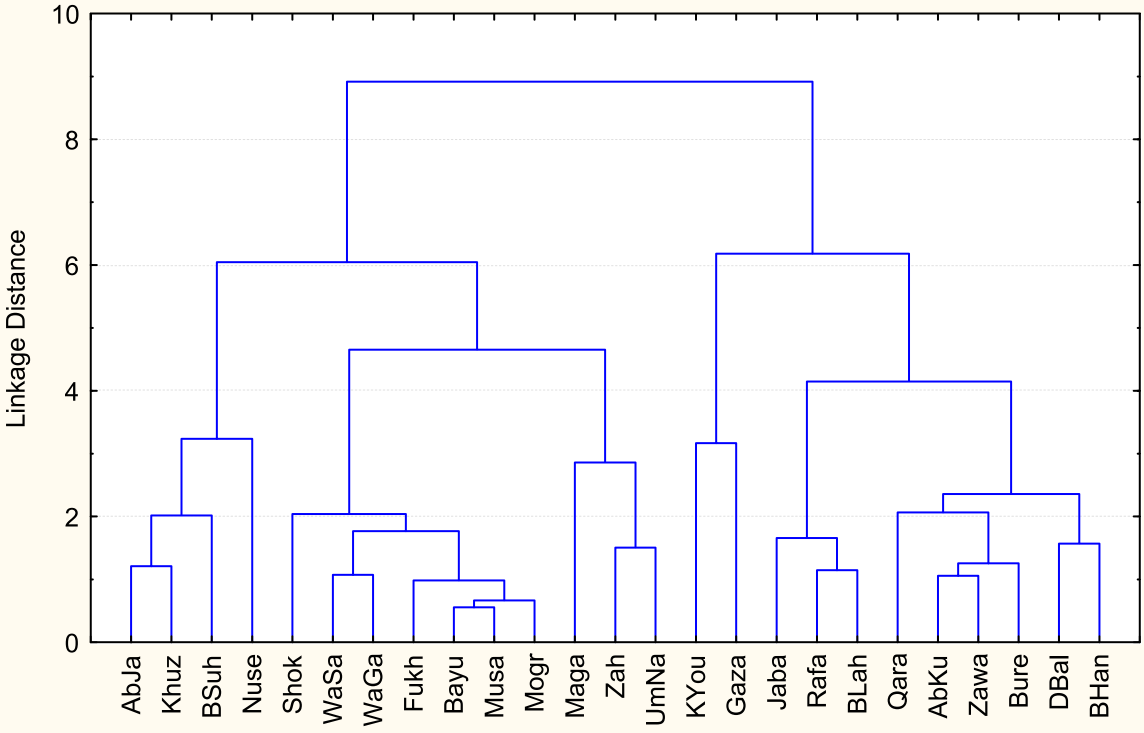


Figure 6.25 Tree diagram for cases- Pollution pressure
Complete Linkage
Euclidean distances



- **State of water quality variables**

The water quality variables classified in the cluster are: Nitrate and Chloride.

Results and discussion

Figures 6.26 explains two unlike groups of variables. The first group includes water abstraction and Chloride. It can be labeled as Nitrate concentration. The second group has only Chloride. It can be labeled as Chloride concentration.

Figure 6.27 indicates two dissimilar clusters of municipalities. The first cluster consists of Beit Hannun, Beit Lahia, Jabalia, Rafah, Gaza and Khan Younis.

The second cluster of municipalities includes Um Alnasser, Al-Zahra', Al-Mograga, Wadi Gaza, Nusseirat, Qarara, Deir El-Balah, Magazi, Wadi Salga, Al-Musadar, Zawaida, El Bureij, Al-Fukhari, Al-Bayuk, Al-Shoka, Bani Suhaila, Abassan Kubra, Khuza'a and Abassan Jadida.

Based on the magnitudes of the linkage distances, the first cluster of municipalities can be identified as "Nitrate" cluster whilst the second cluster of municipalities can be labeled as "Chloride" cluster. The high Nitrate content (see Figure 4.6) in the first group is due to improper management of wastewater and excessive use of agriculture fertilizers and pesticides. The considerable Chloride concentration in the second group is due to either seawater intrusion in coastal municipalities or the salt transport across the eastern border with Israel since the upstream agriculture land in Negev have been irrigated by brackish water. (see Figure 4.5)

Figure 6.26 Tree diagram for variables- State of water quality
Complete Linkage
Euclidean distances

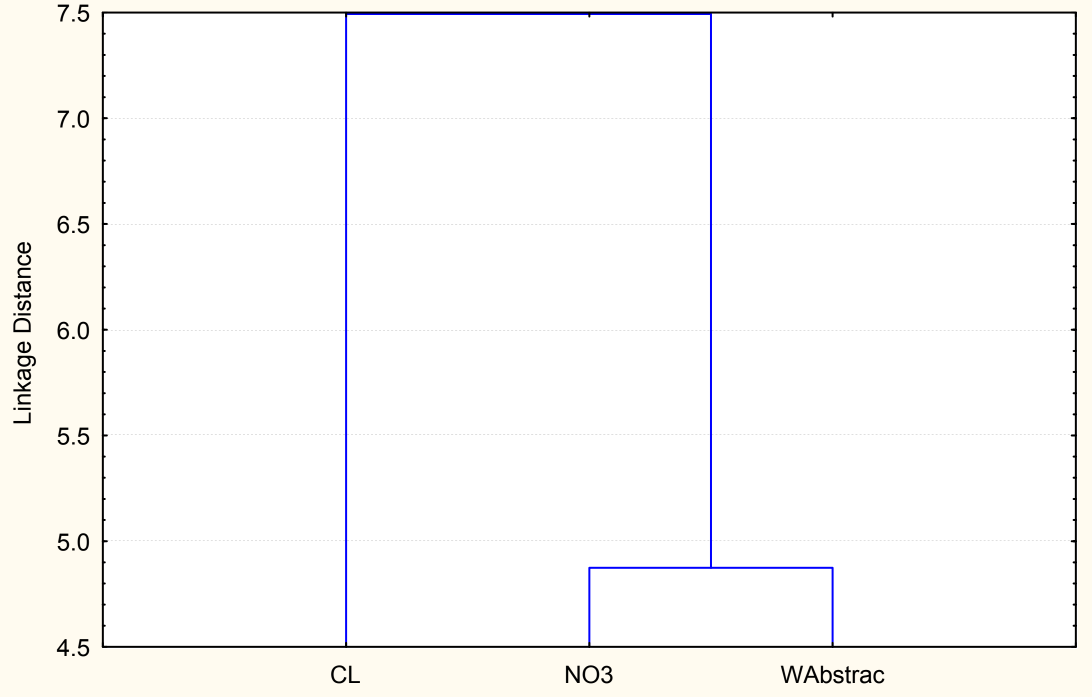
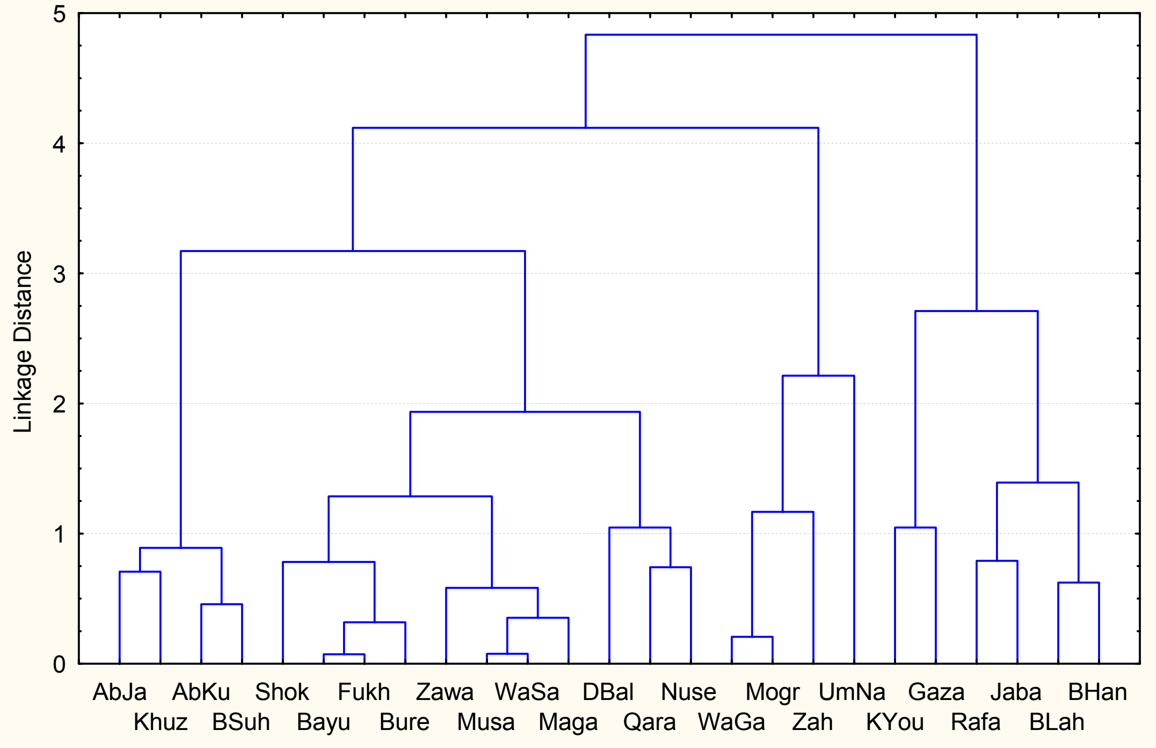


Figure 6.27 Tree diagram for cases- State of water quality
Complete Linkage
Euclidean distances



- **Ecological and public health impact variables**

The ecological and public health impact variables organized in the cluster analysis are: loss in agriculture productivity, loss of wetlands and morbidity.

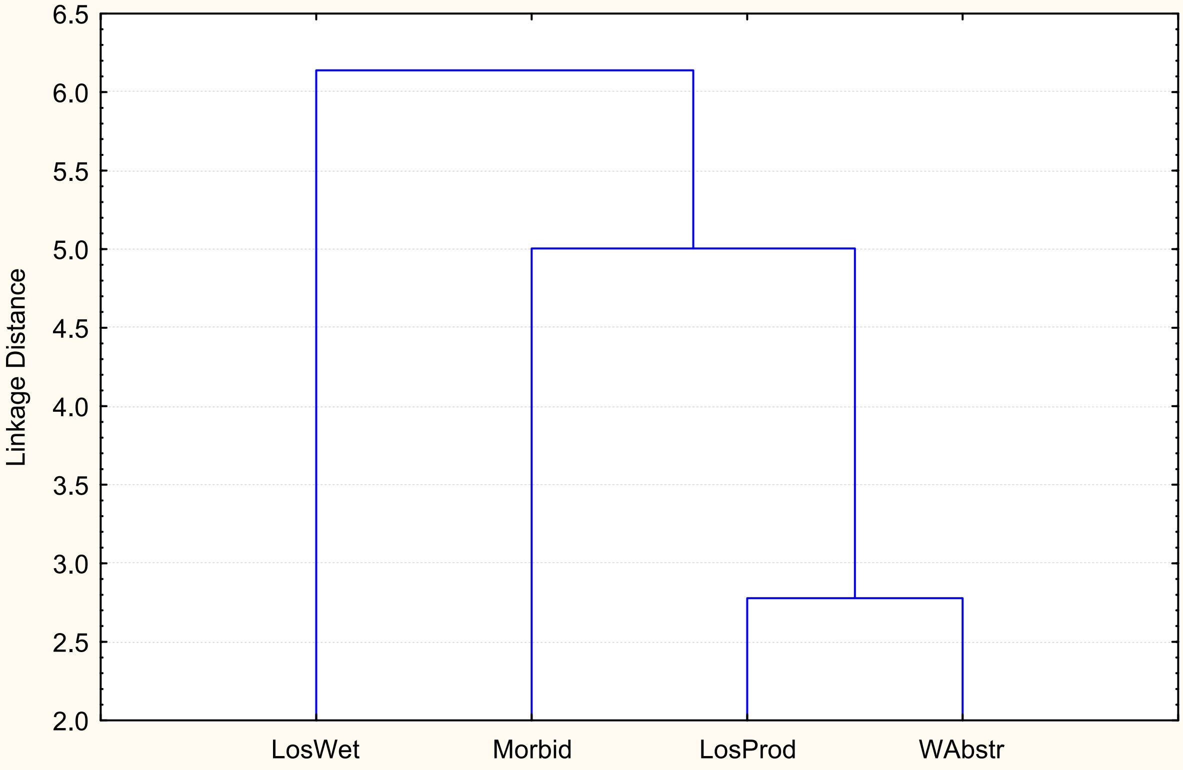
Results and discussion

Figures 6.28 explains two different groups of variables. The first group has the variables water abstraction, loss in agriculture productivity and morbidity. It can be labeled as morbidity. The second group has only loss of wetlands. It can be labeled as ecosystem.

Figure 6.29 indicates two unconnected clusters of municipalities. The first cluster consists of Beit Hannun, Al-Mograga, Nusseirat, Beit Lahia, Deir El-Balah, El Bureij, Qarara, Abassan Kubra, Bani Suhaila, Jabalia, Wadi Gaza, Wadi Salga, Al-Musadar, Zawaida, Al-Bayuk, Al-Fukhari, Abassan Jadida, Al-Shoka,.Magazi and Khuza'a. The second cluster of municipalities includes Gaza, Khan Younis, Rafah, Um Alnasser and Al-Zahra'.

In accordance with the magnitudes of the linkage distances, the first cluster of municipalities can be identified as "ecosystem" cluster whilst the second cluster of municipalities can be labeled as "morbidity" cluster.

Figure 6.28 Tree diagram for variables- impacts
Complete Linkage
Euclidean distances



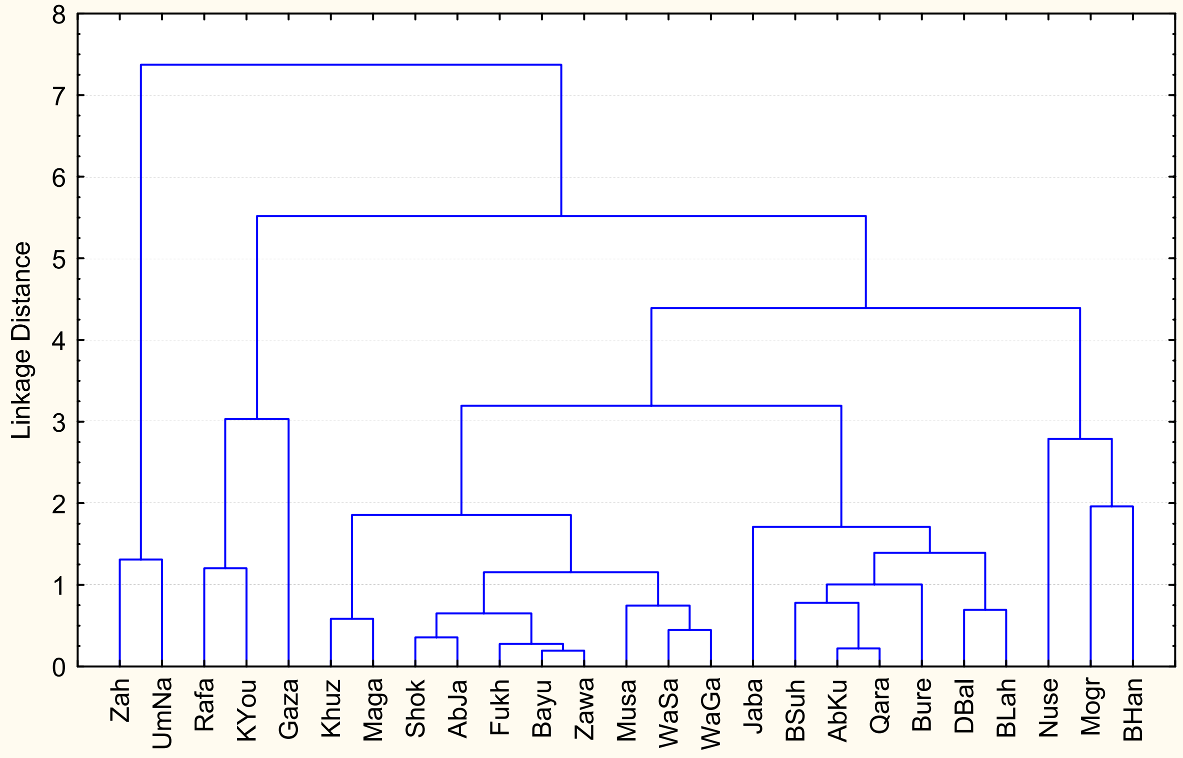


Figure 6.29 Tree diagram for cases- impacts
Complete Linkage
Euclidean distances

- **Management response variables**

The management response variables analyzed in the cluster analysis are: brackish water desalination, storm water harvesting, importation of water and regional water conveyance, treated wastewater, efficiency in water irrigation, efficiency in urban water supply networks, efficiency of information system, water awareness and education and seawater desalination.

Results and discussion

Figures 6.30 presents two dissimilar groups of variables. The first group contains water abstraction, storm water harvesting, efficiency of information system, treated wastewater, importation of water and regional water conveyance, seawater desalination, , brackish water desalination and efficiency in water irrigation. It can be labeled as non-conventional water resources. The second group includes efficiency in urban water supply networks and water awareness and education. It can be labeled as water supply efficiency.

Figure 6.31 indicates two different clusters of municipalities. The first cluster consists Beit Hannun, Beit Lahia, Jabalia, Rafah, Magazi, El Bureij, Zawaida, Deir El-Balah, Nusseirat, Um Alnasser, Al-Zahra', Al-Mograga, Al-Shoka, Al-Bayuk, Wadi Gaza, Wadi Salga, Bani Suhaila, Abassan Jadida, Abassan Kubra, Al-Musadar, Al-Fukhari, Qarara, and Khuza'a. The second cluster of municipalities includes Gaza and Khan Younis. In accordance with the magnitudes of the linkage distances, the first cluster of municipalities can be identified as "water supply efficiency" cluster whilst the second cluster of municipalities can be labeled as "non-conventional water resources" cluster.

Figure 6.30 Tree diagram for variables- Management responses
Complete Linkage
Euclidean distances

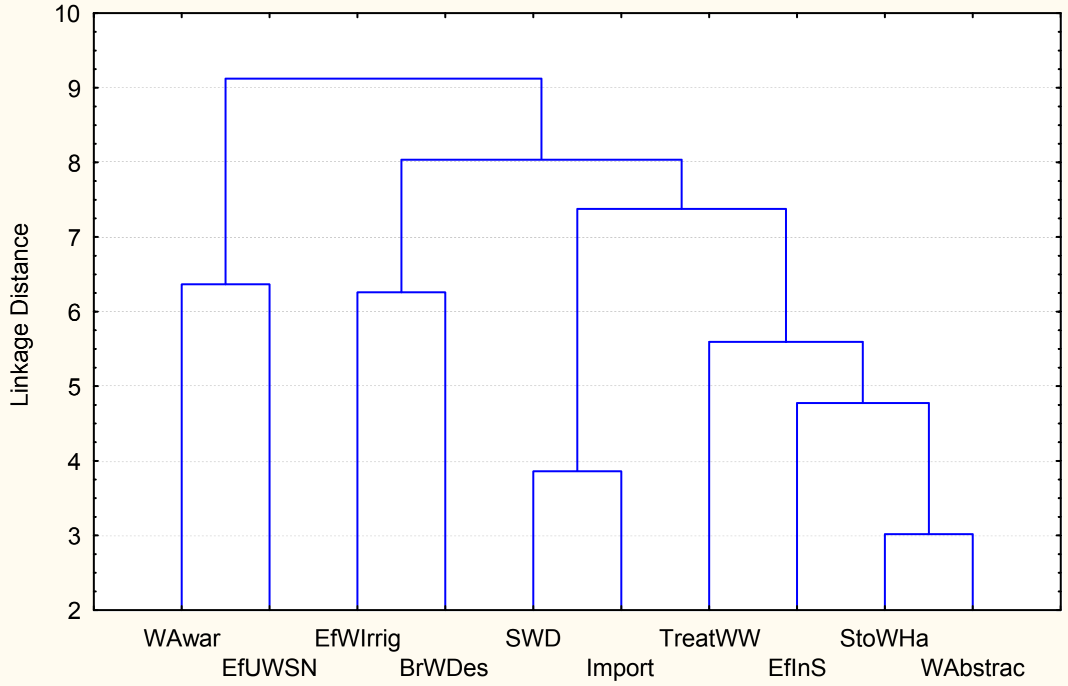
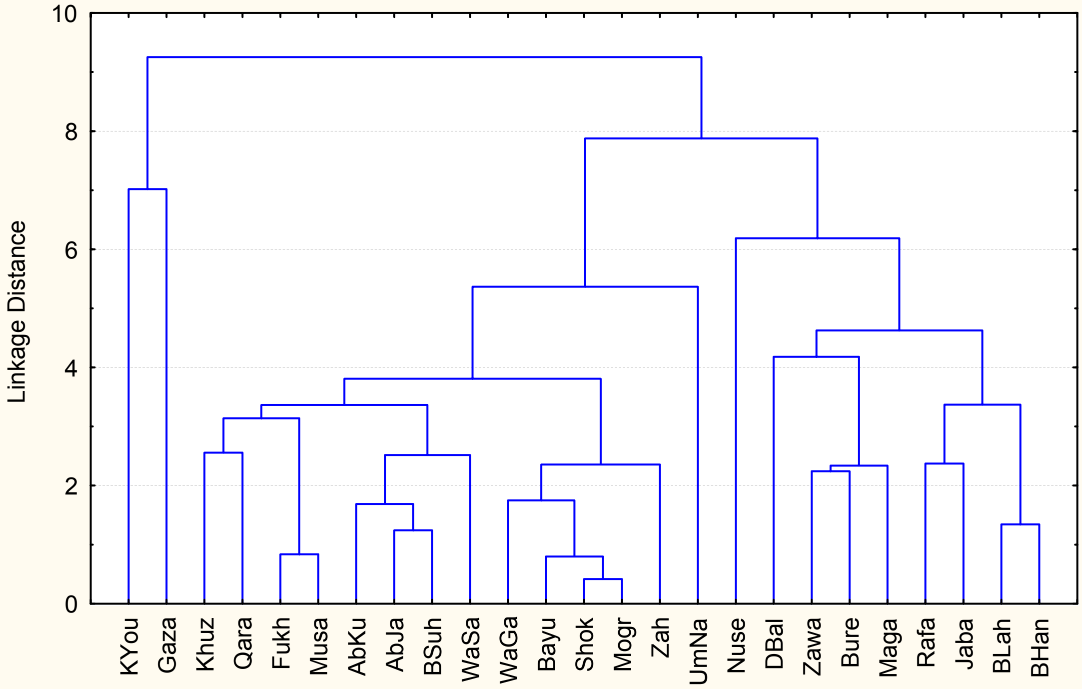


Figure 6.31 Tree diagram for cases- Management responses
Complete Linkage
Euclidean distances



6.3.2 Principal Component and Classification Analysis (PCCA)

The purpose of applying PCCA module (Section 5.2.3) is to reduce the number of variables into a smaller number of dimensions (factors) and to classify variables and clusters of observations with similar characteristics with respect to these factors. Besides, the removed variables from the ANN analysis were mapped into those factors as supplementary variables.

PCCA was carried out for the categories of socio-economic, pollution pressure, state of water quality, impact and management responses variables.

- **Socio-economic variables**

The socio-economic variables analyzed by the PCCA analysis are: population, income per capita, land use, tourism, access to safe water supply, wastewater system coverage, storm water system coverage, water consumption per capita, water price, agriculture water consumption, gender empowerment and unaccounted for water. The variable efficiency of revenue collection was added as a supplementary variable.

Results and discussion

Table 6.26 shows that there are 13 variables in the analysis, and thus the sum of all eigenvalues is equal to 13. The number of factors was chosen in accordance to Kaiser's criterion and Cattell's scree test (Section 5.2.3). The scree plot (Figure 6.32) shows that the point where the continuous drop in eigenvalues levels off is at factor 3. Therefore, three factors were chosen for analysis with a cumulative variance of 71.07%. The remaining eigenvalues each accounts for less than 10% of the total variance.

Table 6.27 presents variances of factors and their loadings from variables. The first factor corresponds to the largest eigenvalue (5.49) and accounts for approximately 42.24% of the total variance. It is most correlated with the variables water abstraction, storm water harvesting, population, income per capita, tourism and unaccounted for flow (negative correlations). The second factor corresponding to the second eigenvalue (2.1) accounts for 16.16% of the total variance. It is highly correlated with wastewater coverage and land use (negative correlation) and water price (positive correlation). The third factor corresponding to the eigenvalue 1.65 accounts for 12.67%. It is significantly correlated with water price (negative correlation) and water consumption per capita (positive correlation). Water price has significant opposition to water consumption per capita. If water price increases then water consumption per capita decreases and vice versa.

Table 6.26 Eigenvalues of correlation matrix- Active socio-economic variables only

	Eigenvalue	% Total variance	Cumulative Eigenvalue	**Cumulative %**
1	5.491750	42.24423	5.49175	42.2442
2	2.100687	16.15913	7.59244	58.4034
3	1.646699	12.66691	9.23914	71.0703
4	1.144744	8.80572	10.38388	79.8760
5	0.970194	7.46303	11.35407	87.3390
6	0.518512	3.98855	11.87259	91.3276
7	0.392655	3.02043	12.26524	94.3480
8	0.300416	2.31089	12.56566	96.6589
9	0.208177	1.60136	12.77383	98.2603
10	0.085048	0.65421	12.85888	98.9145
11	0.081515	0.62704	12.94040	99.5415
12	0.044620	0.34323	12.98502	99.8847
13	0.014983	0.11526	13.00000	100.0000

Figure 6.32 Eigenvalues of correlation matrix- socio-economic variables
Active variables only

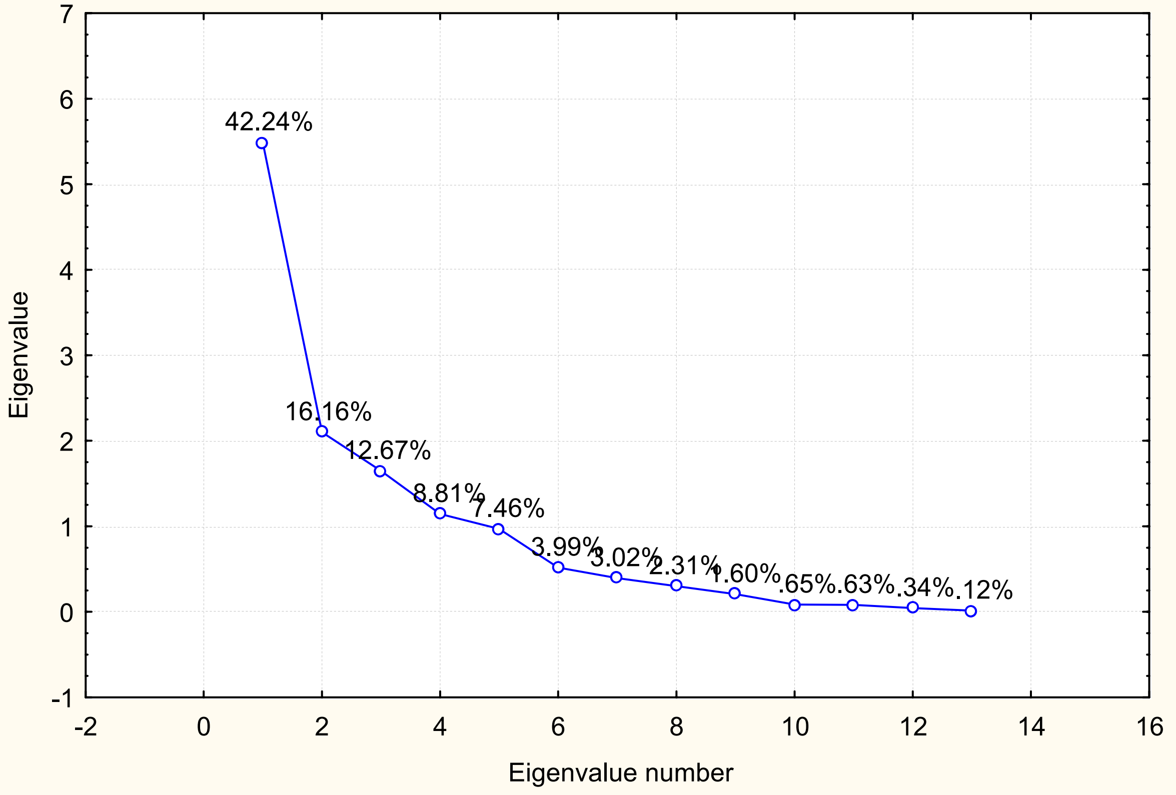


Table 6.27 Factor-variable correlations (factor loadings),-socio-economic variables
Active and Supplementary variables. *Supplementary variable
(Underlined loadings are > .700000)

	Factor 1	**Factor 2**	**Factor 3**
WAbstrac	-0.923470	-0.337573	0.025689
Populat	-0.912708	0.214168	-0.207874
Inccap	-0.880215	-0.179648	0.033090
Lanuse	-0.255049	0.765261	-0.314646
Tourism	-0.818129	0.251356	-0.248628
WSupply	0.439751	0.129049	-0.122759
WWCov	-0.436394	0.701630	-0.035803
StoWCov	-0.915172	-0.128694	0.029050
WCpCap	-0.280646	0.351251	0.762061
Wprice	0.132754	-0.327016	-0.838153
AgWCon	-0.608659	-0.657833	0.054228
GendEmp	-0.143490	0.262400	-0.365124
UFW	-0.766781	-0.048686	0.065001
***EfRevCo**	0.038126	0.272009	-0.236007

Figure 6.33 displays coordinates for the three factors. The graph shows a unit circle with active variables that were used to compute the current factor solution and a supplementary variable that was only mapped into the coordinate system defined by the factors. Because the current analysis is based on correlations, the largest factor coordinate (variable-factor correlation) that can occur is equal to 1.0; also, the sum of all squared factor coordinates for a variable (squared correlations between the variable and all factors) cannot exceed 1.0. The circle can provide a visual indication (scale) of how well each variable is represented by the current set of factors (the closer a variable in this plot is located to the unit circle, the better is its representation by the current coordinate system). Based on the magnitudes of the factor coordinates (variable-factor correlations) for the variables in the analysis, the first factor can be labeled as water abstraction. Factor two can be labeled as land use and factor three can be labeled as water consumption versus water price. Figure 6.34 presents the factor coordinates for all municipalities.

Matching Figure 6.33 and Figure 6.34 for the three factors shows that municipalities of Beit Hannun and Khan Younis are analogous in terms of water abstraction, storm water coverage and agriculture water consumption. Nusseirat, El Bureij and Deir El-Balah are similar in the areas of population, land use, tourism, wastewater coverage and gender empowerment. Qarara is distinguished with income per capita and unaccounted for water. Magazi is differentiated with safe access to water supply and efficiency of revenue collection as a supplementary variable. Gaza, Beit Lahia and Jabalia are similar in terms of water consumption per capita. Zawaida, Wadi Salga, Al-Musadar, Bani Suhaila, Abassan Kubra, Al-Shoka and Al-Bayuk are distinguished with the water price variable.

Figure 6.33 Projection of the variables on the factor-plane (1 x 2) and (1x -3)

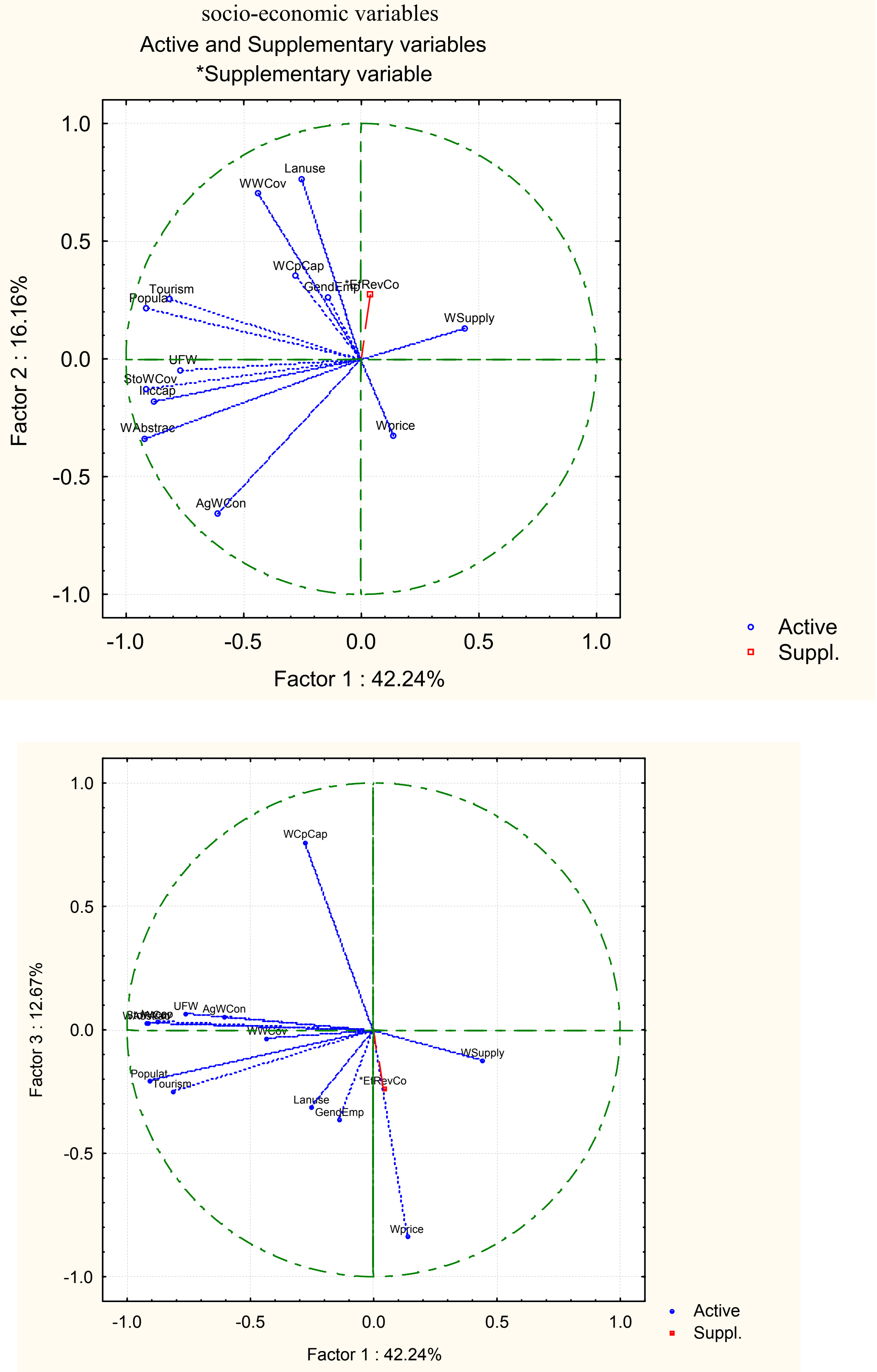
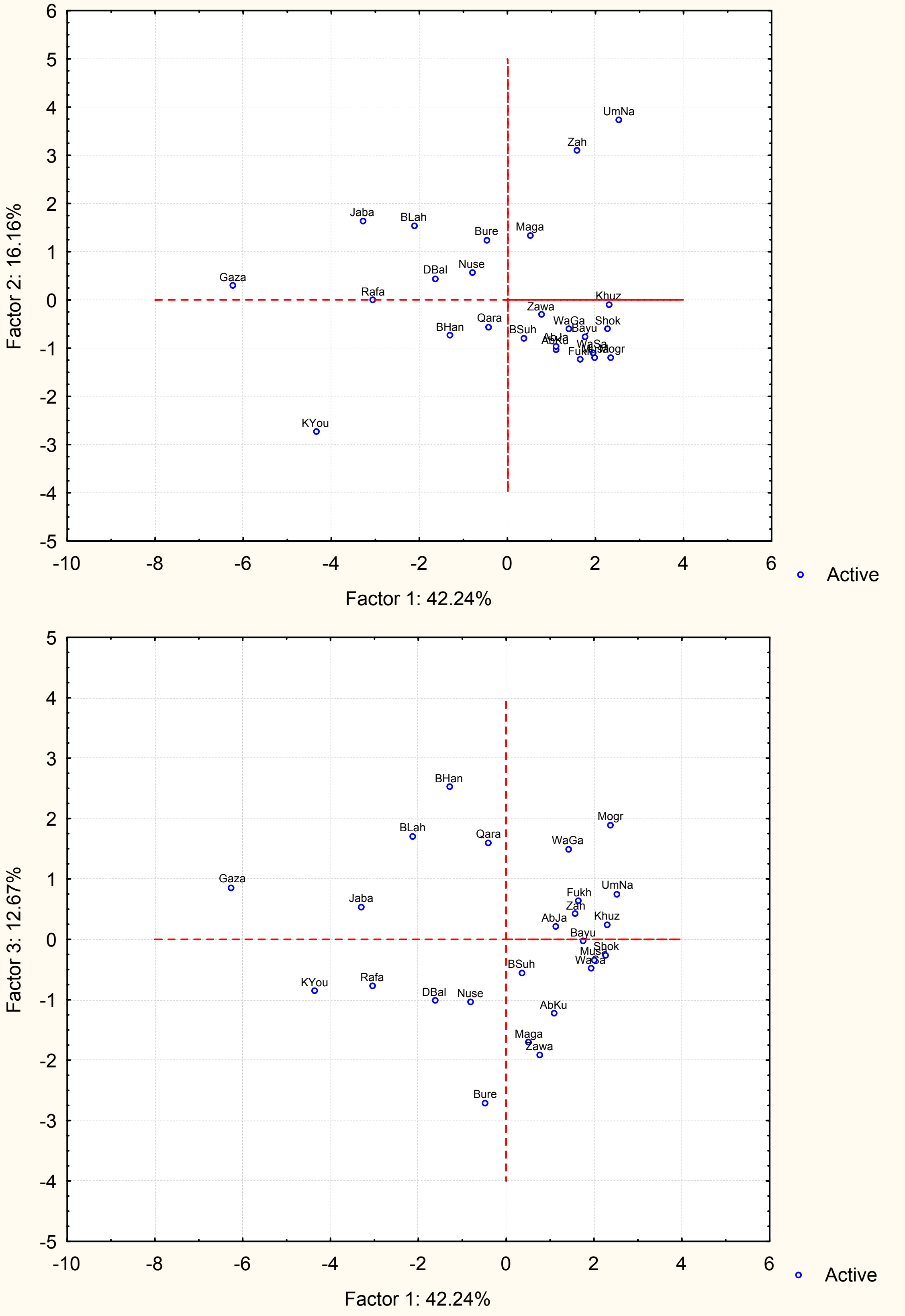


Figure 6.34 Projection of the cases on the factor-plane (1 x 2) and (1x 3) - socio-economic variables



- **Pollution variables**

The pollution variables analyzed in the PCCA analysis are: Total Dissolved Solids, hazardous wastes, generation of domestic wastewater, chemical fertilizers, organic fertilizers, domestic solid wastes, industrial wastewater, CO_2 and seawater intrusion. The variables pesticides and petrol stations were added as supplementary variables.

Results and discussion

Table 6.28 shows that there are three factors with eigenvalues greater than 1.0. The scree plot (Figure 6.35) explains that the point where the continuous drop in eigenvalues levels off is at factor 4. The variance of the fourth factor is less than 4%. Therefore, three factors were selected for analysis with a cumulative variance of 94.56%. Table 6.29 and Figure 6.36 present variances of factors and their loadings from variables. The first factor corresponds to the largest eigenvalue (5.26) and accounts for 58.43% of the total variance. It is most correlated with the variables industrial wastewater, domestic solid wastes, domestic wastewater, hazardous wastes, seawater intrusion and with the supplementary variable pesticides (positive correlation). It has low negative correlation with CO_2 and TDS. The first factor can be labeled as anthropogenic pollution. The second factor corresponding to the eigenvalue (1.89) accounts for approximately 21.02% of the total variance. It is highly correlated with TDS and CO_2 (positive correlation) and can be labeled as TDS. The third factor corresponding to the eigenvalue 1.36 accounts for 15.1%, has low correlation with organic fertilizers and chemical fertilizers, and the supplementary variable pesticides (positive correlation) versus hazardous waste, domestic wastewater, CO_2 and TDS (negative correlation). It can be labeled as rural pollution versus urban pollution.

Table 6.28 Eigenvalues of correlation matrix- Active pollution variables only

	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	5.259003	58.43337	5.259003	58.4334
2	1.891966	21.02184	7.150969	79.4552
3	1.359321	15.10357	8.510290	94.5588
4	0.323456	3.59395	8.833745	98.1527
5	0.062101	0.69002	8.895847	98.8427
6	0.053819	0.59798	8.949665	99.4407
7	0.028052	0.31169	8.977718	99.7524
8	0.019689	0.21877	8.997407	99.9712
9	0.002593	0.02881	9.000000	100.0000

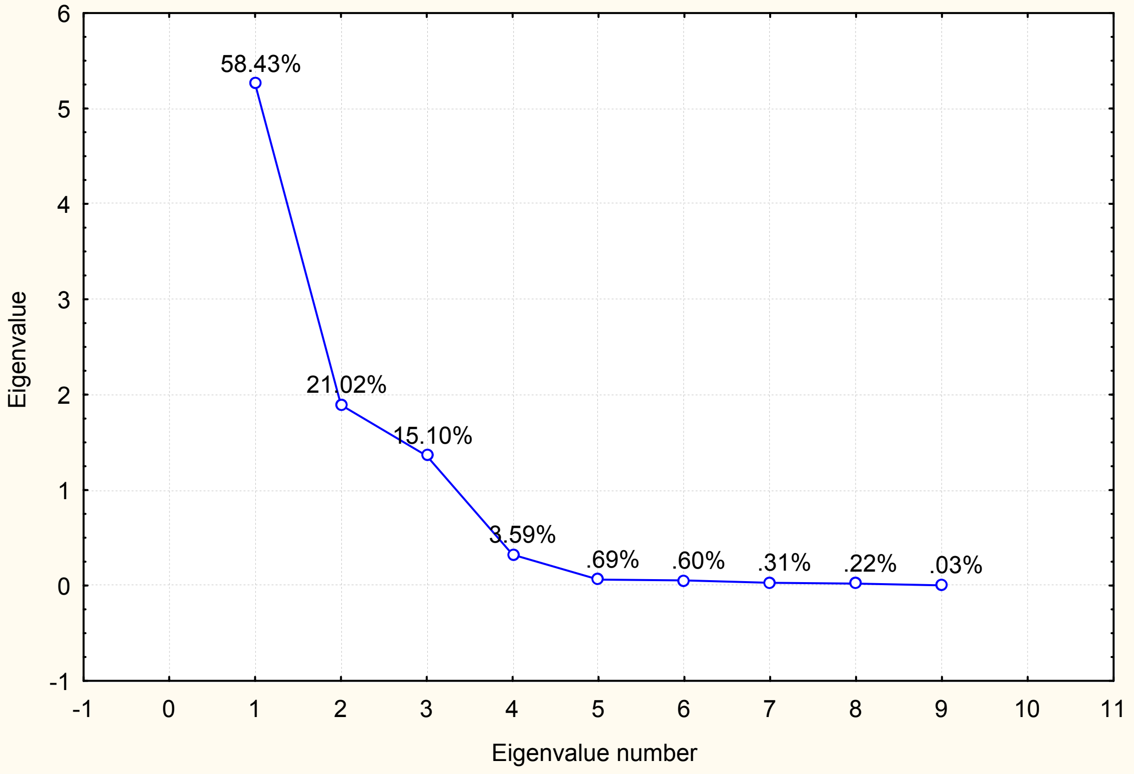


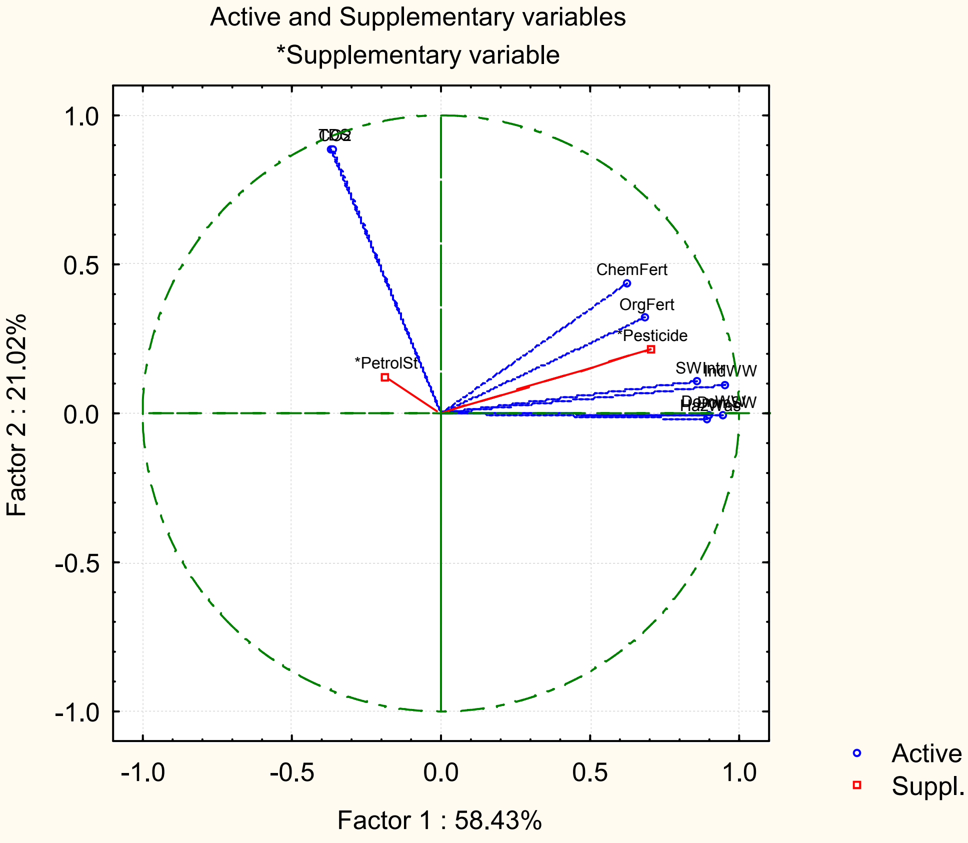
Figure 6.35 Eigenvalues of correlation matrix - pollution variables
Active variables only

Table 6.29 Factor-variable correlations (factor loadings)- pollution variables
Active and Supplementary variables *Supplementary variable
(Underlined loadings are > .700000)

	Factor 1	**Factor 2**	**Factor 3**
TDS	-0.365737	0.888060	-0.271239
HazWas	0.890280	-0.017903	-0.410531
DomWW	0.897473	-0.004479	-0.407691
ChemFert	0.627199	0.436951	0.624185
OrgFert	0.683942	0.320686	0.645067
DomSW	0.944302	-0.009155	-0.251978
IndWW	0.953542	0.096384	-0.077572
CO_2	-0.364437	0.887894	-0.274959
SWIntr	0.855726	0.107148	0.013095
***Pesticide**	0.703369	0.215160	0.574200
***PetrolSt**	-0.189013	0.123281	0.033134

Coinciding Figure 6.36 and Figure 6.37 for the three factors presents that the municipality of Khan Younis is distinguished with chemical and organic fertilizers, seawater intrusion and the supplementary variable pesticides. Gaza, El Bureij and Deir El-Balah are characterized with industrial wastewater. Jabalia and Rafah are distinguished hazardous waste, domestic wastewater and domestic solid waste. Bani Suhaila and Khuza'a are differentiated with TDS and CO_2. Municipalities of Nusseirat, Al-Mograga, Abassan Kubra and Fukhari are similar in terms of the supplementary variable petrol stations.

Figure 6.36 Projection of the variables on the factor-plane (1 x 2) and (1x 3) - pollution variables



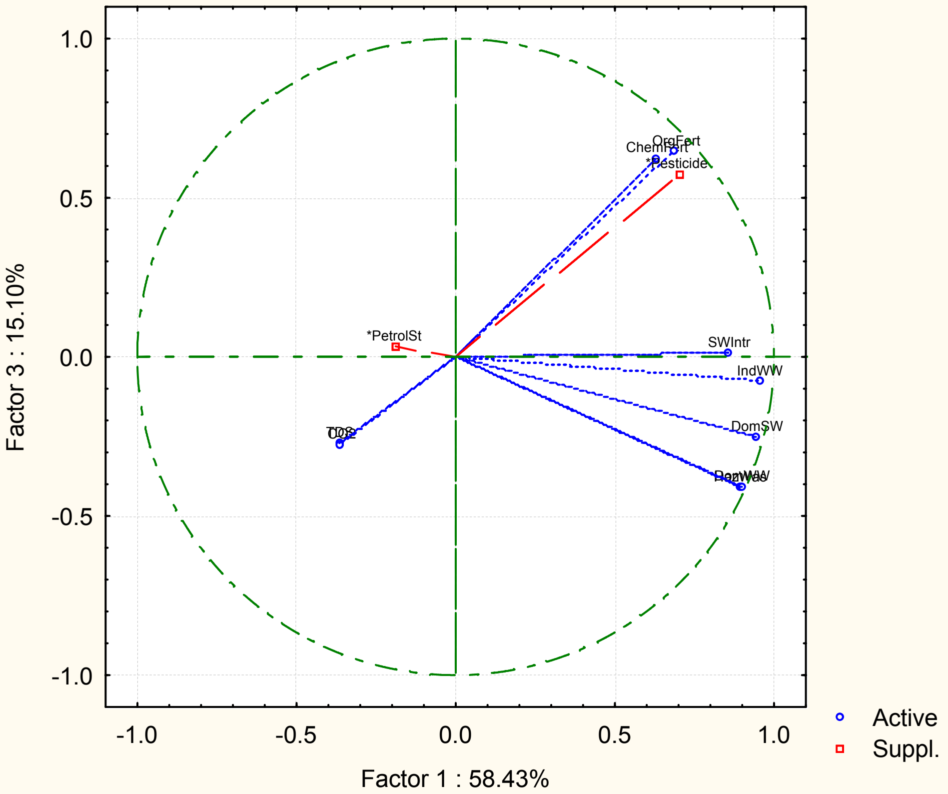
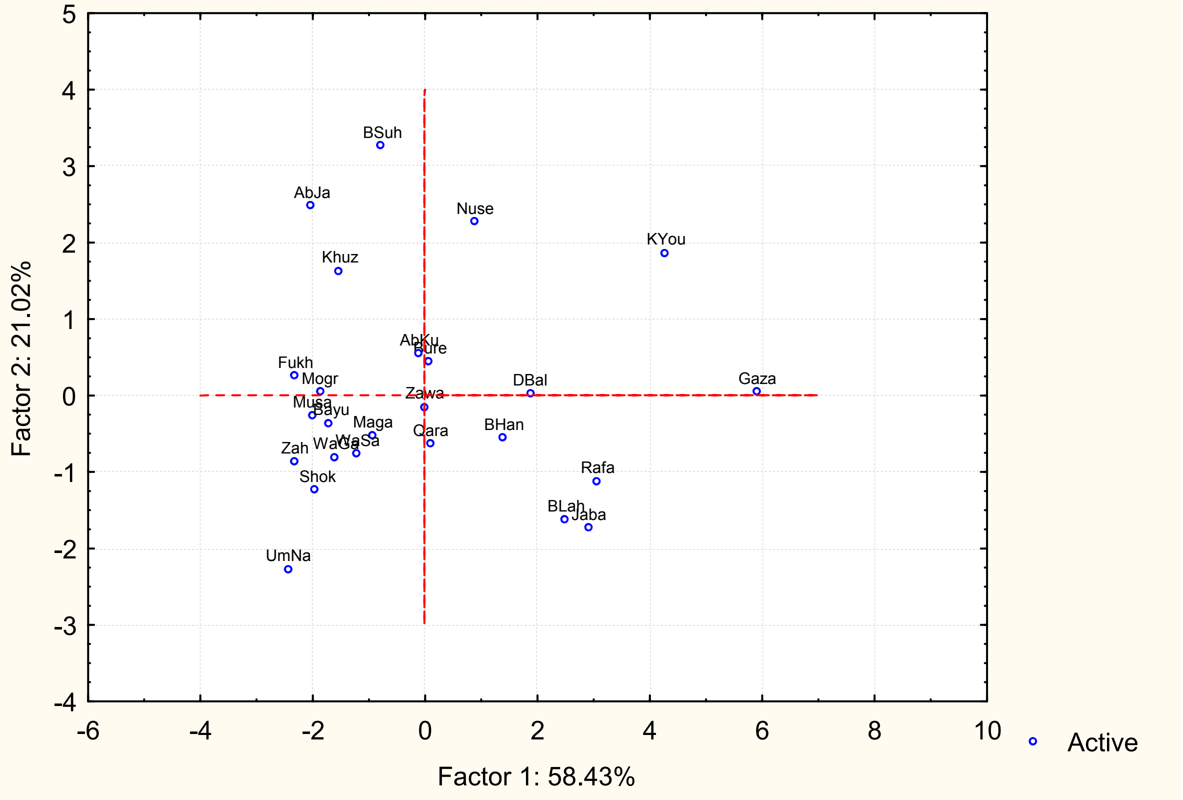
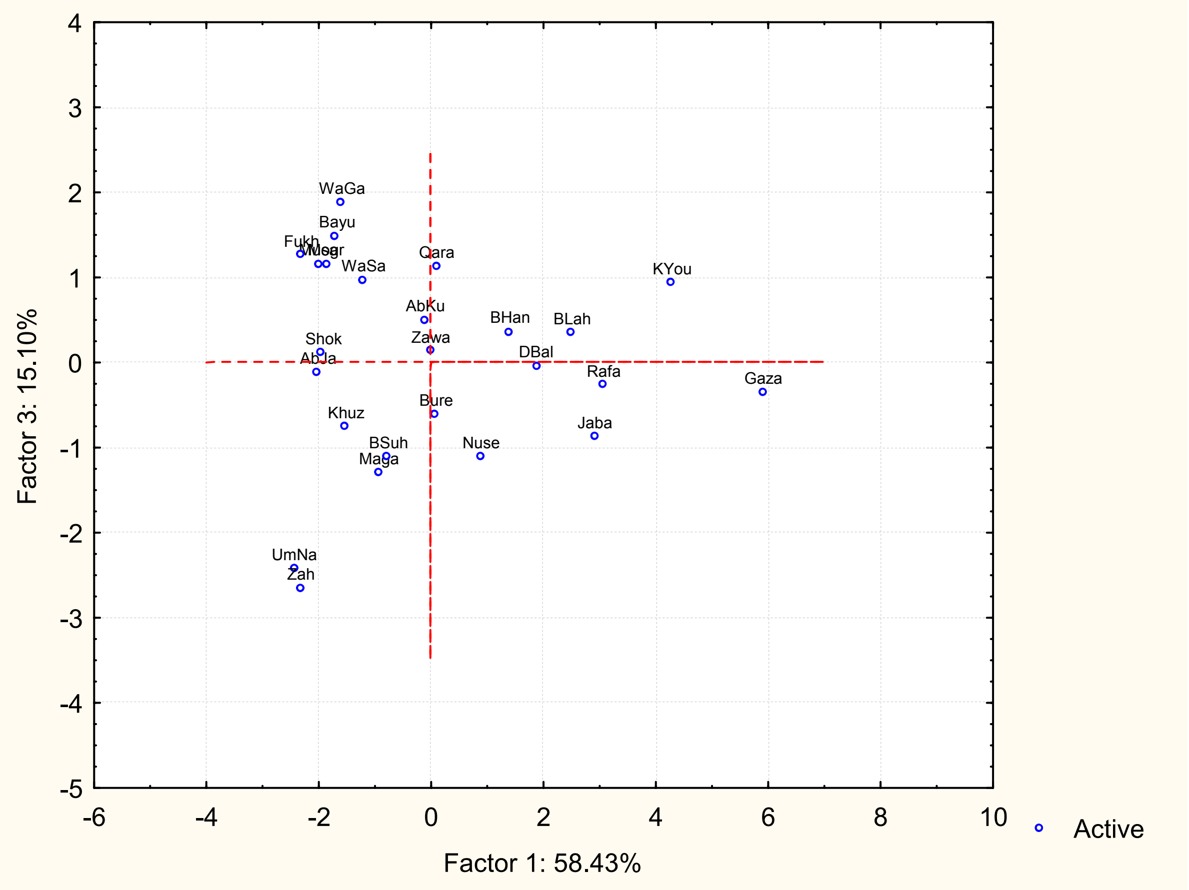


Figure 6.37 Projection of the cases on the factor-plane (1 x 2) and (1x 3) - pollution variables





- **State of water quality variables**

The water quality variables classified in the PCCA analysis are: Nitrate and Chloride. The variables Sodium, Calcium, Magnesium, Potassium, Fluoride, Sulfate, pH, Alkalinity and Total Coliforms were added as supplementary variables.

Results and discussion

Based on the eigenvalues of correlation matrix for the active water quality variables (Table 6.30) and the scree plot (Figure 6.38), two factors were chosen for analysis. The two factors have a cumulative variance of 88.36%. Table 6.31 and Figure 6.39 present that the first factor corresponds to eigenvalue (1.52) and accounts for 50.52% of the total variance. It is largely correlated with the variables Nitrate and water abstraction (high positive correlations). Based on the magnitudes of the factor coordinates (variable-factor correlations) for the variables in the analysis, the first factor can be labeled as Nitrate concentration.

The second factor corresponding to the eigenvalue (1.14) accounts for approximately 37.84% of the total variance. It is highly correlated with Chloride and the supplementary variable Fluoride (negative correlation). The second factor can be labeled as water salinity.

Table 6.30 Eigenvalues of correlation matrix- Active state variables only

	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	1.515594	50.51981	1.515594	50.5198
2	1.135174	37.83914	2.650769	88.3590
3	0.349231	11.64105	3.000000	100.0000

Figure 6.38 Eigenvalues of correlation matrix- state variables

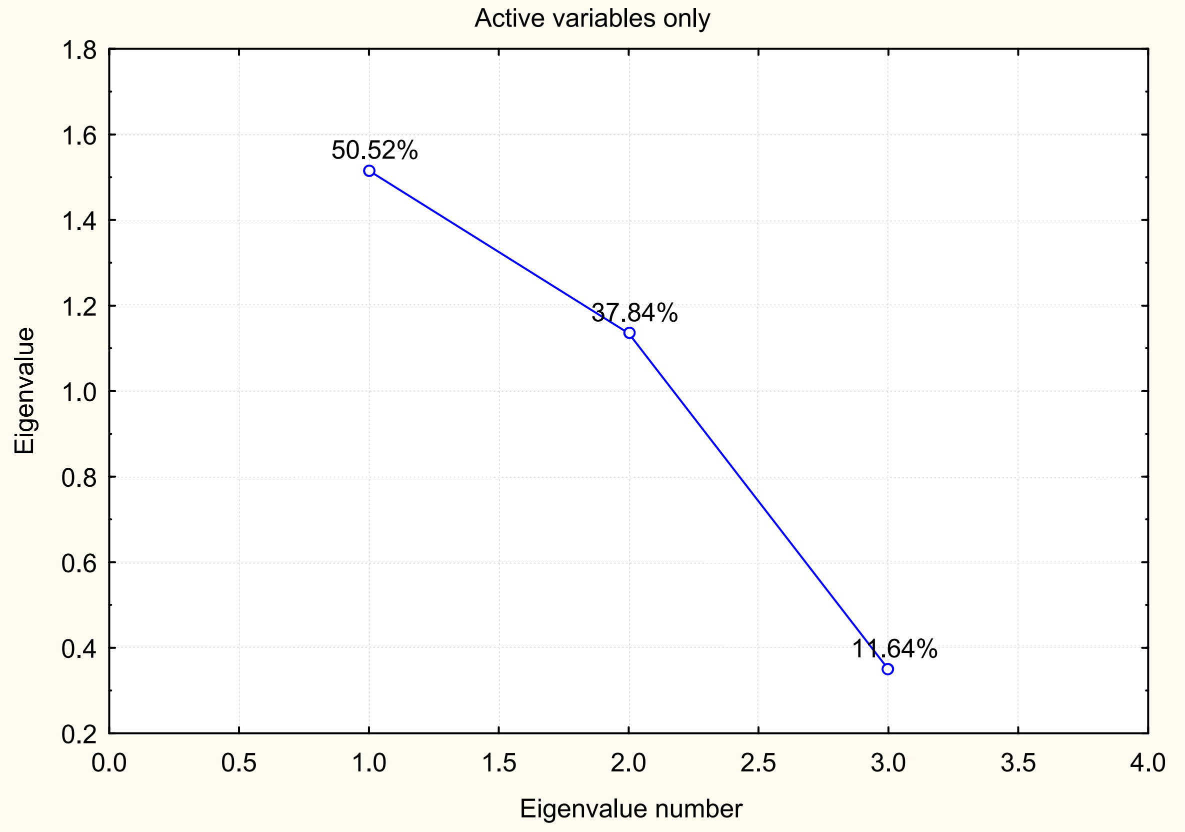


Table 6.31 Factor-variable correlations (factor loadings) – state variables
Active and Supplementary variables *Supplementary variable
(Underlined loadings are > .700000)

	Factor 1	**Factor 2**
WAbstrac	0.817890	0.443151
NO3	0.899787	-0.200052
CL	0.192445	-0.948035
***Na**	-0.138808	-0.613205
***Ca**	0.625967	0.016463
***Mg**	0.592500	-0.126826

***K**	0.028943	-0.686590
***F**	0.137041	-0.721161
***SO4**	-0.128374	-0.646338
***pH**	0.209908	-0.169914
***Alkalinity**	0.515205	-0.240873
***T-Coli**	-0.013511	0.257834

Overlapping Figure 6.39 and Figure 6.40 for the two factors explains that municipalities of Nusseirat, Deir El-Balah, Qarara, Bani Suhaila, Khuza'a and Abassan Kubra are differentiated with Nitrate, Chloride and the supplementary variables Magnesium, Potassium, Fluoride, pH and Alkalinity. Magazi, Um Annaser, El Bureij, Al-Fukhari, Al-Shoka and Al-Bayuk are similar in terms of the supplementary variables Sodium and Sulfate. Zawaida, Al-Mograga, Wadi Gaza, Wadi Salga and Al-Musadar are distinguished with Total Coliform. Beit Hannun, Beit Lahia, Jabalia, Gaza, Khan Younis and Rafah are similar in terms of water abstraction and the supplementary variable Calcium.

Figure 6.39 Projection of the variables on the factor-plane (1 x 2)
state variables
Active and Supplementary variables
*Supplementary variable

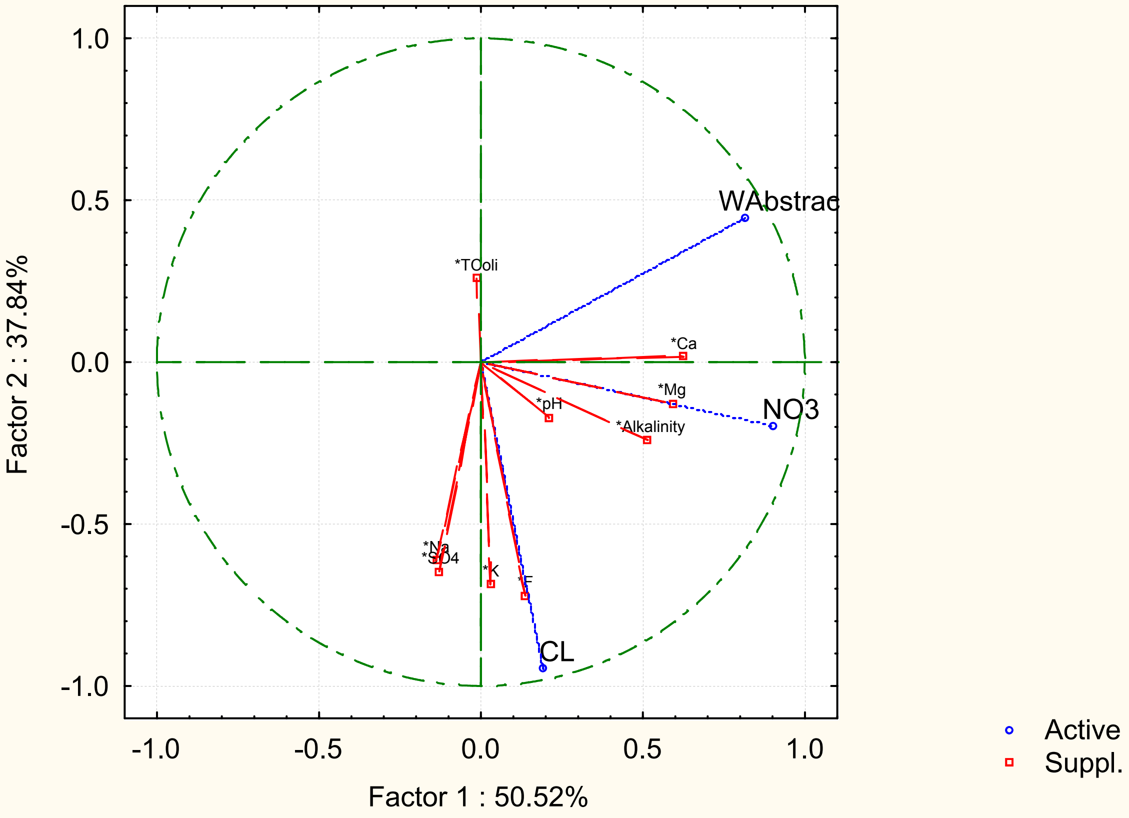
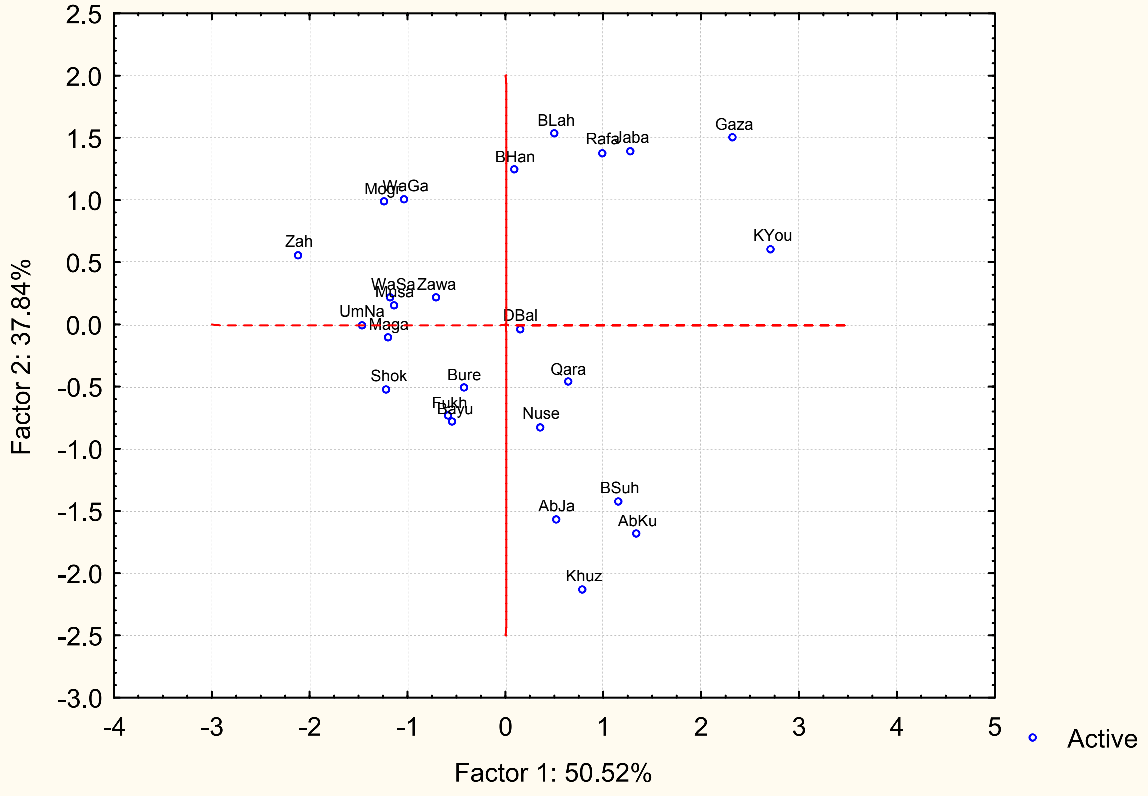


Figure 6.40 Projection of the cases on the factor-plane (1 x 2)- state variables



- **Ecological and public health impact variables**

The ecological and public health impact variables classified in the PCCA analysis are: loss in agriculture productivity, loss of wetlands and morbidity.

Results and discussion

Referring to the eigenvalues of correlation matrix for the active impact variables (Table 6.32) and the scree plot (Figure 6.41), two factors were chosen for analysis with a variance of 85.89%.

Table 6.33 and Figure 6.42 present that the first factor corresponds to eigenvalue (2.56) and accounts for 64.11% of the total variance. It is mainly correlated with water abstraction, loss in agriculture productivity and morbidity (negative correlation). The first factor can be labeled as morbidity caused by water quality problems.

The second factor corresponds to eigenvalue (0.87) and accounts for 21.78% of the total variance. It is most correlated with loss of wetlands (negative correlation). The second factor can be labeled as ecosystem.

Table 6.32 Eigenvalues of correlation matrix,- Active impact variables only

	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	2.564524	64.11311	2.564524	64.1131
2	0.871026	21.77566	3.435551	85.8888
3	0.522003	13.05008	3.957554	98.9388
4	0.042446	1.06115	4.000000	100.0000

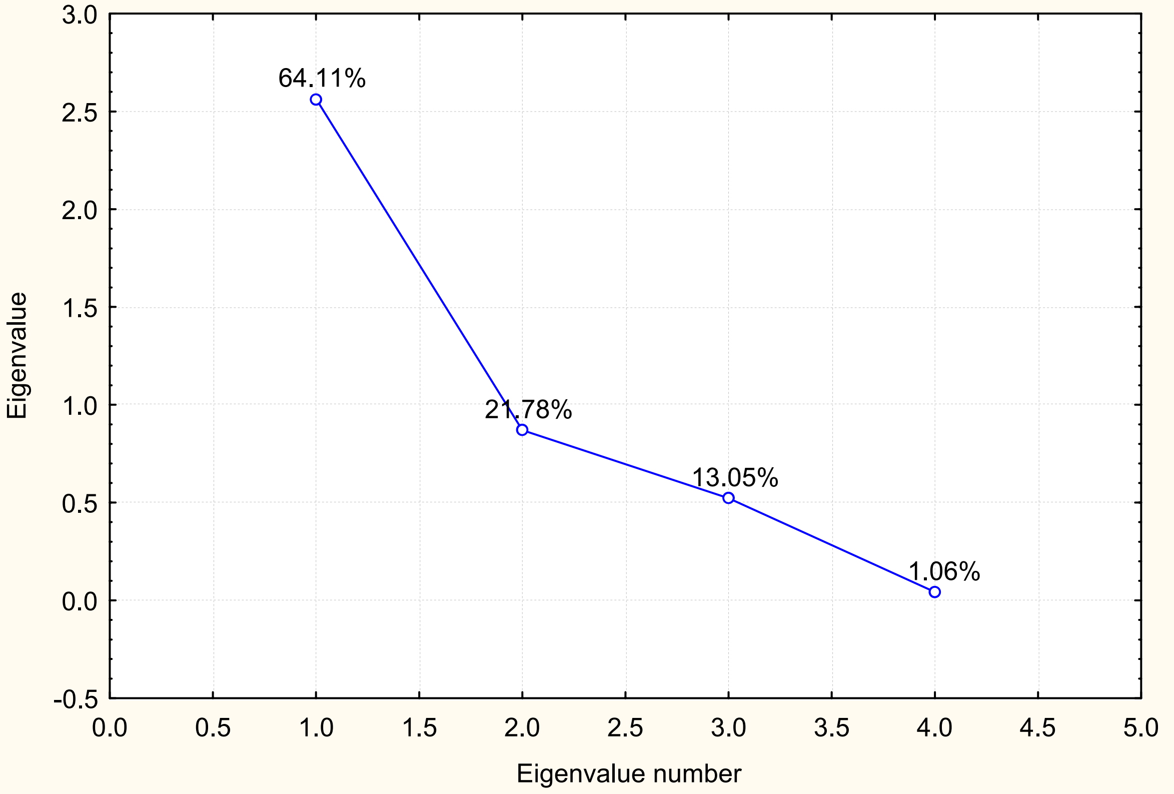


Figure 6.41 Eigenvalues of correlation matrix- impact variables
Active variables only

Table 6.33 Factor-variable correlations (factor loadings)- impact variables
(Underlined loadings are > .700000)

	Factor 1	**Factor 2**
WAbstr	-0.980689	0.109899
LosProd	-0.844795	0.164188
LosWet	-0.450248	-0.892634
Morbid	-0.828475	0.187604

Matching the two factors in Figure 6.42 and Figure 6.43 concludes that municipalities of Beit Hannun, Nusseirat and Gaza are characterized with loss of wetlands. Beit Lahia, Jabalia, Deir El-Balah, Khan Younis, Qarara, Bani Suhaila, Abassan Kubra and Rafah are similar in the areas of water abstraction, loss in agriculture productivity and morbidity.

Figure 6.42 Projection of the variables on the factor-plane (1 x 2)- impact variables

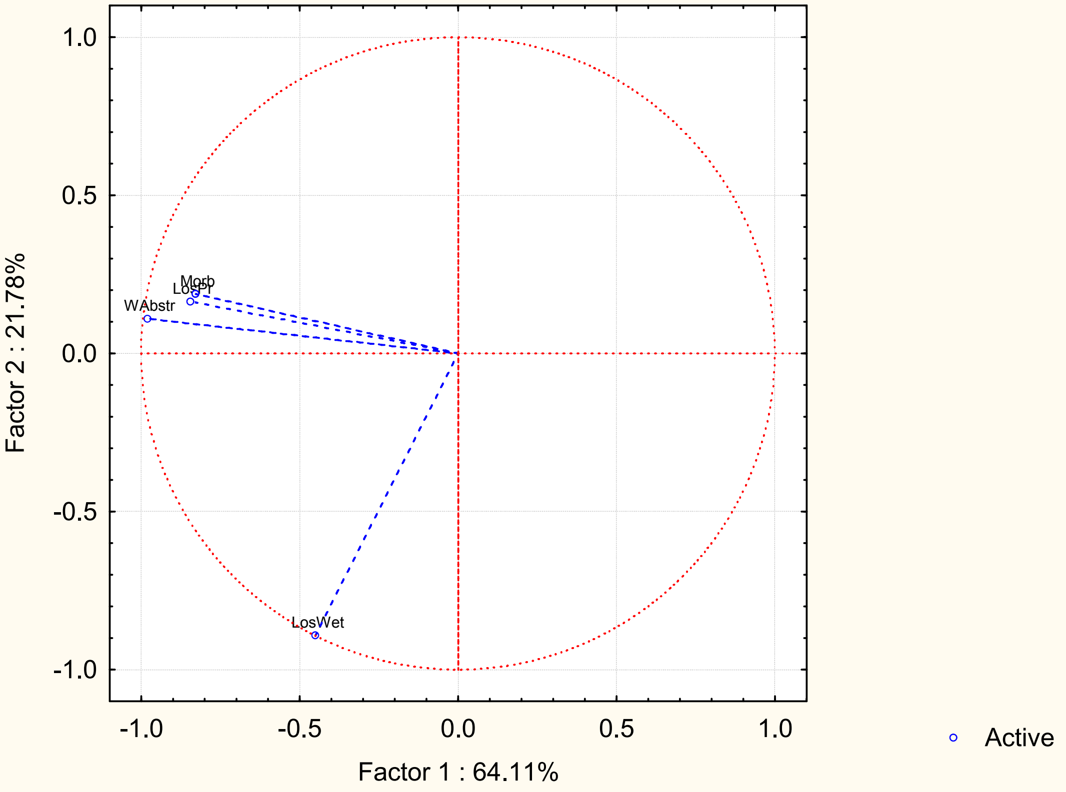
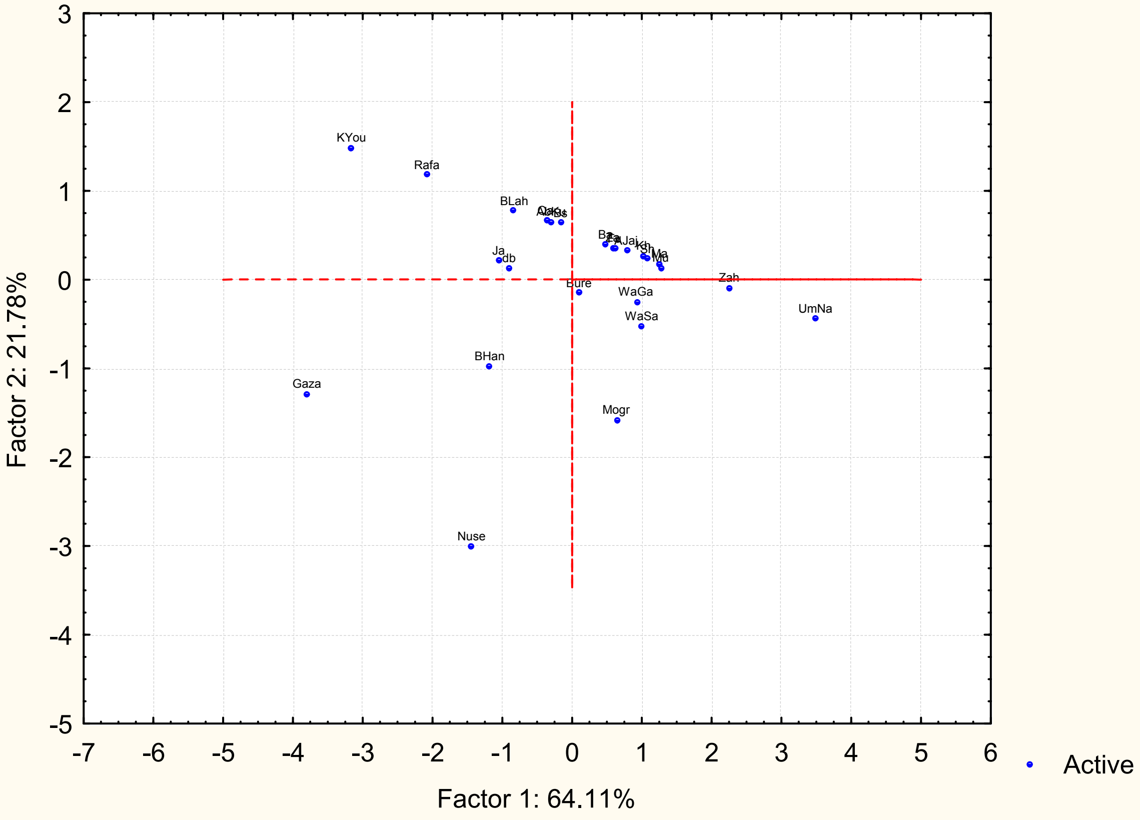


Figure 6.43 Projection of the cases on the factor-plane (1 x 2) - impact variables



- **Management response variables**

The management response variables classified in the PCCA analysis are: brackish water desalination, storm water harvesting, importation of water and regional water conveyance, treated wastewater, efficiency in water irrigation, efficiency in urban water supply networks, efficiency of information system, water awareness and education and seawater desalination.

Results and discussion

According to the eigenvalues of correlation matrix for the active management variables (Table 6.34) and the scree plot (Figure 6.44), two factors were chosen for analysis. Table 6.35 and Figure 6.45 present that the first factor corresponds to eigenvalue (3.71) and accounts for 37.05% of the total variance. It is greatly correlated with water abstraction and storm water harvesting (positive correlations), and efficiency in urban water supply networks (high negative correlation). There is an opposition between water abstraction and water supply efficiency. Hence, the first factor can be labeled as water abstraction versus water supply efficiency. The second factor corresponding to the eigenvalue (1.98) accounts for approximately 19.79% of the total variance. It is highly correlated with importation of water and regional water conveyance and seawater desalination (high positive correlation), and efficiency in urban water irrigation (low negative correlation). The second factor can be labeled as additional water resources versus efficiency in water irrigation. The third factor with eigenvalue (1.34) accounts for approximately 13.38% of the total variance. It has negative correlation with treated wastewater and water awareness, and lower positive correlation with efficiency in urban water irrigation. It can be labeled as irrigation systems.

Table 6.34 Eigenvalues of correlation matrix- Active management variables only

	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	3.705426	37.05426	3.70543	37.0543
2	1.979056	19.79056	5.68448	56.8448
3	1.337773	13.37773	7.02226	70.2226
4	0.903336	9.03336	7.92559	79.2559
5	0.777389	7.77389	8.70298	87.0298
6	0.541114	5.41114	9.24409	92.4409
7	0.366903	3.66903	9.61100	96.1100
8	0.237142	2.37142	9.84814	98.4814
9	0.110646	1.10646	9.95879	99.5879
10	0.041214	0.41214	10.00000	100.0000

Figure 6.44 Eigenvalues of correlation matrix- management variables
Active variables only

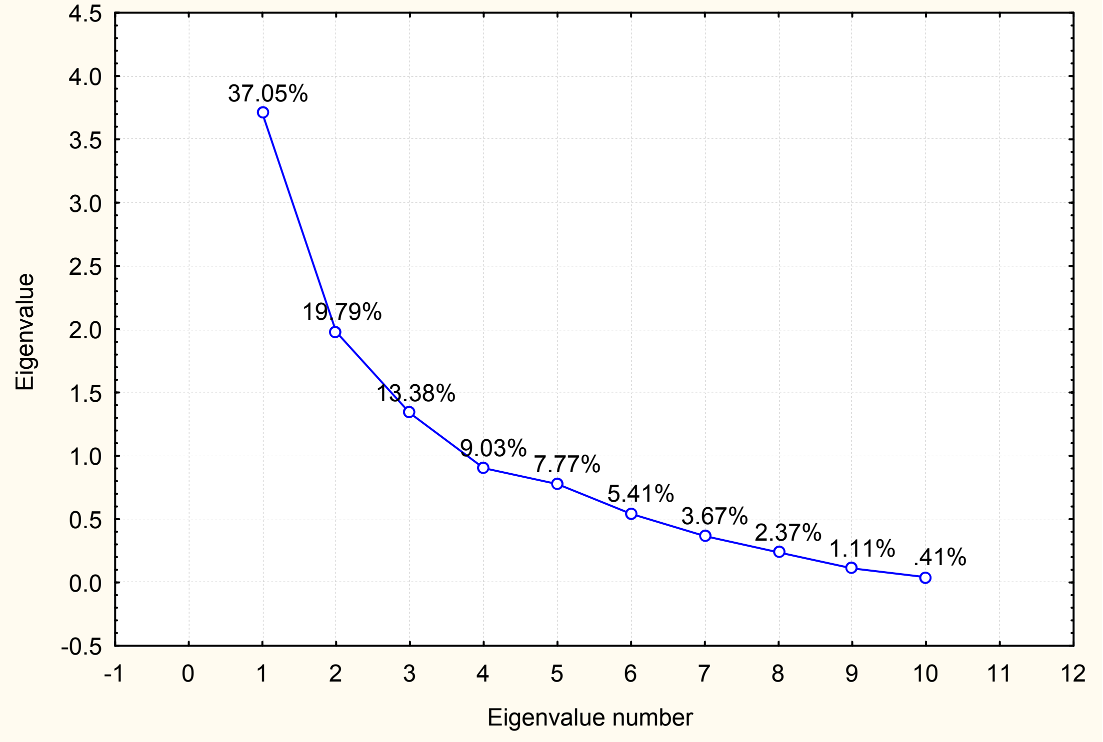


Table 6.35 Factor-variable correlations (factor loadings)- management variables
(Underlined loadings are > .700000)

	Factor 1	Factor 2	Factor 3
WAbstrac	0.929209	-0.224859	-0.118147
BrWDes	0.598295	-0.324191	0.256089
StoWHa	0.827709	0.171131	-0.091953
Import	0.167743	0.855697	0.157429
TreatWW	0.464074	-0.232793	-0.680224
EfWIrrig	0.011295	-0.476357	0.633997
EfUWSN	-0.841151	0.158041	-0.087149
EfInS	0.822438	0.137256	0.049556
WAwar	-0.285842	0.020283	-0.580295
SWD	0.299434	0.858229	0.116377

Coinciding Figure 6.45 and Figure 6.46 for the three factors presents that municipalities of Beit Hannun, Beit Lahia, Jabalia and Gaza are alike in terms of water abstraction and treated wastewater. Rafah, Khan Younis and Bani Suhaila are distinguished with brackish water desalination and efficiency of water irrigation. Nusseirat, El Bureij and Deir El-Balah are characterized with seawater desalination, importation and regional conveyance and effective information systems. .Zawaida is distinguished with efficiency of urban water supply and water awareness. Magazi is differentiated with storm water harvesting.

Figure 6.45 Projection of the variables on the factor-plane (1 x 2) and (1x 3) - management variables

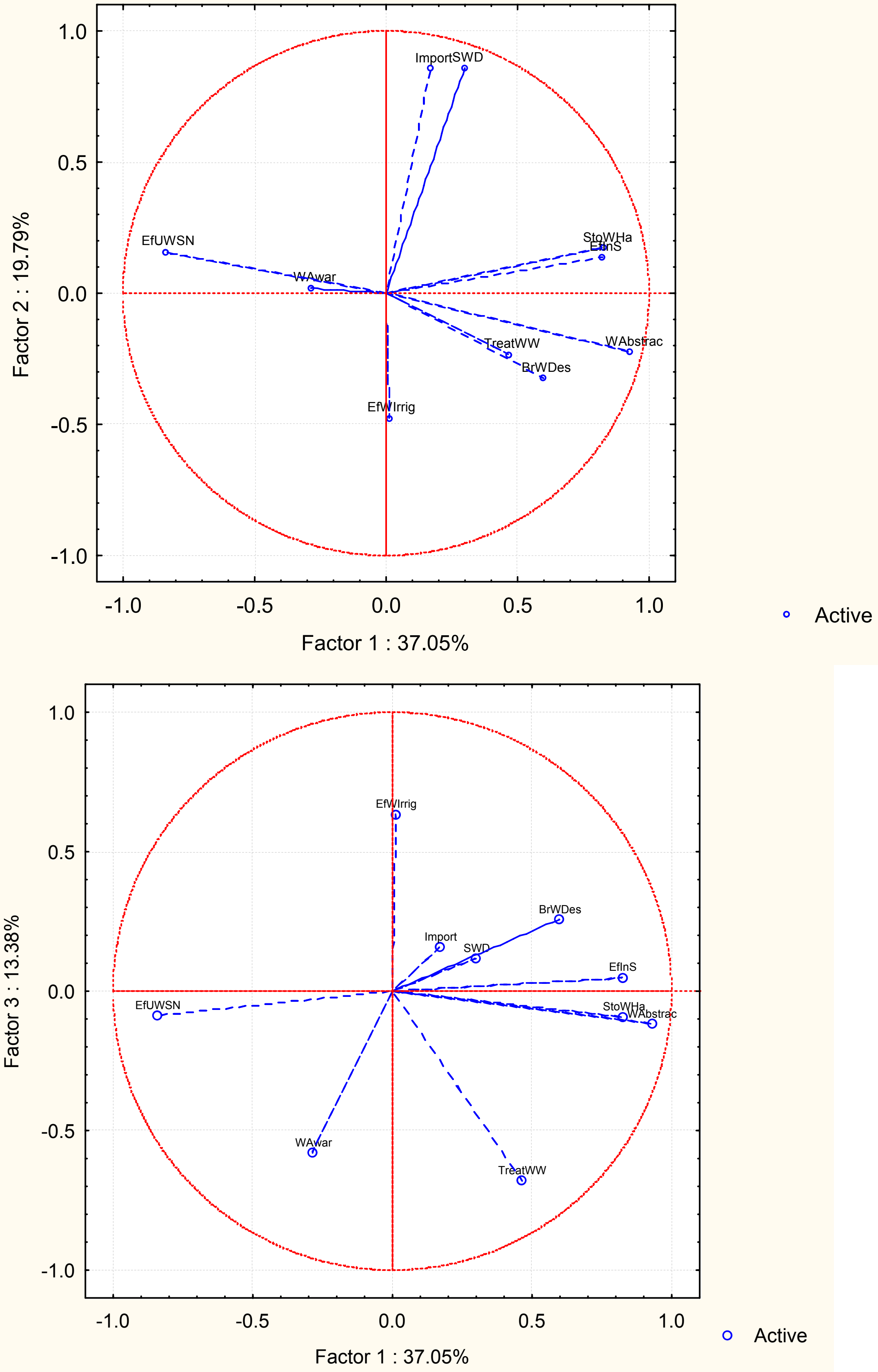
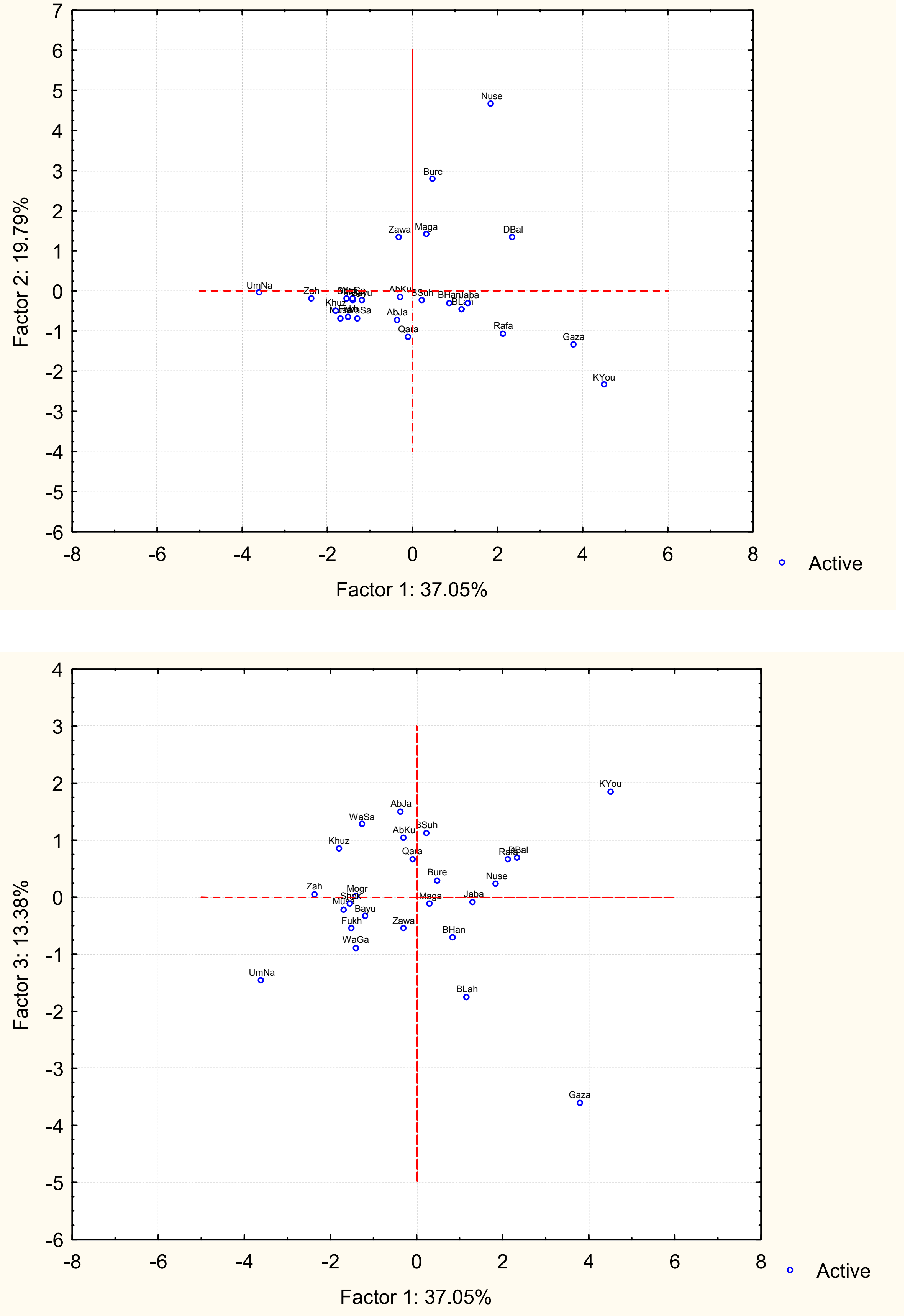


Figure 6.46 Projection of the cases on the factor-plane (1 x 2) and (1x 3) - management variables



- **Comparison of the results of PCCA analysis and cluster analysis**

The results of the PCCA analysis and cluster analysis have similarities and differences for the five categories of variables. Characteristics of the identified groups of variables in the cluster analysis are similar to the corresponding factors in the PCCA analysis. However, the PCCA identified an additional factor per category (i.e. socio-economic, pollution and management response). The PCCA gives more details about the groups of variables (factors) and the association of cases (municipalities) with the corresponding variables. It gives the weight of each group of variables (factor) reflected by the variance value and presents the variables' loadings on factors reflecting their significance and priority. The PCCA also can identify the characteristics of additional (supplementary) cases and variables via projecting and mapping them into the factor space.

Hence, the results of PCCA analysis can be applied for formulating priority strategy programs to handle the water stresses in specified geographical areas. However, the cluster analysis can be used as an early exploratory tool to investigate the hierarchy and shapes of possible groups of cases and corresponding variables.

6.3.3 Factor Analysis

Factor analysis (Section 5.2.3) was used for the purpose of comparison with PCCA results. It reduces the number of observed variables per category to a smaller number of unobserved latent factors which are uncorrelated with each other and classifies variables within these factors.

The number of significant factors resulted from the PCCA analysis for the five categories of variables (Section 6.3.2), were used for the factor analysis. Varimax normalized rotation strategy (Section 5.2.3) was adopted to maximize the variance of factors on the new axes and to obtain a pattern of variable loadings on each factor. The factor analysis was carried out for the categories of socio-economic, pollution pressure, state of water quality, impact and management responses variables.

- **Socio-economic variables**

The socio-economic variables classified by the factor analysis are: population, income per capita, land use, tourism, access to safe water supply, wastewater system coverage, storm water system coverage, water consumption per capita, water price, agriculture water consumption, gender empowerment and unaccounted for water.

Results and discussion

Table 6.36 and Figure 6.47 present the three- factor rotated solution with the cross-loadings of their classified variables. The first factor represents 38.9% of the total variance. It contains inter-correlated observed variables which are: water abstraction, storm water coverage, income per capita, agriculture water consumption, population and unaccounted for water. This underlying factor explains the determinants of the groundwater abstraction from the coastal aquifer.

The second factor represents 18.46% of total variance and has two variables which are land use and wastewater coverage. This latent factor represents the land use as a driver to improve the sanitation services.

The third factor has 13.71% of total variance and includes two inter-correlated and inverse variables which are water consumption per capita and water price. If one increases then the other decreases. The third factor refers to the water price as a determinant of the water consumption per capita.

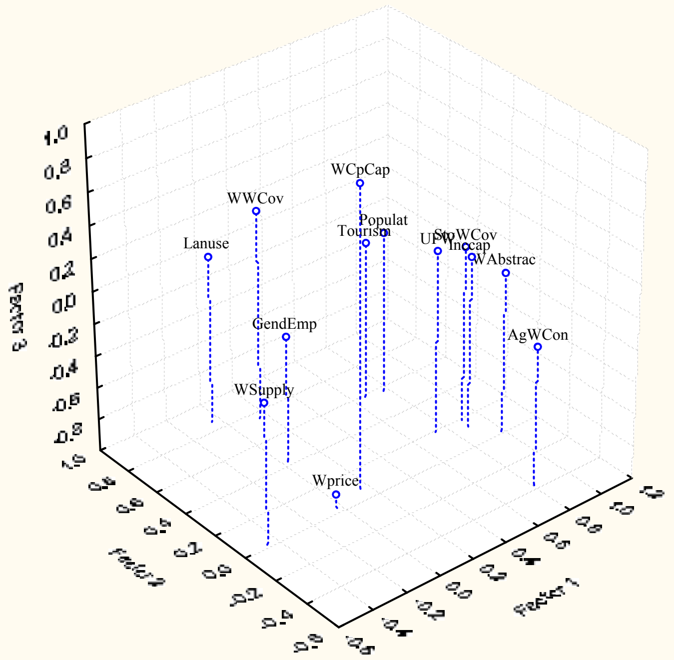
In comparison with the PCCA results for the socio-economic variables (Table 6.27), the factor analysis introduced a new important determinant of water abstraction which is agriculture water consumption and dropped tourism. The remaining variables are similar but they have different factor loadings.

Table 6.36 Factor Loadings- socio-economic variables
(Varimax normalized) Extraction: Principal components
(Underlined loadings are > .700000

	Factor 1	Factor 2	Factor 3
WAbstrac	0.983463	0.012413	0.007622
Populat	0.770753	0.572592	0.013941
Inccap	0.886873	0.128305	0.071697
Lanuse	-0.042702	0.863224	0.051939
Tourism	0.668167	0.589462	-0.020419
WSupply	-0.459694	0.013498	-0.116634
WWCov	0.156144	0.753477	0.303145
StoWCov	0.901226	0.184717	0.092824
WCpCap	0.155229	0.071984	0.868101
Wprice	-0.027634	0.029678	-0.908526
AgWCon	0.804526	-0.375216	-0.134544
GendEmp	0.031418	0.422210	-0.208591
UFW	0.734974	0.187738	0.138261
Proportion of the total variance	0.389021	0.184576	0.137105

Figure 6.47 Factor Loadings, Factor 1 vs. Factor 2 vs. Factor 3 - socio-economic variables

Rotation: Varimax normalized



- **Pollution variables**

The pollution variables sorted in the factor analysis are: hazardous wastes, generation of domestic wastewater, chemical fertilizers, organic fertilizers, domestic solid wastes, industrial wastewater, CO_2 and seawater intrusion.

Results and discussion

Table 6.37 and Figure 6.48 indicate that the first factor stands for 46.32% of the total variance and contains the variables domestic wastewater, hazardous waste, domestic solid waste, industrial wastewater and seawater intrusion. The first factor represents the pollution resulted from socio-economic activities. The second factor has 22.6% of the total variance and includes two inter-correlated variables which are CO_2 and TDS. It reflects the emissions from transport sector and other industrial facilities as a source of global warming and climate change. The third factor has 25.62% of the total variance and contains two variables which are chemical fertilizers and organic fertilizers. This underlying factor represents rural pollution due to excessive uses of fertilizers in agriculture.

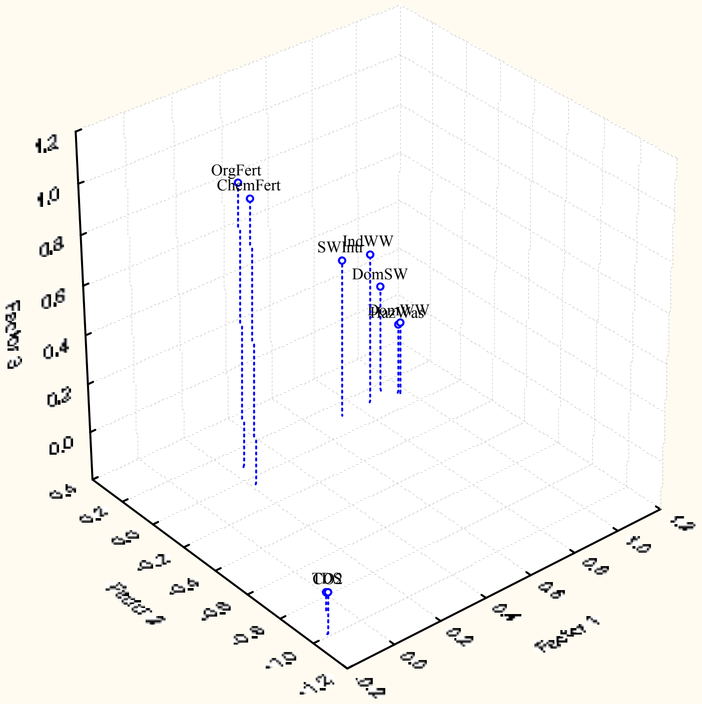
Comparing the results of the factor analysis with the PCCA results for the pollution variables (Table 6.29), two variables were introduced to factor 3 with factor loadings greater than 0.7. The variables are chemical fertilizers and organic fertilizers.

Table 6.37 Factor Loadings-pollution variables
(Varimax normalized) , Extraction: Principal components
(Underlined loadings are > .700000)

	Factor 1	Factor 2	Factor 3
TDS	-0.133561	-0.988687	-0.025363
HazWas	0.971460	0.099280	0.088680
DomWW	0.976576	0.089688	0.099717
ChemFert	0.219673	-0.043555	0.961123
OrgFert	0.252396	0.083279	0.957126
DomSW	0.934006	0.156031	0.242012
IndWW	0.853864	0.118606	0.425909
CO_2	-0.130502	-0.989430	-0.027739
SWIntr	0.723430	0.114489	0.455479
Proportion of the total variance	0.463230	0.226081	0.256277

Figure 6.48 Factor Loadings, Factor 1 vs. Factor 2 vs. Factor 3 - pollution variables

Rotation: Varimax normalized



- **State of water quality variables**

The water quality variables classified in the factor analysis are: Nitrate and Chloride.

Results and discussion

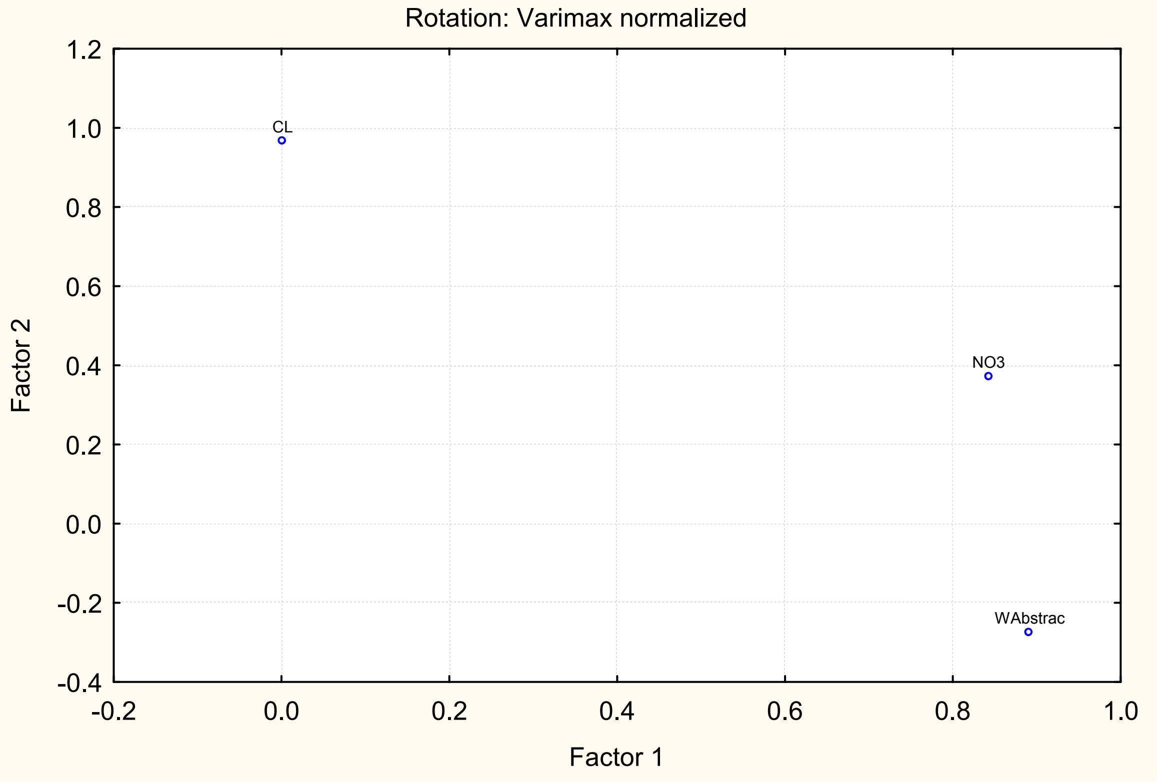
Table 6.38 and Figure 6.49 clarify the two- factor rotated solution with the cross-loadings of their classified variables. The first factor represents 50% of the total variance and contains observed variables which are water abstraction and Nitrate. This latent factor explains that the attractiveness of groundwater users is based on the concentration of Nitrate. The second factor represents 38.33% of the total variance and has a single variable which is Chloride. It refers to water salinity.

The results of factor analysis are similar to the results of the PCCA analysis for state of water quality variables (Table 6.31) except slight differences. Nitrate has the first rank in the first factor of PCCA analysis whilst it has the second rank in factor analysis. There is also a change in the sign of Chloride which indicates a shift in its projection on the factor plane (1x2).

Table 6.38 Factor Loadings- state variables
(Varimax normalized), Extraction: Principal components (Underlined loadings are > .700000)

	Factor 1	Factor 2
WAbstrac	0.889333	-0.272788
NO3	0.842510	0.373916
CL	0.001307	0.967369
Proportion of the total variance	0.500246	0.383343

Figure 6.49 Factor Loadings, Factor 1 vs. Factor 2-
state variables



- **Ecological and public health impact variables**

The ecological and public health impact variables organized in the factor analysis are: loss in agriculture productivity, loss of wetlands and morbidity.

Results and discussion

Table 6.39 presents that the four observed variables are reduced to one unobserved latent factor. This factor represents 64.11% of the total variance and includes the observed variables water abstraction, loss of agriculture productivity morbidity and morbidity. This underlying factor focuses on impacts resulted from water quality deterioration. The decrease in water abstraction will be associated with decrease in the number of water borne diseases due to the high Nitrate concentration in groundwater. In addition, the decrease of water abstraction is connected to the decrease of the loss in the agriculture productivity due to the high Chloride concentration in groundwater.

The results of factor analysis for ecological and public health impact variables are similar to the results of the PCCA analysis for the first factor. The second factor is completely dropped by factor analysis (Table 6.33).

Table 6. 39 Factor Loadings- impact variables
(Unrotated) Extraction: Principal components
(Underlined loadings are > .700000)

	Factor 1
WAbstr	-0.980689
LosProd	-0.844795
LosWet	-0.450248
Morbid	-0.828475
Proportion of the total variance	0.641131

- **Management response variables**

The management response variables classified in the factor analysis are: brackish water desalination, storm water harvesting, importation of water and regional water conveyance, treated wastewater, efficiency in water irrigation, efficiency in urban water supply networks, efficiency of information system, water awareness and education and seawater desalination.

Results and discussion

Table 6.40 and Figure 6.50 present the three- factor rotated solution with the cross-loadings of their classified variables.

The first factor represents 36.37% of the total variance and contains observed variables and their loading magnitude. It is mostly correlated with water abstraction, storm water harvesting and efficiency of information system (positive correlation) and efficiency of urban water supply (negative correlation). The underlying factor focuses on combination of measures to compliment the water abstraction. The second factor represents 20.16% of the total variance and contains two inter-correlated variables which are importation or regional conveyance and seawater desalination. This latent factor reflects the need for additional water resources to bridge the water supply-demand gap. The third factor has 13.69% of the variance with a single variable which is the efficiency of water irrigation. This underlying factor focuses on agriculture irrigation systems.

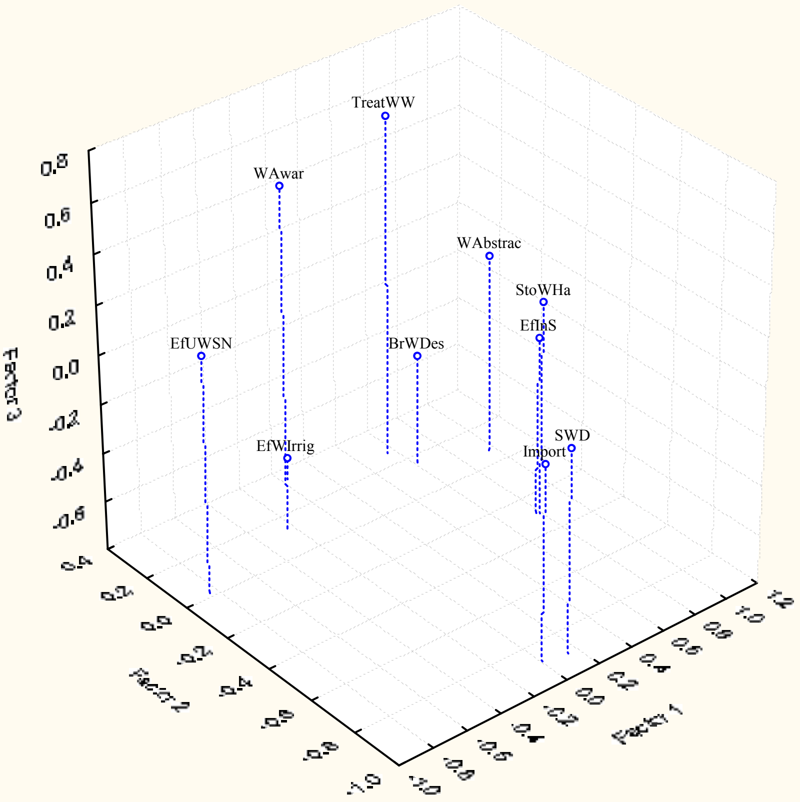
In comparison with the PCCA results for the management response variables (Table 6.35), the factor analysis introduced two variables with factor loadings greater than 0.7. The variables efficiency of information systems and efficiency in water irrigation were introduced to factors 1 and 3 respectively. In addition, the signs of the significant variables in the second factor have changed which indicates a shift in the projection of these variables on the factor plane (1x2).

Table 6.40 Factor Loadings- management variables (Varimax normalized), Extraction: Principal components
(Underlined loadings are > .700000)

	Factor 1	Factor 2	Factor 3
WAbstrac	0.960634	0.069254	0.018321
BrWDes	0.618247	0.159488	-0.347810
StoWHa	0.792099	-0.299945	0.073857
Import	0.006506	-0.886055	-0.001611
TreatWW	0.556891	0.260827	0.595067
EfWIrrig	0.033041	0.346790	-0.712489
EfUWSN	-0.844181	0.015601	0.164991
EfInS	0.779658	-0.291204	-0.070950
WAwar	-0.230833	0.134863	0.589396
SWD	0.139098	-0.905224	0.031343
Proportion of the total variance	0.363687	0.201625	0.136914

Figure 6.50 Factor Loadings, Factor 1 vs. Factor 2 vs. Factor 3- management variables

Rotation: Varimax normalized



6.4 Human health risk assessment (Application to Gaza WWTP)

Gaza WWTP was identified as a potential hotspot and selected for study. Currently, treated and partially treated wastewater has been disposed eventually on the seashore close to bathing areas. So, marine water was chosen as the contaminated media. Chemicals available in this media (Table 4.3) are: Arsenic, Cadmium, Chromium (VI), Copper, Cyanide, Lead, Mercury, Nickel, Phenol, Selenium, Vanadium, Zinc. The possible exposure routes selected are ingestion while swimming and dermal contact while swimming. The possible two scenarios of receptors (Section 5.2.4) are :

1. Adult resident.
2. Child resident.

These two receptors represent the most vulnerable groups of people that are likely affected during swimming.

Other details about input parameters of the software (RISC WorkBench) are shown in Table A3.1.

6.4.1 Results and discussion

The results of the health risk assessment analysis include calculation of potential carcinogenic risks of the chemicals concentrated in marine water, hazard index and clean up levels which referring to the allowable concentration of chemicals.

- ☒ **Carcinogenic risk**

Table A3.2 indicates that Arsenic is the only pollutant that has carcinogenic risk for both adult and child residents receptors. The carcinogenic risk of Arsenic is summarized in Table 6.41 for the two receptors and for the two exposure routes which are ingestion and dermal contact with water. Case 1 shows that the risk from the dermal contact for adults is higher than ingestion of marine water. Case 2 shows that the risk from the dermal contact in this case is lower than ingestion of marine water. The total carcinogenic risk resulted from the dermal contact exposure route is higher compared with the ingestion exposure route (Figure 6.51).

The total carcinogenic risk of Arsenic for both adults and children is close to two cases over a million which is less than the acceptable risk of 1.0E-05 (UNEP, 2004).

Table 6.41 Summary of carcinogenic risk

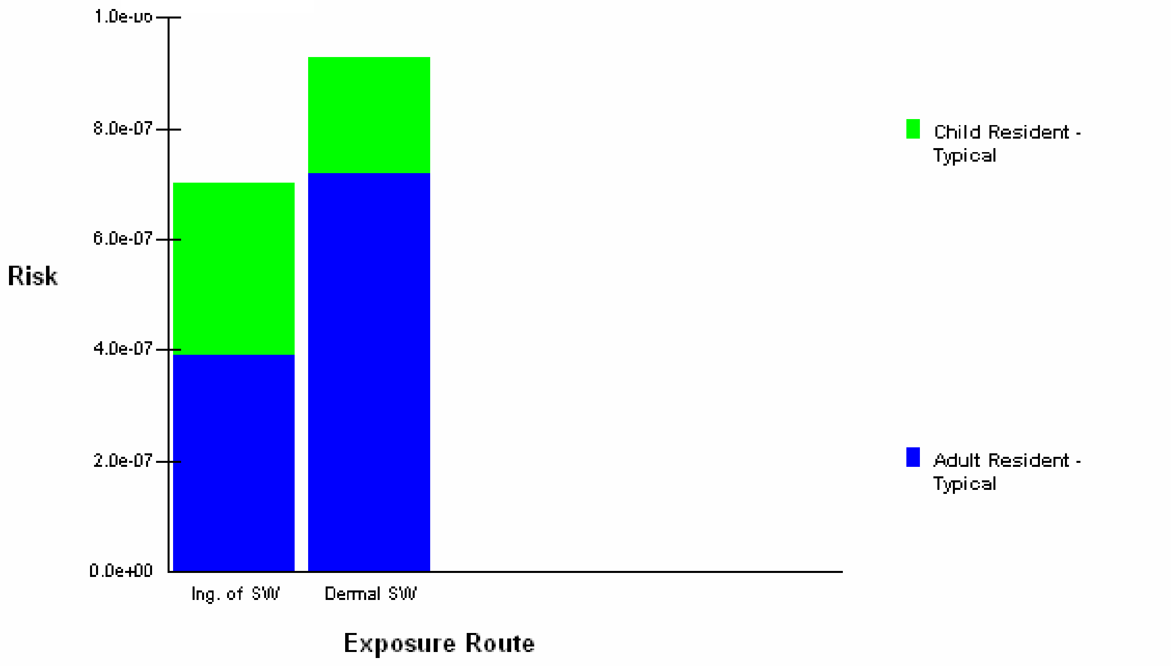
CASE 1: Adult Resident

	Ingestion of marine water	Dermal Contact with marine water	TOTAL
Arsenic	3.9E-07	7.2E-07	1.1E-06
TOTAL	3.9E-07	7.2E-07	1.1E-06

CASE 2: Child Resident

	Ingestion of Surface W.	Dermal Contact with Surface W.	TOTAL
Arsenic	3.1E-07	2.1E-07	5.1E-07
TOTAL	3.1E-07	2.1E-07	5.1E-07

Figure 6.51 **Carcinogenic Risk for Each Route**



6.4.2 Summary of hazard quotients

Figure 6.52 shows that the total hazard index resulted from all chemicals in the two exposure routes is higher in case of adults compared with children.

The total hazard index is higher for children compared with adults in case of ingestion of marine water whilst it is lower in case of dermal contact with marine water. The total hazard index resulted from the dermal contact exposure route is higher than that of the ingestion exposure route (see Figure 6.53).

Arsenic has the highest total hazard index followed by Chromium VI (see Figure 6.54). Selenium has the lowest total hazard index for both adult and child residents (see Table A3.2).

Figure 6.52

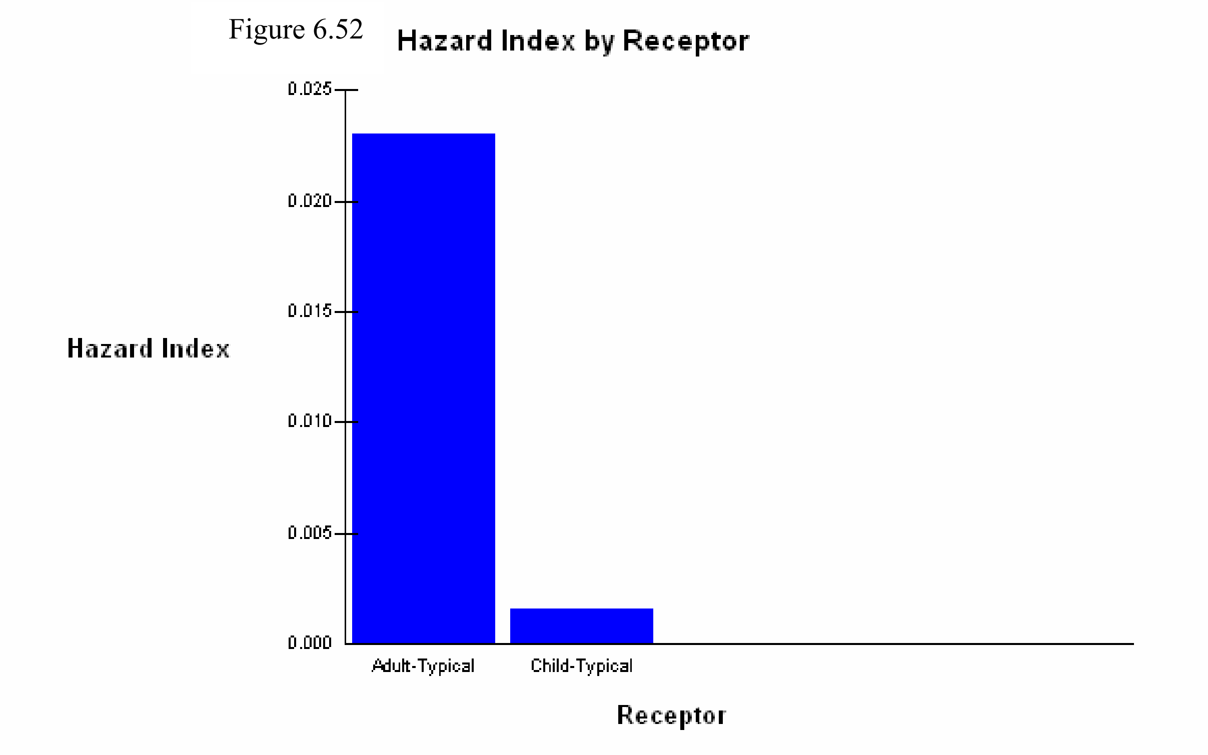


Figure 6.53

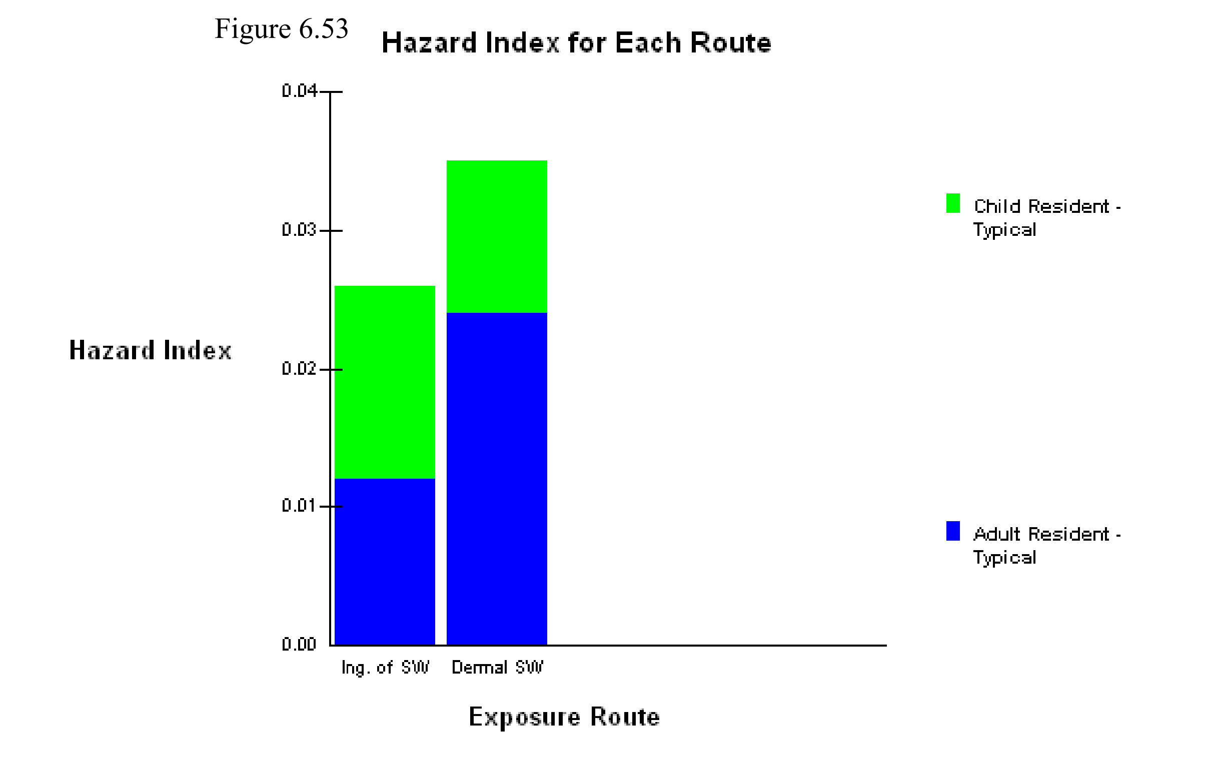
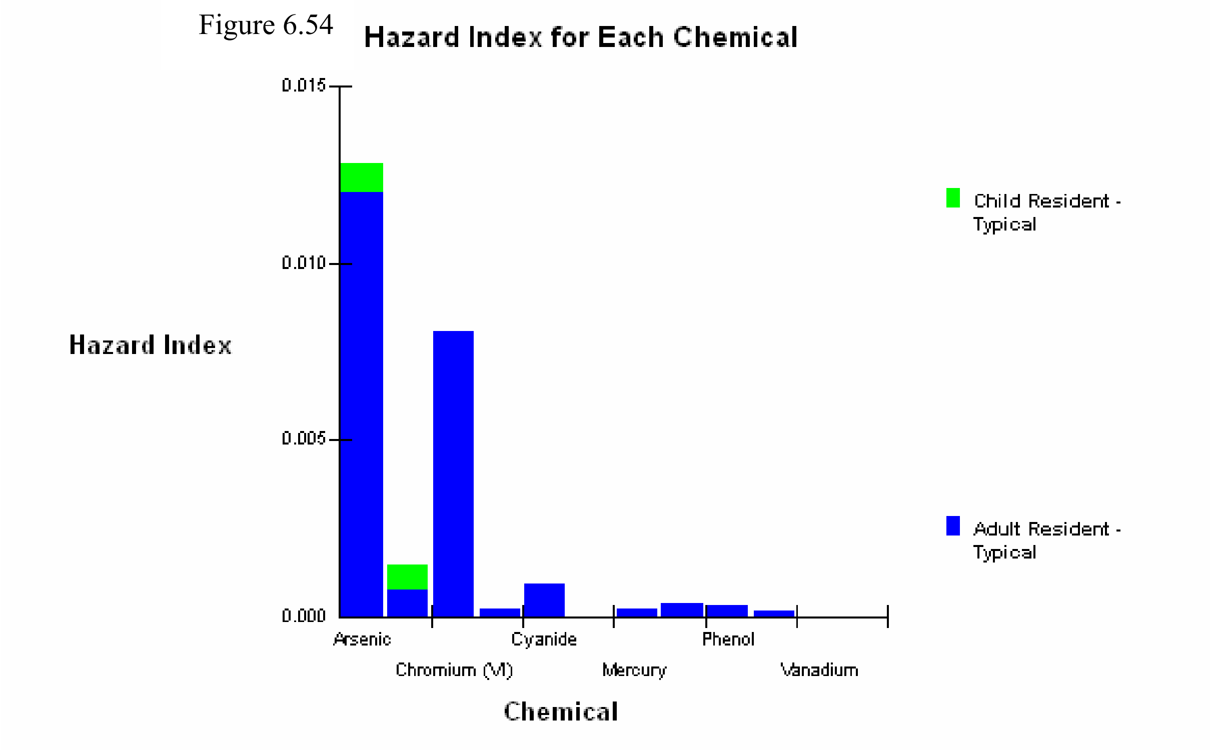


Figure 6.54



6.4.3 Summary of clean-up levels

If the total risk target is one case over one million, then only Arsenic concentration has to be reduced from 0.1 mg.l^{-1} (Table 4.35) to 0.081 mg.l^{-1} (Table 6.37).

Table 6.42 Clean-up levels in surface water; receptor: adult resident -typical

	SSTLs [mg.l^{-1}]	Solubility [mg.l^{-1}]	
Arsenic	8.1E-02	0.0E+00	**
Cadmium	7.7E-01	0.0E+00	**
Chromium (VI)	3.9E+00	0.0E+00	**
Copper	5.7E+01	0.0E+00	**
Cyanide	9.1E+00	0.0E+00	**
Lead	1.6E+01	0.0E+00	**
Mercury	3.2E-01	0.0E+00	**
Nickel	3.1E+01	1.7E+05	
Phenol	2.4E+02	8.3E+04	
Selenium	7.7E+00	0.0E+00	**
Vanadium	1.1E+01	0.0E+00	**
Zinc	6.3E+02	0.0E+00	**

** SSTL exceeds the chemical's solubility.
SSTL indicates site specific target level

6.5 Concluding Remarks

The conclusions of data analysis using the techniques of ANN, basic statistics, multivariate, health risk assessment and expert opinion and judgment can be summarized as follows:

- The results obtained in the ANN analysis indicate that a feed-forward Multilayer Perceptron (MLP) network with a back propagation algorithm proved to be the best ANN structure to model and predict the relationship between the groundwater quantity and quality on one hand and the other categories of independent variables on the other hand. These categories are socio-economic, pollution pressures, state of water quality, impact and management response. Besides, MLP networks can characterize and prioritize the effective variables in each category.

- The ANN models can be used for independent data sets in water and environmental sciences.
- There are significant discrepancies between the results of ANN analysis and expert opinion and judgment in terms of ranking and prioritizing the socio-economic, pollution pressure and management responses variables. These results are consistent for the categories of state of water quality and impact variables. Therefore, the research output assists water managers to gain better understanding about he actual water problems.
- Characterization of the priority effective socio-economic driving forces indicates that water managers and planners can introduce demand-based groundwater management in place of the existing supply-based groundwater management. This ensures the success of undertaking responsive technical, managerial and regulatory measures. Income per capita has the highest priority. Efficiency of revenue collection is not a significant socio-economic factor.
- Selection of the priority pollution determinants of groundwater quality assists water managers and planners to introduce cheap proactive and preventive-based groundwater management policy measures in place of the existing expensive engineering -based groundwater protection actions. Focus should be given to domestic wastewater as the most pressing pollution source followed by domestic solid waste. Petrol stations and pesticides are not significant pollution pressures.
- Definition of the priority water quality determinants influencing the attractiveness of groundwater users makes clear the groundwater quantity- quality interactions and adjusting them to each other to progress towards the provision of appropriate quantities of water of suitable quality. Highlighting the parameter of Nitrate stresses the need to remove Nitrate from groundwater using appropriate techniques. The Chloride parameter demonstrates the need for desalination of both brackish water and seawater. Nine water quality variables have low isignificance. which are Sodium, Calcium, Magnesium, Potassium, Fluoride, Sulfate, Hydrogen ion concentration, Alkalinity, and Total Coliforms.
- All public health and ecological impacts are significant to water sector management. These impacts are morbidity and loss of wetlands and agriculture productivity.

- All water policy and management responses are significant. Sustainable coastal aquifer management must take into consideration technical engineering as well as managerial interventions such that top priority should be given to the reuse of treated wastewater in agriculture followed by desalination of water.
- Arsenic is the only chemical that has carcinogenic risk for both adult and child residents receptors and its concentration has to be reduced by 20%. The total carcinogenic risk of Arsenic for both adults and children is close to two cases over a million. Arsenic has the highest total hazard index followed by Chromium VI whilst Selenium has the lowest for both adult and child residents. The total hazard index resulted from all chemicals in the two exposure routes is higher in case of adults compared with children. The dermal contact exposure route has higher total hazard index compared with the ingestion exposure route.
- The municipalities of Khan Younis and Gaza are characterized by high water abstraction and their need for additional water resources including desalination and regional conveyance of water. They are distinguished also by their significant anthropogenic pollution generated from the socio-economic activities of their large populations. Notably, Gaza municipality is differentiated by CO_2 and industrial wastewater due to concentration of cars and industries in the city.
- Um Alnasser, Al-Zahra', Rafah, Khan Younis and Gaza are classified by their significant morbidity originated from the water borne diseases.
- Municipalities of Beit Hannun, Nusseirat, Gaza, Deir El-Balah and Al-Mograga are characterized by ecosystem due to the existence of wadis within their boundaries.
- Municipalities of Rafah, Gaza and Beit Lahia have high Nitrate concentration due to the overloading of treatment facilities within their boundaries and disposal of effluent into open environment.
- Coastal municipalities as well as municipalities located close to the eastern border of GS are characterized with high Chloride concentration. This is due to seawater intrusion in coastal municipalities and the salt transport from the upstream irrigated agriculture areas in Negev to the downstream along the eastern border of GS (Malach and Pasternak, 1995; Nativ, Adar, Dahan and Nissim, 1997).

Chapter 7 General Conclusions and Recommendations

In this research work, a new conceptual water integrated model has been developed based on cause- effect relationship. The new model depicts the most important elements and sciences related to water and indicates that water resources development and management must be within the ecological sustaining limits of available natural water resources. The new conceptual water integrated model was applied to the life cycle of water resources management in GS.

Principal features of the analysis and findings

The effective variables have been characterized and prioritized using multi criteria analysis with ANN, risk assessment techniques and expert opinion and judgment. The selected variables have been classified and organized using multivariate techniques which are cluster analysis, principal component and classification analysis and factor analysis.

The main findings of these analysis techniques are:

- Income per capita is the most important socio-economic driving force followed by tourism. The remaining effective socio-economic driving forces according to their rank are: agricultural water consumption, water consumption per capita, population, gender empowerment, water supply coverage, wastewater coverage, water price, storm water coverage, unaccounted for water and land use. The variable of efficiency in revenue collection was removed from the ANN due to its low sensitivity.
- Domestic wastewater is the most pressing pollution source followed by domestic solid waste. The remaining pollution variables according to their ranking are: Carbon dioxide, hazardous waste, seawater intrusion, chemical fertilizers, organic fertilizers and industrial wastewater.
- Nitrate and Chloride are the most important and effective water quality parameters.
- There are public health and ecological impacts associated with water sector management. These impacts are morbidity and loss of wetlands and agriculture productivity.
- The water policy elements should be a combination of managerial and technical engineering interventions. Reuse of treated wastewater should have the top priority in the water policy as a potential strategic water resource for agriculture followed

by desalination of water to meet the domestic demand in particular provided that the social affordability has to taken into consideration especially in societies of high poverty lines. Other policy effective measures are: efficiency of urban water supply, storm water harvesting, efficiency of information systems, efficiency in water irrigation, importation and regional conveyance of water and then water awareness and education.

- The health risk assessment application indicated that Arsenic is the only chemical that has carcinogenic risk. The total carcinogenic risk of Arsenic is close to two cases over a million. Arsenic has the highest total hazard index followed by Chromium VI whilst Selenium has the lowest. The total hazard index resulted from all chemicals is higher in case of adults compared with children.
- Municipalities located close to the eastern border of GS are described with high Chloride concentration due to the salt transport as a result of irrigating the agriculture land in Negev with brackish water. Municipalities run WWTP's within their boundaries are characterized with high Nitrate concentration due to the disposal of low quality effluent into open environment.
- Khan Younis and Gaza are characterized by high water abstraction and their need for additional water resources including desalination and regional conveyance of water. They are distinguished also by their significant anthropogenic pollution.
- Um Alnasser, Al-Zahra', Rafah, Khan Younis and Gaza are classified by their significant morbidity originated from water borne diseases.

Deliverables of the research work

The deliverables produced by this research work are original in GS. These deliverables are:

1. A new conceptual water integrated model including five categories which are socio-economic, pollution pressure, state of water quality, impact and management responses. The effective variables under these categories were characterized and prioritized.
2. Prediction model for the relationship between the groundwater abstraction from the coastal aquifer and socio-economic driving forces.
3. Prediction model for the relationship between the groundwater abstraction from the coastal aquifer with water quality parameters.

4. Prediction model for the relationship between the groundwater quality with point and diffuse pollution sources.
5. Prediction model for the relationship between the groundwater abstraction from the coastal aquifer with water policy interventions.
6. Assessment of the human health risk caused by wastewater disposal from Gaza treatment plant into the sea and the required clean up levels to remediate this contaminated site.
7. Classification of municipalities (observations) and water related variables so that the actual water problems and their locations are well identified.

Significance of the research work

This research work was intended to contribute to the advancement of water resources management through the development of new conceptual integrated water model based on systematic and multidisciplinary approach. The new conceptual integrated water model can be applied in the semi-arid Mediterranean region. It has been the first experience that tackled the big picture of IWRM including sustainability concepts. Besides, it has been based on integrated, preventive and ecosystem approaches with the view to optimize water resources management whilst sustaining the ecological limits and carrying capacity of the natural water resources.

The research work defined for the first time, the effective multi criteria parameters for water sector analysis and monitoring besides the geographical areas under water stresses on objective scientific basis. It concludes also the potential interventions needed to ensure water availability; suitability and supply- demand balance. The new model addressed a key objective on the levels of Mediterranean region in general and GS in particular "to achieve sustainable use and management of natural water resources and effective protection of the environment". Protection ensures that the water resources base is utilized wisely so that it can continue to provide benefits for improving people's livelihoods and fostering economic development on sustainable basis.

Expected impacts of the research output on water resources management in GS

Given the differences between the results of the ANN model and the expert opinion about the significance and priority of water related variables under the various categories, the research output assists water decision makers and planners to gain better knowledge and understanding of the actual baseline conditions that ensure the success of undertaking management response measures.

This research study comes as the first attempt to strengthen the integrated approach through studying the life cycle of water resources management and concluding new conceptual water integrated model. It has brought social, economic, environmental, technical, public health and ecosystem factors together. Besides that, it took into consideration the expert opinion and the stakeholders' concerns. Therefore, the new conceptual water integrated model can be the basis for a sustainable national water plan. In addition, the selected and prioritized variables are very useful for the water sector analysis and monitoring.

Selecting and prioritizing the effective socio-economic driving forces assist water managers to devise water demand management measures with the objective of bridging present and future water supply-demand gap and restoring Gaza aquifer as part of nature conservation. This supports the interaction between socio-economic factors and groundwater management such that groundwater becomes a part of the society. Highlighting the factors of access to safe water supply, service coverage of wastewater and storm water systems, income per capita and water price will strengthen the social equity concept. Importance of gender empowerment will allow women to play a central role in the groundwater management. Significance of land use factor requires the adjustment of land use plans to be part of the overall planning and management of groundwater. The UFW factor demonstrates the need to handle the illegal connections, detect the leakage and rehabilitate the water networks and improve the metering system.

Defining and prioritizing the pollution determinants of groundwater quality assist water managers to devise proactive and proper water pollution control measures with the objective of protecting Gaza aquifer. This strengthens the preventive approach and mainstream environmental sustainability into groundwater management.

Characterizing and prioritizing the water quality determinants influencing the attractiveness of groundwater users clarified the groundwater quantity- quality interactions. Hence, limited available financial resources are directed towards the provision of appropriate quantities of water of suitable quality. Highlighting the parameter of Nitrate stresses the need to remove Nitrate from groundwater using appropriate techniques. The Chloride parameter demonstrates the need for desalination of brackish and seawater.

Highlighting the public health and ecological impacts of water quality strengthens the ecosystem approach and introduces the human factor at the center of integrated water resources management.

Describing and prioritizing the significant water policy interventions assist decision makers to enhance the formulation of policies in the water resources context. Focus should be given to reuse of treated wastewater as a strategic resource for agriculture and aquifer recharging. The research output assured that water policy elements should be a combination of managerial and technical engineering interventions.

Classifying the water variables and municipalities under various categories introduces sound and realistic development programs focusing on actual water problems and geographical areas under stresses with their priorities to maximize the allocation of limited available financial resources.

Limitations of the research work

The application of ANN and other classical statistical techniques in this research work have some limitations due to the limited data sets available (25 municipalities). Therefore, the cross verification was used in ANN as a stopping criteria to determine the optimal number of hidden layer nodes whilst avoiding the risk of over training.

The zero values of variables for some cases may affect the results of statistical as well as ANN analysis.

The insufficient data about chemicals available in wastewater due to the lack of testing equipment may underestimate the health and ecological risks of Gaza wastewater treatment as a contaminated site.

Recommendations for improvement in water sector management

1. Water resources management should be based on integrated, preventive and ecosystem approaches.
2. The existing conceptual model of water resources management in Palestine (Figure 3.8) should be elaborated to take into consideration the findings of this research. The suggested model for GS is shown in Figure 7.1.
3. All water policies, plans and programs should undergo Strategic Environmental Assessment (SEA). It is vitally important tool to support the integrated approach of

water resources management and to ensure the water sustainability. SEA makes IWRM mandatory and legally binding.

4. The results of the data analysis should be the basis to conduct SEA for the national water plan (PWA, 2000) to evaluate the validity of the proposed water developmental actions in GS (see Figure 5.1).
5. The national water plan (PWA, 2000) should be reformulated to take account of the priority water problems (see Figure 7.1) and the geographical areas under stresses (see Section 6.3).

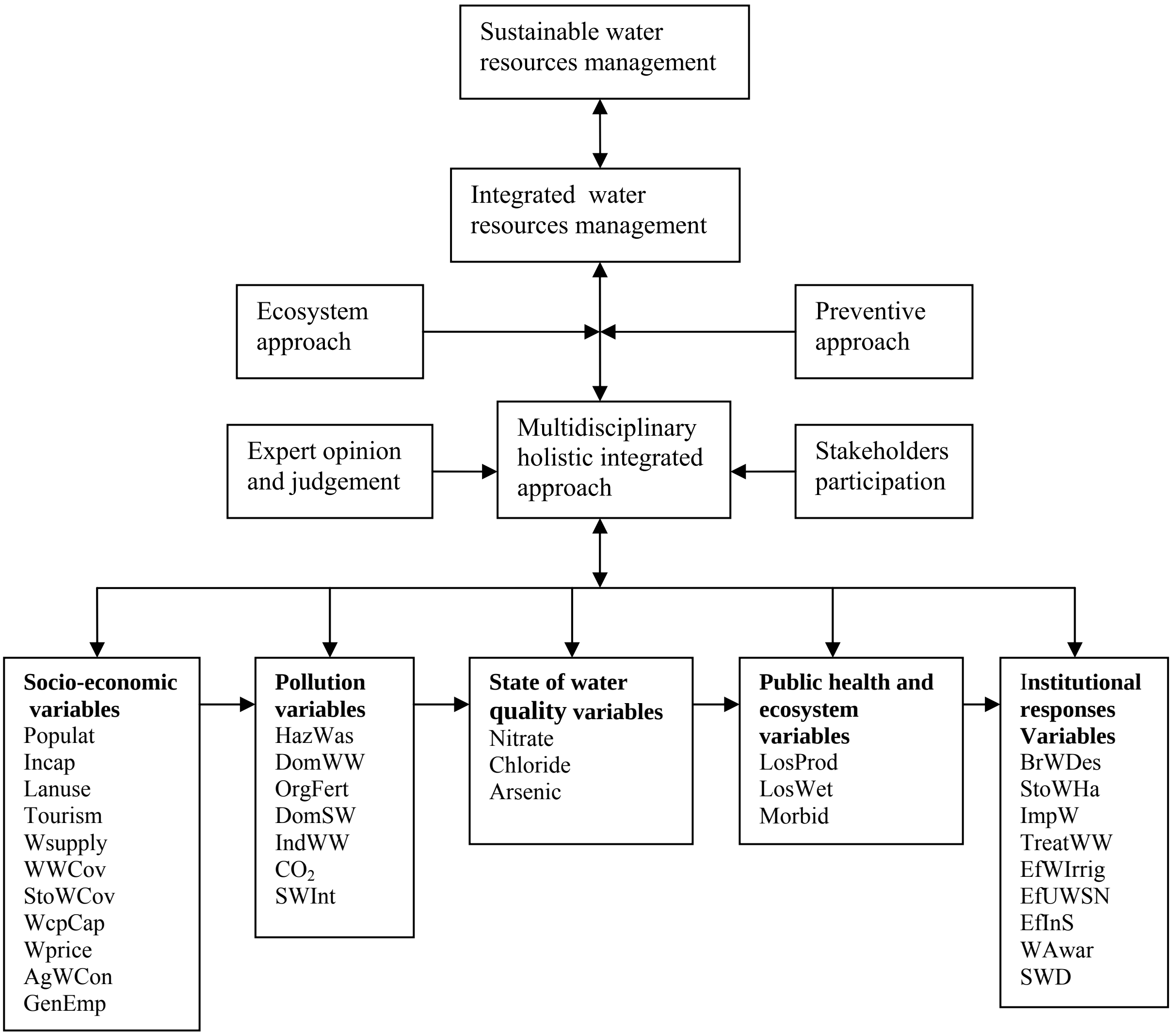


Figure 7.1 Conceptual water integrated model for GS including significant variables
Legend: See Section 4.3

6. The ecosystem water use and demand requirements must be taken into account when calculating the overall water demand.

7. Preparation of salinity management strategy for stream coastal aquifer system using Accelerated Salt TRANsport (ASTRAN) method to handle the saline groundwater in eastern GS. In the current irrigation practices, the slow movement of groundwater tends to cause an accumulation of salts from normal irrigation practice, since drainage water adds salt to the aquifer at a faster rate than it can be naturally transported downstream. ASTRAN method promotes the application of groundwater on downstream agriculture fields instead of nearby fields. That is, fields close to a pumping well should be irrigated by water from upstream wells. Salt in the pumped water can therefore be transported downstream at a faster rate than would occur naturally through flow in the saturated zone (Helweg and Labadie, 1976).
8. Planning and building regulations should allow for cisterns to collect rainwater from the roofs of the residential and public buildings as well as the agriculture green houses.
9. Protection of seawater quality from land based pollution sources since seawater has become a strategic resource for desalinated water.
10. Selection and adaptation of the most appropriate denitrification technology to remediate groundwater. Among the available likely denitrification technologies are: application of biofilm kinetics to the sulfur/lime packed bed reactor for autotrophic denitrification of groundwater (Wang, 1998), using cotton as energy source (Volokita, Abeliovich and Soares, 1999), using acetic acid as a carbon source (Bandpi, Elliott and Mazdeh, 1999), using methane as sole hydrogen donor (Eisentraeger, Klag, Vansbotter, Heymann and dott, 2000), using elemental sulfur (Soares, 2001) and in situ biological denitrification using indigenous bacteria (Abdelouas, Deng, Nuttall, Lutze, Fritz and Crovisier, 1998).
11. Evaluation and selection of the most appropriate technologies for seawater desalination and feasible energy sources. Possible technologies to be considered are: Reverse Osmosis (Jawad, 2001), multi-stage flash (Wazzan and Al-Modaf, 2001), multi-effect distillation (Wade, 2001), electrodialysis (Pilat, 2001). Possible energy sources are renewable energy, hydropower, nuclear and conventional fossil energy sources (Megahed, 2000). Renewable energy sources are solar thermal and photovoltaic (PV) systems, wind power, biomass and oceanic energy (Rodriguez, L.G., 2003).

12. Planning and management of water resources should be adapted to climate change.
13. Planning and regulation of population growth. through reproductive health programs and more women empowerment in work opportunities and development.

Recommended directions for further research

The following areas are recommended for further research:

1. Based on the human health and ecological risk assessment, the value limits for water quality criteria should be defined and compared with the World Health Organization values. This examines the pragmatic validity and suitability of WHO standards for the local conditions.
2. Comparative assessment for various seawater desalination technologies and the potential energy sources with emphasis on nuclear desalination.
3. Selection of the appropriate de-nitrification technologies with the view to clean-up and remediate Gaza aquifer.
4. Selection of the appropriate technologies for wastewater treatment and reuse especially in agriculture and artificial recharge
5. Selection of appropriate water harvesting and water conservation techniques.

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Annexes

Annex A1

Expert Opinion and judgment

A1.1 Expert Opinion and judgment questionnaire

The research work aims to investigate the effective set of indicators that are currently influencing the abstraction from the coastal aquifer to meet the growing water use in GAZA STRIP for domestic, agricultural, industrial and commercial purposes.

The significance of this investigation is that it tackles the big picture of Integrated Water Resources Management (IWRM) which is based mainly on three decisive systems: (1) the natural system, which is of critical significance for the water available quantities and qualities, (2) the human system, which determines the use of water and the pollution of the resource, (3) the institutional and management system which must balance considerations of the natural and human systems and their interdependencies.

The Driver-Pressure-State-Impact-Response (DPSIR) was selected to develop the indicators as a well established framework for cause-effect relationship reflecting the life cycle of water resources management in GAZA STRIP. The Driver includes socio-economic and natural aspects. Pressure refers to the point and non-point pollution sources with emphasis on anthropogenic factors. The state explains the current water quality parameters. Impact presents the ecological and public health consequences. Response represents the measures undertaken by the water administration.

The human system is explained by the socio-economic driving forces, anthropogenic pressures and public health. The natural water system is presented by the state of water and environment, and ecological impacts and the institutional system is reflected by the institutional responses.

The researcher analyzed the effectiveness of the indicators using several classical statistics including multiple linear regression, cluster analysis, factor analysis and principal component analysis. Besides, the artificial neural networks and optimization techniques were used to be compared with the outputs of classical statistics. An additional technique is required for the comparison which is the expert opinion and judgment.

Please would you assign ranks (lower ranking for the most influential indicators) and weights (from 1 to 100) for the independent indicators in every category separately with regards to their influence on the water abstraction as a dependent indicator. Please note that the sum (total) of the weights should be 100. Also, weights (from 1 to 100) for the influence of the 5 categories on the water abstraction are required. Any further comments on the selected indicators will be highly appreciated.

a. Ranking and Weighing of Independent Indicators

Dependent Indicator

1. Water abstraction from the aquifer is the dependent variable for the categories of socio-economic driving forces, state of water quality, impact and management responses variables.
2. Total Dissolved Solids is the dependent variable for the pollution pressures variables

Independent Variables

☒ **Category of driving forces: socio-economic variables**

No.	Indicator	Rank in category	Weight (1-100)
1.	Population		
2.	Income per capita		
3.	Land use		
4.	Tourism		
5.	Access to safe water supply		
6.	Wastewater system coverage		
7.	Storm water system coverage		
8.	Water consumption per capita		
9.	Water price		
10.	Efficiency in revenue/taxation		
11.	Agricultural water consumption		
12.	Gender empowerment		
13.	Unaccounted for water		

☒ **Category of pressure: pollution variables**

No.	Indicator	Rank in category	Weight (1-100)
1.	Hazardous wastes		
2.	Generation of domestic		
3.	Pesticides		
4.	Chemical fertilizers		
5.	Organic fertilizers		
6.	Petrol stations		
7.	Domestic solid waste		
8.	Industrial wastewater		
9.	CO_2		
10.	Sea-water Intrusion or upcoming reflecting Over-pumping		

☒ Category of state: water quality variable

No.	Indicator	Rank in category	Weight (1-100)
1.	Nitrate		
2.	Chloride		
3.	Sodium		
4.	Calcium		
5.	Magnesium		
6.	Potassium		
7.	Fluoride		
8.	Sulfate		
9.	Hydrogen Ion Concentration (pH)		
10.	Alkalinity		
11.	Total Coliforms		

☒ Category of impact: ecological and public health variables

No.	Indicator	Rank in category	Weight (1-100)
	• **Ecological**		
1.	Loss in agriculture productivity		
2.	Loss of wetland		
	• **Public health**		
3.	Morbidity		

☒ Category of institutional responses: management variables

No.	Indicator	Rank in category	Weight (1-100)
1.	Brackish water desalination		
2.	Storm water harvesting		
3.	Importation of water and regional water conveyance		
4.	Treated/partially treated		
5.	Efficiency in water irrigation		
6.	Efficiency in urban water supply		
7.	Efficiency of water information		
8.	Water awareness and education		
9.	Seawater desalination		

b. Comments

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A1.2 Presentation of questionnaire data

Table A1.2.1 Questionnaire data- socio-economic variables

Respon-dent	Populat number	Inccap Eur.y^{-1}	Land-use %	Tourism guest days	WSupply %	WW-Cov %	StorW-Cov %	WCp-Cap l.cap^{-1}.d^{-1}	Wprice Eur.m^{-3}	EfRev-Co %	AgW-Con hm^3.y^{-1}	Gend-Emp %	UFW %
1	2	8	5	11	6	7	10	12	9	15	1	14	16
2	2	7	4	11	1	3	16	9	8	12	10	13	15
3	2	5	4	10	1	8	9	3	11	13	6	15	16
4	12	1	15	3	7	8	4	6	5	9	2	10	11
5	1	11	9	10	8	5	6	2	12	14	4	15	16
6	1	4	7	12	11	10	13	2	3	5	8	14	9
7	2	5	10	13	9	4	14	11	6	8	1	12	15
8	3	4	1	16	5	7	15	6	10	14	2	8	9
9	1	2	4	12	7	8	11	3	5	14	6	9	13
10	1	2	5	14	6	7	10	3	4	12	8	13	16
11	1	2	6	15	10	4	12	8	3	9	11	7	16
12	3	4	14	15	9	13	12	5	2	10	1	16	7
13	1	11	14	15	5	3	10	4	6	12	2	16	7
14	1				5			3	4		2		
15	1	5	11	12	9	4	12	5	3	9	2	7	12
16	1	6	2	6	3	4	6	5	2	4	1	7	7
17	2	10	12	15	8	7	14	11	6	3	1	4	16
18	1	15	4	8	14	7	16	6	5	12	2	10	9
19	1	2	14	15	4	3	10	5	6	13	8	11	12
20	1	2	13	16	3	4	7	5	6	10	9	11	12
21	1	2	13	16	4	3	12	5	6	9	7	10	11
22	1	7	3	13	4	8	16	12	6	11	2	14	15
23	2	7	11	16	12	13	9	8	10	4	5	3	15
24	1	7	4	6	5	5	7	6	6	7	2	5	8
25	4	11	5	15	12	7	16	6	8	13	1	9	14
26	3	8	2	15	6	7	14	4	5	12	1	10	16
27	4	11	10	12	6	8	9	1	5	7	2		
28	3	8	8	16	8	5	8	7	13	14	1	6	15
29	1	9	3	13	8	6	7	5	4	10	2	14	15
30	2	8	12	13	5	3	4	7	6	16	1	11	10

Table A1.2.2 Questionnaire data- pollution variables

Respondent	HazWas	DomWW	Pesticid	ChemFert	OrgFert	PetrolSt	DomSW	IndWW	CO_2	SWIntr
	$t.d^{-1}$	$hm^3.y^{-1}$	$t.y^{-1}$	$t.y^{-1}$	$t.y^{-1}$	numbers	$t.d^{-1}$	$hm^3.y^{-1}$	ppm	$hm^3.y^{-1}$
1	8	1	7	4	6	9	2	5	10	3
2	8	1	7	2	3	9	5	6	10	4
3	7	1	4	5	8	9	3	6	10	2
4	10	3	4	2	1	5	7	6	8	9
5	2	4	5	3	9	7	8	6	10	1
6	6	1	7	2	8	9	4	3	10	5
7	7	1	6	5	4	8	3	9	10	2
8	9	1	7	4	3	8	5	6	10	2
9	2	1	5	4	7	9	6	8	10	3
10	3	1	7	4	8	9	6	5	10	2
11	1	2	6	5	3	9	7	8	10	4
12	9	8	10	6	3	1	4	7	2	5
13	1	7	5	4	6	9	8	2	10	3
14	5	2	10	4	10	10	10	3	10	1
15	3	3	7	2	3	7	3	7	10	1
16	4	4	1	1	2	2	2	3	4	1
17	4	1	3	5	8	9	6	7	10	2
18	9	1	3	4	5	7	6	8	10	2
19	1	2	7	5	6	10	4	9	8	3
20	1	3	7	6	8	10	5	4	9	2
21	1	4	7	8	9	10	6	3	5	2
22	7	4	2	5	3	9	8	6	10	1
23	6	8	7	2	3	10	4	5	9	1
24	6	2	4	3	3	7	5	7	7	1
25	7	2	6	3	4	9	5	8	10	1
26	5	2	6	7	8	9	3	4	10	1
27	7	2	5	8	9	6	3	4	10	1
28	5	2	7	3	7	9	3	6	10	1
29	9	6	5	1	2	8	4	7	10	3
30	6	1	4	3	9	8	7	5	10	2

Table A1.2.3 Questionnaire data- state variables

Respondent	NO3 mg.l^{-1}	CL mg.l^{-1}	Na mg.l^{-1}	Ca mg.l^{-1}	Mg mg.l^{-1}	K mg.l^{-1}	F mg.l^{-1}	SO4 mg.l^{-1}	pH mg.l^{-1}	Alkalinity mg.l^{-1}	T-Coli numbers/100ml
1	1	2	9	10	11	12	3	5	7	8	4
2	3	2	4	6	8	10	5	7	12	11	9
3	2	1	10	6	11	12	4	9	8	7	3
4	2	1	12	2	9	7	3	4	5	11	8
5	4	3	7	6	9	8	5	10	12	11	2
6	2	1	5	9	10	11	4	12	6	7	8
7	2	1	3	7	6	8	5	9	12	10	4
8	2	1	10	9	11	8	6	7	12	5	4
9	2	3	4	5	9	11	10	12	6	7	8
10	1	2	9	8	7	6	4	5	3	10	12
11	2	1	5	8	9	10	11	12	4	6	7
12	1	2	5	6	7	8	4	9	11	10	12
13	1	2	5	8	9	11	10	12	7	6	4
14	2	1						3			
15	2	1					4				3
16	1	2	3	4	5	5	3	5	5	5	2
17	1	2	7	6	8	9	5	10	3	11	4
18	2	1	7	8	9	10	11	12	6	5	4
19	1	2	12	6	11	10	4	5	9	8	7
20	1	2	10	3	9	11	5	6	7	8	12
21	1	2	12	3	6	11	5	10	7	8	8
22	1	2	5	11	10	9	6	7	8	4	12
23	1	11	6	12	7	10	8	9	5	4	2
24	1	2	6	6	6	6	5	6	4	5	5
25	1	2	10	9	8	11	5	12	4	7	6
26	1	2	4	9	10	11	7	12	8	6	5
27	4	1	5				6		9	8	7
28	1	1	6	7	7	7	3	7	7	7	4
29	1	2	5	9	10	6	12	11	7	8	4
30	1	3	4	7	8	9	5	10	17	11	6

Table A1.2.4 Questionnaire data- impact variables

Respondent	LosProd ton	LosWet hectar	Morbid Number
1	2	3	1
2	2	3	1
3	3	2	1
4	1	2	3
5	2	3	1
6	2	1	3
7	1	3	2
8	1	3	2
9	1	3	2
10	2	3	1
11	2	3	1
12	2	1	3
13	3	1	2
14	2	1	3
15	2	1	3
16	2	1	2
17	2	3	1
18	2	3	1
19	2	3	1
20	2	3	1
21	2	3	1
22	2	3	1
23	1	3	2
24	2	3	1
25	2	3	1
26	1	2	3
27	2	1	3
28	2	3	1
29	2	1	3
30	2	3	1

Table A1.2.5 Questionnaire data- management variables

Respondent	BrWDes	StoWHar	ImportW	TreatWW	EfWIrrig	EfUWSN	EfInS	WAwar	SWD
	$hm^3.y^{-1}$	$hm^3.y^{-1}$	$hm^3.y^{-}$	$hm^3.y^{-1}$	%	%	%	Number	$hm^3.y^{-1}$
1	6	3	8	5	1	4	7	2	9
2	3	7	8	6	2	1	5	4	9
3	2	1	7	5	4	3	8	6	9
4	1	3	6	2	4	5	8	7	9
5	1	4	2	3	7	5	6	8	9
6	6	2	8	1	3	4	7	5	9
7	5	6	8	3	1	2	7	4	9
8	3	2	8	4	1	5	7	6	9
9	1	5	2	3	4	6	8	7	9
10	1	6	2	3	5	4	8	7	9
11	5	2	4	1	3	6	8	7	9
12	4	2	8	1	3	5	7	6	9
13	6	4	2	1	5	3	8	7	9
14	1	8	2	5	4	3	6	7	1
15	7	7	3	4	1	2	4	4	9
16	4	4	4	2	1	2	3	3	9
17	5	3	7	4	2	1	8	6	
18	3	4	2	1	5	6	7	8	9
19	1	2	8	3	4	5	6	7	9
20	3	2	8	1	4	5	7	6	9
21	1	8	5	2	4	6	7	3	9
22	6	5	1	4	3	2	7	8	9
23	7	6	8	5	2	1	3	4	9
24	7	5	8	4	2	1	3	6	9
25	7	6	8	5	2	1	3	4	9
26	2	6	7	1	3	4	8	5	9
27	8	6	4	5	2	1	7	3	9
28	8	2	1	6	5	3	4	7	9
29	7	4	8	3	2	1	5	6	9
30	4	3	5	8	6	7	2	1	9

Annex A2

Presentation and Summary of data

A2.1 Presentation of data

Table A2.1.1 Raw data- water abstraction variable

Governorate	Municipality	1 WAbsr $hm^3.y^{-1}$
Northern	Beit Hannun (BHan)	4.75
	Beit Lahia (Blah)	5.76
	Jabalia (Jaba)	7.57
	Um Alnasser (UmNa)	0.18
Gaza	Gaza (Gaza)	31.9
	Al-Zahra' (Zahra)	0.52
	Al-Mograga (Mogr)	1.28
	Wadi Gaza (WaGa)	1.52
Middle	Nuseirat (Nuse)	3.08
	Magazi (Maga)	1.11
	El-Bureij (Bure)	1.90
	Zawaida (Zawa)	1.69
	Deir El-Balah (DBala)	4.48
	Wadi Salga (WaSa)	1.19
	Al-Musadar (Musa)	1.21
Khan-Younis	Khan Younis (KYou)	21.47
	Qarara (Qara)	2.97
	Bani Suhaila (BSuh)	2.02
	Khaza'a (Khuz)	0.95
	Abassan Kubra (AbKu)	2.57
	Abassan Jadida (AbJa)	1.26
	Al-Fukhari (Fukh)	1.64
Rafah	Rafah (Rafa)	10.07
	Al-Shoka (Shok)	1.03
	Al-Bayuk (Bayu)	1.69

Table A2.1.2 Raw data- TDS variable

Governorate	Municipality	2 TDS mg.l^{-1}
Northern	Beit Hannun (BHan)	1078
	Beit Lahia (Blah)	502
	Jabalia (Jaba)	651
	Um Alnasser (UmNa)	1231
Gaza	Gaza (Gaza)	1030
	Al-Zahra' (Zahra)	1930
	Al-Mograga (Mogr)	1646
	Wadi Gaza (WaGa)	1075
Middle	Nuseirat (Nuse)	2675
	Magazi (Maga)	1688
	El-Bureij (Bure)	1900
	Zawaida (Zawa)	1523
	Deir El-Balah (DBala)	1422
	Wadi Salga (WaSa)	1208
	Al-Musadar (Musa)	1512
Khan-Younis	Khan Younis (KYou)	1890
	Qarara (Qara)	1069
	Bani Suhaila (BSuh)	3217
	Khaza'a (Khuz)	2658
	Abassan Kubra (AbKu)	1786
	Abassan Jadida (AbJa)	2952
	Al-Fukhari (Fukh)	1789
Rafah	Rafah (Rafa)	665
	Al-Shoka (Shok)	1224
	Al-Bayuk (Bayu)	1372

Table A2.1.3 Raw data- socio-economic variables

	Municipality	3 Populat numbers	4 Inccap Euro.y	5 Landuse %	6 Tourism guest days	7 WSupply %	8 WWCov %	9 StorWCov %	10 WCpCap $l.cap^{-1}.d$	11 Wprice $Euro.m^{-3}$
Northern	Beit Hannun (BHan)	19496	1347	0.106	2546	90	85	14	140	0.252
	Beit Lahia (Blah)	35123	1350	2.24	3758	100	65	16	151	0.21
	Jabalia (Jaba)	116271	1350	8.63	10914	60	55	20	100	0.227
	Um Alnasser (UmNa)	8236	1335	4.94	712	100	10	10	98	0.21
Gaza	Gaza (Gaza)	408634	1420	2.93	41969	100	95	35	109	0.204
	Al-Zahra' (Zahra)	23532	1325	6.1	2034	100	40	12	90	0.204
	Al-Mograga (Mogr)	4707	1334	0.527	4.25	100	15	13	80	0.204
	Wadi Gaza (WaGa)	3530	1337	0.72	330	100	18	12	85	0.204
Middle	Nuseirat (Nuse)	47853	1344	2.215	4285	100	75	13	67	0.34
	Magazi (Maga)	26335	1332	4.17	1615	100	72	11	43	0.35
	El-Bureij (Bure)	31786	1340	1.755	2413	95	80	13	53	0.36
	Zawaida (Zawa)	14574	1339	1.771	1030	100	40	15	69	0.47
	Deir El-Balah (DBala)	46246	1347	2.345	4108	98	60	15	80	0.347
	Wadi Salga (WaSa)	4707	1333	0.885	400	100	10	12	60	0.343
	Al-Musadar (Musa)	3530	1335	0.714	320	100	12	12	62	0.345
Khan-Younis	Khan Younis (KYou)	158243	1390	0.743	12125	70	10	25	44	0.331
	Qarara (Qara)	11617	1343	1.091	1139	80	10	13	104	0.227
	Bani Suhaila (BSuh)	26952	1341	1.18	2206	98	6	12	61	0.314
	Khaza'a (Khuz)	9715	1330	0.832	651	100	10	10	87	0.306
	Abassan Kubra (AbKu)	20604	1342	0.97	1368	100	10	13	62	0.382
	Abassan Jadida (AbJa)	5939	1336	0.791	466	80	10	12	72	0.319
	Al-Fukhari (Fukh)	3530	1338	0.59	310	100	8	14	63	0.252
Rafah	Rafah (Rafa)	124506	1375	2.17	11544	100	40	23	70	0.31
	Al-Shoka (Shok)	5295	1337	0.826	458	100	8	11	61	0.315
	Al-Bayuk (Bayu)	4707	1339	0.654	415	100	20	10	68	0.32

Continued- Driving forces: socio-economic variables

Governorate	Municipality	12 EfRevCo %	13 AgWCon hm^3.y^{-1}	14 GendEmp %	15 UFW %
Northern	Beit Hannun (BHan)	0.67	4.52	0	37.8
	Beit Lahia (Blah)	0.82	3.52	8.7	38.9
	Jabalia (Jaba)	0.81	1.02	1.3	36.3
	Um Alnasser (UmNa)	0.82	0.027	0	9.4
Gaza	Gaza (Gaza)	0.78	13.28	0.04	37.7
	Al-Zahra' (Zahra)	0.85	0.055	0	10.6
	Al-Mograga (Mogr)	0.72	2.65	0	13.2
	Wadi Gaza (WaGa)	0.76	3.43	0	14
Middle	Nuseirat (Nuse)	0.78	2.28	0	26.4
	Magazi (Maga)	0.8	0.44	0	40.3
	El-Bureij (Bure)	0.98	1.56	25	23.2
	Zawaida (Zawa)	0.77	1.89	0	9.2
	Deir El-Balah (DBala)	0.56	3.41	5.6	45.6
	Wadi Salga (WaSa)	0.75	1.66	0	12.9
	Al-Musadar (Musa)	0.7	1.73	0	13
Khan- Younis	Khan Younis (KYou)	0.79	12.92	0	56.4
	Qarara (Qara)	0.82	1.95	0	39.9
	Bani Suhaila (BSuh)	0.8	1.05	0	33
	Khaza'a (Khuz)	0.9	0.5	0	8.4
	Abassan Kubra (AbKu)	0.88	1.67	1.25	6.1
	Abassan Jadida (AbJa)	0.89	0.88	0	26
	Al-Fukhari (Fukh)	0.74	1.34	0	14.5
Rafah	Rafah (Rafa)	0.79	2.01	0	36.4
	Al-Shoka (Shok)	0.71	0.4	0	12.3
	Al-Bayuk (Bayu)	0.74	1.36	0	14.6

Table A2.1.4 Raw data- pollution variables

Governorate	Municipality	16 HazWas $t.d^{-1}$	17 DomWW $hm^3.y^{-1}$	18 Pesticid $t.y^{-1}$	19 ChemFert $t.y^{-1}$	20 OrgFert $t.y^{-1}$	21 PetrolSt numbers	22 DomSW $t.d^{-1}$	23 IndWW $hm^3.y^{-1}$	24 CO2 ppm	25 SWIntr $hm^3.y^{-1}$
Northern	Beit Hannun (BHan)	0.44	1.17	25.1	115.96	200	4	26	0.055	295	0
	Beit Lahia (Blah)	0.626	2.22	19.67	86.143	220	5	42.5	0.107	290	11.6
	Jabalia (Jaba)	0.977	3.6	5.633	21.365	150	11	85	0.168	291	24.3
	Um Alnasser (UmNa)	0.164	0.315	2.45	1.623	5	2	7	0.0015	296	0
Gaza	Gaza (Gaza)	3.95	15.8	47.09	244.73	714	34	550	0.91	294	44.1
	Al-Zahra' (Zahra)	0.313	0.33	1.956	2.668	7	2	6	0.002	301	0
	Al-Mograga (Mogr)	0.043	0.066	11.56	51	142	1	3.5	0.0025	299	0
	Wadi Gaza (WaGa)	0.032	0.0498	14.29	66	184	1	3.5	0.0028	295	0
Middle	Nuseirat (Nuse)	0.952	0.882	12.51	69	165	4	19.5	0.066	308	10.63
	Magazi (Maga)	0.187	0.69	2.396	15.5	23	1	6.5	0.017	299	0
	El-Bureij (Bure)	0.253	0.676	8.548	40.71	100	2	21	0.025	301	0
	Zawaida (Zawa)	0.168	0.307	10.226	40.51	121	2	9	0.03	298	7.71
	Deir El-Balah (DBala)	0.569	1.2972	28.926	86	218	3	35	0.045	297	20.5
	Wadi Salga (WaSa)	0.066	0.066	12.908	45	106	1	8	0.005	296	0
	Al-Musadar (Musa)	0.05	0.049	9.47	43.8	110	2	2	0.0034	298	0
Khan Younis	Khan Younis (KYou)	1.26	2.22	125.87	590	1352	15	73	0.11	300	56.3
	Qarara (Qara)	0.125	0.304	19.02	91.78	222	2	10	0.016	295	0
	Bani Suhaila (BSuh)	0.205	0.434	10.186	70.248	110	3	19	0.0139	314	0
	Khaza'a (Khuz)	0.061	0.293	4.9	33.91	53	2	8	0.0123	307	0
	Abassan Kubra (AbKu)	0.127	0.376	16.27	88.47	175	3	9.5	0.025	300	0
	Abassan Jadida (AbJa)	0.043	0.152	8.52	58.58	92	2	4	0.007	310	0
	Al-Fukhari (Fukh)	0.028	0.049	11.175	41	140	2	1.5	0.0034	300	0
Rafah	Rafah (Rafa)	1.2	2.7	38.298	103.65	164	13	120	0.154	293	15.6
	Al-Shoka (Shok)	0.047	0.074	7.618	16.43	33	1	5	0.0052	296	0
	Al-Bayuk (Bayu)	0.038	0.066	13.29	62	143	2	2.5	0.004	297	0

Table A2.1.5 Raw data- state variables

Governorate	Municiplaity	26 NO3 mg.l^{-1}	27 CL mg.l^{-1}	28 Na mg.l^{-1}	29 Ca mg.l^{-1}	30 Mg mg.l^{-1}	31 K mg.l^{-1}	32 F mg.l^{-1}	33 SO4 mg.l^{-1}	34 pH mg.l^{-1}	35 Alkalinity mg.l^{-1}	36 T-Coli numbers/100ml
Northern	Beit Hannun (BHan)	52.5	231	181.1	82.5	45	2.53	0.325	28	7.4	261	6
	Beit Lahia (Blah)	71	111	48	74	25	1.56	0.35	26	7.68	229.6	7
	Jabalia (Jaba)	118.27	142.55	89.62	80	38.09	1.7	0.5	35.5	7.618	222.26	38
	Um Alnasser (UmNa)	73	204	60	78	35	2	0.3	27.5	7.65	142.2	10
Gaza	Gaza (Gaza)	131.85	295.3	140	90	40	2.9	1.9	50	7.6	231.35	60
	Al-Zahra' (Zahra)	24.12	265.61	150	28	35	2.2	0.55	56	7.95	149	15
	Al-Mograga (Mogr)	33	197	157	30	28	1.39	0.58	60	7.4	290	25
	Wadi Gaza (WaGa)	36	201	300	35	8.5	2.16	0.62	70	7.7	168	30
Middle	Nuseirat (Nuse)	62.3	938	305	45.5	20.55	8.26	1.65	496	7.7	198	42
	Magazi (Maga)	31.81	597	455	89.5	33	5	1.3	190.5	7.5	205	8
	El-Bureij (Bure)	42.84	794.7	387	62	29	2.8	2.2	137	7.3	220	39
	Zawaida (Zawa)	39.86	507.5	550	12	8.9	2.9	1.25	58	7.2	27	4
	Deir El-Balah (DBala)	47	722	382	62	28	3.07	2.5	158	7.05	238	240
	Wadi Salga (WaSa)	32.76	480	738	32.3	11.5	4	2.45	718	7.1	161	55
	Al-Musadar (Musa)	33.04	505	735	32.5	11.7	4.5	2.35	715	7.3	162	40
Khan Younis	Khan Younis (KYou)	205	528.4	421	106	53	5.49	1.6	205	7.66	241.63	8
	Qarara (Qara)	86.25	759	211	40	26.75	2.9	1.25	108	8.05	245.5	10
	Bani Suhaila (BSuh)	147.5	1007.88	869	68	48.5	6.6	2	540	7.9	317.5	20
	Khaza'a (Khuz)	149	1170	818.5	78.5	51.5	8.85	2.6	594	7.8	284	15
	Abassan Kubra (AbKu)	144.5	1144.8	114.9	75	38.9	4.7	1.95	282.5	7.6	260.5	4
	Abassan Jadida (AbJa)	107.5	1032.5	808.5	65	38	8.45	2.15	624	7.65	276	3
	Al-Fukhari (Fukh)	39.15	870	850	35.4	13.63	11.5	1.8	665	7.6	170.5	8
Rafah	Rafah (Rafa)	76.7	238.67	222.42	37	24	2.95	0.8	84.5	7.8	162.5	40
	Al-Shoka (Shok)	30.5	750	752	31	10.7	10	1.7	741	7.9	158.6	15
	Al-Bayuk (Bayu)	40	890	855	36	14	11.4	1.95	660	7.6	171.4	20

Table A2.1.6 Raw data- impact variables

Governorate	Municipality	37 LosProd ton	38 LosWet hectar	39 Morbid Number
Northern	Beit Hannun (BHan)	458	13.46	192
	Beit Lahia (Blah)	357	0	283
	Jabalia (Jaba)	103	4.32	821
	Um Alnasser (UmNa)	5	0	54
Gaza	Gaza (Gaza)	856	20.66	2634
	Al-Zahra' (Zahra)	9	0	153
	Al-Mograga (Mogr)	171	13.44	31
	Wadi Gaza (WaGa)	221	3.39	24
Middle	Nuseirat (Nuse)	229	28.1	327
	Magazi (Maga)	44	0	124
	El-Bureij (Bure)	156	4.81	184
	Zawaida (Zawa)	190	0	79
	Deir El-Balah (DBala)	342	4.78	314
	Wadi Salga (WaSa)	167	5.28	31
	Al-Musadar (Musa)	173	0	24
Khan Younis	Khan Younis (KYou)	2302	0	2385
	Qarara (Qara)	347	0	224
	Bani Suhaila (BSuh)	186	0	434
	Khaza'a (Khuz)	90	0	128
	Abassan Kubra (AbKu)	298	0	269
	Abassan Jadida (AbJa)	156	0	92
	Al-Fukhari (Fukh)	239	0	60
Rafah	Rafah (Rafa)	700	0	1550
	Al-Shoka (Shok)	140	0	62
	Al-Bayuk (Bayu)	243	0	80

Table A2.1.7 Raw data- management variables

Governorate	Municipality	40 BrWDes $hm^3.y^{-1}$	41 StoWHar $hm^3.y^{-1}$	42 ImportW $hm^3.y^{-1}$	43 TreatWW $hm^3.y^{-1}$	44 EfWIrrig %	45 EfUWSN %	46 EfInS %	47 WAwar Number	48 SWD $hm^3.y^{-1}$
Northern	Beit Hannun (BHan)	0	0.105	0	0	72	62.2	60	6000	0
	Beit Lahia (Blah)	0	0.14	0	3.65	72	61.1	60	19700	0
	Jabalia (Jaba)	0	0.115	0	0	71.2	63.7	65	800	0
	Um Alnasser (UmNa)	0	0.002	0	0	71.2	90.6	0	81800	0
Gaza	Gaza (Gaza)	0.146	0.405	0	18.25	71.2	62.3	80	4400	0
	Al-Zahra' (Zahra)	0	0.005	0	0	71.2	89.4	0	940	0
	Al-Mograga (Mogr)	0	0.03	0	0	71.6	86.8	0	740	0
	Wadi Gaza (WaGa)	0	0.048	0	0	71.6	86	0	7600	0
Middle	Nuseirat (Nuse)	0	0.88	1.51	0	71.6	73.6	60	3550	163
	Magazi (Maga)	0	0.027	0.29	0	71.6	59.7	60	4450	90
	El-Bureij (Bure)	0	0.048	0.884	0	71.6	76.8	60	1890	110
	Zawaida (Zawa)	0	0.063	0.392	0	71.6	90.8	60	6900	50
	Deir El-Balah (DBala)	0.22	0.138	0	0	71.6	54.4	65	680	158
	Wadi Salga (WaSa)	0	0.036	0	0	85	87.1	0	530	16
	Al-Musadar (Musa)	0	0.038	0	0	85	87	0	28500	13
Khan Younis	Khan Younis (KYou)	0.92	0.47	0	0	85	43.6	70	1650	0
	Qarara (Qara)	0	0.0081	0	0	85	60.1	50	4300	0
	Bani Suhaila (BSuh)	0	0.047	0.38	0	85	67	50	1400	0
	Khaza'a (Khuz)	0	0.002	0.222	0	85	91.6	50	3490	0
	Abassan Kubra (AbKu)	0	0.063	0.33	0	85	93.9	50	1100	0
	Abassan Jadida (AbJa)	0	0.024	0.12	0	87	74	50	660	0
	Al-Fukhari (Fukh)	0	0.043	0	0	80	85.5	0	21700	0
Rafah	Rafah (Rafa)	0	0.27	0	2.92	85	63.6	80	600	0
	Al-Shoka (Shok)	0	0.032	0	0	72	87.7	0	1200	0
	Al-Bayuk (Bayu)	0	0.048	0	0	72	85.4	0	1880	0

A2.2 Summarizing data

Definitions

- **Central tendency**

Mean

It means the arithmetic average. All the given numbers are added and then the sum is divided by total count.

Mean = $(\Sigma x_i)/n$

where *n* is the sample size.

Median

The median of a sample is the value for which one-half (50%) of the observations (when all given readings are placed in an increasing order) will lie above that value and one-half will lie below that value. When the number of values in the sample is even, the *median* is computed as the average of the two middle values.

- **Spread**

Standard deviation

The standard deviation is simply the square root of the variance. It is a commonly used as a measure of variation.

The variance refers to the arithmetic mean of the squared differences between each value and the mean value.

The variance of a *population* of values is computed as:

$\sigma^2 = \Sigma(x_i-\mu)^2/N$

where:

μ	is the population mean
N	is the population size.

The unbiased *sample* estimate of the population variance is computed as:

$s^2 = \Sigma(x_i\text{-xbar})^2/n\text{-}1$

where

xbar	is the sample mean
n	is the sample size.

The standard deviation of a population of values is computed as:

$\sigma = [\Sigma(x_i-\mu)^2/N]^{1/2}$

The sample estimate of the population standard deviation is computed as:

$s = [\Sigma(x_i\text{-x-bar})^2/n\text{-}1]^{1/2}$

Percentiles

Lower quartile: 25th percentile or one fourth of the data.

Upper quartile: 75th percentile or three fourths of the data.

Inter-quartile range: (lower quartile, upper quartile).

- **Distribution**

Skewness

Skewness measures the deviation of the distribution from symmetry. If skewness is clearly different from 0, then that distribution is asymmetrical, while normal distributions are perfectly symmetrical.

$\text{Skewness} = n*M_3\ /[(n-1)*(n-2)*s^3]$

where

M_3	is equal to: $S(x_i\text{-Mean}_x)^3$
s^3	is the standard deviation (sigma) raised to the third power
n	is the valid number of cases.

Annex A3

Human health risk assessment (Application to Gaza wastewater treatment plant)

Summary of input and output parameters

Table A3.1 Summary of input parameters- health risk assessment

Scenario	1(Adult)	2 (Child)
Lifetime and body weight		
Body weight (kg)	70.	15.
Lifetime (years)	70.	70.
Ingestion while swimming		
Ingestion rate (ml/hr)	10.	10.
Exp. Freq Surface Water (events/yr)	20.	5.0
Time in Surface Water (hour/day)	2.6	2.6
Exp. Duration Surface Water (years)	9.0	6.0
Absorption Adjustment Factor for Ingestion of water (-)		
Arsenic	1.0	1.0
Cadmium	1.0	1.0
Chromium (VI)	1.0	1.0
Copper	1.0	1.0
Cyanide	1.0	1.0
Lead	1.0	1.0
Mercury	1.0	1.0
Nickel	1.0	1.0
Phenol	1.0	1.0
Selenium	1.0	1.0
Vanadium	1.0	1.0
Zinc	1.0	1.0
Dermal contact while swimming		
Total Skin Surface Area (cm^2)	1.84E+04	6.80E+03
Time in Surface Water (hour/day)	2.6	2.6
Exp. Freq Surface Water (events/yr)	20.	5.0
Exp. Duration Surface Water (years)	9.0	6.0

Dermal Permeability Surface Water (cm/hour)

Arsenic	1.00E-03	1.00E-03
Cadmium	1.00E-03	1.00E-03
Chromium (VI)	1.30E-03	1.30E-03
Copper	1.00E-03	1.00E-03
Cyanide	1.00E-02	1.00E-02
Lead	0.0	0.0
Mercury	1.70E-03	1.70E-03
Nickel	1.00E-03	1.00E-03
Phenol	5.50E-03	5.50E-03
Selenium	1.00E-03	1.00E-03
Vanadium	1.00E-03	1.00E-03
Zinc	6.00E-04	6.00E-04

Absorption Adjustment Factor for dermal exposure to water (-)

Arsenic	1.0	1.0
Cadmium	1.0	1.0
Chromium (VI)	1.0	1.0
Copper	1.0	1.0
Cyanide	1.0	1.0
Lead	1.0	1.0
Mercury	1.0	1.0
Nickel	1.0	1.0
Phenol	1.0	1.0
Selenium	1.0	1.0
Vanadium	1.0	1.0
Zinc	1.0	1.0

Media concentration

Concentration in surface water (mg.l^{-1}) used in calculating carcinogenic risk and hazard index

Arsenic	0.10	0.10
Cadmium	1.00E-02	1.00E-02
Chromium (VI)	0.50	0.50

Copper	0.20	0.20
Cyanide	0.10	0.10
Lead	0.10	0.10
Mercury	1.00E-03	1.00E-03
Nickel	0.20	0.20
Phenol	1.0	1.0
Selenium	2.00E-02	2.00E-02
Vanadium	0.10	0.10
Zinc	5.0	5.0

Slope factors and reference doses

Ingestion Slope Factor [1/(mg/kg-day)]

Arsenic	1.5	1.5
Cadmium	ND	ND
Chromium (VI)	ND	ND
Copper	ND	ND
Cyanide	ND	ND
Lead	ND	ND
Mercury	ND	ND
Nickel	ND	ND
Phenol	ND	ND
Selenium	ND	ND
Vanadium	ND	ND
Zinc	ND	ND

Ingestion reference dose (mg/kg-day)

Arsenic	3.00E-04	3.00E-04
Cadmium	5.00E-04	5.00E-04
Chromium (VI)	3.00E-03	3.00E-03
Copper	3.70E-02	3.70E-02
Cyanide	4.00E-02	4.00E-02
Lead	3.60E-03	3.60E-03
Mercury	3.00E-04	3.00E-04
Nickel	2.00E-02	2.00E-02
Phenol	0.60	0.60

Selenium	5.00E-03	5.00E-03
Vanadium	7.00E-03	7.00E-03
Zinc	0.30	0.30

Dermal slope factor [1/(mg/kg-day)]

Arsenic	1.5	1.5
Cadmium	ND	ND
Chromium (VI)	ND	ND
Copper	ND	ND
Cyanide	ND	ND
Lead	ND	ND
Mercury	ND	ND
Nickel	ND	ND
Phenol	ND	ND
Selenium	ND	ND
Vanadium	ND	ND
Zinc	ND	ND

Dermal reference dose (mg/kg-day)

Arsenic	3.00E-04	3.00E-04
Cadmium	5.00E-04	5.00E-04
Chromium (VI)	3.00E-03	3.00E-03
Copper	3.70E-02	3.70E-02
Cyanide	4.00E-02	4.00E-02
Lead	3.60E-03	3.60E-03
Mercury	3.00E-04	3.00E-04
Nickel	2.00E-02	2.00E-02
Phenol	0.60	0.60
Selenium	5.00E-03	5.00E-03
Vanadium	7.00E-03	7.00E-03
Zinc	0.30	0.30

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Table A3.2 Summary of results- health risk assessment

Scenario	**1(Adult)**	**2 (Child)**
Ingestion while swimming		
Daily Doses and Risk for : Arsenic		
CADD (mg/kg-day)	2.04E-06	2.37E-06
LADD (mg/kg-day)	2.62E-07	2.04E-07
Cancer Risk (-)	3.93E-07	3.05E-07
Hazard Index (-)	6.78E-03	7.91E-03
Daily Doses and Risk for : Cadmium		
CADD (mg/kg-day)	2.04E-07	2.37E-07
LADD (mg/kg-day)	2.62E-08	2.04E-08
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	4.07E-04	4.75E-04
Daily Doses and Risk for : Chromium (VI)		
CADD (mg/kg-day)	1.02E-05	1.19E-05
LADD (mg/kg-day)	1.31E-06	1.02E-06
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	3.39E-03	3.96E-03
Daily Doses and Risk for : Copper		
CADD (mg/kg-day)	4.07E-06	4.75E-06
LADD (mg/kg-day)	5.23E-07	4.07E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	1.10E-04	1.28E-04
Daily Doses and Risk for : Cyanide		
CADD (mg/kg-day)	2.04E-06	2.37E-06
LADD (mg/kg-day)	2.62E-07	2.04E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	5.09E-05	5.94E-05

Daily Doses and Risk for : Lead

CADD (mg/kg-day)	2.04E-06	2.37E-06
LADD (mg/kg-day)	2.62E-07	2.04E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	5.65E-04	6.60E-04

Daily Doses and Risk for : Mercury

CADD (mg/kg-day)	2.04E-08	2.37E-08
LADD (mg/kg-day)	2.62E-09	2.04E-09
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	6.78E-05	7.91E-05

Daily Doses and Risk for : Nickel

CADD (mg/kg-day)	4.07E-06	4.75E-06
LADD (mg/kg-day)	5.23E-07	4.07E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	2.04E-04	2.37E-04

Daily Doses and Risk for : Phenol

CADD (mg/kg-day)	2.04E-05	2.37E-05
LADD (mg/kg-day)	2.62E-06	2.04E-06
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	3.39E-05	3.96E-05

Daily Doses and Risk for : Selenium

CADD (mg/kg-day)	4.07E-07	4.75E-07
LADD (mg/kg-day)	5.23E-08	4.07E-08
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	8.14E-05	9.50E-05

Daily Doses and Risk for : Vanadium

CADD (mg/kg-day)	2.04E-06	2.37E-06
LADD (mg/kg-day)	2.62E-07	2.04E-07
Cancer Risk (-)	0.00E+00	0.00E+00

Hazard Index (-)	2.91E-04	3.39E-04

Daily Doses and Risk for : Zinc

CADD (mg/kg-day)	1.02E-04	1.19E-04
LADD (mg/kg-day)	1.31E-05	1.02E-05
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	3.39E-04	3.96E-04

Dermal contact while swimming

Daily Doses and Risk for : Arsenic

CADD (mg/kg-day)	3.74E-06	1.61E-06
LADD (mg/kg-day)	4.81E-07	1.38E-07
Cancer Risk (-)	7.22E-07	2.08E-07
Hazard Index (-)	1.25E-02	5.38E-03

Daily Doses and Risk for : Cadmium

CADD (mg/kg-day)	3.74E-07	1.61E-07
LADD (mg/kg-day)	4.81E-08	1.38E-08
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	7.49E-04	3.23E-04

Daily Doses and Risk for : Chromium (VI)

CADD (mg/kg-day)	2.43E-05	1.05E-05
LADD (mg/kg-day)	3.13E-06	9.00E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	8.11E-03	3.50E-03

Daily Doses and Risk for : Copper

CADD (mg/kg-day)	7.49E-06	3.23E-06
LADD (mg/kg-day)	9.63E-07	2.77E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	2.02E-04	8.73E-05

Daily Doses and Risk for : Cyanide

CADD (mg/kg-day)	3.74E-05	1.61E-05
LADD (mg/kg-day)	4.81E-06	1.38E-06
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	9.36E-04	4.04E-04

Daily Doses and Risk for : Lead

CADD (mg/kg-day)	0.00E+00	0.00E+00
LADD (mg/kg-day)	0.00E+00	0.00E+00
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	0.00E+00	0.00E+00

Daily Doses and Risk for : Mercury

CADD (mg/kg-day)	6.37E-08	2.74E-08
LADD (mg/kg-day)	8.19E-09	2.35E-09
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	2.12E-04	9.15E-05

Daily Doses and Risk for : Nickel

CADD (mg/kg-day)	7.49E-06	3.23E-06
LADD (mg/kg-day)	9.63E-07	2.77E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	3.74E-04	1.61E-04

Daily Doses and Risk for : Phenol

CADD (mg/kg-day)	2.06E-04	8.88E-05
LADD (mg/kg-day)	2.65E-05	7.61E-06
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	3.43E-04	1.48E-04

Daily Doses and Risk for : Selenium

CADD (mg/kg-day)	7.49E-07	3.23E-07
LADD (mg/kg-day)	9.63E-08	2.77E-08
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	1.50E-04	6.46E-05

Daily Doses and Risk for : Vanadium

CADD (mg/kg-day)	3.74E-06	1.61E-06
LADD (mg/kg-day)	4.81E-07	1.38E-07
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	5.35E-04	2.31E-04

Daily Doses and Risk for : Zinc

CADD (mg/kg-day)	1.12E-04	4.84E-05
LADD (mg/kg-day)	1.44E-05	4.15E-06
Cancer Risk (-)	0.00E+00	0.00E+00
Hazard Index (-)	3.74E-04	1.61E-04

About the Author

Said Mustafa Jalala was born in Jabalia camp, Gaza Strip (Palestine) on January 9th, 1962. He received his degree in Civil Engineering from the Faculty of Engineering of Birzeit University, West Bank (Palestine). During the year 1995, he received advanced professional training in Germany in the field of water and wastewater treatment. In 1998, he received his master's degree from Oslo- Norway in the field of Environmental Impact Assessment for wastewater treatment plants.

In the period 1989-1993, he worked as project engineer for Jabalia sewerage and storm water drainage system funded by UNDP. In May 1993, he joined the environmental health department of UNRWA and worked as a senior planning and design Engineer. In the period 1996-1999, he worked as water and sanitation expert at the Norwegian physical planning project at the Palestinian Ministry of Planning and International Cooperation (MOPIC).

Since April 1999, Mr Jalala has worked as the Director General of the Palestinian Ministry of Environment. He participated in about 120 regional and global workshops, seminars, forums and conferences in more than 40 countries. Among these events are the World Summit for Sustainable Development held in Johannesburg, South Africa in August 2002 and, the annual meetings of UNEP and GEF.

In 2002, he was admitted to the doctoral research program at the Polytechnique school of the University of Lille for Science and Technology, France under the supervision of Professor Jacky MANIA. He conducted his research in the field of multi-criteria parameters of conceptual water integrated model in semi-arid Mediterranean region with application to Gaza Strip.