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Assessment of Informativeness of Groundwater Monitoring in Developing Regions (Gaza Strip Case Study)

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Abstract. Groundwater resource management and planning requires appropriate and accurate data. These data, which can be collected by monitoring networks, may contain too little, enough or redundant information. This study aims to evaluate the monitoring cycle in the Gaza Strip (a developing region) using the entropy theory. The approach employed in this study involves gathering data needs for groundwater resource management and planning in the Gaza Strip) through a questionnaire (survey). The questionnaire outlined the groundwater management and planning objectives, tasks and the data which had to be collected through monitoring activities in the Gaza Strip (monitoring cycle). This article also proposes a flowchart, which is used to evaluate the relation between the objectives, the tasks, the data and the monitoring activities using the entropy theory. The evaluation affirms the informativeness of the collected data when they contain enough, too little or redundant information. From this study it can be concluded that in the Gaza Strip the institutional set-up of the water sector needs to be strengthened, and more data should be collected and the existing monitoring networks should be redesigned for the informativeness of the data.

Key words: data, developing countries, Gaza Strip, groundwater, information, monitoring

1. Introduction

Management of water resources requires information on both the quantity and quality of groundwater in areas where this is the main resource. Groundwater quantity is a result of various natural factors and is also affected by human activities. Moreover, groundwater quality evolves as a function of the natural hydrogeological environment and human activity. The two processes interact fully and continuously, so that a proper management of water resources, from both the technical and economic points of view, requires a complete understanding of both processes. This kind of understanding cannot be obtained without proper information reflecting the two processes. Such information should be supplied to the water resources manager for the purposes of planning, evaluation of water resources systems and investigating the human interface impact. This information can be extracted from data, which are collected by monitoring networks. In fact, groundwater (quality and quantity) monitoring is a complex, difficult and costly process. Setting up a monitoring network is not easy and the network must be frequently assessed and redesigned according to new or emerging information needs. Therefore, a groundwater-monitoring network is more than a data collection system, it is rather an information collection system. The accuracy of decision-making in groundwater resources management projects depends on how much hydrogeological information is available. In addition, the growing concern about groundwater, in particular, has placed significant demands on groundwater management programmes, with special emphasis on the design of monitoring networks and extraction of information from collected data (e.g., Whitfield, 1988; WMO, 1990; Harmancioglu *et al.*, 1996).

An appropriate monitoring network is essential for gathering efficient and informative data for various groundwater management objectives and tasks. Before specifying the monitoring network features (number of wells, temporal frequencies and variables to be monitored), one should examine the information required. It is, however, not easy, to differentiate between data and information through the monitoring network whereby the data are collected. In the context of groundwater quality, these data may include chemical concentration at a specific depth in the aquifer (groundwater quality variables), while for groundwater quantity the data may concern, for example, the groundwater level and the hydraulic conductivity. A time series of these data can be transferred to information, such as mean value, extreme value, and the spatial and/or temporal variability of the groundwater variables. This information can be used to describe the regional and local prospect of the aquifer. The Regional (national) approach for the assessment and redesign of the groundwater monitoring network has already been undertaken by developed countries. For example, Chilton and Foster (1996) described the national approach in the United Kingdom, while Jedlitschka (1997) applied a similar approach in Germany.

In this article, the national approach is adapted to the Gaza Strip (a developing region). This approach is used to suggest specific groundwater management objectives and tasks. Groups of data are identified according to these objectives and tasks. The framework for evaluating the collected data according to the information needs, which are specified according to the objective and tasks, is outlined. Evaluation of these data is based on the entropy theory which measures the information content and the mutual information in a time series of data (e.g., Husain, 1989; Harmancioglu and Alpaslan, 1992; Yang and Burn, 1994). This framework is applied to the data collected from the: (1) groundwater quality monitoring network (Chloride) and (2) groundwater level monitoring network, in the Gaza Strip.

2. Groundwater Status in the Gaza Strip

As in most countries in the world, groundwater is the main source for public, industrial and agricultural water supply in Gaza Strip (Figure 1). The new developments, the population growth and the presence of settlements have caused serious problems of groundwater over-exploitation and groundwater pollution. Groundwater over-exploitation has been detected in many parts of the Gaza Strip aquifer and has resulted in many serious problems, including:

- Depletion of the aquifer and drop in the groundwater level
- Salinity
- Nitrate increment

Figure 2 shows a contour map of Chloride (Cl), which indicates the aquifer salinity. According to the WHO standard, freshwater should have a Cl concentration of less than 250 mg/L. This fresh water exists mainly in the Northern Governorate and the Southern Governorate where the Israeli settlements are located. The Cl concentration in the rest of the Gaza Strip area exceeds the WHO standard and is thus a major salinity problem (Figure 2). The salinity is mainly due to seawater intrusion or upcoming, disposal of industrial wastes into the aquifer, lateral groundwater flow from Israel, soil water interaction in the unsaturated zone due to recharge and return flows, and mobilization of deep brines. The seawater intrusion and upconing

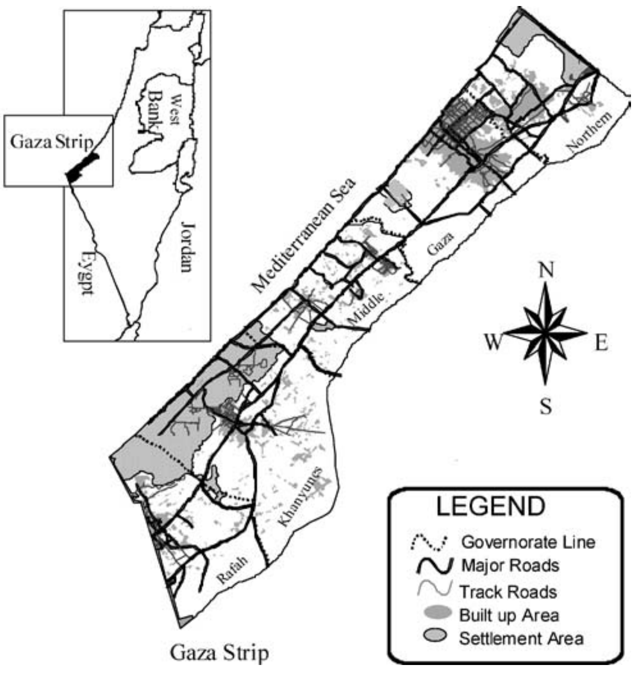

Figure 1. Location map of Gaza Strip, Palestine.

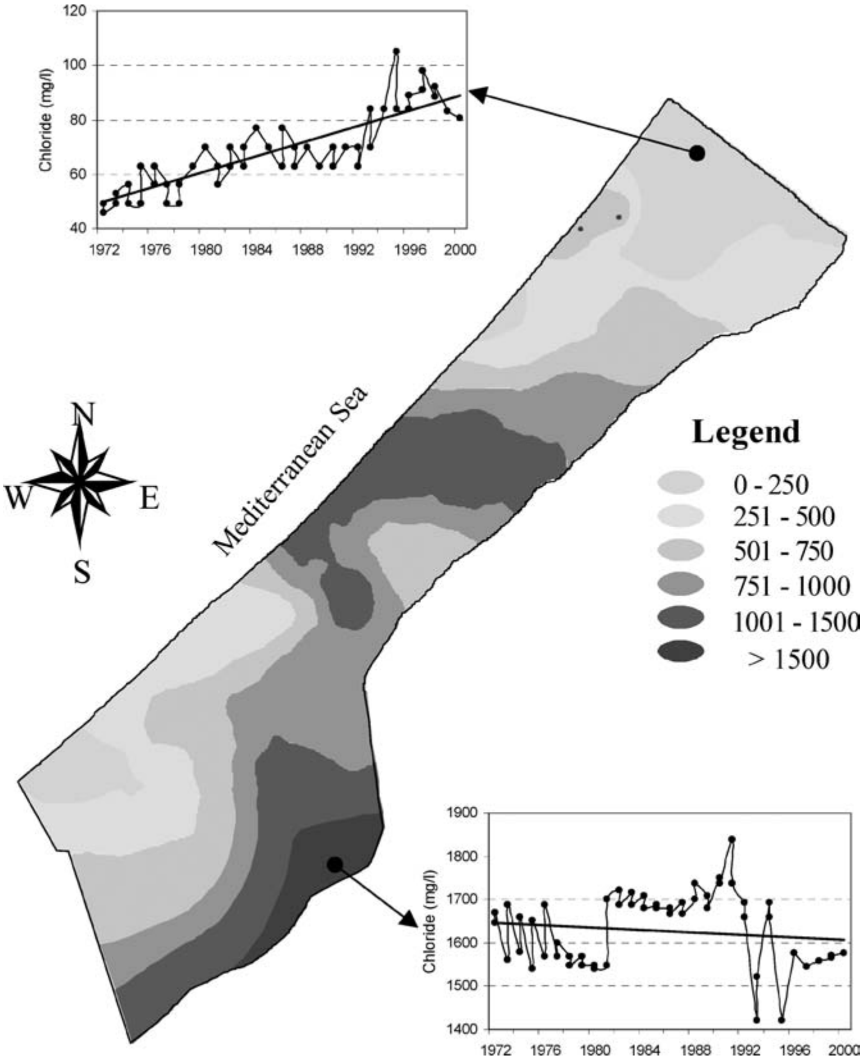

Figure 2. Average Chloride concentration (mg/L) distribution map of the Gaza Strip, for year 2000.

of brines in some areas may be due to water imbalance in the aquifer, since the rate of water extraction exceeds the rate of groundwater replenishment.

The Gaza Strip aquifer is also vulnerable to pollution from various sources, such as domestic waste discharge and disposal and agriculture activities. Nitrate (NO_3) contaminants and other pollutants from domestic waste have been found in different areas of the aquifer. Figure 3 presents the spatial variation of Nitrate concentration in the Gaza Strip for the year 2000. The Nitrate concentration in the Gaza Strip exceeds the WHO standard (50 mg/L), particularly in urban areas and the refugee camps, where the waste water system is not working properly.

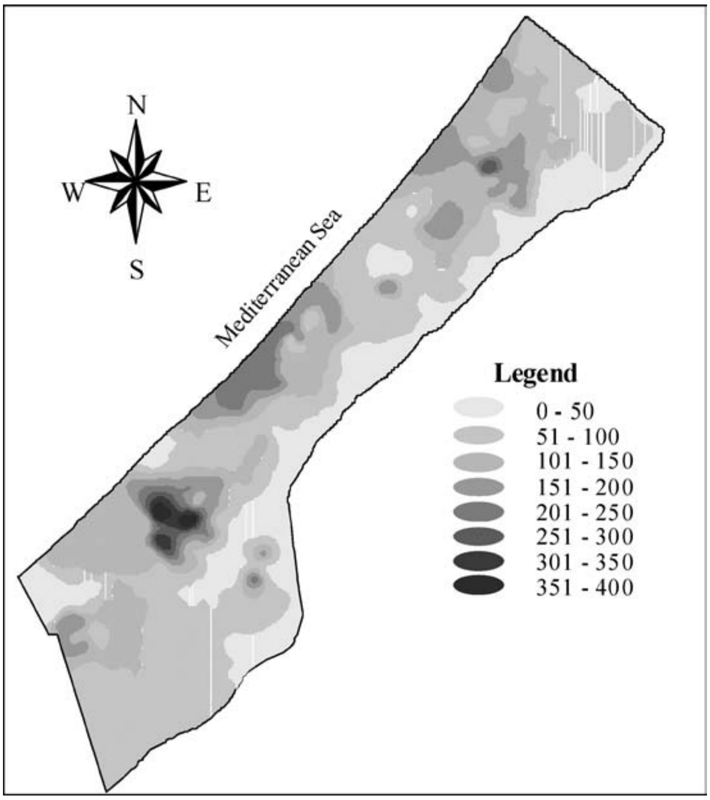

Figure 3. Average nitrate concentration (mg/L) distribution map of the Gaza Strip, for year 2000.

Groundwater (quantity and quality) monitoring in the Gaza Strip has not yet been developed into a national (regional) monitoring system. The Water Resources Management and Planning Department in the Palestinian Water Authority (PWA) realized how very necessary it was for the national groundwater monitoring and management to be strengthened. In order to establish an optimal national groundwater monitoring system and to manage the groundwater information using the latest technology, collecting appropriate and informative data is highly essential (PWA, 2000).

3. Methodology

The methodology followed in this study consists of: analyzing the questionnaire data, designing the required data matrix and evaluating the groundwater monitoring cycle in the Gaza Strip. The questionnaire was developed as a preliminary task in devising a suitable methodology for specifying the information needs for water resources management. This methodology is part of ongoing research that aims to optimally design groundwater-monitoring networks based on maximising the information gained and, therefore, minimising the cost of the monitoring network (Mogheir and Singh, 2002). The minimising of costs might come from the reduction of the number of monitoring wells in the network. The questionnaire consists of five parts: water resources management objectives, tasks, required information, method for obtaining the required data, and data availability.

The data matrix was also developed to gather the water resources management objectives, tasks and the required data. This matrix was arranged using:

1. The documents available on the water sector on the Gaza Strip;
2. Personal interviews and a questionnaire discussed with Palestinian Water Authority (PWA), Ministry of Planning and International Cooperation (MOPIC), Hydrology Group (HG), Ministry of Health (MOH), and Ministry of Environmental Affairs (MEnA). These organizations form the water sector in the Gaza Strip;
3. International project documents from Europe and the U.S.A., such as the Coastal Aquifer Management Program (CAMP).

The groundwater monitoring cycle in the Gaza Strip links the groundwater resources objectives, tasks, the required data and the monitoring strategy (number of monitoring wells and temporal frequency). This cycle is illustrated by a flowchart, which is used to evaluate the monitoring strategy according to the informativeness of the data.

4. Results and Discussions

The questionnaire was completed by some departments and sections that are involved in managing the water sector in the Gaza Strip. The specification of the information needs relied on the results of the questionnaire and also included a review of several water resources management documents and some personal discussions with water resources professionals in the Gaza Strip. A copy of the questionnaire is presented in Appendix A. This questionnaire was undertaken by the PWA which is mainly responsible for water resources management in the Gaza Strip.

4.1. THE GAZA STRIP WATER SECTOR INSTITUTIONS

The institutional situation in the water sector of the Gaza Governorates is rather complex and irregular. The Gaza Governorates were under the Israeli occupation from 1967 to 1994. After the Oslo agreement, the Gaza Governorates came under the Palestinian control. The Palestinians received a populated area with no infrastructure system and limited water resources. Solving the problem of the water sector became very urgent. Therefore, there were many donor-financed projects to build the Palestinian water sector. In addition, there were many research centres playing an important role in addressing the scarcity of water resources (PWA, 2000).

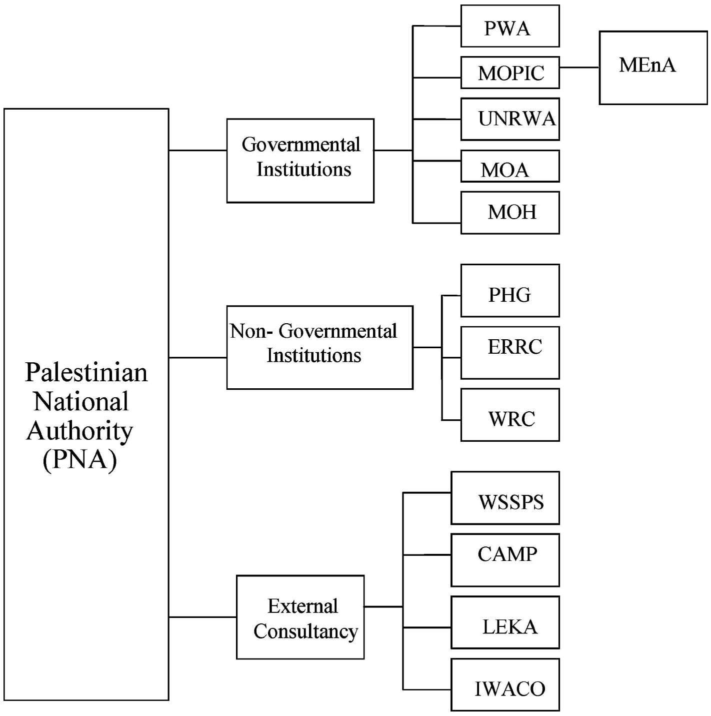

Figure 4. Institutional setup of water sector departments in the Gaza Strip.

The institutions involved in the water resources sector in the Gaza Strip are described in Figure 4. The institutions are classified into: governmental institutions, non-governmental institutions and external consultancy.

4.1.1. *Governmental Institutions*

4.1.1.1. Palestinian Water Authority. The Palestinian Water Authority (PWA) obviously anticipated its establishment in January 1996, in order to be recognised as a key organisation in the management of water resources throughout Palestine. The creation of the PWA was an important, long-awaited step towards the efficient management of available resources, development of water projects, and full supervision of the implementation of projects through government bodies, municipal councils or individuals. The PWA comprises 4 departments:

- Water Resources and Planning Department, mainly in charge of policy strategy, water data bank, and hydrological analysis.
- Regulation Department, in charge of licence fees and tariffs, control, and consumer affairs.
- A technical Department, in charge of quality assurance and standards, personnel training and research.

- An administrative Department, dealing with economics, personnel management and services.

The main aim of the PWA is to control the knowledge and utilisation of local resources while facilitating the initiatives taken by various public and private promoters. The institutional framework of the PWA deliberately separates the regulatory and service activities. The rationale underlying this is that it is impossible for a resource developer to regulate resources effectively (PWA, 2000).

4.1.1.2. Ministry of Planning and International Cooperation. The Ministry of Planning and International Cooperation (MOPIC) plays an important role at a macroeconomic level in integrated planning, while sectorwise planning is the basic responsibility of the operating ministries in charge of implementation. Because the water projects are highly demanding and several kinds of resources, such as human, material and financial resources, are needed to carry out all of the activities required for their development, MOPIC has been directed to work in liaison with all PWA operating ministries for medium and long term results. MOPIC plays an important part in Palestinian development by coordinating the need for water equipment and infrastructure between urban and rural zones. It has been decided to establish a Water Regional Development Plan as a framework for social and economic references to organise water action programmes in space and in time. Recently, the MOPIC water-related tasks were moved to the newly created Palestinian Environmental Authority (PEnA), which subsequently became the Ministry of Environmental Affairs (MEnA).

4.1.1.3. United Nations Relief and Work Agency. The United Nations Relief and Work Agency (UNRWA) has been involved in advising on the implementation of water supply and environmental sanitation in refugee camps, and works very closely with the PWA and MOPIC on municipal and regional utility-oriented lines to involve them more in water and environment programme management.

4.1.1.4. Ministry of Agriculture. This Ministry of Agriculture (MOA) consists of several departments, each having different tasks. Among these departments there is one concerned with water in relation to agriculture, called the General Department of Soils, Irrigation and Agriculture Mechanisation. This department consists of several sections, such as: (i) land and soil survey, (ii) land reclamation, (iii) land protection and soil fertility, (iv) water harvesting and farm irrigation techniques, (v) new water resources, (vi) laboratory of soil and water, (vii) hydrology and hydrogeology, (viii) agriculture mechanics, and (ix) maintenance department. It is important to note that this department has now been transferred to the PWA. Only the laboratory is still under the supervision of MOA, and it provides all agricultural wells data (PWA, 2000).

4.1.1.5. Ministry of Health. The Ministry of Health (MOH) has one department dealing with the problem of water quality and its effects on human health. The department is named the Environmental Health Department. This department has its own laboratory which analyzes all data collected from municipal wells. The analyses include all the chemical and the biological characteristics of the water.

4.1.2. *Non-Governmental Institutions*

4.1.2.1. Palestinian Hydrology Group. The Palestinian Hydrology Group (PHG) was founded in 1987 as an independent specialised institution dedicated to building a Palestinian capacity research and develop water resources. Given the rapidly deteriorating water situation in the Gaza Strip and the neglect of adequate water supply infrastructure, the PHG has concentrated on carrying out the development work to encourage more effective and efficient use of existing water resources.

4.1.2.2. Environmental and Rural Research Centre. The Environmental and Rural Research Centre (ERRC) was established in 1991 as part of the Islamic University of Gaza to develop environmental research studies and serve the Palestinian community with this vital and very important field. The Centre's laboratory was set up in 1993 and it embarked on some scientific studies in the field of wastewater treatment and reuse, and its negative effects on the environment in the Gaza Strip. Other studies have been conducted in the field of drinking water monitoring and solid waste.

4.1.2.3. Water Research Centre in Elazhar University. The Water Research Centre (WRC) is linked to the Geology Department of Elazhar University. It has its own laboratory and library. The centre has been involved in some projects related to water resources in the Gaza Strip. Examples of such projects are the geophysical investigation of the aquifer in the southern part, constructing the desalination plant in the Southern part of Gaza Strip, and the Harvard model of the Middle East Area (PWA, 2000).

4.1.3. *External Consultancy*

External consultancy companies participate in studying and implementing projects related to the water sector. Metcalf & Eddy, LEKA, Carlbro and IWACO are some of these companies. Metcalf & Eddy have finished the feasibility study for the Master Plan for the Gaza Governorate, which includes the sewerage and the storm water works. The same company is directing the coastal aquifer management program in the Gaza Strip (Metcalf & Eddy, 2000a). LEKA has finished the project of rehabilitation and upgrading the water supply network in the Gaza Governorates (LEKA, 1999). IWACO has completed some studies relating to environmental profiles for the Gaza strip. The information available in such profiles has been updated and included in the Water Sector Strategic Planning Study (WSSPS) (PWA, 1999). The most recent project was the Gaza Costal Aquifer Management Program

(CAMP). This program provided the draft of an integrated management plan for the Gaza Strip, with a groundwater model and survey, and suggested relocation for all the groundwater wells (Metcalf & Eddy, 2000a).

4.2. DATA MATRIX SET-UP

Information needs play an important role in the monitoring cycle. That is because monitoring networks for groundwater management should match the information requirements of the water manager. These information requirements are closely related to the water manager's duties. The idea that monitoring without defining the information needs prior to designing the actual network will be a waste of money is becoming more widely accepted. Another critical issue for information needs is the effectiveness of monitoring. The network is effective if the information deemed necessary to answer management questions is provided. In developing countries (the Gaza Strip), groundwater (quantity and quality) monitoring has not yet developed into a national monitoring system. In order to establish an optimal national groundwater monitoring system, the information needs for that purpose must be specified. A data matrix, which describes the data required for fulfilling the water resources objectives and the tasks covered by the questionnaire conducted on the PWA, is shown in Table I. Tables II–IV detail the data required, which are classified into seven groups: water quantity, water quality, agricultural, industrial, economic, social, water management data.

The data presented in Tables II–IV are tailored for the Gaza Strip case. Optimal data collection is costly and the PWA is initially developing a Water Resources Information System based on the data presented in these tables. The data included in the tables are recommended by the WHO standard and USA standards (Metcalf & Eddy, 2000b). However, there are some other data contained in the WHO and U.S.A. standards which are not included in the tables. These data include surface water data, organic chemical data, inorganic chemical data, etc. They are excluded because the main water resource is groundwater, and the main groundwater quality problems are salinity and increased nitrate levels. The data recommended in the above tables can be updated for monitoring purposes, and according to the future groundwater quality problems.

It is recommended that the data presented in Table II, the set of water quality data in Table III, and part of the data in Table IV are collected by the PWA or in conjunction with MOH. The other groups of data, such as agricultural data, industrial data and social data, may be collected or supported by other institutions, such as MOA and MOPIC.

Analysis of the questionnaire results and the water sector documents revealed that the Gaza Strip (a developing region) has not yet stored enough data to start asking what should be done with the observed samples, or how these data can be evaluated. Instead, they are concerned more with the selection of sampling sites,

Table I. Matrix of the required data for water resources management in Palestine

	The required data						
Objectives							
Improved the understanding of the groundwater system.	Water quantity	Water quality	Agricultural	Water resources			
Environmental protection of the groundwater system.	Water quality	Agricultural	Industrial	Social			
Promotion of water conservation strategies.	Water quantity	Agricultural	Industrial	Social	Economical	Water resources	
Monitoring health and environmental parameters in the groundwater system.	Water quality	Agricultural	Industrial	Social			
Maximisation of the available resources by reuse and recharge options.	Water quality	Water quantity	Agricultural	Industrial	Social	Economical	Water resources
Tasks							
Physical surveys of aquifer modelling and management.	Water quantity	Water quality	Agricultural				
Application of reuse and recharge of the treated wastewater projects.	Water quantity	Water quality	Agricultural	Industrial	Social	Economical	Water resources
Constructing desalinisation plants in deferent locations.	Industrial	Social	Economical	Water resources			
Design and construction of new monitoring wells.	Water quantity	Water quality	Agricultural	Industrial	Economical	Water resources	

Table II. Water quantity data group (see Table I)

Precipitation	Evapotranspiration	Soil moisture	Groundwater	Well properties	Aquifer properties*
• Depth	• Evaporation: potential and actual rates	• Infiltration rate	• Levels	• Type of well	• Geology of the aquifer
• Intensity	• Evapotranspiration: potential and actual	• Moisture content	• Groundwater and surface water interaction	• Year of drilling	• Porosity
• Effective precipitation		• Soil moisture tension		• Depth	• Hydraulic conductivity
• Depth-duration-frequency curves		• Quality of soil moisture		• Diameter	• Transmissivity
				• Pumping rate • Type of pumps	• Specific yield

*The aquifer properties have also a direct influence on the quality of the groundwater system (see Table III).

sampling intervals, and variables to be observed. As soon as adequate data banks are built up, the region will face the same problems as those currently confronting developed regions, the major one being the lack of agreement between the objectives and available data (e.g., Ward *et al*., 1986).

4.3. QUANTIFICATION OF THE INFORMATION NEEDS

After determining the data needs for the water resources management objectives and water sector tasks in the Gaza strip, the question may arise as to how much of such data should be transferred to information? Furthermore, how can this information be quantified to judge if there is shortage of, enough or redundant information? For example, as shown in Figure 5, the main objective of water resources management for the PWA and MOH was to protect against and control pollution in water resources (mainly the salinity in the aquifer). The task to be performed, therefore, is groundwater quality monitoring. Consequently, the data required, specified in Tables I and II, are the water quantity and quality data. The information required is a description of the spatial distribution of salinity in the aquifer. The existing groundwater quality monitoring wells measure chloride (Cl) twice a year as an indicator of the aquifer salinity. The number of monitoring wells is 417 wells with Cl time series collected since 1972.

Figure 5 shows a flowchart which was used to evaluate and redesign the existing groundwater quality monitoring network (spatial locations and temporal frequency) according to the water resources objectives and tasks. The entropy theory was used to evaluate the existing data for describing the regional salinity phenomenon and other water quality issues. The entropy theory was also used to check the adequacy of the existing data (number and location of wells and temporal

Table III. Water quality, agricultural, and industrial, social data groups (see Table I)

Water quality						
Fresh water		Treated waste and storm water	Pollution sources	Agricultural data	Industrial data	Social data
Chemical	Biological					
• PH	• Virological	• BOD	• Type of pollution	• Irrigated area	• Type of industries	• Acceptance of people for reducing the consumption of water
• EC	• Bacteriological	• COD	• Location	• Type of crop	• Quantity of industries	• Acceptance of people for using the treated wastewater
• TDS	• Toxic organism	• Suspended solid	• Quantity	• Crop consumption	• Effect of industries on the water	• Willing to pay
• HCO_3		• N_{tot}		• Water consumption	• Water consumption	
• Cl		• Faecal coliform				
• NO_3		• Quantity of treated water				
• Na						
• SO_4						
• F						
• K						
• Ca						
• Mg						
• Hardness						
• NO_2						

Table IV. Economical and water resources data groups (see Table I)

Economical data	Water resources data
• Cost of water	• Water consumption
• Cost of monitoring	• Water production
• Projects cost, for example, desalination of seawater	• Projected water demand
	• Population

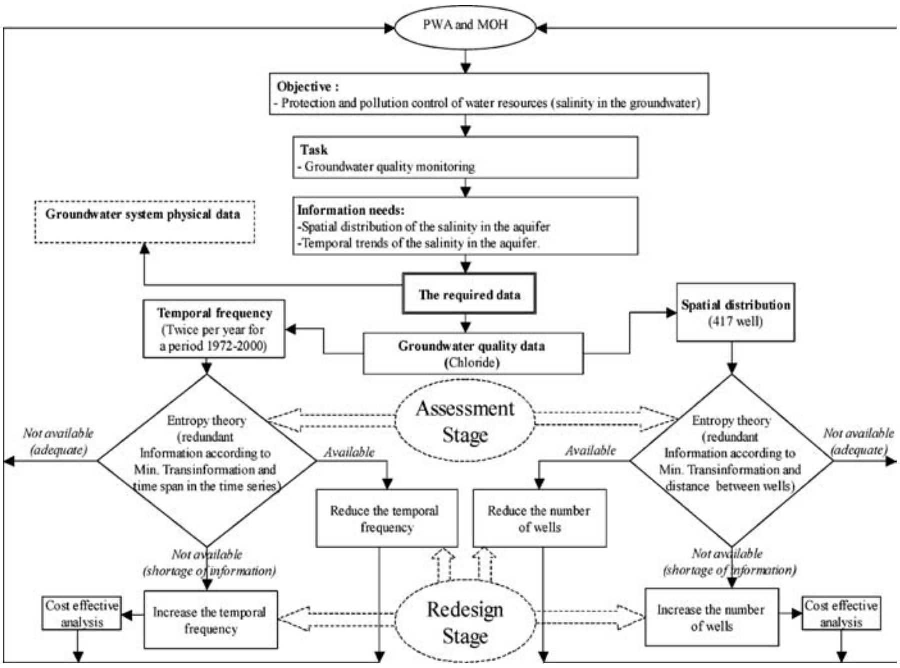

Figure 5. Assessment of the groundwater quality monitoring cycle in the Gaza Strip (Chloride data).

frequency), determine whether these give enough, redundant or not enough information (adequate, redundant or shortage of information) about the spatial salinity. The main criteria have been used in such studies are transinformation or joint entropy (e.g., Harmancioglu *et al.*, 1999; Mogheir and Singh, 2002; Mogheir *et al.*, 2003a). The assessment stage can indicate whether or not the existing monitoring networks provide adequate information. The same criterion may be used to evaluate the temporal frequency, based on transinformation as a function of the time of measurement.

The role of the entropy theory in spatial distribution analyses is to quantify the information in the time series of Cl of 417 wells, assess whether the information is

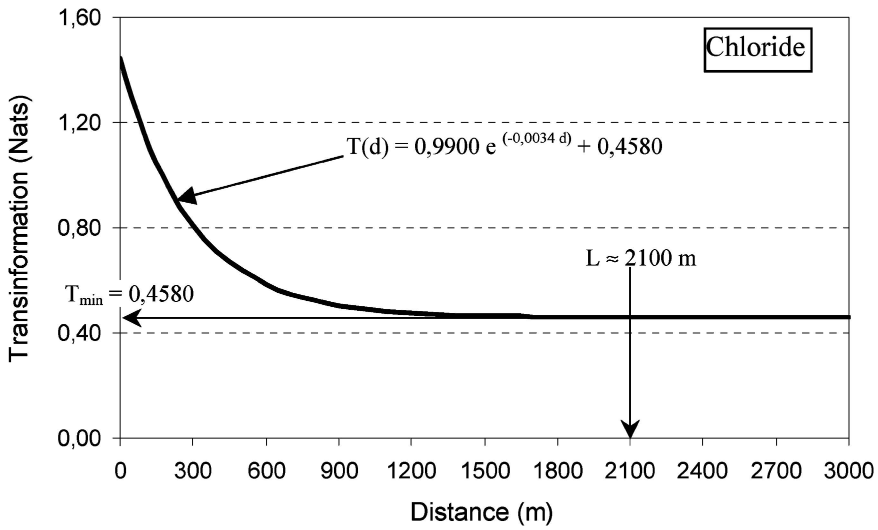

Figure 6. Transinformation as a function of distance, represented by an exponential decay curve, for the groundwater quality monitoring network in the Gaza Strip; the Chloride data used were collected from 1972 to 2000. In the figure: T(d) = Trans-information as a function of distance; $T_{\min}$ = minimum Trans-information and L = distance at which Trans-information reaches its minimum value.

enough, redundant or insufficient, and redesign the monitoring well locations according to the output of the assessment stage. The fundamental step in this approach is the estimation of the transinformation as a function of distance (T-Model), in order to estimate the spatial variability of chloride and other water quality parameters. As an example, Figure 6 shows the T-Model, which is expressed by an exponential decay curve, for chloride. The T-Model has four parameters: the initial transinformation, the minimum transinformation, the transinformation decay rate and the distance at which the T-Model reaches its minimum value. Information on how the entropy theory is applied and how to construct the T-Model presented in Figure 6 can be found in the literature (e.g., Mogheir, 2003; Mogheir *et al.*, 2003b).

For accurate assessment and redesign of the location of the monitoring wells an accurate estimation of the T-Model parameters is essential. The minimum transinformation value ($T_{\min}$) and the distance at which the T-Model reaches its minimum value (L) are the main parameters by which the redundant information percentage is computed. The existing monitoring wells were assessed using the $T_{\min}$ and L values. For example, the maximum redundant information percentage available in the Gaza Strip groundwater quality monitoring network was 92% and the minimum distance between the existing wells was 24 m. This revealed that the network should be reduced to attain the minimum redundant information (Mogheir, 2003).

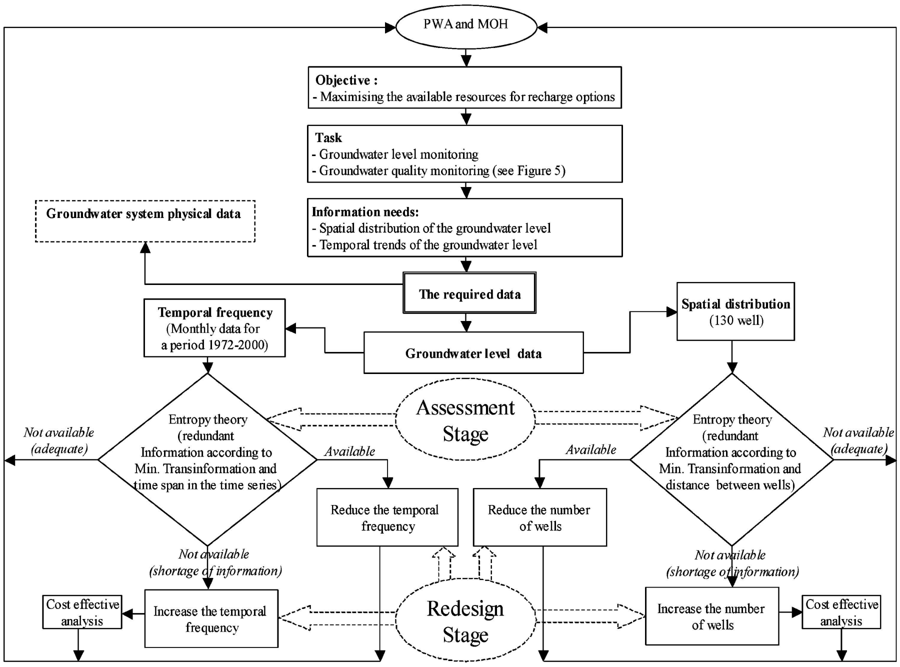

Figure 7. Assessment of groundwater quantity monitoring cycle in the Gaza Strip (groundwater level data).

As shown in Figure 5, the assessment steps are followed by redesigning steps as if the available information is redundant or insufficient. The redesign stage recommends reducing or extending the existing monitoring wells. The temporal frequency can be also redesigned according to the same criteria. In order to obtain the optimal groundwater monitoring network a cost effective analysis for spatial distribution and temporal frequency should be made, if the decision is to extend the monitoring network and increase the temporal frequency.

The same approach may be used for evaluating and redesigning the ground water quantity monitoring networks (Figure 7).

5. Conclusions

This study describes a methodology appropriate for gathering data according to the water resources management and planning objectives and tasks. The methodology is based on a survey (questionnaire) discussed and completed by departments in the water sector. Analysis of the questionnaire and other documents revealed that the water resources management and planning system seems to be non-structured and poorly organised. That is due to the following:

Table V. The available data in the water sector institutions

Institution	Number of wells	Temporal frequency	Groundwater data
PWA and MOA	207 wells	Once a month, none in 1994	Groundwater level
	100 wells	Twice a year	Groundwater abstraction
	600 wells	Twice a year, 1970–2000,	EC, Cl, and $N0_3$
	45 wells	Twice a year, 1986–1994	Major ions and coliforms
MOH	70 wells	Twice a year	Major ions and coliforms
UNRWA	60 wells	4 times a year	Major ions and coliforms
PHG	35 wells	Twice a year, 1991–1995	Major ions and coliforms
	70 wells	Twice a year, 1993–1995	Major ions and coliforms

1. The absence of a centralized system for water resources management, which involves outlining the tasks for each department in the water sector.
2. The overlapping of objectives and tasks in the water sector departments.
3. The inadequacy of existing institutions in terms of handling water resources management and planning problems. Moreover, the organisation responsible for water management is not yet fully functional.
4. The available data are not functionalised according to proper objectives and tasks. The data collection is merely an exercise, with no real appreciation of why these data are collected. Is it necessary to collect more data?
5. The water sector departments have collected some data from the available monitoring networks, as Table V shows. But this Table indicates that the data being collected in the water sector is inadequate for the purposes defined; the following are also required: precipitation, soil moisture, evaporation, properties of the aquifer, well properties, surface water, certain water quality parameters, agricultural data, industrial data, social data, economic data, and water resources data.
6. It also can be concluded that if the data are collected according to the information needs, and are then properly organised, the full structure of the information system (institutions, monitoring networks, monitoring instruments, data, software) can be established.

6. Recommendations

1. A central information system should be constructed within the Palestinian Water Authority (PWA), since this Governmental institution seems to be the

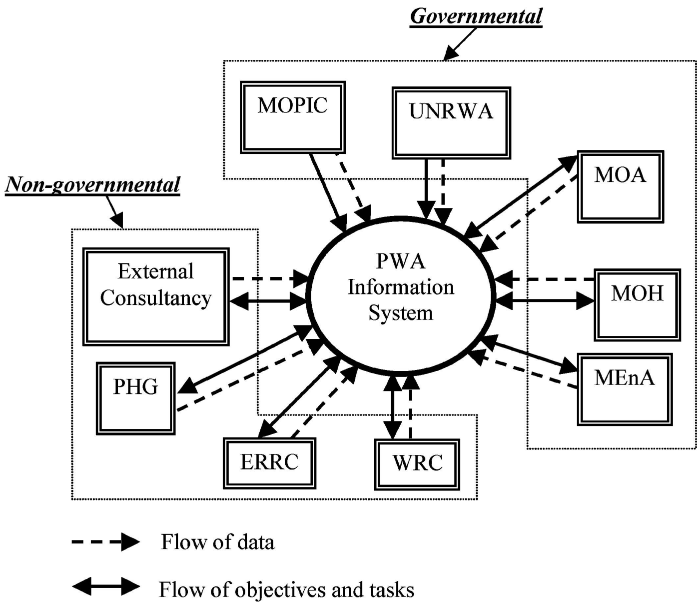

Figure 8. Schematisation of the relation between Palestinian Water Authority (PWA) and other institutions (MOA – Ministry of Agriculture, MOPIC – Ministry of Planning and International Cooperation, UNRWA – United Nations Relief and Work Agency, MOH – Ministry of Health, MEnA – Ministry of Environmental Affaires, PHG – Palestinian Hydrology Group, ERRC – Environmental and Rural Research Centre in the Islamic University of Gaza, WRC – Water Research Centre in Elazhar University and External Consultancy).

main body responsible for water resources management and planning in Palestine. A systematic diagram is given in Figure 8, illustrating the idea behind centralising the information system in the PWA and its relation with other institutions.

2. Centralising water resources management in the PWA should reduce the overlapping of the tasks in various water sector departments. Each department could thus specify its tasks according to the water resources management plan that will be provided by the PWA.
3. Much more attention should be paid to institutional issues, to enable the institution to handle water resources management and planning problems.
4. The data already available in each department should be collected, reviewed and stored in the proposed central information system in the PWA, according to the information desired.
5. The available monitoring networks should be reviewed and updated by reducing or extending the number of monitoring stations according to the minimum redundant information and maximum information gained.

Appendix A: The Questionnaire Filled Out by the Director General of the Palestinian Water Authority (PWA)

I Water Resources Management Objectives

In this section, some water resources management objectives are listed. Indicate the relevant items to your authority and if you have different objectives, please note them in the space provided. According to your authority, rank the items from the most important objective to the less important one.

_2_ Improved understanding of the groundwater system.
_3_ Environmental protection of the groundwater system.
_6_ Promotion of water conservation strategies.
_5_ Monitoring health and environmental parameters in the groundwater system.
_7_ Maximisation of the available resources by reuse and recharge options.
_1_ Optimisation of water resources utilisation and enhancement of water resources sufficient to meet the future demand at an affordable cost.
_4_ Irrigation and water conservation.
_8_ Water and wastewater tariff.

II Water Resources Management Tasks

According to the above-mentioned objectives, the water resources tasks should be specified. Each authority has different tasks to meet the water resource objectives. In the following section some typical water resources tasks are listed. According to your work plan (if available) for the coming period, please indicate these tasks or identify new tasks which may differ from the listed tasks.

_1_ Physical surveys for aquifer modelling and management.
_2_ Application of reuse and recharge of the treated wastewater projects.
_3_ Constructing desalinisation plants in different locations.
_6_ Design and construction of new monitoring wells.
_4_ Storm water harvesting.
_5_ Application of recharges from storm water.
_8_ Improvement of the sewerage network.
_7_ Minimisation of the water and wastewater losses by improving the system.

III The Required Information

The implementation of each task requires information. Collection of this information may be the main task for the monitoring network. According to your tasks, indicate the most critical information. Notice that the information should be mainly on groundwater quality. Examples are given as follows:

_2_ Characteristics of the groundwater system.
_1_ Pollution sources.
_3_ Travelling time for the pollutants.
_4_ Trends of increasing or decreasing the groundwater quality and quantity.
_5_ Existence of heavy metals in groundwater.
_6_ Effect of Israeli side through intensive pumping in the surrounding area.
_8_ Infiltration rate and its affect on ground water quality.

IV Method for Obtaining the Required Data

The data can be collected in many ways: monitoring network, models, information system, etc. The Gaza Strip can be considered as a developing country, in which the data is scarce and the methodology to collect data is very limited. Therefore, what do you think is the most suitable methodology for collecting the data for groundwater resources management?

_1_ Monitoring network.

_3_ Models.

_2_ Information systems.

_7_ Historical data.

_6_ Experiments.

_5_ Regional cooperation.

_4_ Test Holes and/or exploration wells (new drilling).

V Available Data

In your department, if you are collecting groundwater data, please fill the following table. This table include what variables are being measured, the number of observation wells measuring these variables, and at which frequency the variables are measured.

Variable	Number of wells	Frequency
Water level	140	Monthly
Chloride and nitrate	1280	Twice per year
Major ions	100	Twice per year

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