Isotope techniques for monitoring groundwater salinization

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Isotope techniques for monitoring groundwater salinization.

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ABSTRACT

Salinization of water resources is one the most widespread processes that degrades water-quality and endangers future water exploitation. In many areas, particularly in arid and semi-arid zones, ground-water salinization limits the supply of potable fresh water. This problem is intensified in coastal aquifers where human activities result in accelerating water-quality deterioration. Also in in-land basins ground-water salinization can be one of the most important factor that affects the water quality. Monitoring and identifying the origin of the salinity are crucial for both water management and remediation. Yet the variety of salinization sources, particularly in unconfined aquifers, makes this task difficult. The International Atomic Energy Agency has been actively involved in the development and application of isotope techniques to a wide spectrum of hydrological problems including the development and management of water resources facing salinity risk. The paper provides a brief overview of the role of isotopes in groundwater salinization investigations. A new co-ordinated research project aimed at optimising the application of isotope methods for groundwater salinity studies is also presented.

INTRODUCTION

Steady increase in the salinity of most of the major aquifers being used for water supply in the arid and semi-arid regions of Africa, Asia and West Asia provides evidence of water quality deterioration. This salinization is often due to inflow of saline dense water during heavy withdrawals of fresh water from coastal aquifers and / or mobilisation of saline formation waters by over-exploitation of inland aquifer systems. Water pollution (salinization) cases due to extensive irrigation and use of fertilisers and other pesticides are also growing. Since there are several sources for the groundwater quality deterioration, it is necessary to characterise the specific processes involved. Isotope techniques are particularly effective for identifying the source of salinity and renewability of groundwater

ROLE OF ISOTOPE APPLICATIONS IN GROUNDWATER SALINIZATION INVESTIGATIONS

The fundamental relationships between $\delta^{18}O$ and $\delta^{2}H$ (fig.1) and between $\delta^{18}O$ and salinity (fig. 2) have been used in previous studies to identify different salinization pathways. These includes wash and flushing of airborne salts by precipitation or by dissolution of evaporitic minerals from the surface, the soil or aquifer formations; and encroachment of sea water or admixture of connate brine pockets. Although this basic approach is still valid, in the past decade, new isotope tools for investigating the dissolved component (such as $\delta^{37}Cl$, $\delta^{11}B$) have appeared,

mainly as the results of methodological investigations or in isolated case studies. In addition, saline waters are often old waters and advances using long lived radioisotopes (^{39}Ar, ^{81}Kr for example) and gas accumulations which may be studied isotopically (^{4}He) have appeared. Advances in the measurement (AMS techniques), use and understanding of ^{14}C, especially using organic carbon, have also provided new impetus to dating approaches. In the real world therefore, where salinity problems appear to be of a mixed origin, there is now a need to apply a multiple isotope approach to understand the groundwater systems.

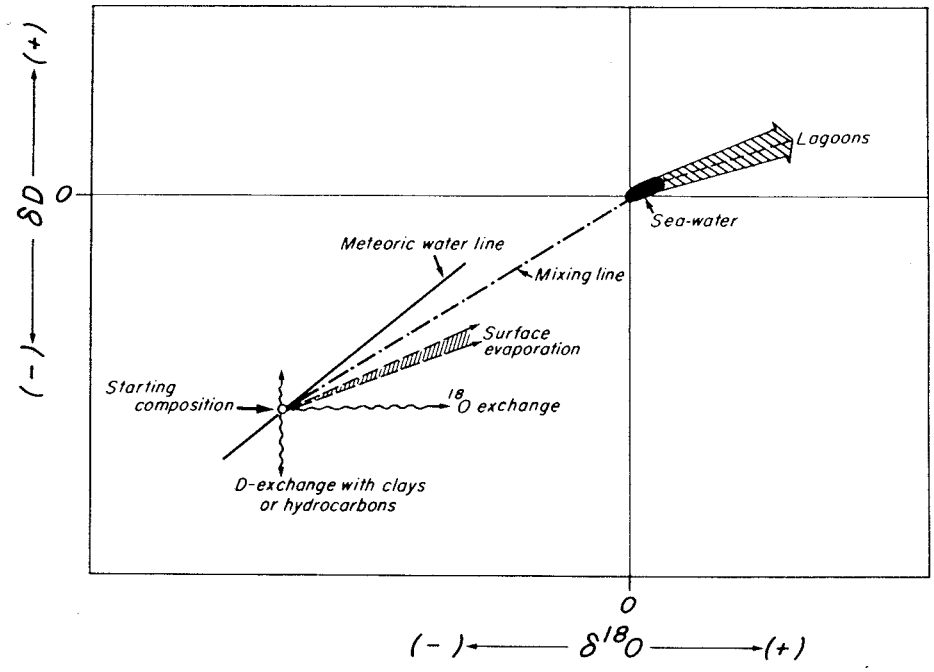

Figure 1 : Change in isotopic composition of water , associated with different salinization processes : δ D versus $\delta^{18}O$ (IAEA technical report series 210, 1981)

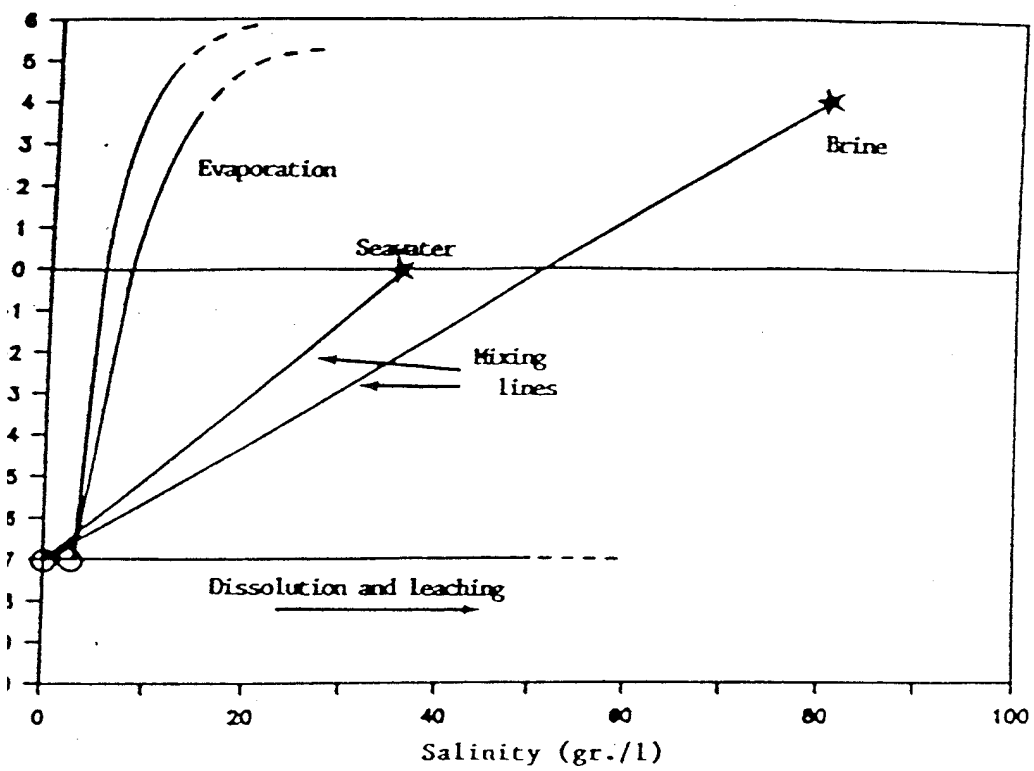

Figure 2 :: Change in isotopic composition of water , associated with different salinization processes, $\delta^{18}O$ versus salinity (Gonfiantini and Araguas, Symp. Tecnología de la Intrusión en acuíferos costerias, Ponencias Internationales, 1, IGME Madrid, 1988)

The specific and role of different isotopes for groundwater salinity studies are summarised in table 1

A substantial amount of basic data and results of applied field investigations using different isotopes have already been published (1 to 18).

SUMMARY OF IAEA ACTIVITIES IN SALINITY STUDIES

The IAEA has a long tradition and has accumulated a wide experience in the use of isotopic techniques for water resources studies and is acting as the international focal point in promoting the practical application of isotope methods in a wider scale. Over the past decades, the Isotope Hydrology Section of the IAEA has monitored more than 40 research contracts and technical co-operation in this field, including determination of origins of groundwater salinization, assessment of groundwater resources in coastal areas and islands, and evaluation of irrigation activities on groundwater quality [8, 12, 13, 14]. In these studies, both naturally occurring stable and radioactive isotopes were used.

Two TECDOCs were recently published by the Agency on isotope field applications for groundwater studies in the Sahel and in the Middle East, respectively in 1993 and 1996 which provide in-depth analysis of isotope results in the aquifer systems studied as well as a basis for more effective planning for future isotope investigations in these two regions [8, 12]. Moreover, one of the main

recommendations from the outputs of the CRP entitled “Groundwater pollution” was that further work should focus on groundwater salinization [13].

During the past decade, a series of books, reviews or benchmark papers relating to salinity have been published either at an international level [4, 6, 15 to 22], relating to country specific questions [9 to 11, 16, 23 to 28] or to methodological aspects

Geochemical/isotopic tool	Role in evaluating salinity
Cl	Master variable : inert tracer in nearly all geochemical processes ; use in recharge estimation and to provide record of recharge history.
Br/Cl	to determine geochemical source of Cl.
^{36}Cl	Half-life 3.01 x 105 a. Thermonuclear production ; use as tracer of Cl cycling in shallow groundwater and for recharge estimation. Potential value for dating over long time spans and also for study of long term recharge processes. However, in situ production must be known.
$^{37}Cl/^{35}Cl$	Fractionation in some part of the hydrological cycle, mainly in saline/hypersaline environments may allow fingerprinting.
Mg/Ca	Diagnostic ratio for (modern) sea water
Sr, I, etc.	Diagenetic reactions release incompatible trace elements and may provide diagnostic indicators of palaeomarine and other palaeowaters.
Nutrients (NO_3, K, PO_4)	Nitrate accumulation may accompany Cl in aerobic arid environments. Nutrient elements characteritic of irrigation returns.
$d^{18}O$, $d^{2}H$	Essential indicators with Cl of evaporative enrichment and to quantify evaporation rates, in shallow groundwater environments. Diagnostic indicators of marine and palaeomarine waters.
$d^{87}Sr$	Additional indicator of source of groundwater salinity especially in carbonate environments.
$d^{34}S$	Indicator of evolution of seawater sulphate undergoing diagenesis. Characterisation of evaporite and other SO_4 sources of saline waters.
$d^{11}B$	Additional indicator of salinity source.
^{14}C, $d^{13}C$	Additional indicator for modern sea water and for dating of saline waters. Half-life 5730 a. Understanding of carbon geochemistry is essential to interpretation.
Organics	Indicator species (e.g. fatty acids) to characterize marine waters of different age. Pesticides etc. diagnostic of irrigation sources of salinity.

Table 1: Role and applications of chemical elements and isotopes in salinity problems

THE MULTI-ISOTOPE ISOTOPE APPROACH

The IAEA has launched a new initiative aimed at investigation origin of salinity (salinization processes) and impacts on coastal fresh water resources using a combination of stable and radiogenic isotopes deuterium ($\delta^{2}H$), oxygen ($\delta^{18}O$), carbon-14 (^{14}C), sulphur ($\delta^{34}S$), boron ($\delta^{11}B$) and strontium ($\delta^{87}Sr$) isotopes. The studies will be carried within the framework of a CRP entitled "Origins of salinity and impacts on fresh groundwater resources. Optimisation of isotope techniques". Several proposals from contract holders from China, Israel, Jordan, Tunisia, Morocco, Korea, Pakistan were evaluated in terms of how they meet several pre-defined criteria which were found to be the most important for the selection of one site to be used as a flagship site were a multiple isotope approach study will be performed by an international team (Table 2).

The Souss-Massa coastal plain in south-west Morocco was proposed as the main site and commonly accepted that this offered scope for study of both coastal (saline intrusion) and inland basin problems. Taking in to account the geological, hydrogeological and climatic context of the region, several sources could be involved

for the groundwater salinity: (1) present day marine intrusion, (2) old marine intrusion, (3) water rock interaction and dissolution of evaporites, (4) concentration by evaporation, (5) antropogenic pollution. Interpretation of the first chemical and isotopic results give indications on the sources of salinity. In particular the Br/Cl and Sr/Ca ratios were used to distinguish (1) marine influenced areas (present day or paleo seawater intrusion?) (2) evaporites influenced areas (3) in a few localised wells near the downstream part of the oued Souss a wastewater. Nitrates show in the south of the basin the influence of the agricultural influence.

This study will give the opportunity to apply a multi-isotope approach of the salinity problem using on the same site several isotope tracers in combination. These will include $^{11}B/^{10}B$, $^{87}Sr/^{86}Sr$, ^{129}I, ^{36}Cl, ^{37}Cl, ^{81}Br, together with the more classical isotopes such ^{18}O, ^{2}H, ^{13}C, ^{14}C, ^{34}S, $^{18}O_{SO4}$. It is anticipated that the study will allow to establish a precise cartography of the extent of the salinity that is needed for a better water resource management. In fact, the economy of the region depends mainly on agriculture, tourism, and maritime fishing. Increases in population and economic development generate growth in demand for water and a multiplication of pollution sources and this requires good management of the environment in order to preserve good quality and sufficient quantity of water.

Although the flagship site is the main target of the CRP, it was agreed that the opportunities for collaboration between all participants was required and networking approach would be adopted to achieve these goals (fig.3).

Table 2 a : Priority criteria for selection of a sampling site – I.

Criteria	China	Jordan	Israel	Morocco
1. Good data base available from the site including good time series of change over past decades	10 years of data collected. Good database.	Long history of studies (30 years) and data collection. Good database (major elements?)	Database is available to some extent. 30 –40 years of record.	Data collected from 1993 and on. Good database available.
2. Knowledge of site geology (lithostratigraphy and structure)	Good geology maps.	Basic geology in the area is good, details are not available.	Geology well known and well constrained.	Geology well known. Seismics are made and good cross-sections available.
3. Wells correctly made, and knowledge of hydrodynamic parameters	Wells not mapped for depth. Sampling is only made in shallow and deep levels. Multi layer aquifer	Yes.	Some wells are good; most of the wells are pumping wells.	New wells are in good condition, old wells not very good. Phreatic aquifer.
4. Piezometric fluctuation, flow conditions and water balance	Piezometric data are available.	Piezometric data not collected. No water balance calculations made.	Pretty good water balance and pietziometric data.	New pietzometric data.
5. Geophysical and salinity logs in wells	Geophysical logging is made.	No, nothing is made.	Geophysical data may exist, but not known.	No geological logging.
6. Supporting data on water chemistry	Salinity is a serious problem in the area. The carstic system is the new target for drilling for fresh water.	Water chemistry is collected.	Water chemistry known very well known.	Good backup on the water chemistry.
7. Social and economical aspect related to groundwater exploitation and water uses	It indeed has a socio- economical impact in the area that is very expansive.	Very large need for drinkable water in the area. Salinity is a serious problem for the area.	Not an immediate problem but a potential problem	Salinity has a significant socio and economical importance. Conflict between agricultural and drinking demand.
8. New drilling	New drilling can be made.	New drilling can be made.	No new drilling.	No new drilling is planned.
9. Is there good concept-ualization of salinity question – are we clear of added value of isotope studies	Yes. Isotopes can be used to define the origin of salinity. Verification of the model. Paleo-storage of salinity?	Isotopes could be valuable for defining end-members and origin of the salt.	There will be an added value to use isotopes.	Isotopes will strengthened the conceptual model.
10. Are there any logistic obstacles for working	No problem to work in the area. Full access to sampling. Easy to work with authorities.	No problem for a international team. Government wells can be sampled.	No problems with logic, however the political situation uncertain.	No logistic and sampling problems
11. Extrapolate to other regions	Yes. Possible to extrapolate to other areas in China.	Yes. Unique – a truly arid environment.	Yes. Unique – a truly arid environment.	Type basin

Table 2 b: Priority criteria for selection of a sampling site - II.

Criteria	Pakistan	Republic of Korea	Tunisia
1. Good data base available from the site including good time series of change over past decades	Data are available for the last 5 years. A significant change in chemistry is observed.	Database exists. Salinity is monitored, no changes are observed. The monitoring program has been running since 1983.	Good database since 1963.
2. Knowledge of site geology (lithostratigraphy and structure)	Maps are most likely available at the geological department.	Very good geological description of the area.	Geology well known.
3. Wells correctly made, and knowledge of hydrodynamic parameters	Correctly made wells. Sampling are made at different depth. Wells with certain screening.	Wells are correctly made.	Wells are not correctly made.
4. Piezometric fluctuation, flow conditions and water balance	There is a draw down observed inducing a seawater inflow.	Nice, simple piezometric situation. No sea level changes.	Excellent piezometric data for 10 pieziometers. 90 wells have fairly good data.
5. Geophysical and salinity logs in wells	No geophysical and salinity logs made.	Some geophysical logging is made in the eastern part Cheju Island.	Geophysical logs are available. Not on salinity.
6. Supporting data on water chemistry	Chemistry is well known.	Chemistry well known.	Water chemistry quiet good. Major elements are analyzed.
7. Social and economical aspect related to groundwater exploitation and water uses	Problems can be defined. The authorities want to know the origin of the water salinity.	Scientific interest and local government concern.	Not a supply problem. The problem has an impact on the agriculture in the area.
8. New drilling	New drilling could be on a strong request.	Not much new drilling.	No new drilling is planned.
9. Is there good concept-ualization of salinity question – are we clear of added value of isotope studies	Yes isotopes are expected to have an added value. Origin of salinity.	Isotopes will be a useful tool to understand the "old water", hydrothermal input and past and present saltwater intrusions.	Isotopes can be justified in the search for the sorces, such as Messinian evaporatic impact, gypsum deposits and recycling of the irrigation water. An added value is expected.
10. Are there any logistic obstacles for working	Logistics OK, however, there are limitations for an international team.	No.	No logistical problems.
11. **Extrapolate to other regions**	Yes, typical of modern delta in the Indian subcontinent.	Could be extrapolated to similar volcanic island environments.	The problem is typical for the circum-Mediterranean.

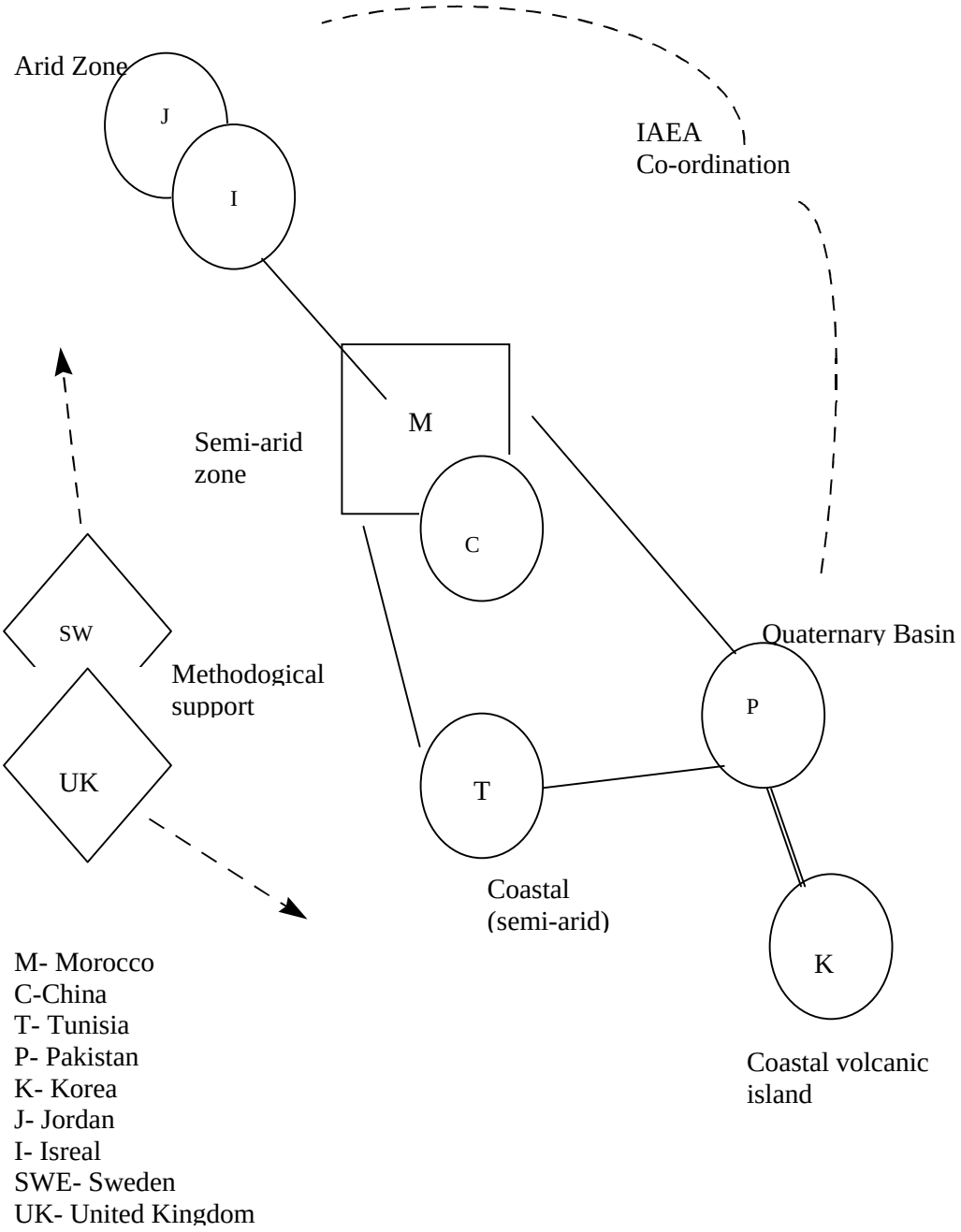

Figure.3 : Network for salinity investigation within the CRP

CONCLUDING REMARKS

The wide range of groundwater salinity problems in terms of its origin and prevention, especially in the context of the deterioration of water quality resulting from pollution or exploitation of groundwater resources, makes necessary the use of integrated geochemical and isotopic methods to interpret salinity issues. The Agency will continue to support the efforts in field applications of isotope techniques in water resources development activities in Member States and, to improve the existing methodologies or develop new ones.

References

[1] Proceedings of Symposia on Isotope Hydrology, 1970, 1974, 1979, 1983, 1987, 1991, 1993, 1995,1997, 1999.

[2] Isotopes in Lake Studies Proceedings of an Advisory Group Meeting held in Vienna, 1979. STI/PUB 511.

[3] Arid Zone Hydrology: Investigations with Isotope Techniques. Proceedings of an Advisory Group Meeting held in Vienna, 1980, STI/PUB 547.

[4] Stable isotope Hydrology: Deuterium and Oxygen-18 in the water cycle. Monograph prepared under the aegis of the IAEA/UNESCO Working Group on Nuclear Techniques in Hydrology of the International Hydrological Programme, 1981.STI/DOC/10/210.

[5] Palaeo-climates and Palaeo-waters: A collection of Environmental Isotope studies. Proceedings of an Advisory Group Meeting held in Vienna, 1983, STI/PUB/621.

[6] Guidebook on Nuclear techniques in Hydrology, 1983 edition. STI/DOC/10/91/2.

[7] Studies on Sulphur Isotope Variations in Nature. Proceedings of an Advisory Group Meeting held in Vienna, 1983, STI/PUB/747.

[8] Stable and radioactive isotopes in the study of the Unsaturated Soil Zone. Proceedings of the final meeting of the joint IAEA-GSF Co-ordinated Research Programme, 1984 IAEA-TECDOC 357.

[9] Estudios de hydrologia isotopica en America Latina - Isotope Hydrology investigations in Latin America. Proceedings of a regional seminar held in Mexico City, 1989. IAEA-TECDOC 502.

[10] Les ressources en eau au Sahel. Etudes hydrogéologiques et hydrologiques en Afrique de l'Ouest par les techniques isotopiques. Proceedings of a regional seminar held in Dakar, project RAF/8/012, 1993. IAEA-TECDOC 721.

[11] Isotope hydrology investigations in Latin America,1994, IAEA-TECDOC 835.

[12] Isotope field applications for groundwater studies in the Middle East. Proceedings of the final meeting held in Ankara of a Research Co-ordination Project,,1994. IAEA-TECDOC 890.

[13] Application of isotope techniques to investigate groundwater pollution. Proceedings of the final meeting of a Research Co-ordination Project,1998. IAEA-TECDOC 1046.

[14] Isotope techniques in water resources investigations in arid and semi-arid regions. Proceedings of the final meeting of a Research Co-ordination Project,1998. IAEA-TECDOC in preparation.

[15] Clark I., Fritz P.,1997. Environmental isotopes in hydrogeology. Lewis Publishers.

[16] Fontes J. Ch., Edmunds W.M., 1989. The use of environmental isotopes techniques in arid zone hydrology. A critical review. Unesco, IHP.

[17] Fritz P., Fontes J.Ch., 1980. Handbook of environmental isotope geochemistry, vol. 1, the terrestrial environment , Elsevier.

[18] Fritz P., Fontes J.Ch., 1986. Handbook of environmental isotope geochemistry, vol. 2, the terrestrial environment , Elsevier.

[19] Braitsch, O., 1971. Salt deposites. Their origin and composition. Pp. 297, Springer Verlag Berlin-Heidelberg-New York

[20] Hermann, A. G.; Knipping, B., 1993. Waste Disposal and Evaporites. Springer Verlag, Berlin-Heidelberg-New York.

[21] Bear J., Cheng A.H.D., Sorek S., Ouazar, D., and Herrera, I. , 1999 Seawater Intrusion in Coastal Aquifers - Concepts, Methods and Practices. Kluwer Academic Publishers, Dordrecht, The Netherlands.

[22] Custodio E., Bruggeman G.A., 1987. Groundwater problems in coastal areas. Unesco. Studies and Reports in Hydrology, 45.

[23] Vengosh A., and Rosenthal, A., 1994. Saline groundwater in Israel: Its bearing on the water crisis in the country. Journal of Hydrology , 156; 389-430.

[24] Salameh, E. , 1997. Water Quality Degradation in Jordan. Royal Society for the conservation of Nature, 179pp.

[25] Salameh E., and Rimawi A., 1992. The Curative, Thermal, Mineral Water of Jordan. WRSC No. (15), Amman, University of Jordan.

[26] Winckler, G.; Suess, E.; Wallmann, K., de Lange, G. J.; Westbrook, G. K., Bayer, R., 1998. Excess Helium and argon of radiogenic origin in Mediterranean brine basins.

[27] Vengosh, A. Spivack, A.J., Artzi, Y. and Ayalon, A. (1999) Boron, strontium and oxygen isotopic and geochemical constraints for the origin of the salinity in ground water from the Mediterranean Coast of Israel. Water Resource Research 35, 1877-1894.

[28] Han, L.-F., Gröning, M., 1998. Chlorofluorocarbons: New Transit Tracers for Groundwater Dating. IAEA, Water & Environmental News, No.2, January, 1998.

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