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Radon-222 Concentrations in the Groundwater along Eastern Jordan Rift

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Abstract: Determining the concentration of the radon 222 in the groundwater, determine the relationship between the radon concentrations and the water temperature and the water electrical conductivity are the main purposes of this study. The Jordan Valley classified as high radiant area because of the Jordan Valley contains a high active faults and the strata are high fractured. The main shallow aquifer in the study area consists of gravel and the second shallow aquifer consists of limestone, while the deep aquifer consists of sandstone. A total of 53 groundwater samples from the wells and springs in the study area were collected in order to achieve these objectives. The well samples were collected from hand pumps and tube wells covering different hydrogeological areas in the study area. The samples were analysed by using RAD7 instrument. The major physical-chemical parameters have been measured directly during sampling with a portable HANNA instrument with a multi-parameter probe (T, pH and EC). The radon-222 content in water may serve as a useful tracer for several hydrological processes. To understand the factors that control the occurrence of radon in groundwater of Jordan valley, Radon variation in tube wells and hand pumps varies from minimum amount 0.28±1.5 to the maximum amount of 44.31±3.2 Bq L^{-1} with an average of 6.2±2.5 Bq L^{-1}. A significant positive correlation between radon concentration and water temperature was observed in areas suggesting that radon concentration increases with temperature increasing and negative correlations between radon concentrations and the water salinity.

Key words: Groundwater, hydrology, Jordan valley, radon 222, RAD7

INTRODUCTION

Water is very essential in the daily lives of humans, in Jordan and other countries in the Middle East, the major uses of water in these countries are for mainly human water supply for house hold activities, irrigation, livestock watering and sometimes certain amount goes into the industrial sectors. Radon is a radioactive noble gas that is produced by radioactive decay of radium and it is soluble in water. Radon 222 is an alpha-emitting noble gas that is found in groundwater with different concentrations depending on the host rocks. Radon from natural sources is responsible, together with its decay products, for more than 50% of the population-weighted annual effective dose arising from all natural sources (UNSCEAR, 2000). Radon-222 has a short half-life (t1/2 = 3.82 day) means that it can be used to determine the recent history of groundwater. There are three naturally occurring isotopes ^{219}Rn, ^{220}Rn and ^{222}Rn, which are daughters of ^{223}Ra, ^{224}Ra and ^{226}Ra, respectively. In this study are concerned only with the ^{222}Rn isotope; the ^{219}Rn and ^{220}Rn isotopes have half-lives of less than one minute and are therefore precluded from analyses. From here on the term 'radon' refers solely to Radon 222 and 'radium' to Ra 226, which are members of the ^{238}U decay series (Fig. 1). The release of radon from mineral grains may occur via a different ways as ejection from the surface during the decay process or diffusion through

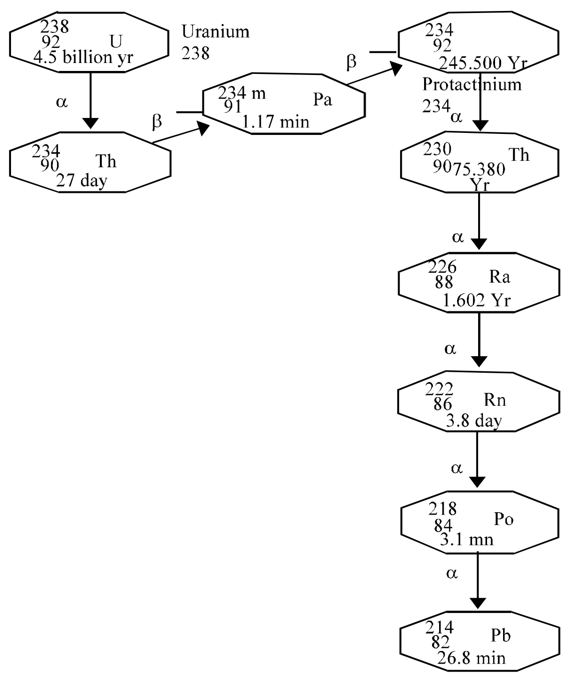

Fig. 1: Shows the series of animations from Uranium (238). Which present in the all sediments and rocks until reach to a stable element lead (Pb214) passing through radon (Rn-222) and radium (Ra226) animate alphas and betas particles

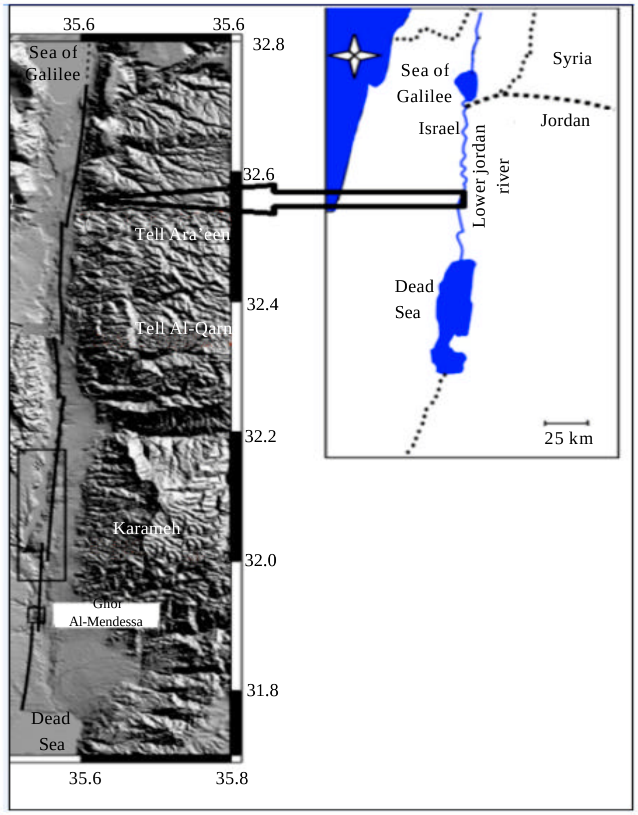

Fig. 2: Shows the location of the study area (Jordan Valley) which is the border between the Arabian plate and African plate, the study area extends from northern corner of the Dead sea to Tabrius (sea of Galille)

pores, fractures and Joints. Surface waters generally contain very low concentrations of dissolved radium and similarly low concentrations of dissolved radon (Osmond and Cowart, 1992; Porcelli and Swarzenski, 2003).

Because of the radium and radon are soluble in water, then ground water moves through radium/radon bearing soil and rocks they are dissolved and transported with the water. Radon concentration level and radon risk will be increased with high radium and Uranium content in ground water. Large scale mobility characteristics are influenced by additional factors such as rock and soil geochemical characteristics and geological structures like faults, shears, thrusts and so on Choubey and Ramola (1997).

The high level of radon in groundwater results from radium present in the rocks through which groundwater flows. Therefore, the high radon concentration in water is coming from different sources; one of these sources is the uranium in the surrounding rocks (Dickson, 1990). Other factors, like intensity of joining, presence of shear zones, degree of metamorphism, soil porosity, uranium mineralization, have been found to influence radon concentration in groundwater. In general the concentration of radon in a geological environment is changed depending on the rock types. As well the radon indoor in Jordan was studied by Al-Khateeb *et al*. (2012) found that the average indoor radon concentration was about 36.3-72.3 Bq m^{-3}.

Radon has been studied since the 1960s for tectonic mapping and mineral exploration (Segovia *et al*., 1999, Virk, 1995; Wattananikorn *et al*., 1995). As well the radon 222 concentrations have a good correlation with different factors such as geology, porosity, shears, thrust, faults, uranium mineralization and many other factors (Abu-Jarad *et al*. 2003; Fleischer and Mogro-Campero, 1978; Choubey *et al*., 1994, 2001, 2002; Choubey and Ramola, 1997; Przylibski, 2000; Veeger and Ruderman, 1998; Wiegand, 2001).

The study area is the Jordan Valley (JV). It is a part of the Dead Sea Transform (DST), a plate boundary zone which separate Arabian and African Plates (Fig. 2). The DSF extends from The Red Sea in the south to Sea of Galilee (Lake Tiberius) in the north. The fault is a left lateral, comprised of a zone of en-echelon strike-slip faults. Motion along the DST initiated in the Miocene and has cumulative lateral displacements (Garfunkel, 1981). Due to different extensional forces along the DST a deep depression has formed such as Aqaba-Elate, Wadi Araba, Dead Sea and JV.

The Jordan Valley is a 110 km long morphotectonic features that extends from the northern shoreline of the Dead Sea to the Sea of Galilee. The eastern escarpment of the JV can be sub-divided into distinct terrains zones. These are (1) The highlands (800 m-1000 m) above sea level, (2) The escarpment, encompassing the east slope of the valley (up to 800 m above sea level), (3) The foothills from -200 m to the sea level, (4) The rift valley floor. The JV floor is gradually slopes from 220 m below sea level in the north (Sea of Galilee) then heading southward to the northern shore of the Dead Sea (about 420 m below sea level). The coordinate of the study area is 31°40' and 32° 40' Latitude and 35°40'-36°00' Longitude.

The aims of this study were; to measure the radon concentrations in the groundwater, to measure the physical properties of the groundwater in the study area, to find the relationship between the radon 222 concentrations and the water temperature and to find the relationship between the radon 222 concentration and the electrical conductivity the groundwater in the study area.

The geological setting of the study area is summarized as the following.

Triassic and Jurassic systems consist of Zerqa Group, which subdivided into two formations Z1 and Z2 the Z1 formation related to Triassic period and consists of sandstone, calcareous, limestone, shale and gypsum. The Jurassic formation Z2 mainly consists of limestone, marl, dolomite, sandstone and shale. This formation distributed in the JV side wadis. The Cretaceous system consists of the Kurnub group K, which lies with conformity on the Azab formation Z2 of Zarqa group. The K group is a predominantly deposits at the base of Cretaceous and subdivided into two units. The lower one massive white sandstone with thin dolomite and shale bands, where the upper one is varicoloured sandstone containing thin intercalations of limestone, shale, dolomite and marl. The Kurnub group is overlain with conformity by deposits of upper Cretaceous-lower Tertiary (Belqa group). The Ajlun group falls within the Cenomamian and Turonian epochs and outcrops extensively along the escarpment of the JV. The group is essentially a carbonate sequence and consists of seven litho-stratigraphic subdivisions (A1-7) Turonian age. These divisions based in water bearing characteristics of the sediments and separate the sequence on the aquifers and aquicludes. The Belqa group ranges in age from Santonian to Upper Miocene. The carbonate rocks of this group are conformable with the underlying Ajlun group. In the study area the group subdivided into two formations B1 and B2 and its exposures occur mainly along the escarpment in the Northern part of the JV. Both formations B1 and B2 could be recognized as an aquifer. The Upper Tertiary system is an undifferentiated formation of the JV group, where it consists of mainly conglomerates and marl. The deposits of this formation associated with the tectonic activity which initiated the rift valley. The JV groups lie unconformable on the older systems and are overlain by Quaternary system. It consists of the Lisan formation and recent sediments. The Lisan formation is lacustrine deposits and lies uncomfortably on the older system in the JV the Lisan formation appears not deformed by the tectonic activity. The Recent superficial deposits are composed of fan, talus and terrace river deposits. The terraces cut at various stages in the formation of the wadis and covered with the terrace alluvium Fig. 3.

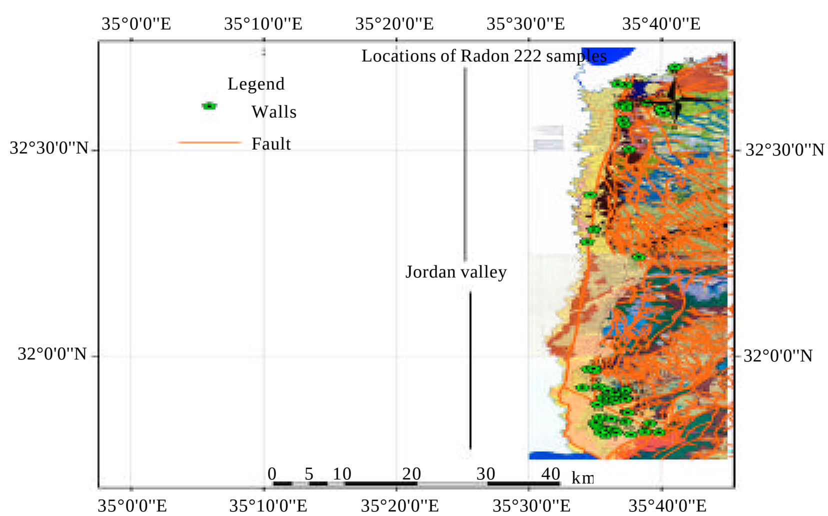

Fig. 3: Geological map and structural map (red lines denoted to the faults) of Jordan valley, the most of the area covered by cretaceous rocks at the highlands, while the foot of the Jordan valley covered by recent deposits consists of marl, clay, gravel and salt layers, the green circles denoted to the locations of the radon samples from the wells and springs

MATERIALS AND METHODS

Materials: A total of 53 water samples were collected and analysed for radon concentration. All these water sources are used for domestic and for irrigation purposes. The sampling sites for radon measurements studies were tube wells and hand pumps. Water samples from the tube wells/hand pumps were measured for radon during the month of July-August and the weather conditions during the sampling period were hot and fairly stable. Water was collected after running tube wells and hand pumps for about 15 min. This procedure was adopted to avoid the mixing of radon present in the casing. For radon measurement, a 10l water sample was collected by using bucket and hose from the wells at a depth around 2 m below water surface. The sampling bottle with 250 mL capacity has been sinking into the bucket until filled up to the edge and then immediately closed to avoid losses of radon by degassing. The major physical-chemical parameters have been measured directly during sampling with a portable HANNA instrument with a multi-parameter probe (T, pH and EC). The stability and precision of the measurements were found to be nominal and are well within 5% of the mean of data for temperature and conductivity. Radon concentrations have been determined using a RAD-7 radon detector and its accessory Rad-H_2O, produced by the Durridge Company.

Methods: The RAD-H_2O method employs a closed loop aeration scheme whereby both the air volume and water volume are constant and independent of the flow rate. In this scheme, the air re-circulates through the water and continuously extracts the radon until a state of equilibrium develops. Radon concentrations have been determined in the laboratory within a few days and on a 250 mL sample. Then results have been corrected considering the radioactive decay from the time the sample is collected to the time the sample is counted. The Decay Correction Factor (DCF) is a simple exponential function with a time constant of 132.4 h (that is the mean life of Rn 222 atom, given by the half life of 3.825 days multiplied by 24 h day^{-1} and divided by the natural logarithm of 2).

The RAD-7 is an alpha particle detector that uses a solid state detector to detect alpha particles with different energy levels. A solid state alpha detector can convert the energy from an alpha particle to an electrical signal. This makes it possible to identify the specific element that decay since every element emits alpha particles with different energy levels. Inside the RAD-7 is a hemisphere that is coated with an electrical conductor. An ion-implated silicon alpha detector is placed in the centre of the hemisphere see Fig. 4. A high voltage power circuit

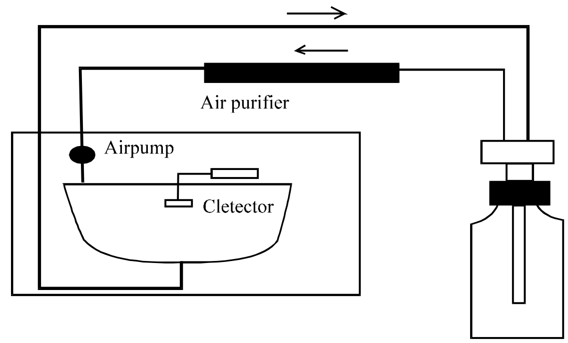

Fig. 4: Shows the schematic drawing of the RAD-7 H_2O detector. It shows the close path of the gasses which come from water sample that collected in 100 mm bottle (# 1) these gases pass through plastic cylinder filled with $CaSO_4$ dryer (# 2) and then to the detector in RAD 7 instrument (# 4) passing through the pump (# 3)

creates a high electrostatic field within the measurement chamber. This electrostatic field makes the positively charged radon daughters, polonium-214, 214Po and polonium-218, 218Po, absorb onto the surface of the detector. This means that when the polonium isotopes decay and emit alpha particles the alpha particles enter the detector and electrical signals with specific energy level will be produced and recorded. The radon concentration is then calculated from the decay of the radon daughters 214Po and 218Po and not from the decay of radon itself. This technique gives the RAD-7 a quick response time since the half-life of the 218 Po, is only 3.05 min and the secular equilibrium is reached after only 12 min.

The H_2O accessory of RAD-7 has been used at laboratories for more than a decade and has a detection limit of 0.370 Bq L^{-1}. The water sample is collected in a 40 mL or a 250 mL vial depending on the expected concentration. If the concentration is expected to be higher than 100 Bq L^{-1} the 40 mL vial is recommended and if the concentration is expected to be lower than100 Bq L^{-1} the 250 mL vial should be used. The water sample in the glass vial is aerated when the air pump inside the RAD-7 chamber pumps air into the vial through a plastic tube. The air is then led via a gas purifier into the RAD-7 chamber. This creates a closed loop of air between the vial and the RAD-7 chamber. The RAD-7 chamber is sensitive to moisture and the relative humidity has to be kept below 10% to get good measurements. Therefore the gas purifier (a plastic cylinder filled with $CaSO_4$) seen in Fig. 4 is used to absorb moisture in the ingoing air. The water sample is aerated for five minutes to get all the radon from the water into the air circulation. After the first five min of aeration the RAD-7 waits for five minutes to get the 218Po in equilibrium with the radon (Senior and Vogel, 1995). Then the decay of 218Po is counted for four (in some samples 10 cycles were used) five-minute-periods and the result is printed. The results show four calculated radon concentrations and a statistical uncertainty for each measurement. A mean value for the radon concentration in the four measurement cycles is presented as well as a standard derivation calculated for the four radon measurements.

RESULTS AND DISCUSSION

Radon 222 activities in the groundwater and electrical conductivity of the 53 samples were measured. The radon 222 concentrations and temperature were measured for 31 samples from wells and springs in the Jordan valley area and the coast of the Dead Sea. The concentrations of the radon for the samples were in the range 0.28-44.3 Bq L^{-1} (Table 1) with a mean value of 6.2 Bq L^{-1}. Table 1 shows the radon concentrations for the different wells and springs, the temperatures of the 31 groundwater samples and for the electrical conductivity for all the groundwater samples.

As well the locations of water samples, the geology and faults in the study area are shown in Fig. 3.

Radon concentration in 53 samples are taken at a depth of 50-130 tube wells and hand pumps and the samples from the springs varies from 0.28°0.8-44.5°3.4 Bq L^{-1} with an average of 6.2°2.6 Bq L^{-1}. The highest radon concentration was found in the samples that were collected from springs. That is because the groundwater passing through rocks with high concentration of radon, passing through a fault and the slope of the area is too high. Then the flowing of groundwater is fast and less than the half life of the radon 222 (3.8 day). Whereas, a few higher radon values were also found in the Northern part of the Jordan valley because of the water in these wells is hot "Thermal water". This water is flowing from the deep aquifer that has a high concentration of Uranium daughters. Therefore, radon data for both the springs and wells were treated similarly. In addition to radon other physicochemical parameters of water like temperature and conductivity were also measured in the field in order to find the impact of these parameters on radon concentration. A negative correlation was found between radon 222 concentrations and electrical conductivity on one hand as shown in Fig. 5 the radon concentration were decreasing while the electrical conductivity increase. On the other hand a positive correlation was found between radon concentration and temperature as shown in Fig. 6 the radon concentration were increasing if the water temperature increase.

Table 1: Radon 222 concentration, temperature and conductivity of water in tube wells and hand pumps in different hydrogeologic areas and the coordinates of the samples

Well name	Sample (No.)	North	East	E.C.	Rn -(Bq m^{-3})	TEMP (°C)
BH-1-9	1	1136338	211284	3370	3960	26.7
BH-2-9	2	1135343	206620	3350	3510	28.6
BH-3-9	3	1136098	205987	5860	8080	28.3
BH-4-9	4	1136646	206689	7140	9310	28.1
BH-5-9	5	1136960	207458	5120	6590	27.3
BH-6-9	6	1137828	205585	4080	7050	28.7
BH-7-9	7	1138268	205323	4060	8920	27.8
BH-8-9	8	1138863	205429	3800	13690	29.9
BH-9-9	9	1139811	207281	6950	9870	27.9
BH-10-9	10	1140137	205839	9600	4050	29.3
BH-11-9	11	1143636	205607	6770	5550	28.5
BH-1-1	12	1219207	208547	870	7400	48.0
AB1355	13	1220349	208314	930	4840	48.1
BH-2-1	14	1224629	208726	1120	550	48.8
BH-3-1	15	1224398	208134	1660	700	53.2
BH-4-1	16	1224305	208013	1750	2790	49.9
BH-1-2	17	1229682	208715	2220	280	36.3
SP-1-2	18	1234613	214443	1290	7830	38.4
BH-2-2	19	1223628	208745	780	2470	28.8
BH-1-3	20	1222380	212951	830	3290	26.7
BH-2-3	21	1222452	213009	790	10290	26.3
BH-3-3	22	1222564	212875	810	6760	26.8
BH-4-3	23	1222113	213144	860	9160	25.9
BH-5-3	24	1223392	212823	750	15810	30.0
BH-6-3	25	1224866	211178	810	4020	29.0
BH-1-8	26	1190894	205076	3350	6150	28.6
BH-2-8	27	1190735	204996	3400	8820	26.0
SP-1	28	1187427	204259	2920	6760	28.6
SP-2	29	1200086	204565	1740	24520	26.3
SP-3	30	1212393	209128	1130	44310	25.3
SP-ADSEH	31	1230048	207687	3880	6640	26.5
AB1018	32	1145560	208660	1305	4030	
AB1024	33	1145475	206240	1920	3140	
AB1028	34	1146020	208455	1435	3970	
AB1030	35	1136120	207870	2054	4500	
AB1044	36	1144500	207020	3625	3800	
AB1054	37	1148540	205690	6650	2150	
AB1066	38	1138570	211845	3940	2870	
AB1070	39	1145220	207150	2635	2070	
AB1076	40	1148135	203775	1535	3540	
AB1088	41	1141500	209235	4380	2170	
AB1096	42	1135510	209640	4200	2220	
AB1098	43	1139060	208990	2810	3540	
AB1108	44	1144780	207750	2960	3420	
AB1112	45	1147450	206730	3165	2940	
AB1116	46	1146800	207680	2510	2170	
AB1118	47	1136220	212950	1550	4900	
AB1132	48	1183360	210400	2665	5100	
AB1142	49	1147450	208950	935	4700	
AB1175	50	1152825	205300	2325	3140	
AB1178	51	1153120	204510	5110	2980	
AB1179	52	1153290	205100	3662	3200	
AB1189	53	1145100	208950	952	4210	

This is mainly due to the fact that the samples come from different geohydrological units having distinct characteristics. Further, the lack of correlation may also be due to the mixing of groundwater from different levels of aquifers. As well the groundwaters which have a very low radon 222 concentration due to the connection between the aquifer and the surface which means that the some of the radon spread into the atmosphere.

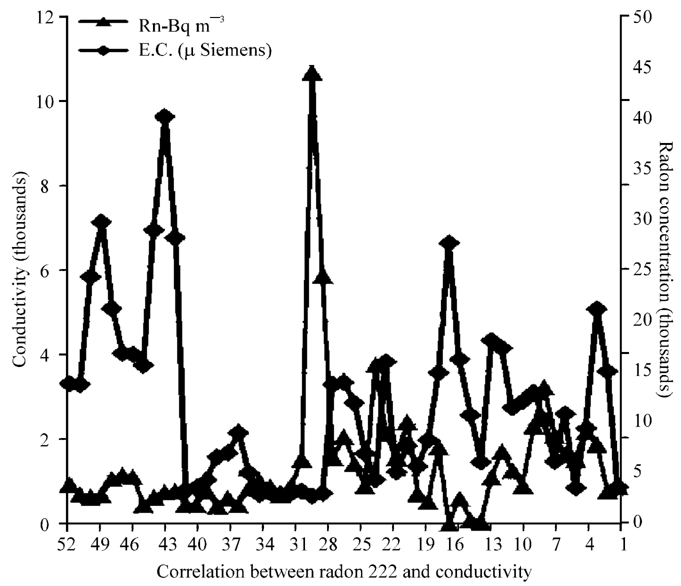

Fig. 5: Shows the relationship between radon 222 and the electrical conductivity. The left vertical scale is the conductivity of the water samples (in thousands) micro Siemens, the right vertical scale is the Rn 222 concentrations (in thousands) Bq m^3 and the top horizontal scale is the water sample number. This figure shows the negative relationship between the Rn 222 and EC

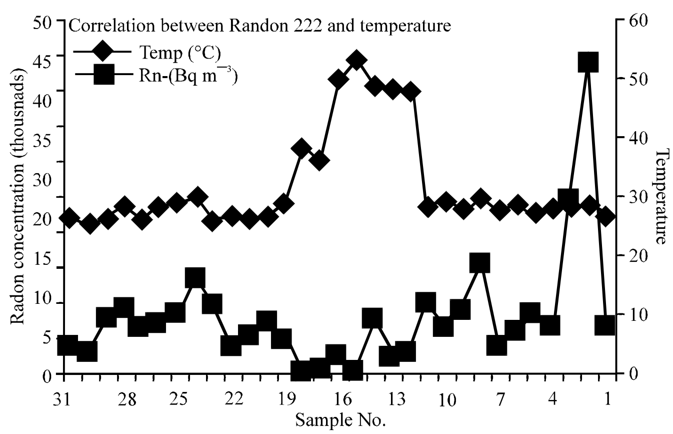

Fig. 6: Shows the correlation between radon 222 and the groundwater temperature, the vertical left scale is the radon 222 concentrations (in thousands) Bq m^{-3}, the right vertical scale is the temperature (in celsius) and the bottom horizontal scale is the water samples number, this curves show the positive relationship between the Rn 222 and the water temperature

Geologically, all the samples that collected from the southern part of the Jordan valley are located in the younger Jordan gravels that consist of a poorly sorted mixture of clay, sands, gravels and large boulders of quartzite and sandstone. Because of heterogeneous lithology and highly porous gravels, the radon emanated is easily dissolved in infiltrated water that reaching the underground water.

The plots of radon concentration vs. Electrical conductivity (Fig. 5), Field relationship and the lithologs of the wells indicate that aquifers of this area consist of at least two layers. Deep strata consisting of sand gravel mainly deposited by the Jordan valley deposits and derived from the rocks present in the catchment of Jordan valley. These gravel deposits, called Younger Jordan gravel, have very high porosity and permeability but are poor in uranium-rich minerals. The other shallow aquifers comprising limestone have relatively low porosity and permeability. These are mainly derived from the erosion of the crystalline rocks of are rich in uranium containing minerals. The uranium-rich minerals associated with sand and long residence time of water in the shallow aquifer is possibly responsible for higher radon concentration at shallow depth.

The concentrations of Radon 222 in wells and springs in this study are much higher than that in springs in Ajlun city which has done by Rabadi and Abumurad (2008). While the results of this study is coinciding with the results that have been obtained by Al-Bataina *et al.* (2005) if the highest value 44.3 Bq L^{-1} excluded from this study.

CONCLUSION

The area considered in this study was the Jordan valley and the eastern coast of the Dead Sea. This study was carried out on the radon concentration in the groundwater and springs along the Jordan Valley and the eastern coast of the Dead Sea. Many samples were collected and analyzed for the radon 222 activity by using the RAD 7 instrument. In addition the temperature and the electrical conductivity of the ground water were measured directly in the field for the same samples that got for the radon 222 measurements. The concentrations of the radon 222 were found in the range 0.28- 44.3 Bq L^{-1}. The correlations between the radon concentration and the temperature and electrical conductivity were carried out. The following have been found in this study; the relationship between the radon concentrations and the temperature is positive that means that by increasing the temperature the radon concentration increase. On the other hand the relationship between radon concentrations and electrical conductivity is negative. That means if the electrical conductivity increase then the radon decreasing. The highest of the radon concentrations were found in the spring surrounding the Jordan Valley and the hot groundwater at the northern part of the Jordan Valley. The high contrast of the radon concentration in the well was considered because of the groundwater flowing from different aquifers and the radon spread in the atmosphere from the upper aquifer "conglomerate". The highest of radon concentrations was found at the northern part of the Jordan Valley that equal 44.3 Bq L^{-1} where the formation is basalt.

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