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Isotopic and Chemical Evidences of Natural Hot Spring Recharge into the Dumaguete Aquifer, Philippines

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ABSTRACT

Geoscientific investigations on the quality of groundwater in the Dumaguete aquifer reveal that it is influenced by the natural recharge of hot springs from the outflow of the geothermal system. Although the concentrations of the major ions are still within the drinking water standard, mixing of this hot spring water and meteoric water results to three types of groundwater in the study area, which are: (1) $Na+K-Cl+SO_4$ waters, (2) $Ca+Mg-HCO_3+CO_3$ waters and (3) $Ca+Mg-Cl+SO_4$ waters. Typical deep groundwater are found in the area of well 46 in the south, relatively Cl-rich waters are within well 54 and the rest of the wells to the northeast are discharging mixed hot spring and typical groundwater. Chemical simulation indicates that Okoy River contributes to the deep groundwater aquifer in the area of wells 49, 53, 54 and 55, and significant recharge comes from the hot spring and deep groundwater. Apparently, local precipitation does not seem to significantly contribute to the deep and shallow groundwater aquifers since recharge mainly comes from elevation between 1100 and 1300 masl. The different water types are also distinguished based on their isotopic composition, and the hot spring water appears to influence the quality of water in wells 49 and 54, while both wells 53 and 55 are being recharged dominantly by meteoric and river water, respectively, with only minor recharge from the hot spring. Moreover, isotopic data indicate that recharge for both shallow and deep aquifers occur only during the rainy season, with very minimum recharge, if at all, during the dry season.

Groundwater dating using chlorofluorocarbon (CFC) provided significant information that further validated isotopic data. Wells in the south in the area of well 46 have older groundwater (>60 years old) than the wells within well 55, which have young groundwater of about ten (10) years old. There is binary mixing of old water and young water in the wells, where about 20% of the water in well 56, for instance, is less than forty (40) years old while the remaining 80% is more than fifty (50) years old. CFC data further confirm that well 55 is influenced by infiltration from both Okoy and Banica Rivers due to its proximity to the river systems.

1. INTRODUCTION

Stable isotopes and hydro-geochemistry were applied in the understanding of the natural migration of thermal waters from the outflow of the Southern Negros Geothermal Field to the shallow groundwater aquifer in Dumaguete City. The geoscientific tools used in the study were stable isotopes of ^{18}O and ^{2}H, chemistry and chemical simulations, tritium when applicable, dating with CFC and numerical flow simulations.

This study is a cooperation between PNOC-Energy Development Corporation (PNOC-EDC) and the International Atomic Energy Agency (IAEA) under RAS/8/092 with the title: *Investigating the Environment and Groundwater Resources in Geothermal Areas*. It is the aim of the investigation to classify the different groundwater in Dumaguete City through isotopes and chemistry and identity the recharge mechanisms for the groundwater aquifers. An understanding of the different sources of recharge would provide valuable information for groundwater management.

The investigation covers the Okoy and Banica watersheds with an approximate area of 86 and 53 km^2, respectively (**Figure 1**). Since it has been established that the geothermal operation of PNOC-EDC has no detrimental effect on the chemistry of the hot springs (Caranto et al., 2002), the study focuses on the natural contribution of the hot springs to the Dumaguete Aquifer.

This paper, therefore, presents a detailed analysis of the different shallow groundwater reservoir characteristics and recharge mechanisms from different water sources based on isotopic and geochemical data.

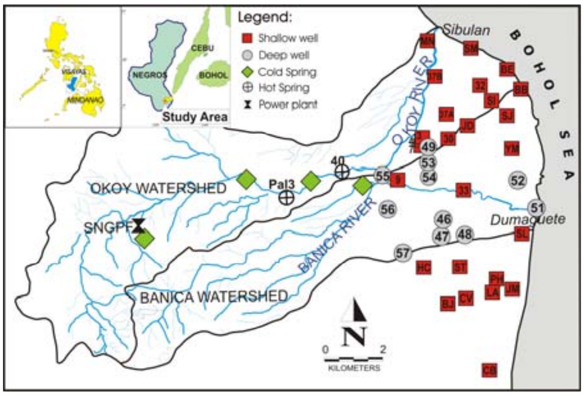

Figure 1. Location map of different water sources

2. HYDROGEOLOGY

The main lithology covering the headwaters of the Okoy and Banica watersheds are Quaternary volcanic deposits composed of andesitic lavas and dacite pumice flows. In the lower Okoy Valley where the Okoy and Banica Rivers nearly converge, the rugged terrain breaks into a gentle plain where the lithology is composed mainly of Quaternary alluvial deposits of sands, clays and gravels with minor marine deposits of limestone and corals. A transition zone which is composed of reworked pyroclastic materials exists between the pyroclastic deposits and the Quaternary Alluvium on the southern side of Banica River.

Pumping tests data from local water district wells indicate that shallow wells have higher hydraulic conductivity values ($25x10^{-5}$) relative to the deeper wells with only about

5x10^{-5}. Transmissivity values of the deeper wells range from 1.91 to 30.1 x 10^{-3} m^2/s.

Depth to water table is less than two (2) meters below ground level (mbgl) near the coast to about 70 mbgl at well 55. Groundwater flow is generally perpendicular to the coast, except for a significant drawdown in wells 46, 47 and 48 of about 25m and 20m, respectively, since 1985. However, sporadic data since 1990 show that the water level in all deep wells have recovered, suggesting that recharge is complementing the groundwater extraction of the deep and shallow wells. **Figure 2** shows the simplified hydrogeological map along the Okoy and Banica watersheds.

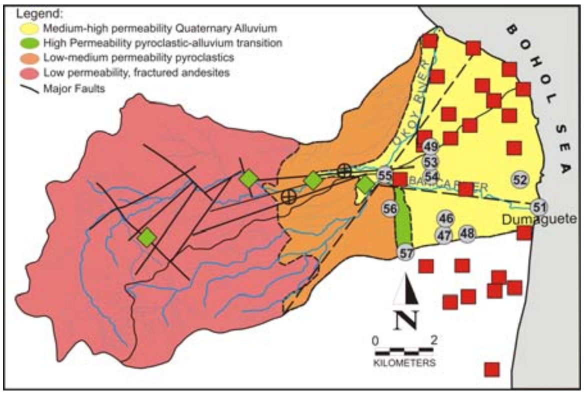

Figure 2. Simplified hydrogeology map of Okoy and Banica watersheds.

3. HYDROLOGY

Most of the land area in the headwaters of Okoy and Banica watersheds are composed of steep terrains covered with forests, grass and shrubs. Farther downslope, several lands were already converted for agricultural purposes where rice, corn and other root crops are cultivated all year round. Towards the low lying areas of Dumaguete City and Sibulan, urban development have already converted around 7% of the area, while coconut trees and bananas still cover around 45% of the other areas (SWECO, 2001). Agricultural area covers less than 2% of Dumaguete City.

The project area falls under the Type III climate of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) Coronas Climate Classification, which is characterized by no very pronounced maximum rain period with dry season lasting from one to three months. February to May is relatively dry compared to the rainy season from June to January. Annual precipitation in Dumaguete City is 1216mm, which is relatively lesser than that in the Southern Negros Geothermal Production Field (SNGPF) with an average annual precipitation of 2500mm. At Dumaguete City, ambient air temperature is coldest during the month of January with 25°C and warmest during May with 28°C. Relative humidity ranges from 76% in April and 81% in January.

Historical mean annual discharge data for the Okoy river system is estimated at 1544 mm while it is roughly 1488 mm for Banica River system. Hydrograph analyses indicate that pre-1984 baseflow averages 83% and decreased to about 66% from 1984-1988 (Geotechnica, 1994). This variation is attributed to the decreased rainfall after 1984 resulting to the lowering of the groundwater hydraulic heads. The direct runoff is calculated at 948 mm/year for Okoy and 664mm/year for Banica watershed.

Evapotranspiration for Okoy and Banica watersheds were estimated at 1211 and 1325 mm/year, respectively. Net recharge is then calculated to be 314 mm/year for Okoy and 322 mm/year for Banica watershed (SWECO, 2001).

4. GEOCHEMISTRY

4.1 Chloride with time of geothermal wells and springs

Long-term monitoring of geothermal wells show slight enrichment in chloride due to steam production, and the pressure drop in the reservoir have decreased the input of outflowing water into the peripheral hot springs like Pal 3, as clearly indicated in **Figure 3**. This strongly validates that the hot spring Pal 3 is part of the natural outflow and the geothermal production has indeed indirectly reduced the hot spring recharge into the groundwater aquifer significantly, and clearly indicates no negative impact on the groundwater quality (Caranto et al., 2001). This decline in chloride concentration is also manifested in the exploration well-turned monitoring well N1.

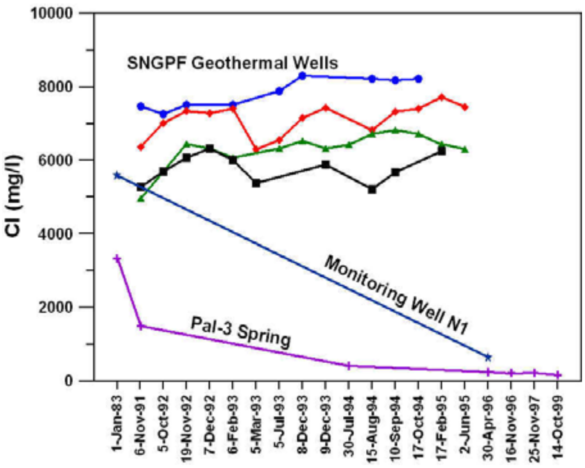

Figure 3. Long-term chloride concentration of geothermal wells, monitoring well and hot spring Pal 3

4.2 Groundwater System

Field physico-chemical parameters and basic chemistry data indicate three different types of groundwater in the study area. Field sampling temperature and electrical conductivity (EC) showed a similar trend that groundwater in the south is colder and less conductive (<300μs/cm) than the groundwater in the northeast (EC is 400-1000 μs/cm). Groundwater near hot spring Pal3 has relatively higher temperature with conductivity of more than 1000μs/cm.

The piper diagram of the different water samples, as shown in **Figure 4**, shows an apparent dilution trend derived from the hot spring to the groundwater aquifer tapped by wells 49, 53, 54, 55 and the shallow wells to the northeast. Two end-members were derived from the diagram, which are the typical groundwater (recharge from precipitation) and Cl-SO_4 water (represented by the hot spring). Mixing of these types of water results to three different water types, which are: **(1) Ca+Mg - HCO_3+CO_3; (2) Na+K - Cl+SO_4; and, (3) Ca+Mg - Cl+SO_4.** The spatial distribution of these water types are shown in **Figure 5**. **Table 1** shows the typical chemistry of selected water sources.

Table 1. Chemistry of Selected Groundwater Sources in Dumaguete City (in mg/l)									
Source	Code	pH	Na	K	Ca	Mg	Cl	SO4	HCO$_3$
Cold Spring	24	7.63	11.1	1.67	19	5.06	10.8	13	91.4
Hot Spring	40	7.13	175	18.5	12.7	1.22	385	97	247
Cold Spring	44	7.11	12	1	28	6.1	4	88	1127
Cold Spring	50	6.82	14.6	3.67	28.1	8.15	51.8	13	128
Shallow Well	3	6.59	25.4	6.71	41.6	4.71	18.9	102	69.6
Shallow Well	32	7.69	37.7	7.9	92.2	11.3	93	110	151
Mainit Sh. Well	MN	7.47	142	17.9	61.4	9.55	158	19	265
Si Market	SM	7.45	58.3	13.5	50.3	12.7	63	31	0.48
Deep Well	46	7.1	11.5	2.3	27.7	7.45	3.16	27	123
Deep Well	47	7.13	11.7	2.26	26.9	8.38	3.14	25	124
Deep Well	48	7.34	10.4	2.24	22.6	7.16	2.96	27	110
Deep Well	49	7.47	49.3	6.03	45	7.17	64.5	98	88.2
Deep Well	51	7.27	19.9	6.42	55.4	13.2	27.7	40	185
Deep Well	52	7.43	13	3	28	7.3	12	28	80.5
Deep Well	53	7.05	57	6.19	39.6	8.07	75	73	86.8
Deep Well	54	7.23	121	16.3	53.4	11.4	195	89	89.9
Deep Well	55	6.92	72.2	6.13	38.4	5.68	71	94	87.2
Deep Well	56	6.96	9.82	2.75	21	6.69	3.02	34	82.2
Deep Well	57	7.03	14.1	2.37	37.2	9.89	6.44	19	138
Banica River	BR	7.57	7.65	2.81	17	5.12	8.23	40	48.4
Okoy River	OR	7.64	18.6	3.59	51	4.52	20	115	34
Hot Spring	Pal 3	6.76	250	34	9	5.6	223	144	390

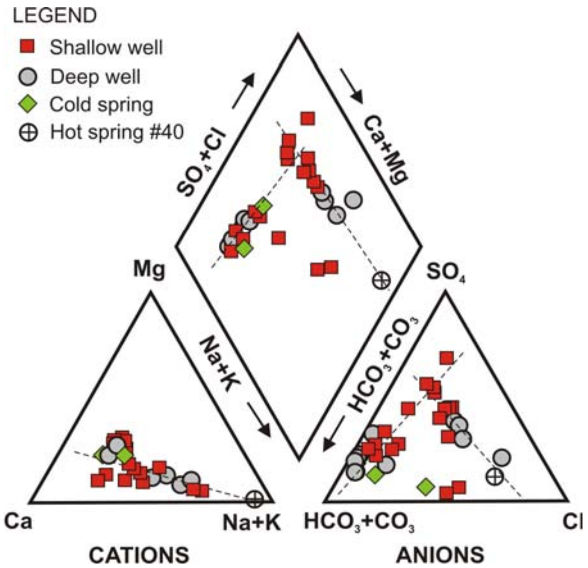

Figure 4. Piper diagram of different water sources

To determine the fractions of different water sources in specific wells, chemical simulations were conducted using PHREEQC for windows that included stable isotopes of ^{2}H and ^{18}O to narrow down the possible mixing equations. The end members that were assigned in the simulation were rainwater (represented by the chemistry of the shallow wells), deep groundwater with relatively elevated solutes (represented by wells 49, 53, 54 and 55), deep groundwater with low TDS (represented by well 46, 47 and 48), river water from both Okoy and Banica Rivers, and hot spring water from Pal 3 and 40. Results of the preliminary chemical simulation calculations are shown in **Table 2**.

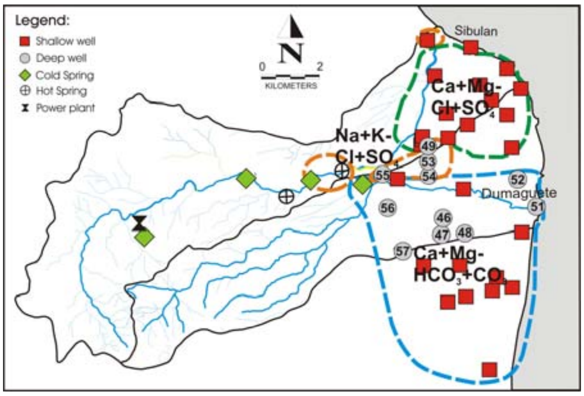

Figure 5. Spatial distribution of the different types

Table 2. Chemical Simulation Results

Solution End-Member	Solution Fractions (%)			
	Okoy/ *(Banica)* River	Hot spring (Pal 3)	Deep Ground water	Rainfall/ Shallow Ground water
Well 54	34	39	26	0
Well 55	62	20	18	0
Well 49	69/*(5)*	18	5	2
Well 48	0	0	100	0

Okoy River appears to have a significant contribution to the deep groundwater aquifer within the area of wells 54, 55, and 49. These wells apparently also extract water mixed with 18-39 % hot spring water, with well 49 and 54 as the least and most affected, respectively. The deep well 48, which is located south of the project area, is extracting only deep groundwater that is recharged from high elevation.

5. ISOTOPE HYDROLOGY

5.1 Local $\delta^{18}O$ and $\delta^{2}H$ in Precipitation

Available isotopic data from 1991 to 1997 at the Global Network for Isotopes in Precipitation (GNIP) stations within PNOC-EDC's geothermal field were used to determine the Local Meteoric Water Line (LMWL), which has an equation $\delta^2H = 8*\delta^{18}O + 12.5$. Seasonal variations in $\delta^{18}O$ values range from -2 to -9 $^{0}/_{00}$ between dry and rainy season, respectively. The list of isotopic composition of the different water sources is found in **Table 3**.

Table 3. Stable isotope composition of selected water sources in Dumaguete City

Source	Code	Average (in $^{o}/_{oo}$)	
		^{2}H	^{18}O
Deep Well	46	-49.25	-7.57
Deep Well	47	-49.85	-7.73
Deep Well	48	-48.49	-7.57
Deep Well	49	-47.23	-7.55
Deep Well	50	-47.64	-6.78
Deep Well	51	-47.90	-7.42
Deep Well	52	-47.99	-7.45
Deep Well	53	-46.56	-7.07
Deep Well	54	-48.42	-7.33
Deep Well	55	-44.54	-7.21
Deep Well	56	-46.24	-7.47
Deep Well	57	-47.55	-7.30
Shallow Well	32	-47.96	-7.39
Shallow Well	3	-45.59	-6.94
Cold Spring	24	-46.69	-7.49
Cold Spring	44	-47.68	-7.57
Shallow Well	30	-43.94	-7.01
Okoy River	OK	-45.83	-7.01
Banica River	BR	-48.39	-7.33
Hot Spring	40	-47.55	-6.84
Hot Spring	Pal3	-44.5	-6.32

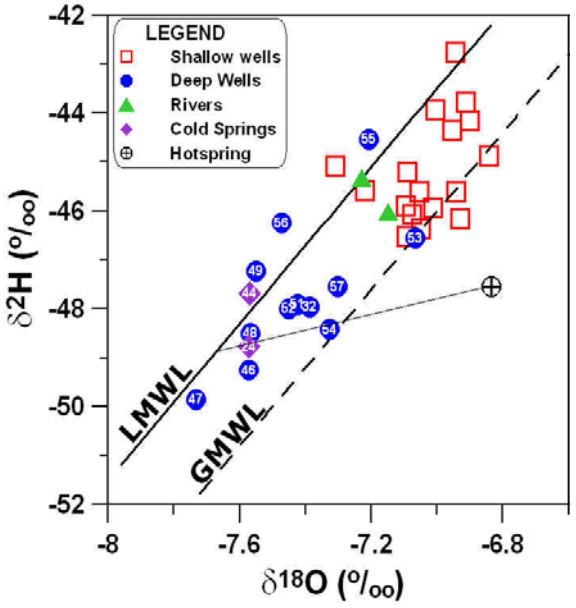

Figure 6. Plot of δ2H and δ18O of different water sources in the study area.

5.2 Groundwater, Hot spring and Geothermal Water Recharge

Shown in **Figure 6** is the plot of δ^2H and $\delta^{18}O$ composition of the different water sources in the study area, which indicates two different water groups: the shallow, relatively enriched groundwater being produced by the shallow wells and some deep wells, and the deep groundwater which is tapped by the deep wells. Okoy and Banica Rivers appear to influence the shallow groundwater. Cold springs have the same isotopic composition as the deep water, which suggests the same elevation of recharge. A dilution line indicates that the water in well 54 is a mixture of rainwater and hot spring water that resulted to the slightly elevated chloride concentration in the well.

The plot also suggests different recharge elevations for the shallow and deep groundwater. As validated in the cross plot of station elevation against weighted mean of $\delta^{18}O$ in **Figure 7**, the recharge elevation for the shallow groundwater is at 1100 masl, while the deep groundwater is recharged at around 1300 masl. The difference of only 200 meters in the recharge elevation explains the small variation in the isotopic composition of the shallow and deep water. A cold spring that is located at 800masl is also recharged by the same deep aquifer water. One limitation of this graph is that the recharge from local precipitation and river systems is not considered, but is elaborately discussed in the preceding section on chemical simulation.

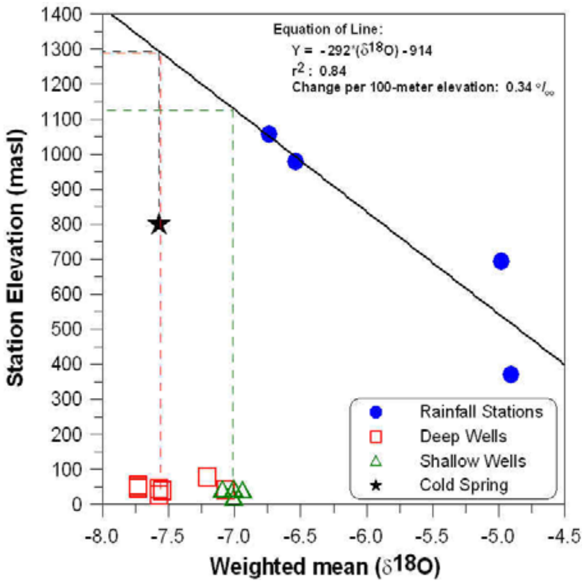

Figure 7. Recharge elevation of surface, shallow and deep water sources based on isotopes

Figure 8 shows the stable isotope composition of the geothermal water at Palinpinon, the hot springs and the different types of groundwater. The isotopic values of the precipitation recharging the geothermal system, as deduced from the andesitic and geothermal water dilution line, is -46.6 $^{o}/_{oo}$ for δ^2H and -4.7 $^{o}/_{oo}$ for δ^{18}O, which indicates that the geothermal system is recharged by about 14% magmatic water and 86% from precipitation.

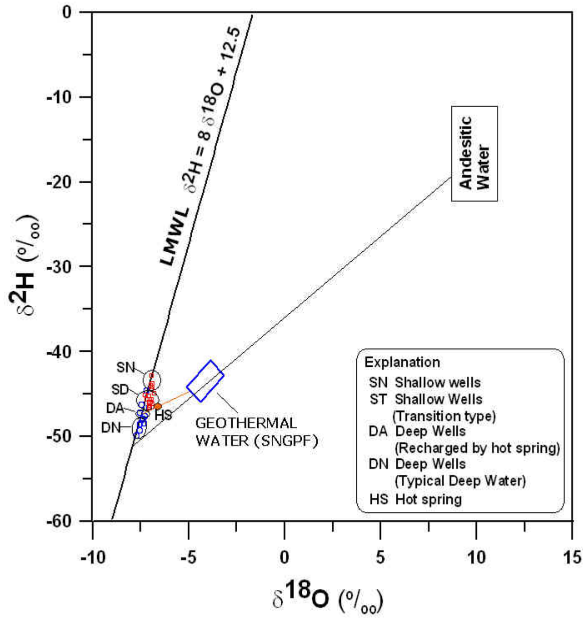

Figure 8. Isotope composition of groundwater relative to geothermal and andesitic waters

The groundwater isotopes also further validate the varying recharge elevations for the different water types, while the regression line generated from the geothermal system to the hot springs indicates hot spring recharge into wells 49 and 54. Wells 53 and 55 appear to be less influenced by the thermal water. Only well 54 and MN well show a distinct dilution from the hot springs. Water sources with less than 20 mg/l chloride are not influenced by the hot spring, but there appears to be a transition type of water in between. This isotope data validates the chemistry data that the wells to the northeast of the project site are tapping water that is composed of mixed hot spring and typical HCO_3 water.

Although it has been established that the recharge elevation of the shallow and deep groundwater is more than 1000 masl, seasonal isotopic variation shows that recharge to the groundwater occurs only during the wet season, which is from June to November. This is clearly shown in **Figure 9**, which plots the average isotopic composition of rainfall from four stations during wet and dry seasons and the average shallow and deep groundwater isotopic values. Hence, local precipitation during the dry months has no influence, if at all, on the shallow and deep groundwater recharge.

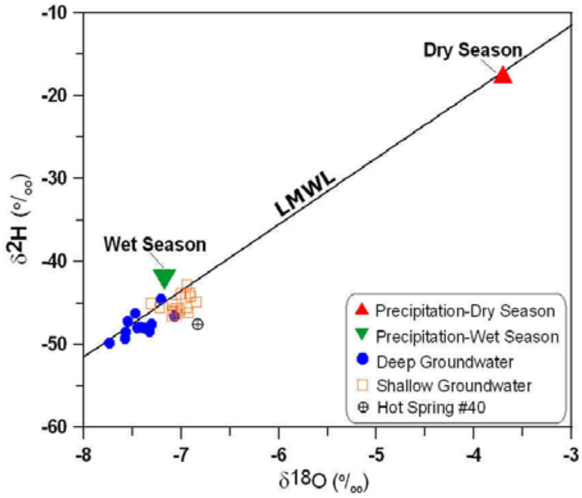

Figure 9. Seasonal variation in rainfall isotope and average groundwater isotope composition

5.3 Groundwater Dating with ^{3}H and CFCs

Available tritium (^{3}H) data from selected shallow and deep groundwater wells, which ranges from 0.8 to 5, does not provide conclusive information on the groundwater mean residence time due to the low level of tritium concentration in Philippine atmosphere.

Complimentary chlorofluorocarbon (CFC) data from selected deep wells, on the other hand, provided a clearer understanding on the relative ages of groundwater and the mixing ratios of relatively young (<50 years) and old (>50 years) water. There appears to be a binary mixing between young water and relatively older water. Well 55 has about 90% of modern water, which suggests that 90% of the water being pumped by the well is less than 50 years old and 10% is more than 50 years old. All the water being extracted by well 47 is older than 50 years, and the other wells are pumping 10-20% of relatively young water. The calculated recharge year of the groundwater against the fraction of modern water in each well denotes that 90% of the water in well 55 is 10 years old and the less than 20% of the water in wells 46, 54 and 56 are 40, 36 and 32 years old, respectively. **Table 4** shows the obtained CFC data.

Table 4 CFC data of selected water sources in Dumaguete City

Water Source	Determined CFC Conc.			Recharge Year			Apparent Ages			Concentration Ratio		
	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113
	(pmol/kg)						Years			Calc. CFC/CFC modern air		
47	0.11	ND	0.01	1961	<1940	<1970	39	>60	>30	0.04	ND	0.04
46	0.29	0.09	0.01	1966	1960	< 1970	34	40	>30	0.12	0.06	0.05
54	0.66	0.13	0.02	1972	1964	1976	28	36	24	0.33	0.11	0.11
56	0.75	0.29	0.05	1972	1968	1979	28	32	21	0.31	0.20	0.23
55	1.58	1.2	0.12	1981	1990	1986	19	10	14	0.67	0.87	0.58
Okoy River	2.24	1.26	0.18	1990	1994	1991	10	6	9	0.99	0.95	0.90

9. CONCLUSIONS

The quality of groundwater in the Dumaguete City aquifer is influenced by the natural recharge of hot springs from the outflow of the geothermal system. Mixing of this hot spring water and meteoric water resulted to three types of groundwater, which are: (1) $Na+K-Cl+SO_4$ waters, (2) $Ca+Mg-HCO_3+CO_3$ waters and (3) $Ca+Mg-Cl+SO_4$ waters. The water in the first group is located 2 to 3 kilometers downstream from hot spring 40. Deep wells 55, 49, 53 and 54 are extracting diluted thermal fluids with relatively elevated Cl, SO_4, Na, K, values, but still within the drinking water standards. The second type is being tapped by wells located south of the study area, which represents the typical deep groundwater. The third type, which is a transition type, is the water in wells located northeast.

Chemical simulation indicated that Okoy River contributes to the deep groundwater aquifer in the area of wells 49, 53, 54 and 55, and significant recharge comes from the hot springs and deep groundwater. Apparently, local precipitation does not seem to contribute to the deep and shallow aquifers. The area within well 46 is recharged only from high elevation and represents the deep groundwater.

The different water types are also distinguished based on their isotopic composition, and hot spring water appears to influence the quality of water in wells 49 and 54, while the wells 53 and 55 are being recharged dominantly by meteoric and river water, respectively, with only minor recharge from the hot spring. The water tapped by well 54 indicates a mixture of rainwater and hot spring water. Calculated recharge elevation for the shallow wells is 1100 masl while that of the deep wells is 1300 masl. Recharge for both aquifers occurs only during the rainy season.

Groundwater dating using CFC provided significant information that further validated isotopic data. Wells in the south in the area of well 46 has older groundwater (>60 years old) than the wells within well 55, which has young groundwater of about 10 years old. There is binary mixing of old water and young water in the wells, where about 20% of the water in well 56 is less than 40 years old while the remaining 80% is older. Deep well 55 appears to be influenced by infiltration from both Okoy and Banica Rivers systems.

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