

Groundwater Recharge in the Southern Amargosa Desert Using Surface-Runoff Chemistry-11489

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ABSTRACT

Accurate estimates of groundwater recharge are necessary components for understanding long-term sustainability of groundwater resources and predictions of groundwater flow rates and flow directions. Amargosa Desert regional groundwater studies show that the surface runoff infiltration occur in the arroyos following runoff producing storms, and this infiltration is considered to be a major source of groundwater recharge. The present study attempts to investigate how water chemistry evolves during the surface runoff and infiltration processes, in the southern Amargosa Desert. In this ongoing study, four surface runoff samplers (SRS) were installed at two different arroyos in the southern Amargosa Desert to capture the surface runoff water. The sampling process included sediment, precipitation, and SRS water samples. In total, four SRS, six sediment, and two precipitation samples were collected between September, 2009 and January, 2010. Analysis of chloride and the stable isotopes of water show substantial overlap of values with underlying groundwater consistent with the concept that infiltration of surface runoff is a major contributor to groundwater recharge in the study area. Groundwater ion concentrations represent a large collection of infiltration events occurring over time, and an exact match with surface runoff samples is unlikely. The SRS design proved its ability to function in arid weather conditions and capture surface-runoff. Further sample collection, statistical analysis, and infiltration modeling will be required to fully describe the evolution of water chemistry between infiltration and old groundwater.

INTRODUCTION

Previous studies of the Amargosa Desert regional groundwater indicate that groundwater recharge occurs from infiltration of stream-flow in the ephemeral arroyos and infiltration of precipitation and runoff on the mountain ranges. Water may infiltrate from melting snowpack in the mountains primarily on volcanic or carbonate rocks or adjacent to the mountains from streams flowing over alluvium (fans and channels) [1]. Groundwater moves through permeable zones under the influence of hydraulic gradients from areas of recharge to areas of discharge in the regional system. Water quality studies of precipitation, surface water, and groundwater isotopic and common ion concentrations, in addition to the computer simulation of the groundwater system in the vicinity of the Amargosa Desert [2, 3, 4, 5, 6, 7, 8, and 9] have concluded recharge water is entering the groundwater system north of Yucca Mountain and have determined that recharges from Fortymile Wash, Oasis Valley, and Amargosa River are a significant source of groundwater.

Groundwater in the southern Amargosa Desert occurs in several interconnected, complex groundwater flow systems. The water moves along relatively shallow and localized flow paths that are superimposed on deeper, regional flow paths [1]. Regional groundwater flow is predominantly through conduits in the carbonate rocks. This flow field is influenced by complex geologic structures created by regional faulting and fracturing that can create conduits or barriers to flow. Infiltration of precipitation and runoff on high mountain ranges is thought to be the largest source of groundwater recharge. Springs and evapotranspiration are the dominant natural groundwater discharge processes [1]. The southern Amargosa Desert includes the major discharge areas of Oasis Valley, Fortymile wash, and Amargosa River, which are Ash Meadows Alkali Flat–Furnace Creek (Franklin Playa). Near Yucca Mountain and in areas immediately to the south, vertical gradients are dominantly upward from the carbonate-rock aquifer into the intermediate system and flow is toward discharge areas to the south and southwest. Groundwater in the southern Amargosa Desert may either flow through fractures in the southeastern end of the Funeral Mountains and discharge in the Furnace Creek area or flow southward and discharge at Alkali Flat [1].

PREVIOUS STUDIES

Winograd and Thordarson [10] described the groundwater in the southern Amargosa Desert as a mixed type, which graded into a (Na+K) HCO₃/mixed type to the west. Claassen [2] divides the water chemistry in the Southern Amargosa Desert into three groups: volcanic, carbonate and mixed ground waters. Claassen [2] found that the north-central part of Amargosa Desert has the lowest values of Na⁺, Ca²⁺, HCO₃⁻ and SO₄²⁻, with ion concentrations increasing sharply to the east and west. This coincides with the presence of highly permeable sands and gravels within the center of the Amargosa Desert. Amargosa Desert has been modeled as a system that is closed to atmospheric CO₂ [2 and 3] because Pco₂ decreases along the flow path. Assuming cooler recharge conditions during Pleistocene time, Claassen [2] used δ¹³C, δ²H and δ¹⁸O to support his hypothesis that water was recharged to the valley fill primarily through runoff infiltration and overland flow from Pleistocene studies of the southern Amargosa Desert [11, 12, and 13] indicate that the mineralogy itself is likely to be a factor in controlling the dominance of K, Mg and Ca minerals, and it appears to be controlled with respect to montmorillonites, illites, feldspars, quartz polymorphs, chlorite, and deposits of sepiolite, dolomite, and calcite. Bish [14] noted that sodium is the dominant alkaline exchangeable cation in the shallow smectites, whereas deeper smectites contain subequal Na⁺, K⁺ and Ca²⁺.

White [15] found that evapotranspiration causes Total Dissolved Solids (TDS) increase, calcium increases due to CaCO₃ input from carbonate rocks, and potassium and fluoride. White [15] also found that in water containing moderate amounts of Mg²⁺, the principal alteration product is montmorillonite, Mg²⁺ is deficient, but Na⁺ and K⁺ were present, zeolites such as clinoptilolite, mordenite, analcime and chabasite would form.

Winograd and Thordarson [10] first suggested the flow path from Pahute Mesa to Oasis Valley to Amargosa Desert, and this path shows an increase of K-montmorillonite, K-feldspar and Ca-montmorillonite precipitation along the flow paths. They explained this by either the thermodynamics of the system being most conducive for K⁺ and Ca²⁺ ion exchange within the montmorillonites, or an increase in Ca²⁺ to the system through weathering of carbonate detritus or inflow from a carbonate aquifer. For the area of Oasis Valley and Amargosa Desert, both of these are likely to be factors in controlling the dominance of K and Ca minerals.

Potentiometric heads and hydrochemical data indicate that the Alkali Flat (also known as the Franklin Lake Playa), located in the southern end of the Amargosa Desert is a major discharge area for the alluvial aquifer system. Estimated discharge at Alkali Flat is about 10,000 acre-feet per year [16]. Discharge at the playa occurs primarily through evapotranspiration, the principal component of which is bare-soil evaporation [16]. Some groundwater may flow beneath the mountain at the south end of the playa and continue southward [16]. Regional water table maps of the alluvial aquifer [16] also suggest that a portion of the flow in the alluvial aquifer may be moving southwest through the abutting carbonate rocks of the Funeral Mountains, and discharging into Death Valley.

This study explores the relationship between rainfall-runoff and groundwater chemistry, during a flood event in the southern Amargosa Desert Region, Nevada, and presents an evidence of runoff chemical signature on the infiltration and groundwater recharge.

DESCRIPTION OF THE STUDY AREA

The Amargosa Desert (Figure 1a) is located in the southern portion of Nye County in south central Nevada, within the Great Basin, and is part of the Death Valley groundwater basin. The Funeral Mountains separate the Amargosa Desert from Death Valley to the southwest, and a series of mountain ranges bound the north and east extents of the desert. The Amargosa River is a major drainage component (over 8,047 km²) of the unique closed-basin, hydrologic regime known as the Great Basin. This river system begins in the Oasis Valley, turns southeast to run through the Amargosa Desert, continues until it turns northwest, and terminates in Death Valley from its southeast extension. As a result of a dry, semi-arid, continental climate, the Amargosa River and its tributaries are ephemeral streams that are dry most of the time except in a few relatively short reaches where discharging springs maintain small, perennial base flows. Fortymile Wash and Beatty Wash (in addition to the Washes in Crater Flat and Rock Valley) are the major tributaries of the upper Amargosa River, which drains through several small, populated areas downstream (Figure 1a).

Ash Meadows and Franklin Playa (Figure 1b) basins are portions of Amargosa Desert, and located in the central and southern part of the Amargosa Desert respectively. Almost all the underground flow of the Amargosa River drainage through Amargosa Valley is thought to evaporate at Franklin Lake Playa at the south end of the valley, ending at Eagle Mountain.

The Amargosa River channel cuts through this area of obvious evaporation, and carries runoff from large or localized storm events out of the valley [17]. Franklin Lake playa is one of the principal discharge areas of the Furnace Creek Ranch-Alkali Flat ground-water-flow system in southern Nevada and adjacent California (Figure 1b).

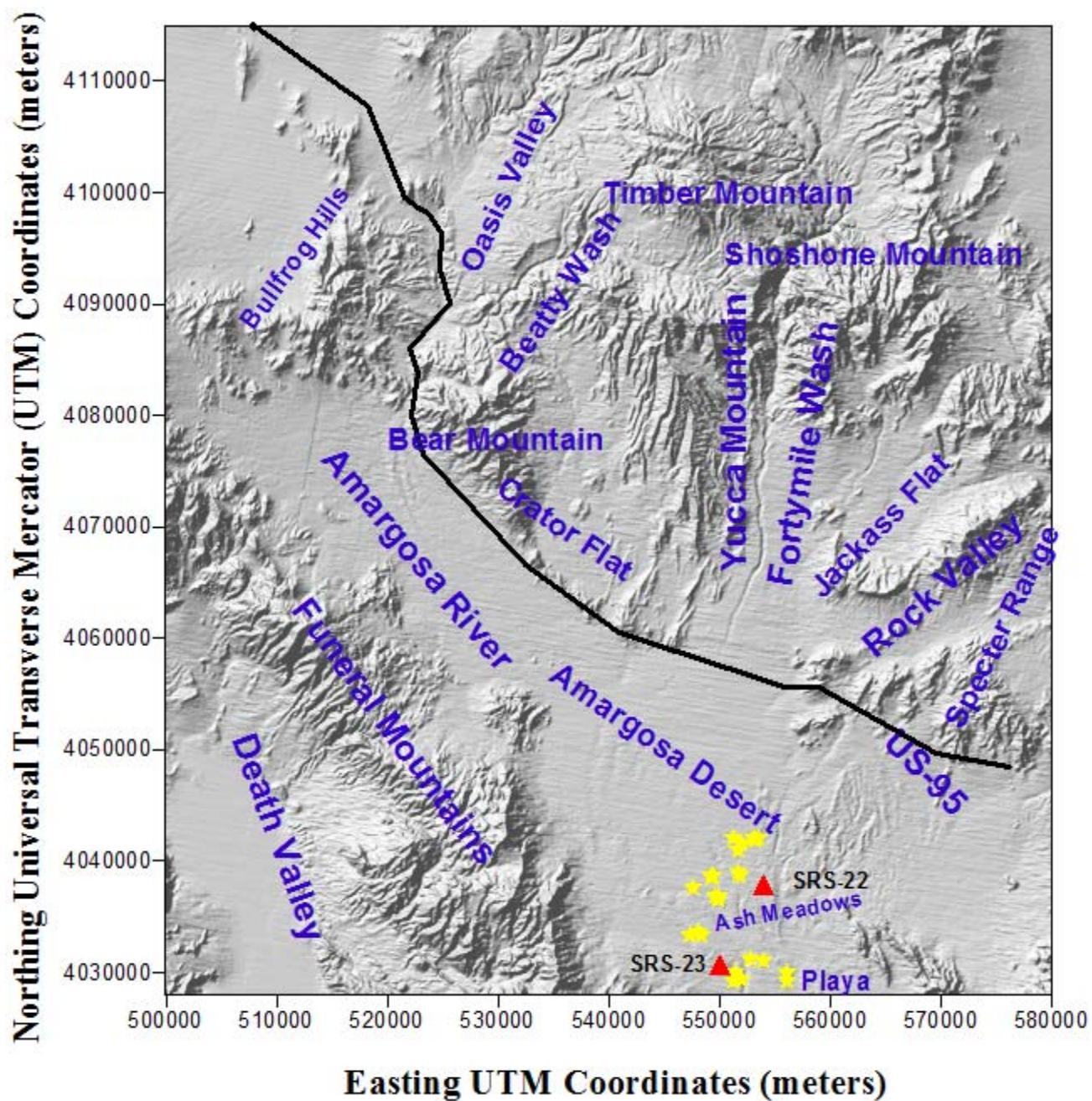


Fig. 1a. DEM map for the study area showing locations of Amargosa Desert Region, Amargosa River, Ash Meadows, and Franklin Playa, NV. Red triangles represent site SRS-22 and SRS-23, and the yellow stars represent the selected groundwater wells around the site locations.

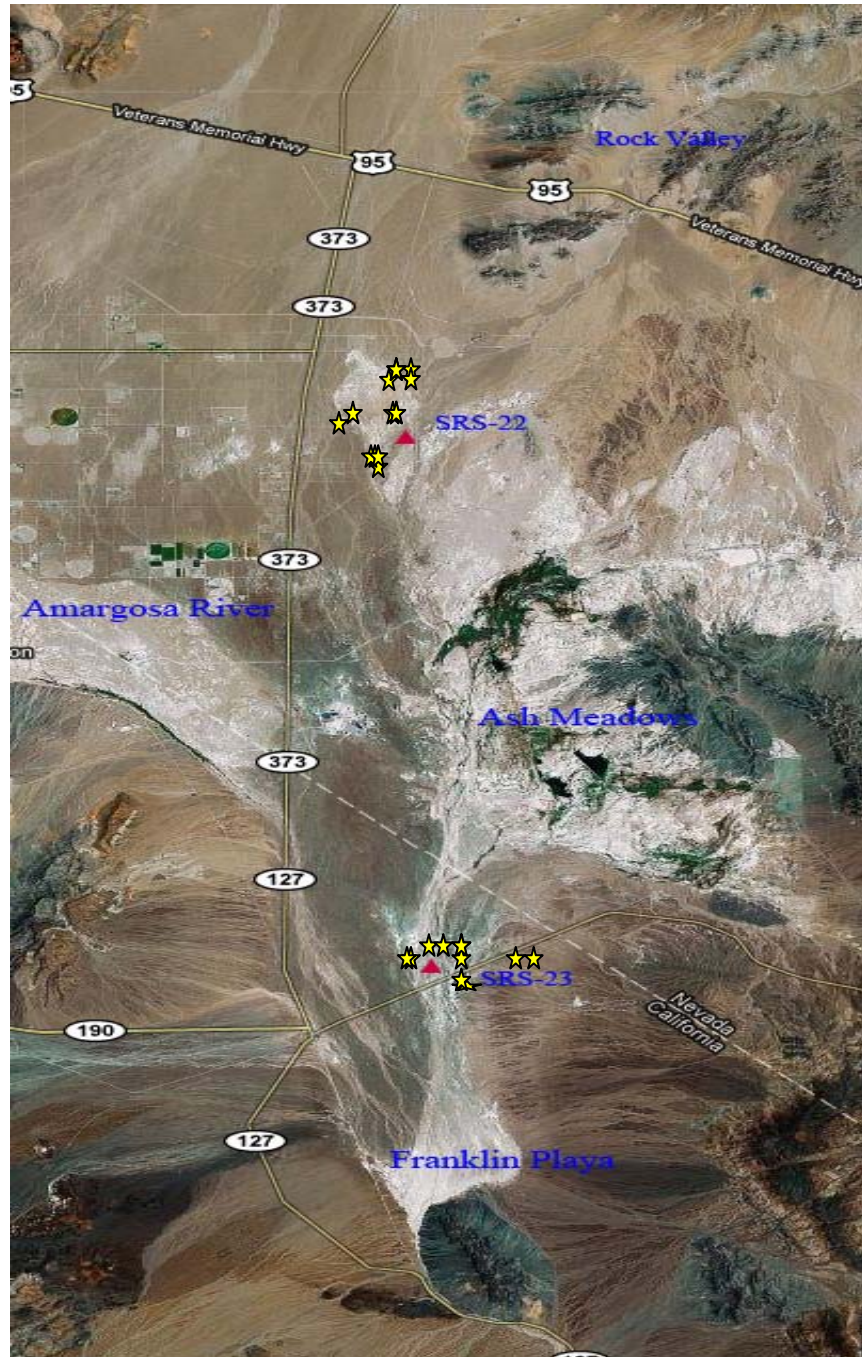


Fig. 1b. Google earth map of the study area. Red triangles represent site SRS-22 and SRS-23, and the yellow stars represent the selected groundwater wells around the site locations

The present climate in the Amargosa Desert region is arid to semiarid, with average annual precipitation ranging from less than 130 millimeters (mm) at lower elevations to more than 280 mm at higher elevations [18]. Precipitation associated with a weather disturbance moving eastward from California has caused the most extensive regional runoff in Fortymile Wash and Amargosa River in February 1969 [19].

METHODS

Research included site selection, SRS design construction and field emplacement, and sample analysis criteria as described in a previous paper [20] in detail. This paper will be focused on the chemical analysis results.

Four SRS have been installed at two different arroyos in the southern Amargosa Desert to capture runoff water believed to be an important source of groundwater recharge in the area. The first site is SRS-22, located in a tributary of Rock Valley Wash (lower reaches) 0.13 miles east of Mecca Road; the second site is SRS-23, located in the upper Mud and Alkali Flat, 0.36 miles up-gradient from Ash Meadows road. Each location includes two SRSs, one filled with washed silica sand (WSB), and the other filled by natural alluvium (NAB) from the same site. The samples collected from these sites included sediment, precipitation, and SRS. Sediment samples were collected from each site at the time of the SRS installation, and also shortly after two storm events, one occurring in September 2009 and the other occurring in January 2010; following these storms, SRS samples were collected from the WSBs at each location,. Additionally, after the January 2010 precipitation event, samples were collected from rain gauges at each site along with a NAB runoff sample from site SRS-23. In total, four SRS-WSB, one SRS-NAB, six sediment, and two precipitation samples were collected during September, 2009 and January, 2010.

Groundwater chemistry data for 25 groundwater wells around SRSs were obtained from Nye County Nuclear Waste Repository Project Office (NWRPO) [21] and Los Alamos National Laboratory [22] and compiled into a single database. The chemical data includes Cl, SO₄, total alkalinity, Na, Ca, K, Mg, TDS, F, Si, δ²H, and δ¹⁸O.

RESULTS AND DISCUSSION:

Table 1 below shows the measured amount of water accumulated in the rain gauges and SRS from WSBs, and NABs from sampling locations after two storm events that occurred in the study area in September 2009, and January 2010.

Table I. The Measured Amount of water accumulated in the rain gauges, and SRS from WSBs, and NABs after two storm events that occurred in September 2009, and January 2010.

Location	Collection Date	Cumulative rain gauges precipitation (mm)	Amount of accumulated water in WSB (Liter)	Amount of accumulated water in NAB (Liter)
SRS-22	9/24/2009	0	0.10	0
SRS-23	9/24/2009	0	0.10	0
SRS-22	1/26/2010	47	1.90	0
SRS-23	1/26/2010	34.3	3.11	3.10

In September 2009, the rain gauges were empty (dried by evaporation), but two 100 ml samples were collected from WSBs; the NABs did not yield any samples. In January 2010, the rain gauge in SRS-22 measured 47 mm of rain water, and 1900 ml of water accumulated in the SRS-22 WSB, whereas the NAB yielded no water. In the same time, the rain gauge in SRS-23 measured

34.3 mm of rain water, 3110 ml of water accumulated in the WSB, and 3100 ml of water accumulated in the NAB. At the time of sampling, type of sediment and thickness of the sediment layer above each bucket indicated the presence of surface water runoff in the study area. The rain gauges are simple (low cost) collectors that are open to the atmosphere. Rain gauge readings and chemistry were subject to unknown amounts of evaporation prior to collection so the readings should not be equated with precipitation amount or initial chemistry. The rain gauges included both wet-fall and dry-fall since the last time they were emptied.

Box plots (Figures 2-13) below show the major ion concentrations in addition to TDS, $\delta^2\text{H}$, and $\delta^{18}\text{O}$ comparison between the SRS, precipitation, sediment, and selected groundwater wells in the study area.

Figure 2, shows significant evaporative concentration occurs between precipitation and groundwater (by a magnitude of three). Chloride is a conservative ion and thus tracks evaporative concentration of waters. Also, Chloride is highly soluble and has few geologic sources, making it an excellent tracer of evaporative concentration. Concentrations of chloride are approximately similar in the SRS and groundwater, even when the data shows that the groundwater has higher salinity (TDS). The chloride trend can be described as groundwater \approx SRS \approx sediment \approx precipitation. This is consistent with the hypothesis that infiltration of surface runoff from storms has been a dominant source of groundwater in this area.

Figure 3, shows the box plots of alkalinity for each group, alkalinity increases greatly between precipitation and sediment, decreases slightly between sediment and SRS, and then increases slightly when going from SRS to groundwater. The alkalinity trend can be described as groundwater \approx sediment $>$ SRS $>$ precipitation. This may be caused by precipitation and dissolution equilibrium of calcium carbonate, carbonate rocks, and from silicate mineral weathering reactions which increase both sodium and alkalinity, and this matches with White [15]. The H_2CO_3 contributes H^+ , which attacks silicate minerals resulting in the release of cations (M^+) and the formation of bicarbonate by the reaction:

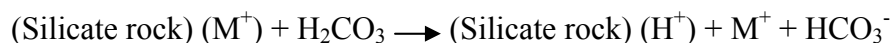


Figure 4, shows the box plots of TDS for the different groups, with TDS increasing between precipitation and sediment, decreasing between sediment and SRS, and then again increasing between SRS and groundwater. The TDS trend can be described as groundwater $>$ sediment \approx SRS $>$ precipitation.

Figure 5, shows the box plots of sulfate concentrations for the different categories. Sulfate increases between precipitation, sediment, SRS, and groundwater, can be described as groundwater $>$ SRS \approx sediment $>$ precipitation. The increase in sulfate moving from surface runoff to groundwater may be due to longer flow paths in the southern Amargosa Desert which allow more water/rock interaction and hydrothermal alteration of older volcanic rocks, i.e. secondary mineralization believed to have formed under closed conditions.

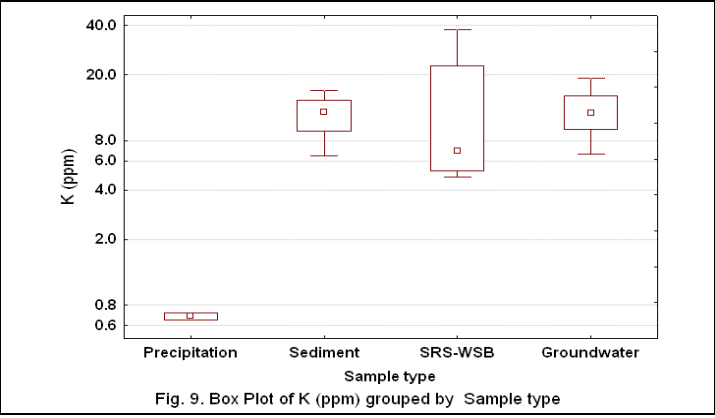
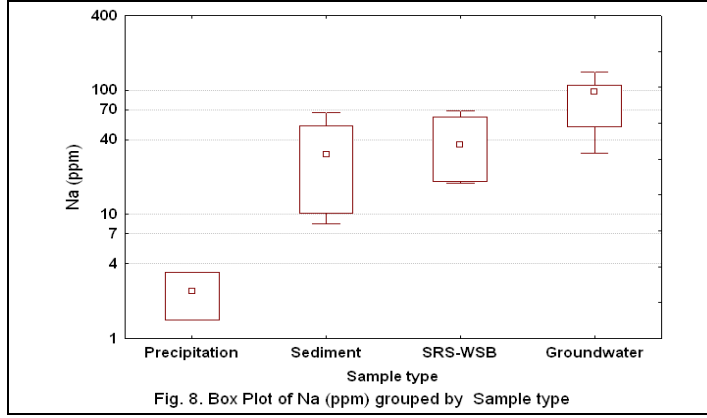
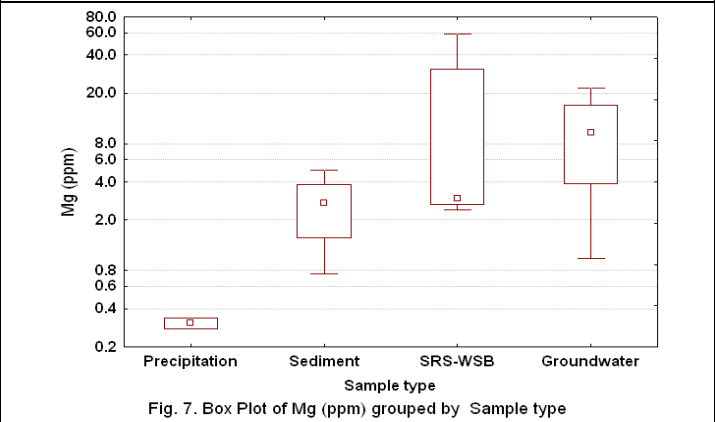
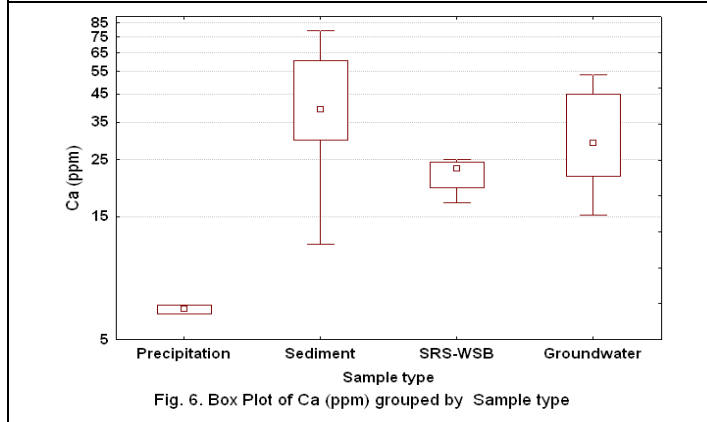
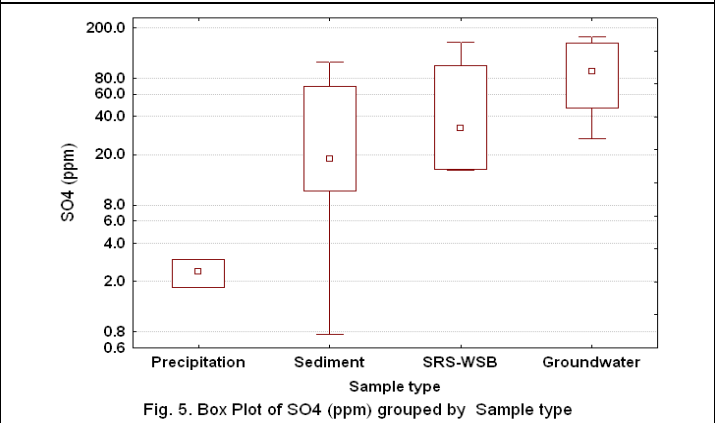
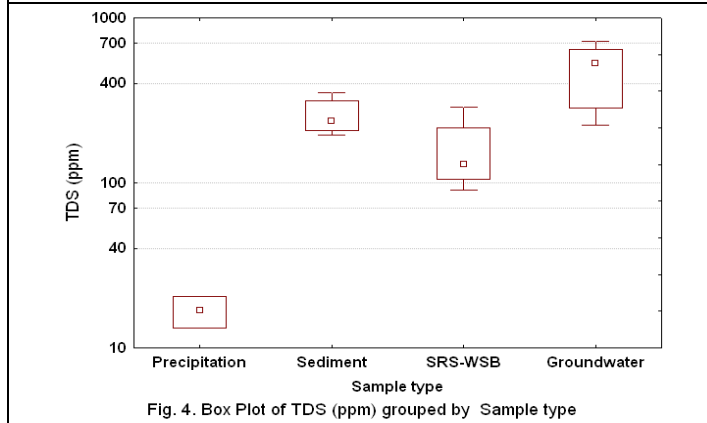
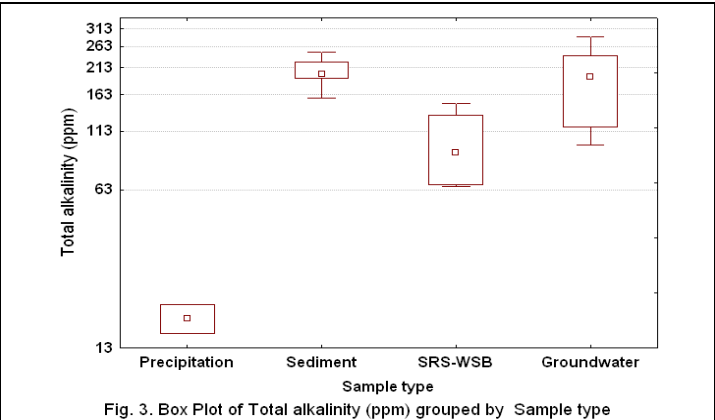
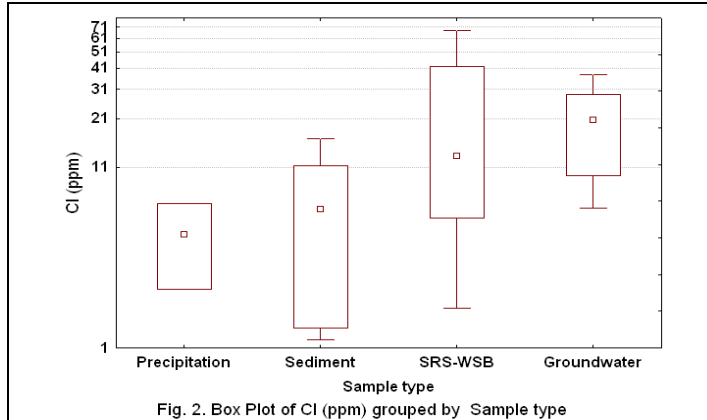


Figure 6, shows the box plots of calcium concentrations in each group, with calcium increasing between precipitation and sediment, and then decreasing between sediment, groundwater, and SRS. The calcium trend can be described as sediment \approx groundwater \approx SRS > precipitation. Weathering causes enrichment of calcium concentrations, in the form of CaCO_3 originally derived from carbonate rocks along the flow paths.

Figure 7, shows the box plots of magnesium in the different categories, with the trend being described as groundwater \approx SRS \approx sediment > precipitation. Increasing of magnesium in the groundwater may be caused by the $(\text{Ca}+\text{Mg}) \text{HCO}_3$ carbonate aquifer.

Figure 8, shows the box plots of sodium concentrations in the different categories. Sodium appears to concentrate by evaporation and increase in amount between precipitation, sediment, SRS, and groundwater. Unlike chloride, sodium increases when moving from the SRS to groundwater group. The sodium trend can be described as groundwater > SRS \approx sediment > precipitation. Most of the alkalinity in the area's groundwater is non-carbonate $(\text{Na}+\text{K}) \text{HCO}_3$, derived from weathering of silicate rocks rather than dissolution of carbonate rocks, and would account for this increase in sodium. Sodium also may originate as a result of ion exchange with calcium in infiltrating water.

Figure 9, shows the box plots of potassium concentration in the different categories, with potassium increasing greatly between the precipitation and sediment group, decreasing slightly between sediment and SRS groups, and then again increasing slightly from the SRS to groundwater group. The potassium trend can be described as groundwater \approx sediment \approx SRS > precipitation.

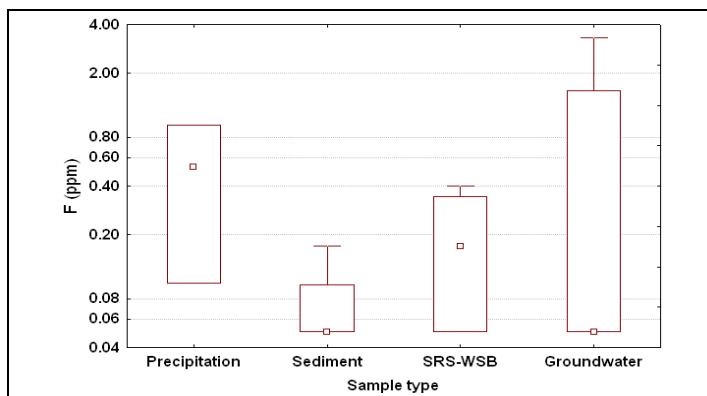


Fig. 10. Box Plot of F (ppm) grouped by Sample type

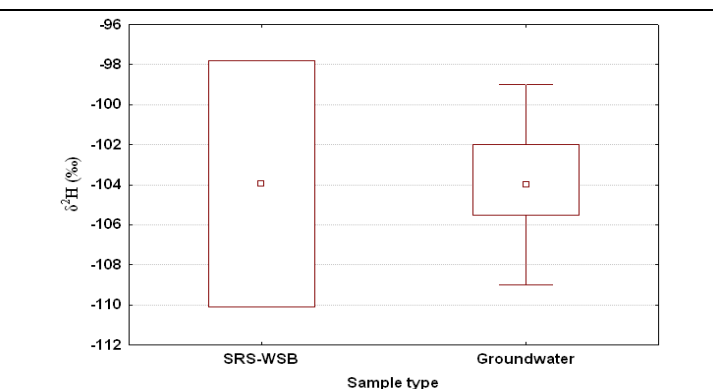


Fig. 11. Box plot of $\delta^2\text{H}$ grouped by sample size

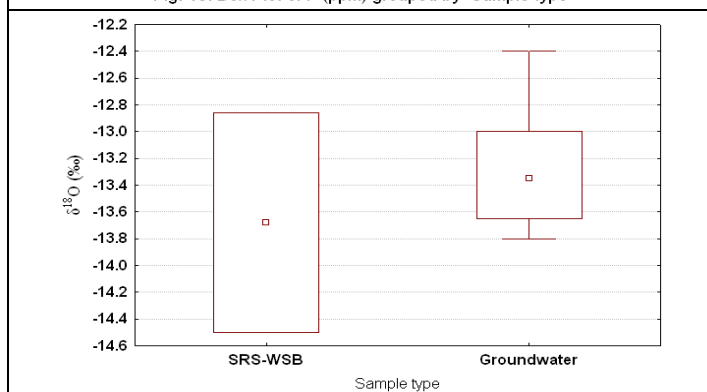


Fig. 12. Box plot of $\delta^{18}\text{O}$ grouped by sample size

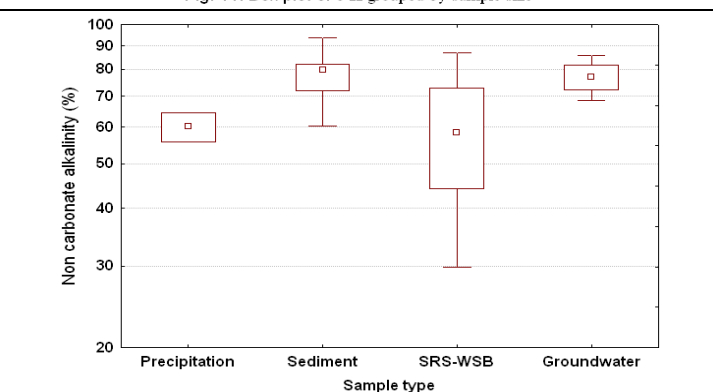


Fig. 13. Box Plot of Non carbonate alkalinity (%) grouped by Sample type

Figure 10, shows the box plots of fluoride in the different categories. The fluoride trend can be described as precipitation > SRS \approx sediment \approx groundwater.

Figures 11 and 12, show the box plots of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ in the SRS and groundwater respectively; $\delta^2\text{H}$ is similar in the SRS and groundwater; $\delta^{18}\text{O}$ is slightly increased between SRS and groundwater. Once below the evaporation zone, recharging ground waters generally do not undergo phase changes. Therefore, oxygen and hydrogen isotopes do not experience further fractionation and may be considered to be conservative in the flow system. Exceptions to this may occur during diagenetic mineral formation or where exchange with calcite may cause a shift towards heavier $\delta^{18}\text{O}$ values [23], and this explained the slightly increased of $\delta^{18}\text{O}$ between SRS and groundwater. The $\delta^2\text{H}$ and $\delta^{18}\text{O}$ results indicate that water runoff is a major source of groundwater recharge in the study area.

Figure 13, shows the box plots of non carbonate alkalinity for the different groups, non carbonate alkalinity is approximately the same in the precipitation and SRS and increases slightly in the sediment and groundwater. The non carbonate alkalinity trend can be described as groundwater \approx sediment > SRS \approx precipitation. The non carbonate alkalinity forms 80%, and 60% from total alkalinity in the groundwater/sediment, and precipitation/SRS, respectively. Increasing of non carbonate alkalinity in the groundwater may be caused by the Na/HCO₃ aquifer.

CONCLUSIONS

Because the degree of evaporation is unknown the changes in chemistry between precipitation and SRS samples is best viewed in terms of the changes in chemical signature rather than in terms of individual concentrations. In non runoff producing storms the water has time to react with soil minerals prior to evaporation. When near complete evaporation of the water occurs the isotopic signature of the water will be lost, but any dissolved ions (and dry-fall) will remain in the shallow soil and sediments. When surface runoff occurs the new precipitation mixes with shallow soil moisture and dissolves some of the precipitated salts in the desiccated soil. The soil samples represent a leaching of the shallow sediment in the stream bottom, but the most soluble salts in these samples (e.g., chloride) may have been leached by a runoff event prior to sampling. The soil leaching process also provided less contact time between soil and water than the infiltration process.

Chloride and the stable isotopes of water show substantial overlap of values with underlying groundwater, consistent with the concept that infiltration of surface runoff is a major contributor to groundwater recharge in the study area. Groundwater concentrations represent a larger collage of infiltration events than have been collected in the surface runoff sampling making an exact match unlikely.

With the exception of fluoride, all other analytes are higher in groundwater than the SRS samples. This is consistent with dissolution and weathering of minerals during and subsequent to the infiltration process, but not with large amounts of additional evaporation prior to deep infiltration. The influence of transpiration on the chemistry of infiltrating water is more complicated than that of evaporation given that chloride uptake differs between plants; leading to a combination of evaporative concentration at depth and transport to the surface with eventual recycling in leaves and dead plant materials.

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