Title
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Author
Washington, Lauren

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Lauren Washington

Center for Marine Biodiversity and Conservation
Scripps Institution of Oceanography

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Abstract

Fire is an important disturbance mechanism in southern California’s scrubland and forest ecosystems. However, humans have altered natural fire regimes. The frequency and intensity of fires has been increasing over the last 20 years, and this trend is expected to continue increasing as a result of climate change. Recent studies have found an increase in heavy metal concentrations from the burning of organic material following wildfires. High concentrations of heavy metals can cause severe health problems in humans. Sediment samples were taken before, during and after the rainy season from thirty sites in three watersheds throughout San Diego County. Samples were analyzed for heavy metal concentrations to measure a possible wildfire signature. No wildfire signature was found three years after the most recent wildfire. As a result, sampling should ideally begin immediately following a wildfire.

The second part of this study conducted a study which measured southern California resident’s knowledge on the long term effects of wildfires such as heavy metal contamination. Respondents were aware of the recent increase of wildfires and the expected continuing trend. Respondents were also aware of the possible release of contaminants into the environment from the burning of home material. However, respondents were unaware of the possible release of contaminants from the burning of organic material. Residents should be educated on this issue especially residents in remote locations where the probability of a wildfire occurring is high.

Introduction

Fire is a natural and important disturbance mechanism in southern California's scrubland and forest ecosystems (Stein and Brown 2009). However, human activities, such as fire suppression and increased anthropogenic ignitions, have altered natural fire regimes (Syphard et al. 2005). Due to changes in climate, the frequency, intensity and duration of wildfire seasons are expected to continue increasing (Westerling et al. 2006). A growing population will also lessen the interface between humans and wildlands increasing conflicts between humans and wildfires.

Wildfires not only cause physical damage to an area, but also cause the release of metals into the environment by the burning of organic material (Yamasoe et al. 2000). The release of these metals can adversely affect water quality in streams, lakes and reservoirs. After a wildfire, increases in sediment runoff have been linked with increases in metals (Stein and Brown 2009). Runoff can affect waters downstream of burned areas all the way to the coastline. This can be extremely harmful since watersheds affected by wildfires in southern California frequently drain into waterbodies that support sensitive resources or which have been designated as impaired under Section 303(d) of the Clean Water Act (Stein and Brown 2009).

Heavy metals are naturally found in the environment. As trace elements, some heavy metals (e.g. copper and zinc) are essential to maintaining the metabolism of many organisms, including humans. However, high levels of heavy metals can lead to poisoning as well as other serious health issues. This poisoning is caused by the bioaccumulation of metals in tissue over time through exposure of heavy metals.

Most studies on wildfires and heavy metals have sampled ash fallout generated by a fire (Plumlee et al. 2007, Sabin et al. 2005, Gerla and Galloway 1998). The release of metals from organic material and its effects on water quality during a wildfire are poorly understood. It is also unknown how long this metal signature can be seen in the sediment and soil as well as which metals are shown in the signature.

Wildfires in San Diego

In 2003, the Cedar Fire began about 25 miles east of San Diego in the Cleveland National Forest (The City of San Diego 2010). By the time the fire was extinguished, it was the largest wildfire in California history burning 280,278 acres (The City of San Diego 2010). A few years later, in 2007, the Witch Creek Fire burned 197,990 acres in San Diego County (CAL FIRE 2007).

San Diego's watersheds provide important beneficial uses for human communities as well as plant and animal life. Therefore, it is important to understand how these wildfires may affect water quality, but also sediment and soil quality.

Burned Watersheds in San Diego County

The San Luis Rey Watershed is located in northern San Diego County. The watershed is approximately 562 square miles and is the third largest watershed in the County (Project Clean Water 2007). The cities of Oceanside and communities of Fallbrook, Bonsall and Valley Center are located in this area (Project Clean Water 2007). Almost half (49%) of the watershed is privately owned while 37% is publicly owned and 14% are Tribal Indian Reservations (Project Clean Water 2007). A majority of the watershed is undeveloped open spaces and parks (68%) (San Diego Coastkeeper 2010). The developed areas include: residential (14%), commercial (3.4%), industry (0.3%) and agriculture (13%) (San Diego Coastkeeper 2010). For this study, the San Luis Rey Watershed will act a "control" for an area of a watershed less exposed to a wildfire during the 2003 and 2007 wildfires.

The San Dieguito Watershed is approximately 346 square miles located in west-central San Diego County (Project Clean Water 2007). It includes the cities of Del Mar, Escondido, Poway, San Diego and Solana Beach (Project Clean Water 2007). The current population of this watershed is 125,000 and is expected to rapidly increase since a majority of the open space is available for development (Project Clean Water 2007). The majority of this watershed is undeveloped open spaces and parks (60%) while the rest is used for residential (19%), commercial (5.5%), industry (0.4%) and agriculture (13%) (San Diego Coastkeeper 2010). Lake Hodges, Lake Sutherland and Lake Poway are three of the five water storage reservoirs for the watershed (Project Clean Water 2007). The majority of the watershed was burned in the 2007 Witch Creek Fire, and a very small percentage was burned in the 2003 Cedar Fire.

The San Diego Watershed is approximately 440 square miles and is the second largest hydrologic unit in San Diego County (Project Clean Water 2007). This watershed also contains the largest population (~450,000) of the County's watersheds which include the major cities of San Diego, La Mesa, El Cajon, Poway and Santee (Project Clean Water 2007). A majority of the San Diego watershed is undeveloped (58.4%) land in the upper, eastern portion of the watershed (Project Clean Water 2007) while the lower area is highly urbanized with residential (14%), commercial (7.9%) and industry (0.7%) (San Diego Coastkeeper 2010). The watershed includes significantly less agriculture (1.2%) than the other two watersheds (San Dieguito and San Luis Rey Watersheds) in this study

(San Diego Coastkeeper 2010). There are five reservoirs in this watershed (El Capitan, San Vicente, Lake Jennings, Lake Murray and Cuyamaca) which supply water to up to 760,000 residents in San Diego County (Project Clean Water). A majority of the watershed (70%) was burned in the 2003 Cedar Fire (The San Diego Wildfires Education Project 2004), mostly in the eastern portion. This watershed was burned again in the area around the El Capitan Reservoir in the 2007 Witch Creek Fire.

Goals of Study

The aim of this study is to identify a possible wildfire metal signature in sediment from burned watersheds as well as identify what metals are shown dominant in the signature. The San Diego and San Dieguito watershed were used for this study because a majority of each watershed was burned in 2003 or 2007. Each watershed (excluding the San Luis Rey watershed which is acting as the "control") included sample sites from the upper (burned) portion of the watershed down to the lower (coastal, unburned) portion of the watershed. This was to test the possibility that metals released by wildfires are carried away from the wildfire area, overtime, by run-off and metals end up in unburned areas to act as contaminants from the wildfire.

Methods

Study Area Sites

Samples were collected from streams in order to identify metals that are transported down the watershed though the aquatic system. There were three watersheds sampled in San Diego County: the San Diego Watershed (with sample sites unburned, burned in 2007, and twice burned in 2007 and 2003), the San Dieguito Watershed (with sample sites unburned and burned in 2007), and the San Luis Rey Watershed (with no sample sites burned in 2003 or 2007). All sites were complied in ArcGIS Desktop Version 9.3 (ESRI 2008) on The University of California, San Diego campus using U.S. Federal Government GIS wildfire files (MTBS 2010) (Figure 1).

The unburned sites in the San Dieguito and San Diego watersheds were sampled to test for the metal signature from both wildfires in each watershed downstream from the burned area. The unburned sites in the San Luis Rey watershed are used as control sites for the study. Even though the upper portion of this watershed was burned in 2007, it was chosen as the “control” since all watersheds in San Diego County were burned in 2007 or 2003 and there was no option for a perfect control in this study. Additionally, a small portion of the San Luis Rey watershed was burned compared to the San Diego and San Dieguito watersheds where a strong majority of the watershed was burned. The sites sampled in the San Luis Rey watershed were close to the coastline.

Sample Collection

If possible, samples were collected in water. Only the upper 2cm of sediment from the streambed was collected. There were three replicates taken at each sample site independently of each other. All replicates were taken in a $1m^2$ portion of the riverbed. Sediment samples were taken within eight days of each other to avoid any weather influence on data. Sediment samples were collected three times throughout the year: before, during and after the rainy season. This was to measure the metals concentration during times when sediment should be moving down the watershed due to the rains. There were a total of 270 samples taken for this study.

Samples were collected in polyethylene vials and closed tightly for transportation. After a day of sample collection, sediment was brought to the lab at Scripps Institution of Oceanography.

Locations of sample sites were recorded on site using the Garmin eTrex Legend HCx Personal Navigator Global Positioning System (GPS), and mapped on ArcGIS Desktop Version 9.3 (ESRI 2008) at the UCSD GIS lab.

Sample Processes

Sediment samples were oven dried at 60˚C for up to 2 months after collection. When sediment was dry, samples were homogenized using a hand grinder. The hand grinder was placed in nitric acid 1% and deionized water after each sample that was homogenized to avoid contamination of samples. All manipulations were conducted to avoid metals contamination, using acid washed vials and supplies that were soaked for 3 days in nitric acid 1% and deionized water. After 3 days, the vials were rinsed with deionized water and left to dry. After they were completely dry, they were used to contain 0.1g of sediment as measured using a Sartorius CP225D digital microscale.

Metals were extracted from sediment by adding 3.5mL of 1M HCl, as measured in weight units using the Sartorius microscale. Samples were then placed on a mechanical shaker for 24 hours. Tubes were then taken off the shaker to allow sediment to settle on the bottom overnight. The acid solution (thus containing the extracted metals) was then transferred to another tube for the sample to be measured for metals concentration.

Sediment samples were analyzed for 15 heavy metals simultaneously (Ag, Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Se, Sr, Ti, V and Zn), in order to provide a metals signature. Metals were measured by inductively coupled plasma optical emission spectrometry

(ICP-OES), using a PerkinElmer 3700 Optical Emission Plasma Spectrometer (with AS90 Autosampler), available at the SIO Analytical Facility.

After metal concentrations were measured, data was processed in Microsoft Excel to calculate the mean for each metal using the three replicates as well as to calculate standard deviation. At this stage of the analysis, data were not processed yet for statistical significance considering that analysis of some samples is still on-going.

Survey

A survey comprised of 25 questions (Appendix I) was constructed on the website surveymonkey.com. The goal is this survey was to measure southern California resident's knowledge on the long-term effects of wildfires, such as possible heavy metal contamination. The survey was posted online for 40 days. These questions asked for information about the respondent and their knowledge of wildfires and environmental impacts associated with wildfires. All respondents were current residents of southern California and completely anonymous.

Results

Sediment Samples

Aluminum, iron and manganese had the highest concentrations in all three watersheds when compared to other metals in the same watershed (Figure 2-4). The upper watershed sites contained the highest concentrations of aluminum and manganese (Figure 2). The San Dieguito watershed contained the highest concentrations of aluminum, iron and manganese in the coastal sites (Figure 1). For the San Diego watershed, the inland sites contained the highest concentrations of aluminum and manganese (Figure 4). Overall, the San Dieguito watershed contained the highest concentrations of aluminum, iron and manganese (Figure 2-4).

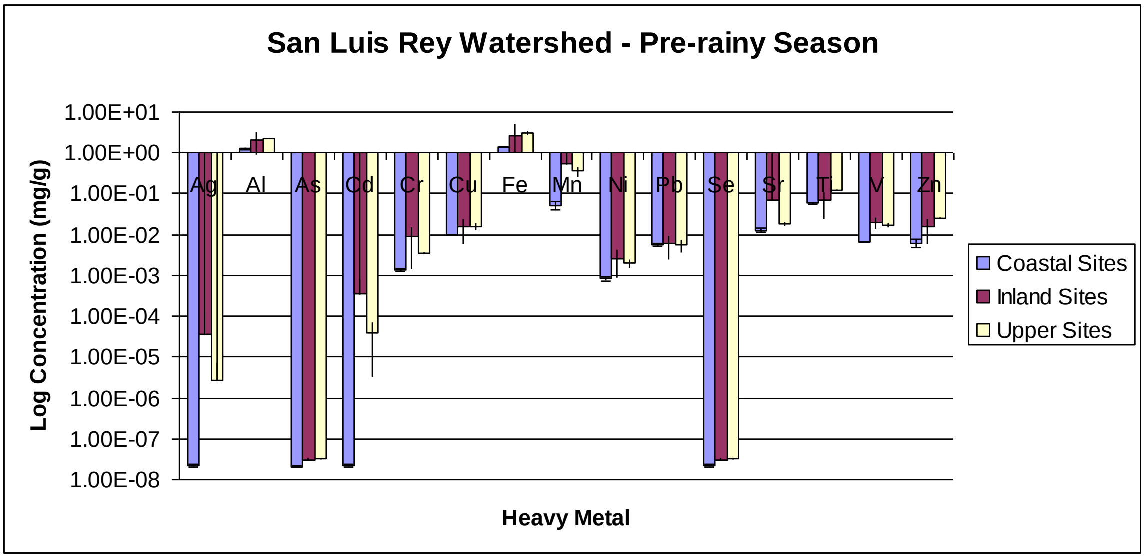

Figure 2: San Luis Rey Watershed – Pre-rainy season metal concentrations (mean ± SD)

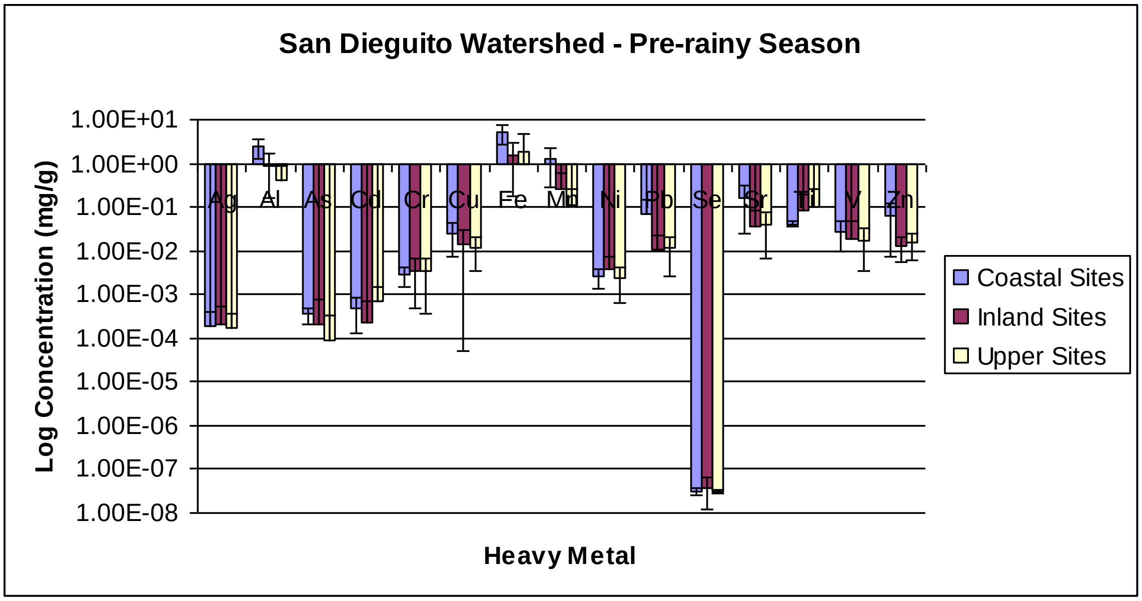

Figure 3: San Dieguito Watershed – Pre-rainy season metal concentrations (mean ± SD)

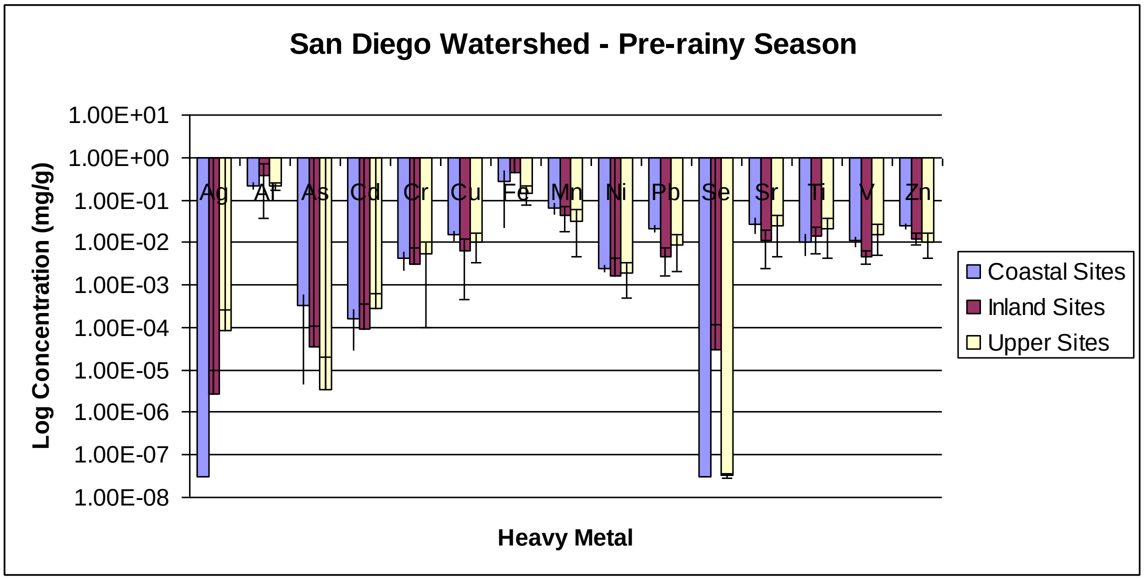

Figure 4: San Diego Watershed – Pre-rainy season metal concentrations (mean ± SD)

A. Burned vs Unburned – Pre-rainy season samples

Aluminum showed a distinct difference between burned and unburned areas for pre-rainy season samples. The unburned control sites (San Luis Rey) contained more aluminum than the unburned non-control sites (San Dieguito and San Diego watersheds), and both contained more aluminum than all burned areas (Figure 5). The more recently burned 2007 sites had a higher aluminum concentration than the less recently burned 2003 sites (Figure 5). However, the burned twice (2003 and 2007) sites contained the least amount of aluminum (Figure 5).

Copper also showed a difference between burned and unburned areas though it was less pronounced (Figure 6). Unburned non-control and unburned control sites had greater concentrations of copper than all burned sites (Figure 6). However, the unburned non-control sites were slightly higher than the unburned control sites (Figure 6). The more recently burned 2007 sites contained the highest concentration of aluminum among the burned areas followed by the twice burned sites and then the 2003 burned sites (Figure 6).

Cadmium and nickel had distinct differences between burned and unburned areas. Cadmium and nickel both had the highest concentrations in the 2007 burned sites (Figures 7 and 8). The twice burned, unburned non-control and unburned control sites all contained about the same amount of nickel (Figure 7) while cadmium slowly decreased from twice burned to unburned non-control and then unburned control sites (Figure 7). For both cadmium and nickel, the lowest concentration was in the 2003 burned sites (Figures 7 and 8). Cadmium also had its lowest concentration in the unburned control sites (Figure 7).

Lead had differences between burned and unburned sites with clearly less variation. There were visually large differences between the unburned non-control sites and the other sites which contain similar concentrations (Figure 9). The more recently burned 2007 and twice burned sites are similar in the concentration of lead while the burned 2003 and unburned control sites are visually equal and have the least amount of lead (Figure 9).

The unburned non-control sites visually contain a significantly greater amount of zinc than the other sites (Figure 10). The more recently burned 2007 and unburned control sites contain a similar amount of zinc greater than the similarly concentrated 2003 burned and twice burned sites (Figure 10).

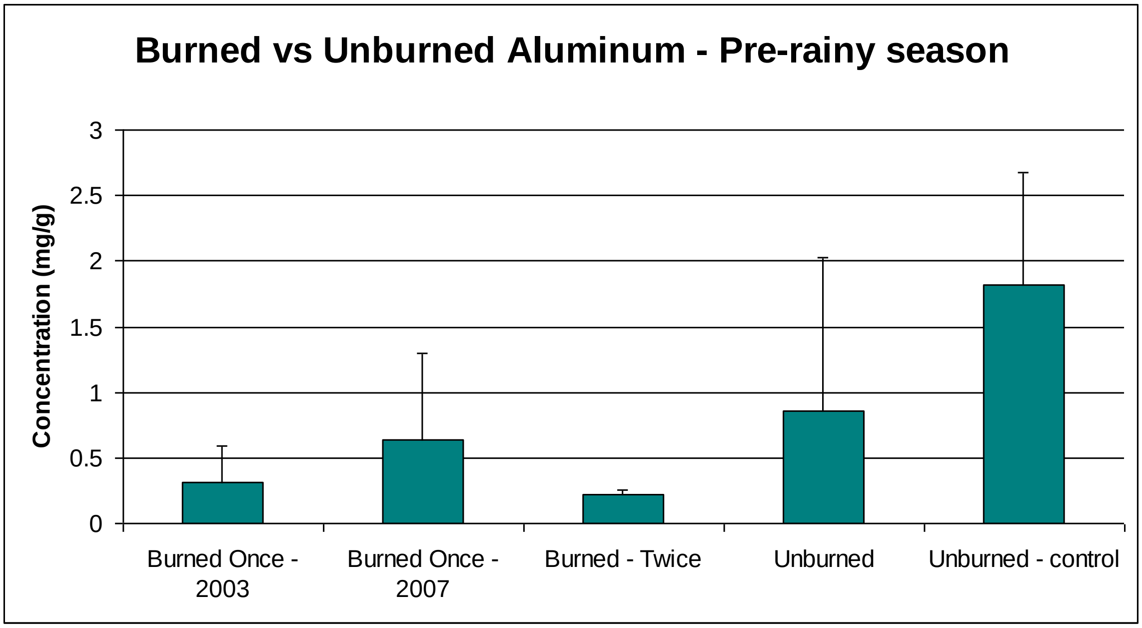

Figure 5: Concentration (mean + SD) of Aluminum for burned once and twice watersheds, during the pre-rainy season.

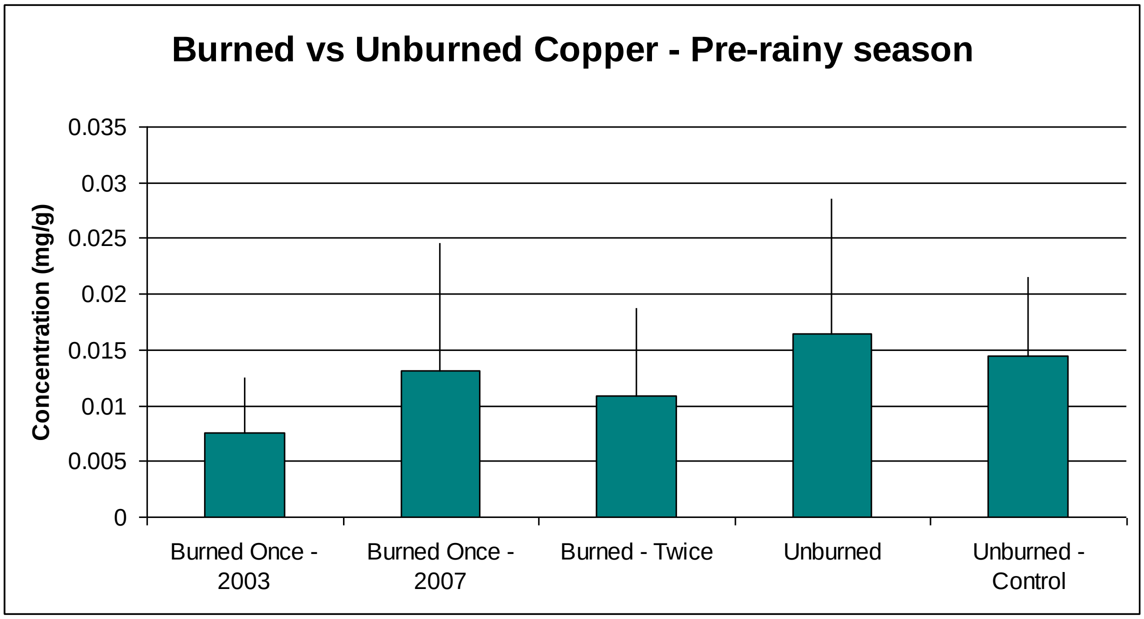

Figure 6: Concentration (mean + SD) of Copper for burned once and twice watersheds, during the pre-rainy season.

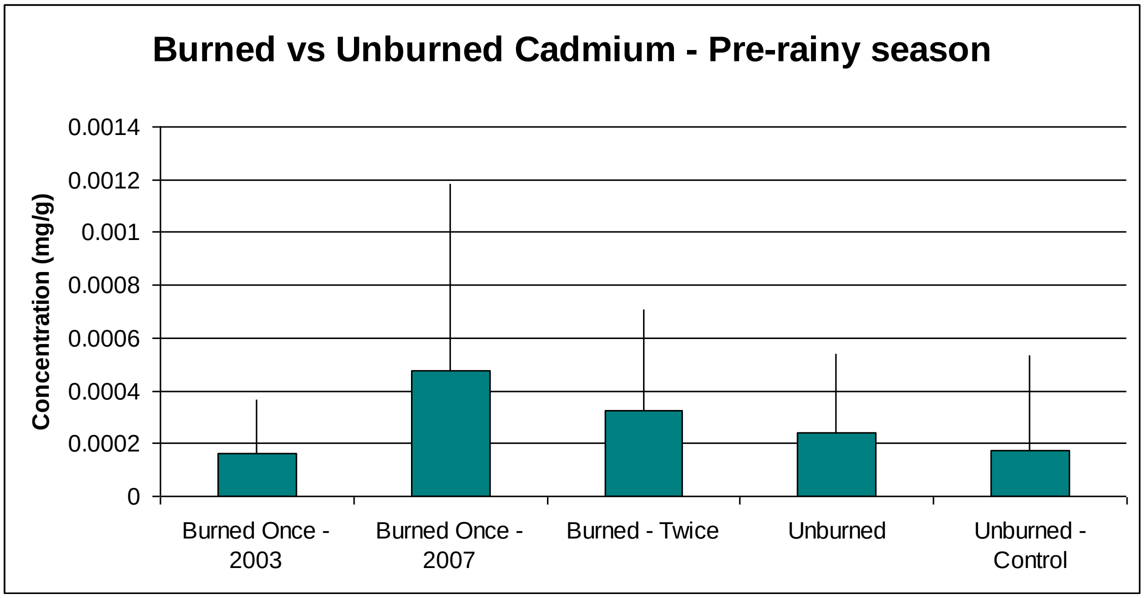

Figure 7: Concentration (mean + SD) of Cadmium for burned once and twice watersheds, during the pre-rainy season.

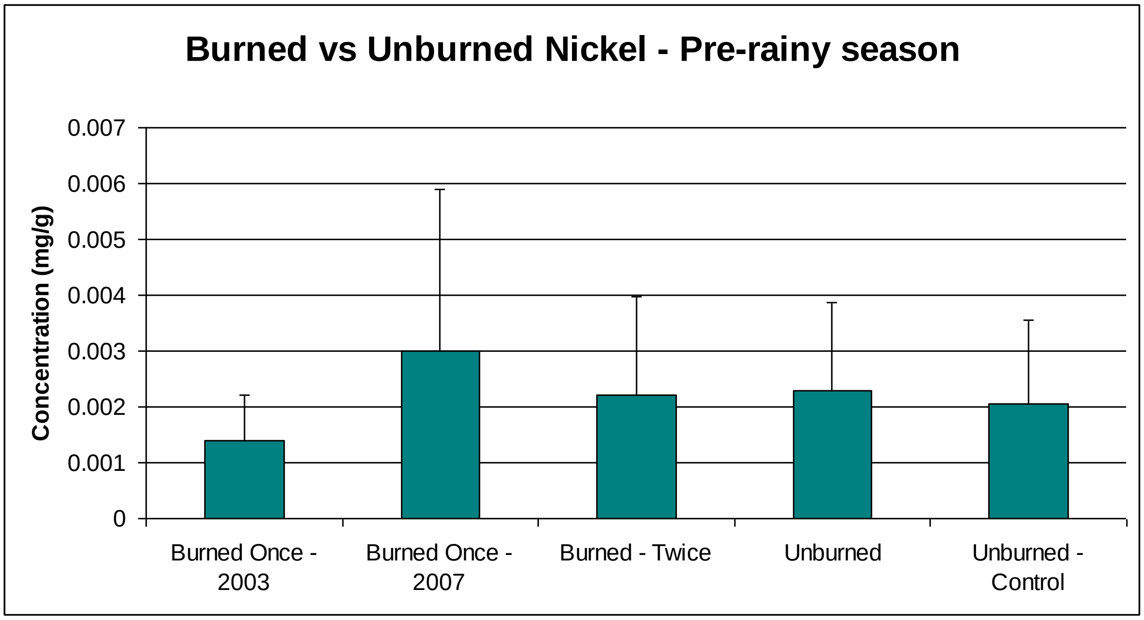

Figure 8: Concentration (mean + SD) of Nickel for burned once and twice watersheds, during the pre-rainy season.

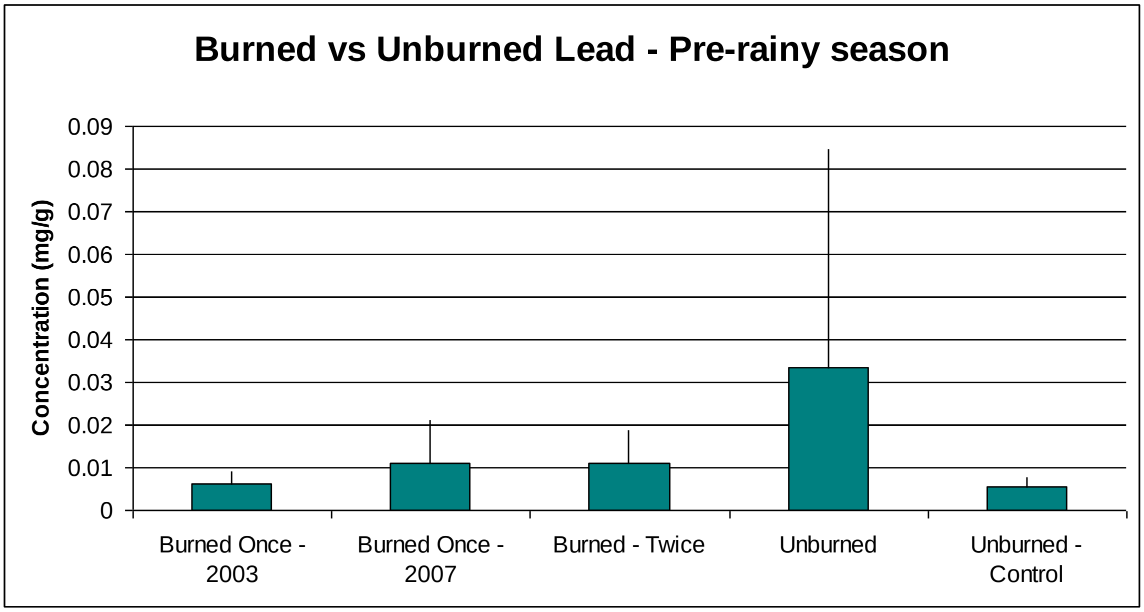

Figure 9: Concentration (mean + SD) of Lead for burned once and twice watersheds, during the pre-rainy season.

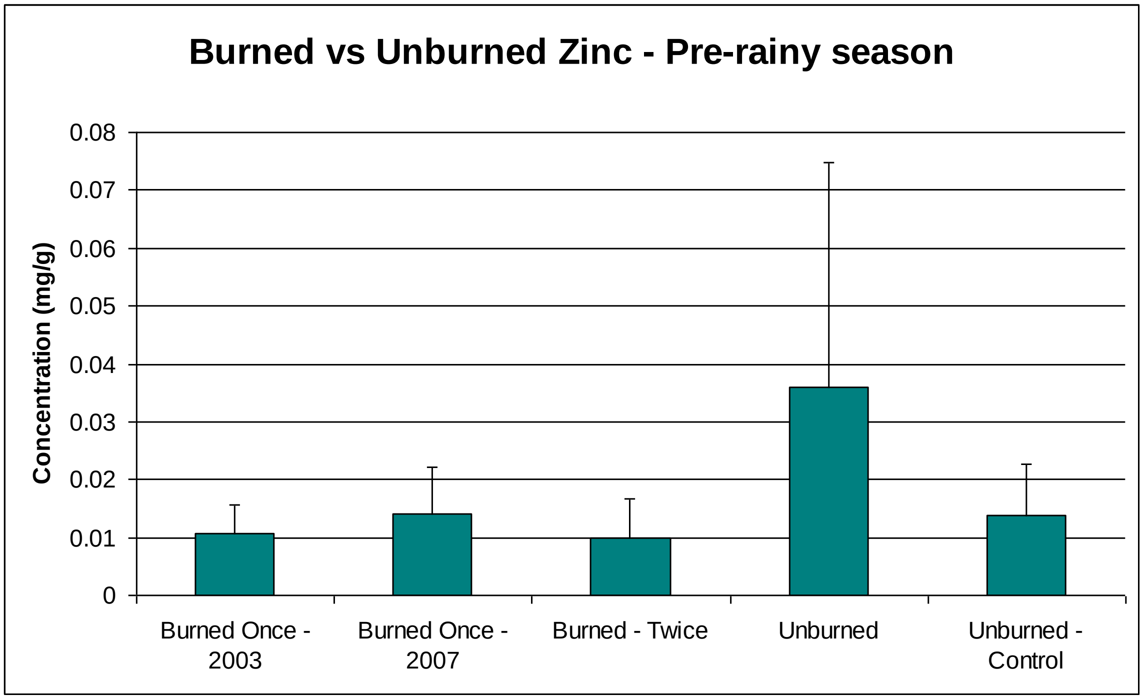

Figure 10: Concentration (mean + SD) of Zinc for burned once and twice watersheds, during the pre-rainy season.

B. Burned vs Unburned – Pre-rainy and during rainy season samples

There was a difference between pre-rainy and during rainy season samples (Figures 11-16). Depending on the particular burned sites, unburned sites or metal, the concentration may be higher or lower between the two seasons. Aluminum had the most consistently noticeable difference between seasons compared with other metals in all sites (Figure 11-16).

Concentrations of copper were visually similar from one season to another in all burned areas (Figure 12). However, the concentration of copper was the greatest in all unburned areas during the rainy season (Figure 12).

Cadmium and nickel were higher in the unburned sites for the rainy season compared to pre-rainy season concentrations (Figures 13 and 14). However, these concentrations were not as visually significant for nickel in the unburned non-control sites (Figure 14). With the exception of cadmium concentrations in burned 2003 sites, cadmium and nickel were higher in pre-rainy season samples for burned sites (Figures 13 and 14).

Lead concentrations were noticeably higher for both the pre-rainy and during rainy season samples in the unburned non-control sites compared to all other sites for both seasons (Figure 15). Pre-rainy and during rainy season lead concentrations were visually similar to each other in the burned 2003 and burned 2007 sites (Figure 15). The concentration of lead was the greatest during the pre-rainy season in unburned non-control sites (Figure 15).

The concentration of zinc was visually similar between seasons for burned 2003 and twice burned sites (Figure 16). During rainy season concentrations were significantly (visually) higher for burned 2007 and all unburned sites (Figure 16).

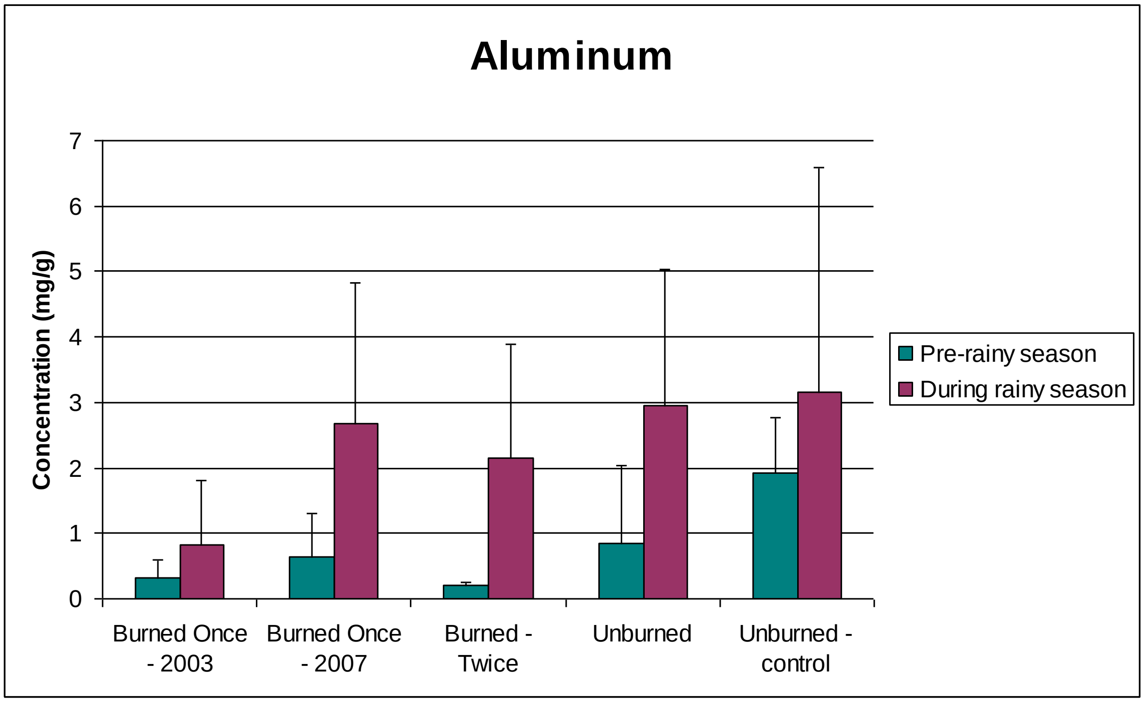

Figure 11: Concentration (mean + SD) of Aluminum for burned once and twice watersheds, during the pre-rainy and during rainy season.

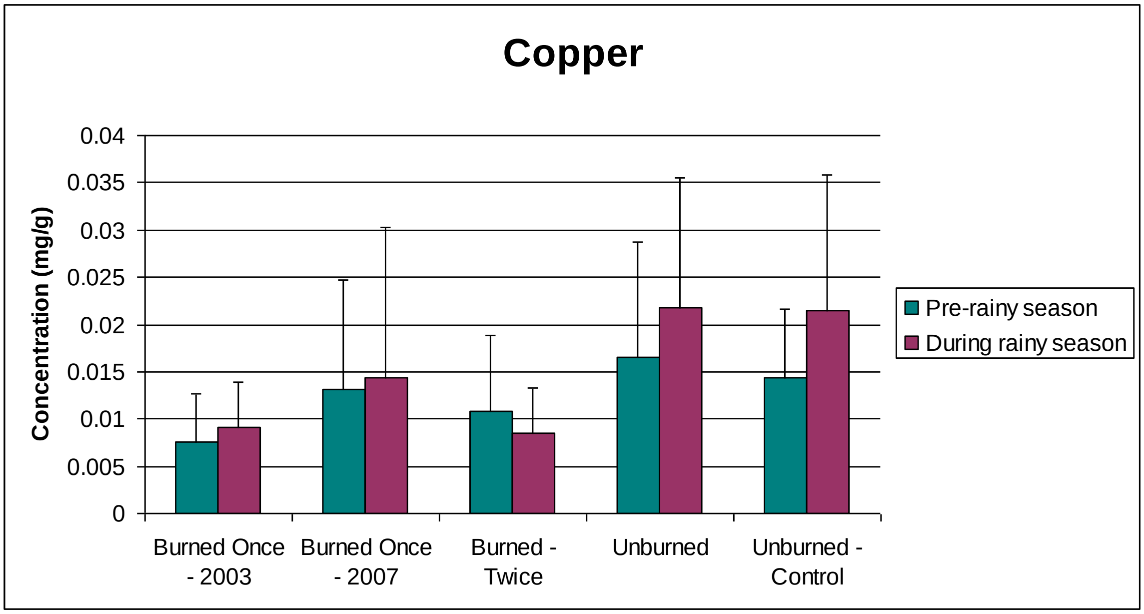

Figure 12: Concentration (mean + SD) of Copper for burned once and twice watersheds, during the pre-rainy and during rainy season.

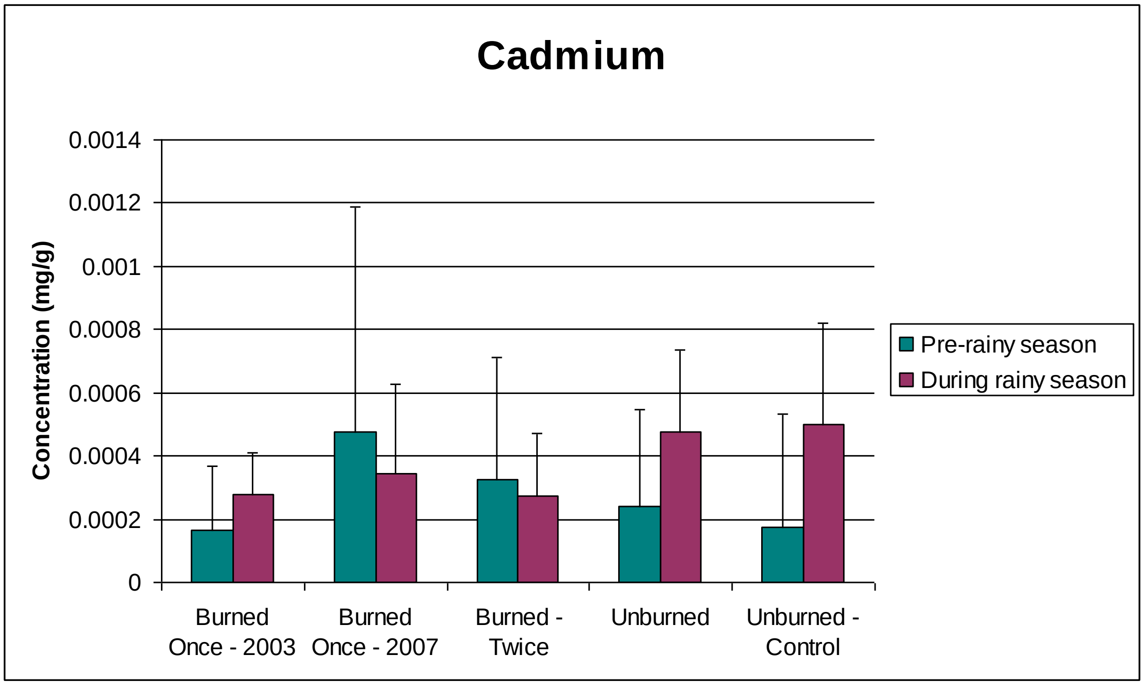

Figure 13: Concentration (mean + SD) of Cadmium for burned once and twice watersheds, during the pre-rainy and during rainy season.

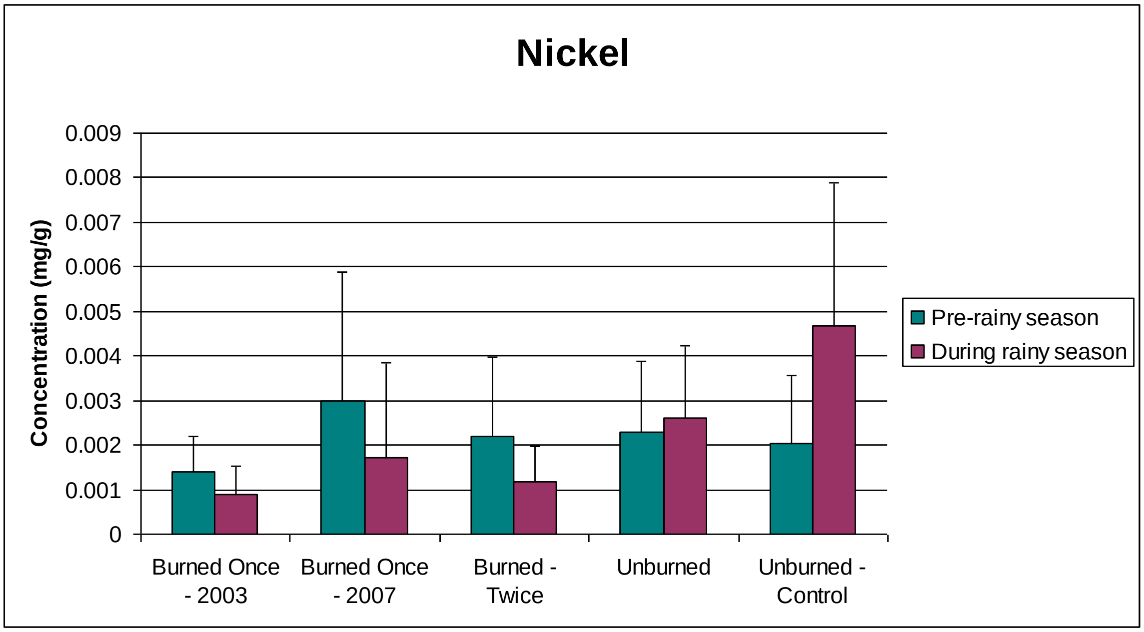

Figure 14: Concentration (mean + SD) of Nickel for burned once and twice watersheds, during the pre-rainy and during rainy season.

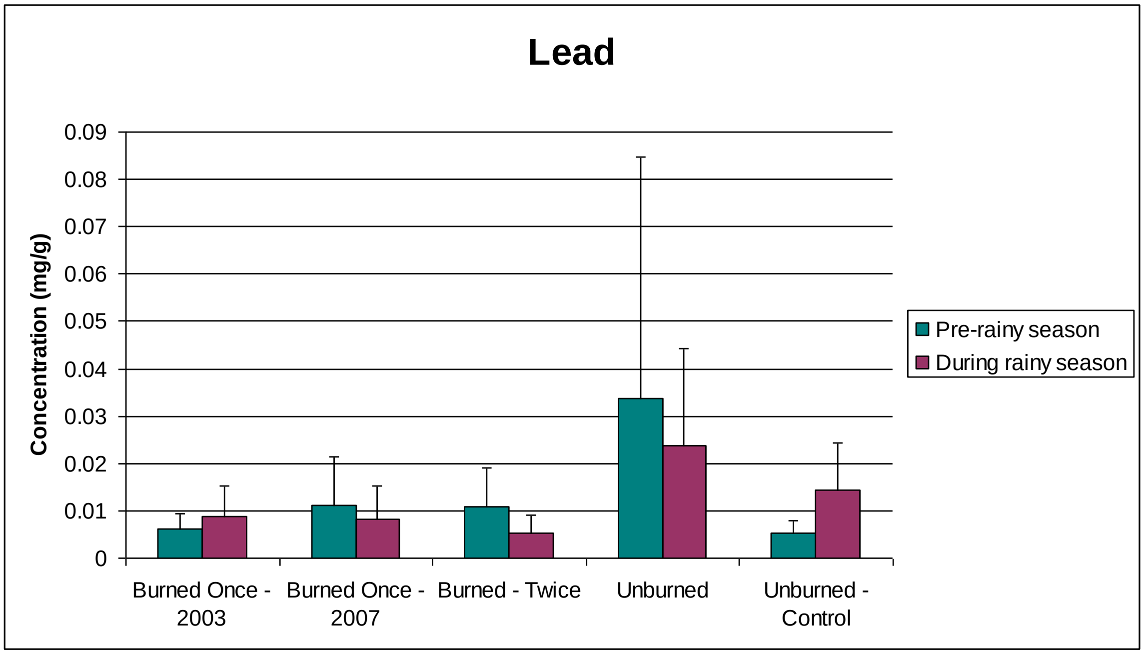

Figure 15: Concentration (mean + SD) of Lead for burned once and twice watersheds, during the pre-rainy and during rainy season.

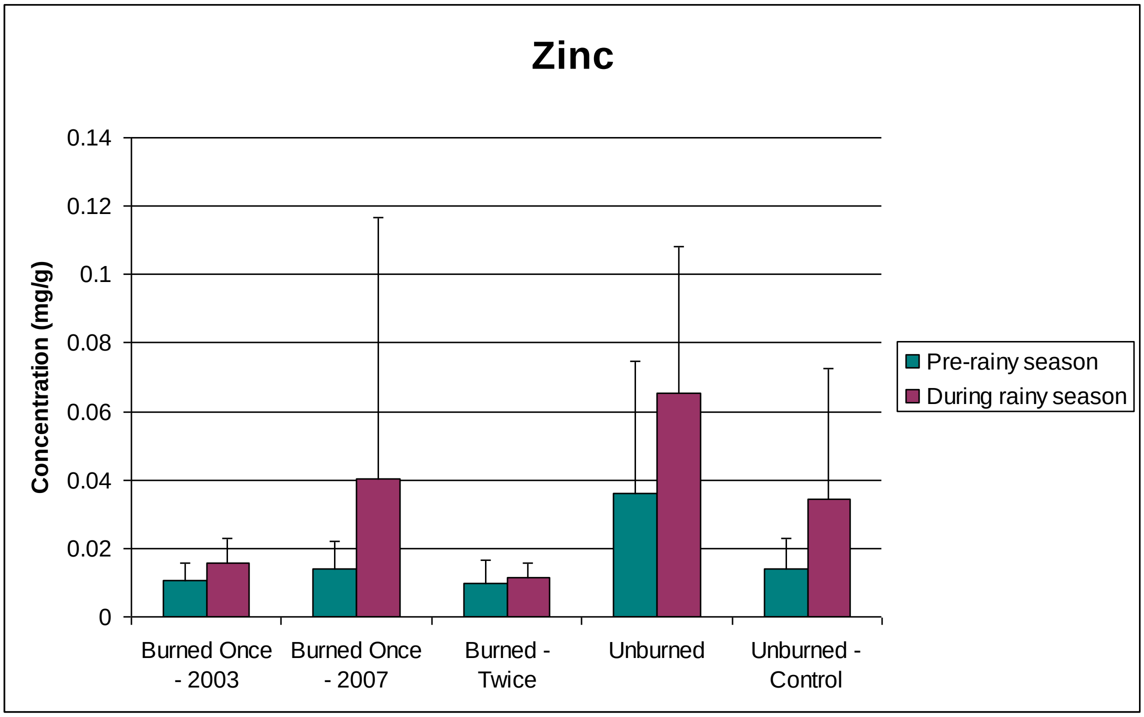

Figure 16: Concentration (mean + SD) of Zinc for burned once and twice watersheds, during the pre-rainy and during rainy season.

C. Coastal, Inland and Upper Watershed Sites - Pre-rainy and during rainy season samples

The concentrations of aluminum for coastal, inland and upper watershed sites in the San Diego watershed were very low overall compared to other watershed concentrations (San Dieguito and San Luis Rey Watershed) in similar sites (Figures 17-19). The San Dieguito coastal watershed sites contained the highest concentrations of aluminum compared to the coastal sites in other watersheds, and the concentrations between the pre-rainy and during rainy season samples were similar (Figure 17). For inland sites, the San Luis Rey watershed had higher concentrations of aluminum for both pre-rainy and during rainy season samples compared to other watersheds in similar seasons (Figure 18). The San Luis Rey watershed's pre-rainy season and the San Dieguito watershed's during rainy season aluminum concentrations were higher than all other concentrations for upper watershed sites (Figure 19).

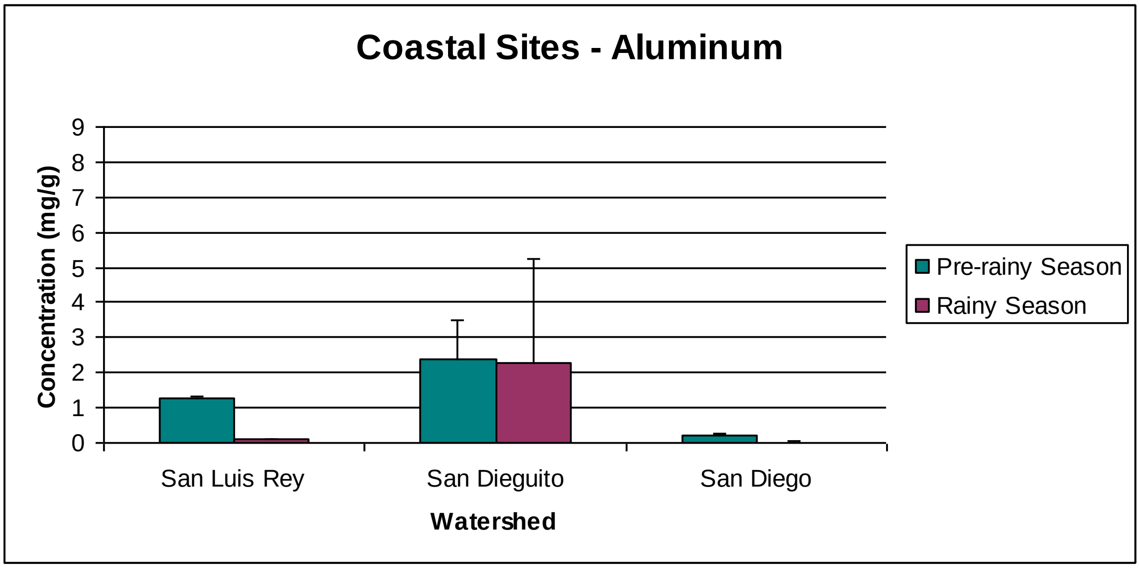

Figure 17: Concentration (mean + SD) of Aluminum for coastal sites in all three watersheds, during the pre-rainy and during rainy season.

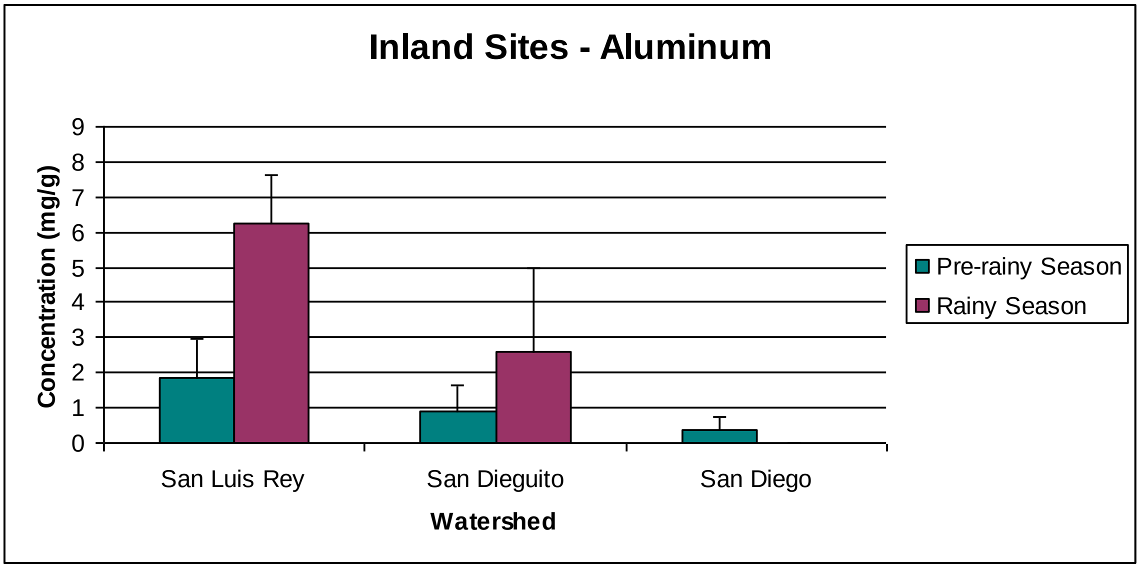

Figure 18: Concentration (mean + SD) of Aluminum for inland sites in all three watersheds, during the pre-rainy and during rainy season.

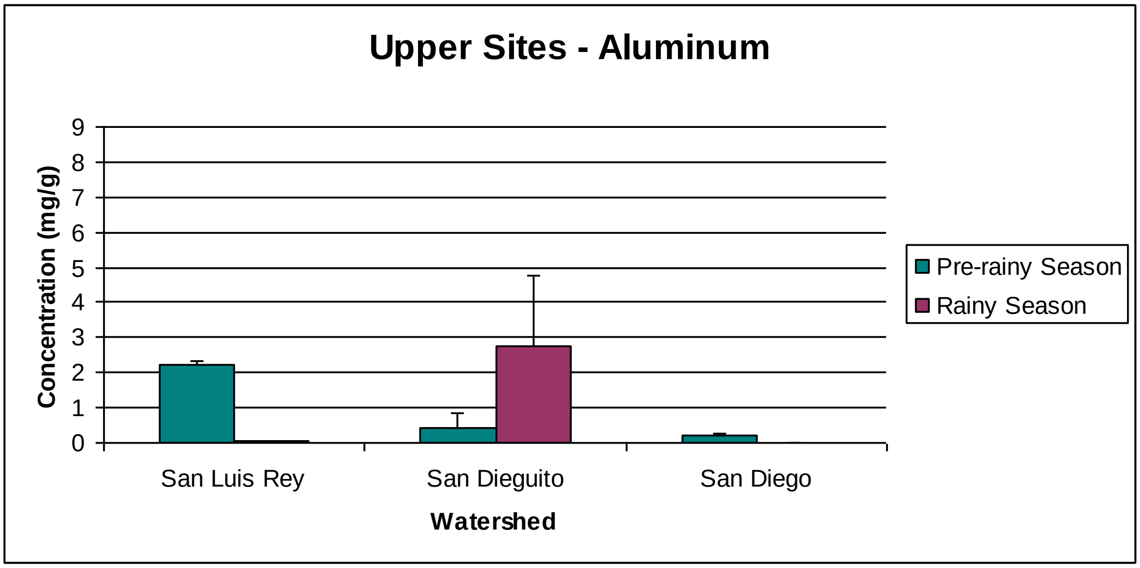

Figure 19: Concentration (mean + SD) of Aluminum for upper watershed sites in all three watersheds, during the pre-rainy and during rainy season.

There were higher concentrations of copper during the rainy season in both coastal and inland sites for all watersheds (Figures 20 and 21). Copper concentrations for both the pre-rainy and during rainy season were higher in the San Dieguito watershed for all coastal sites (Figure 20). For inland sites, the San Luis Rey watershed overall had higher concentrations of copper for both the pre-rainy and during rainy season samples compared to other watersheds in similar seasons (Figure 21). Upper watershed sites for the San Dieguito and San Diego watersheds were similar in copper concentrations (Figure 22).

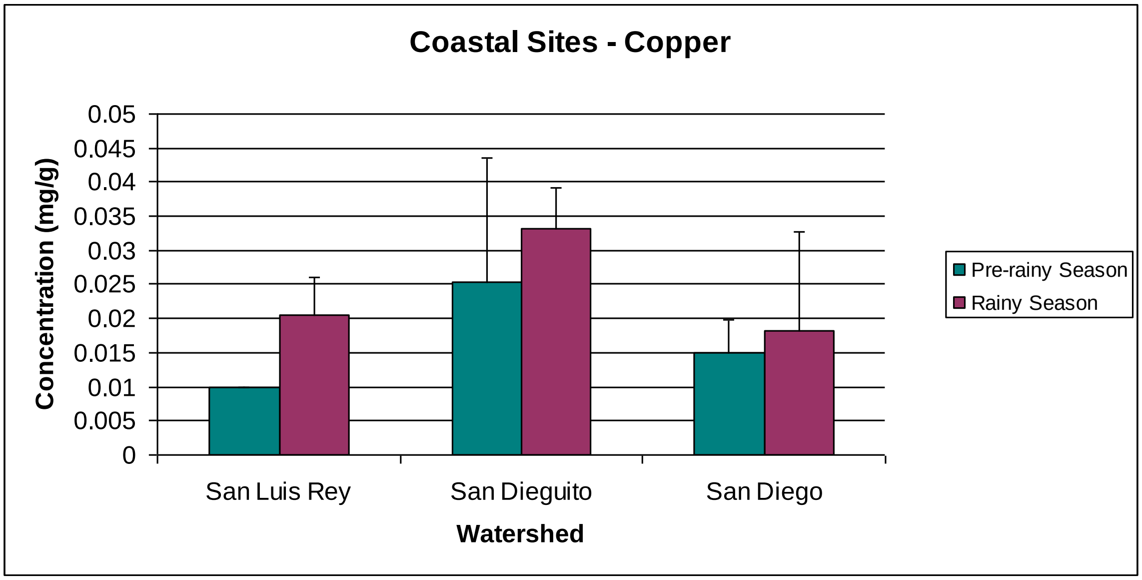

Figure 20: Concentration (mean + SD) of Copper for coastal sites in all three watersheds, during the pre-rainy and during rainy season.

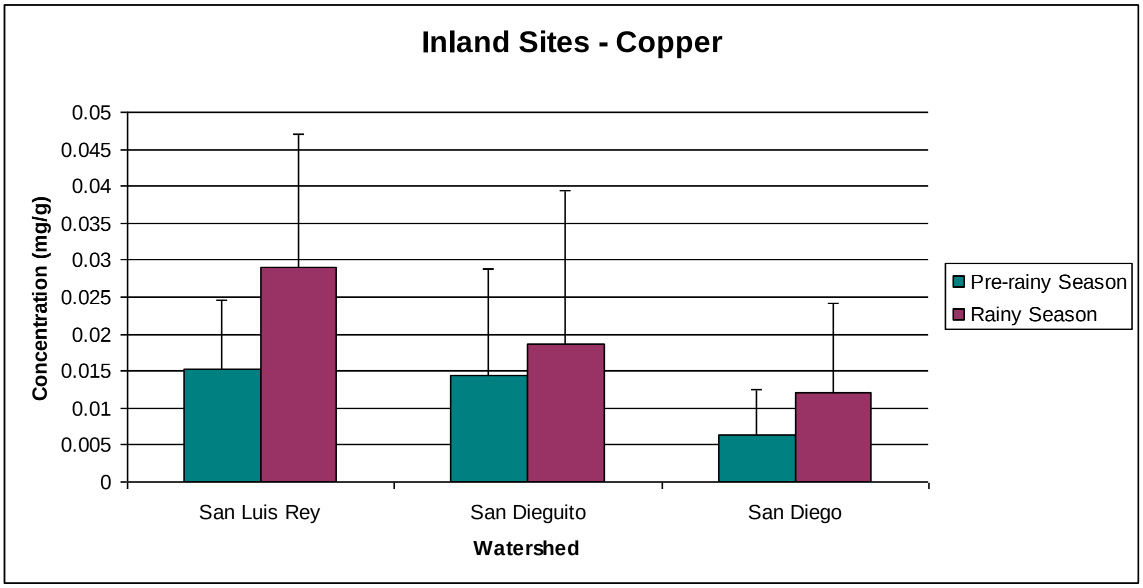

Figure 21: Concentration (mean + SD) of Copper for inland sites in all three watersheds, during the pre-rainy and during rainy season.

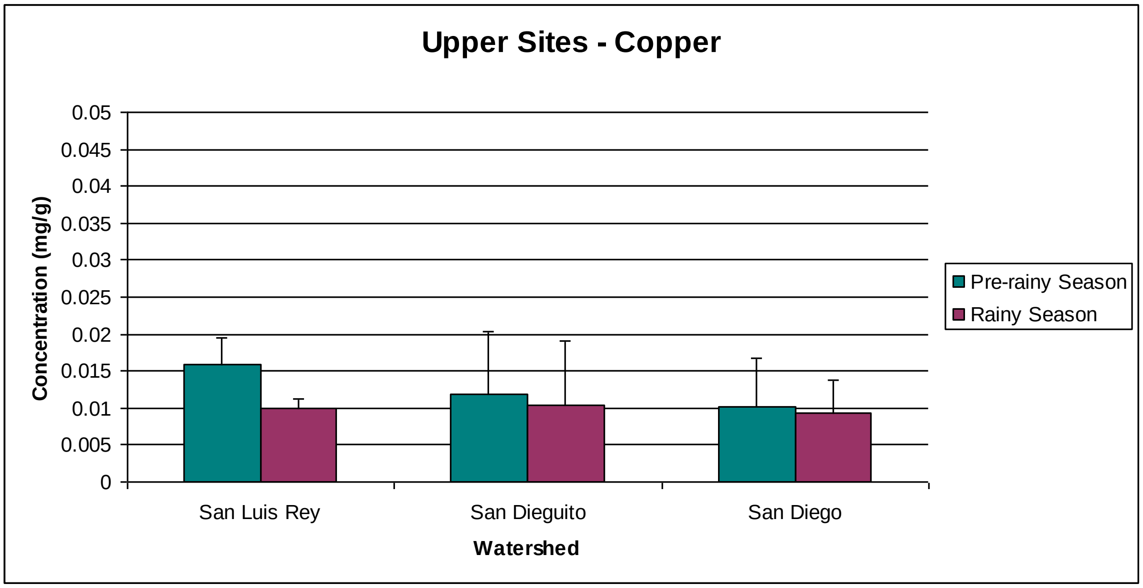

Figure 22: Concentration (mean + SD) of Copper for upper watershed sites in all three watersheds, during the pre-rainy and during rainy season.

Cadmium and nickel had greater concentrations during the rainy season for the San Luis Rey and San Dieguito watersheds coastal sites (Figures 23 and 24). The San Luis Rey watershed’s coastal sites had the lowest concentration of both cadmium and nickel for the pre-rainy season compared with other concentrations of the same metal (Figures 23 and 24). The San Diego watershed had the lowest concentrations of both cadmium and nickel for the inland sites for the comparable seasons (Figures 25 and 26). The inland sites for San Luis Rey had greater concentrations for cadmium and nickel during the rainy season (Figures 25 and 26). Overall, every watershed had low concentrations of cadmium and nickel in the upper watershed sites compared with other sites except for pre-rainy season cadmium concentrations in the San Dieguito watershed (Figures 27 and 28).

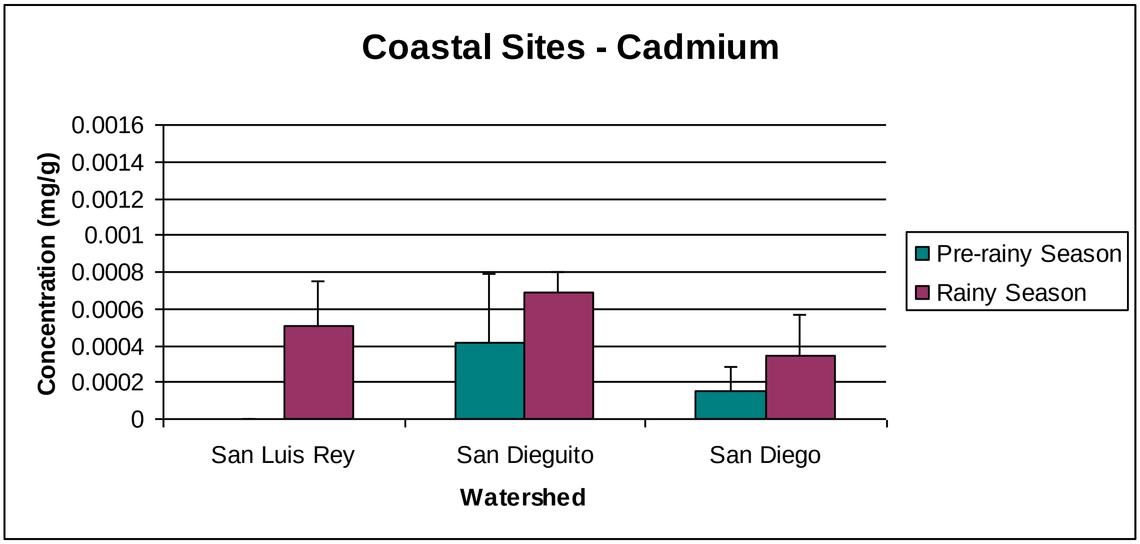

Figure 23: Concentration (mean + SD) of Cadmium for coastal sites in all three watersheds, during the pre-rainy and during rainy season.

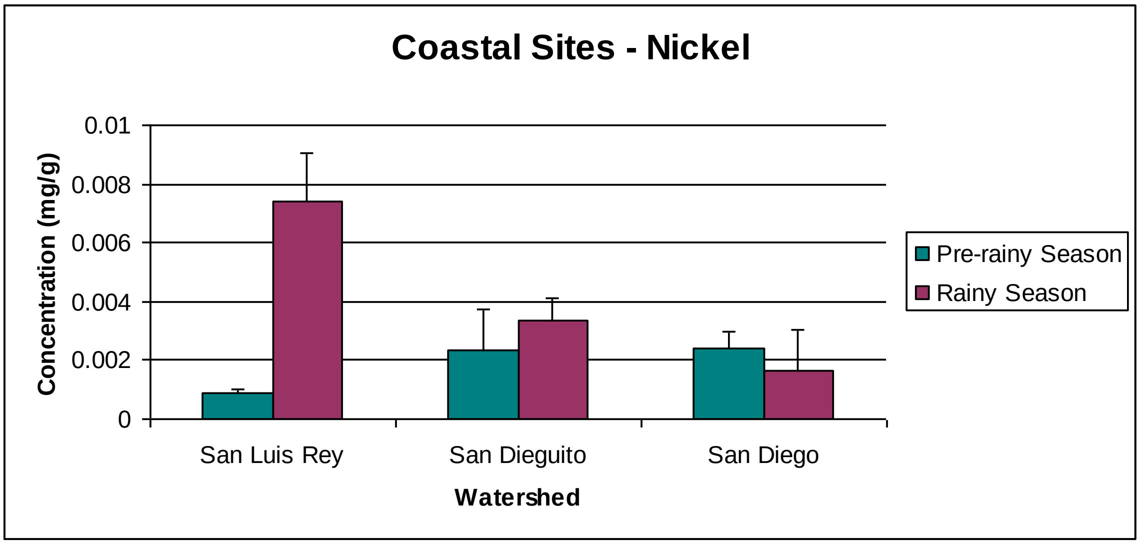

Figure 24: Concentration (mean + SD) of Nickel for coastal sites in all three watersheds, during the pre-rainy and during rainy season.

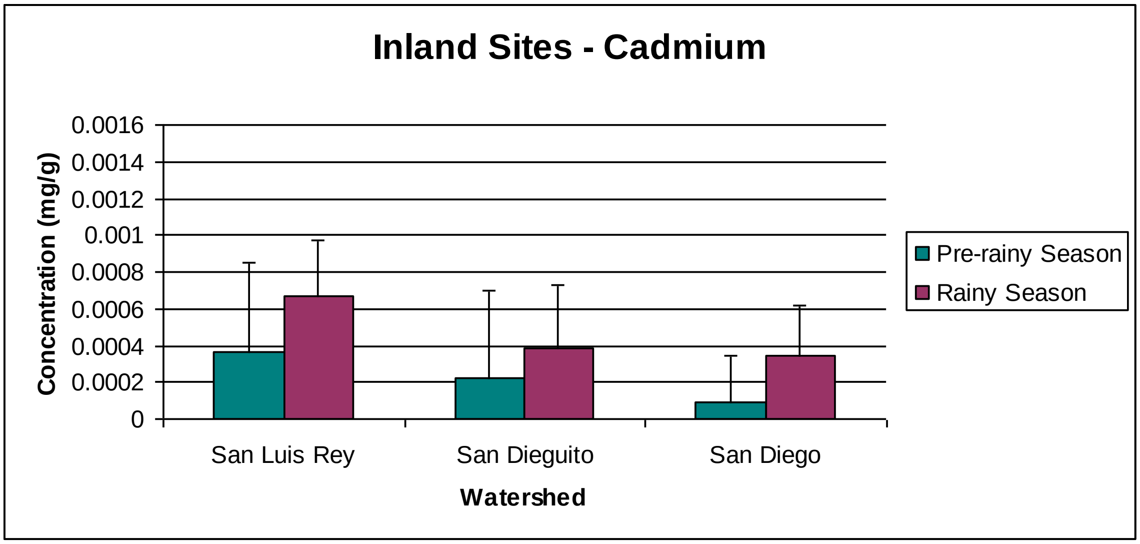

Figure 25: Concentration (mean + SD) of Cadmium for inland sites in all three watersheds, during the pre-rainy and during rainy season.

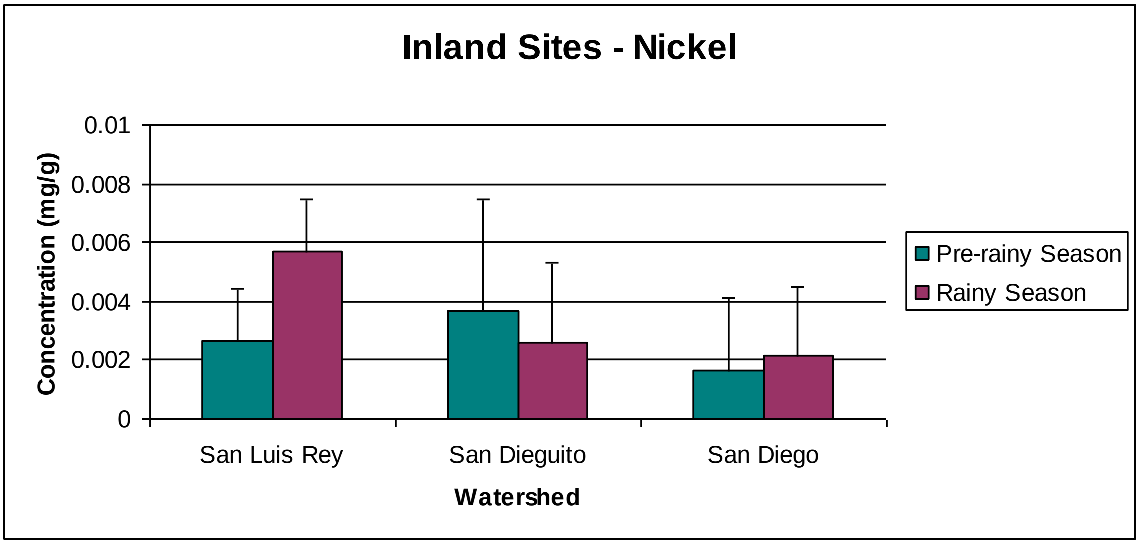

Figure 26: Concentration (mean + SD) of Nickel for inland sites in all three watersheds, during the pre-rainy and during rainy season.

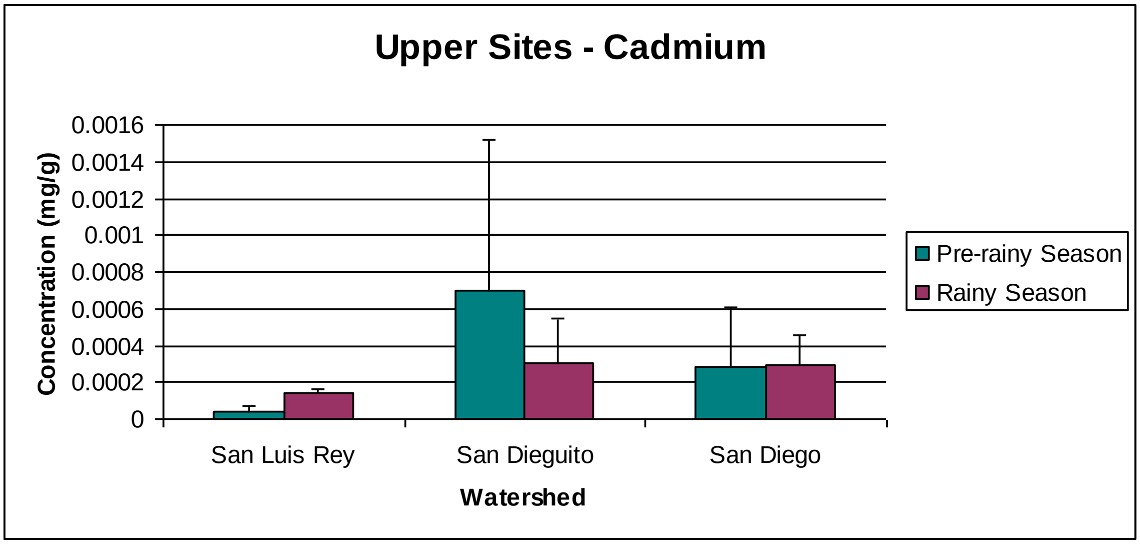

Figure 27: Concentration (mean + SD) of Cadmium for upper watershed sites in all three watersheds, during the pre-rainy and during rainy season.

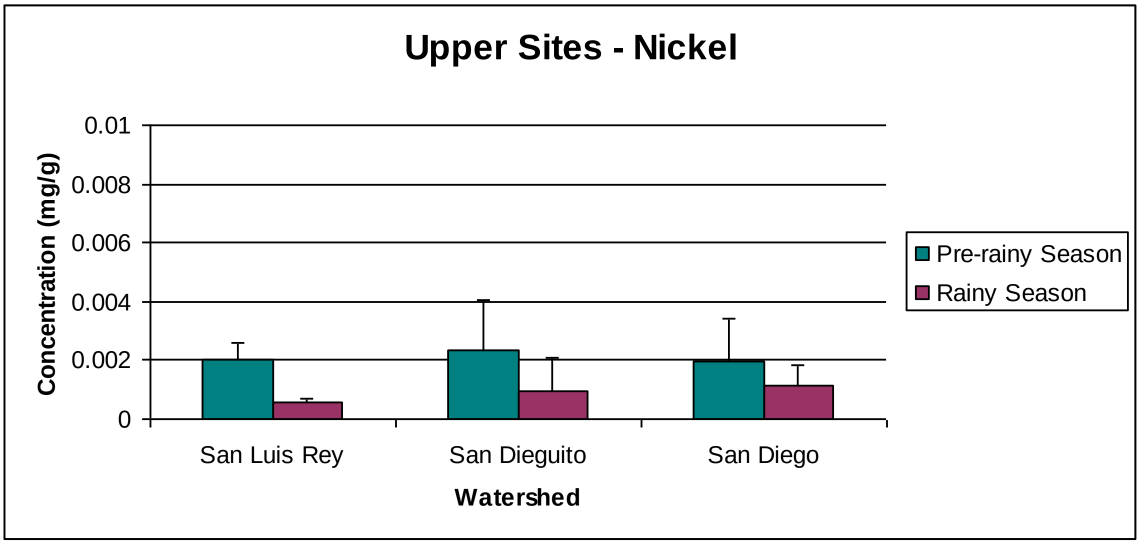

Figure 28: Concentration (mean + SD) of Nickel for upper watershed sites in all three watersheds, during the pre-rainy and during rainy season.

All watersheds showed similarly low concentrations of lead for the inland and upper watershed sites (Figures 30 and 31). These sites also had little variation between the pre-rainy and during rainy season samples (Figures 30 and 31). Coastal sites varied between watersheds (Figure 29). The San Dieguito watershed had the highest concentration of lead for both the pre-rainy and during rainy season samples with the pre-rainy season being higher (Figure 29). The San Diego watershed had lead concentrations similar between the two seasons (Figure 29), and the San Luis Rey watershed varied significantly (visually) between the pre-rainy and during rainy season (Figure 29).

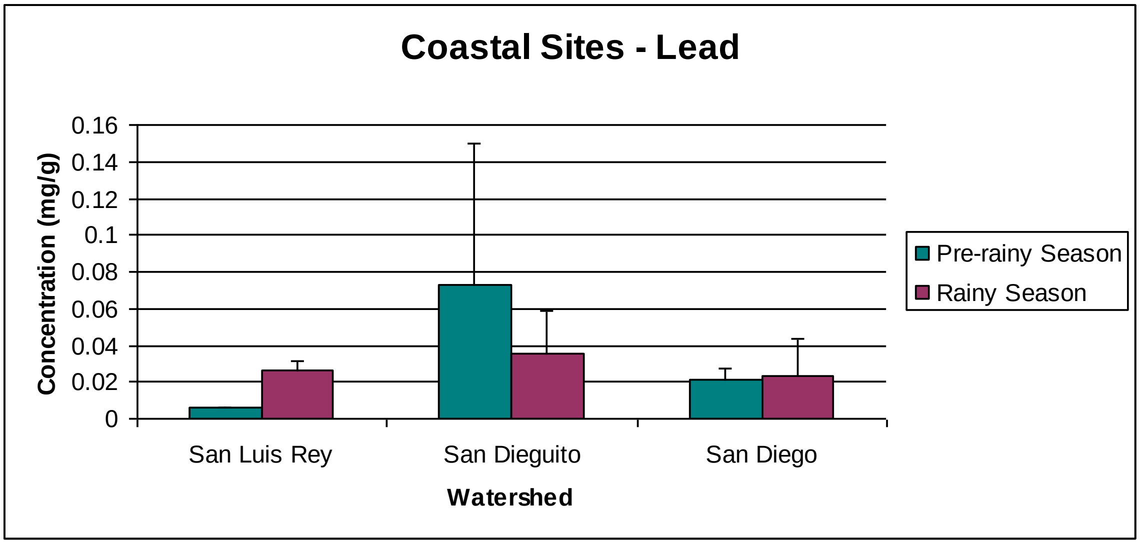

Figure 29: Concentration (mean + SD) of Lead for coastal sites in all three watersheds, during the pre-rainy and during rainy season.

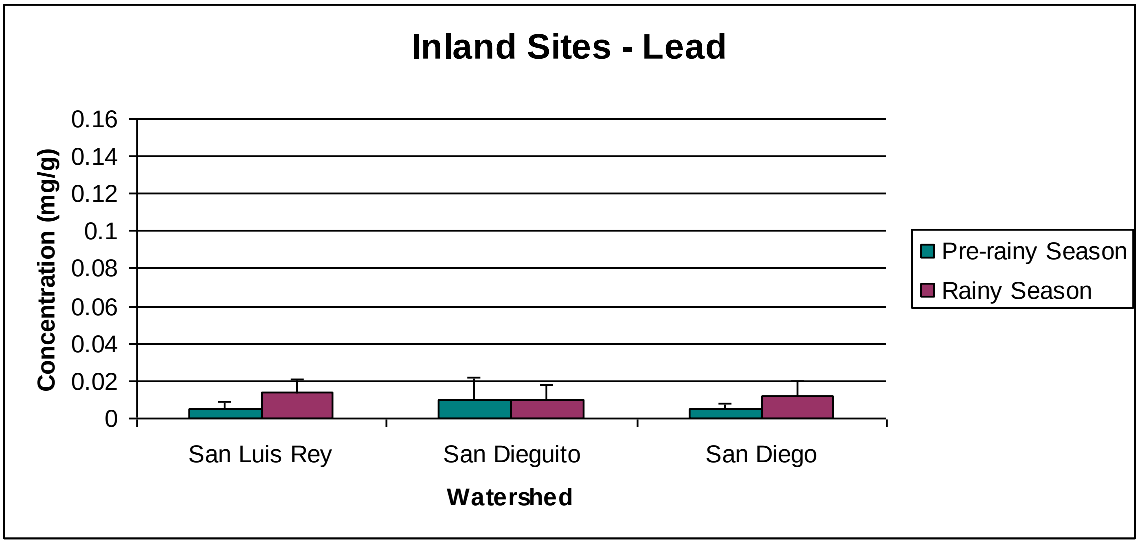

Figure 30: Concentration (mean + SD) of Lead for inland watershed sites in all three watersheds, during the pre-rainy and during rainy season.

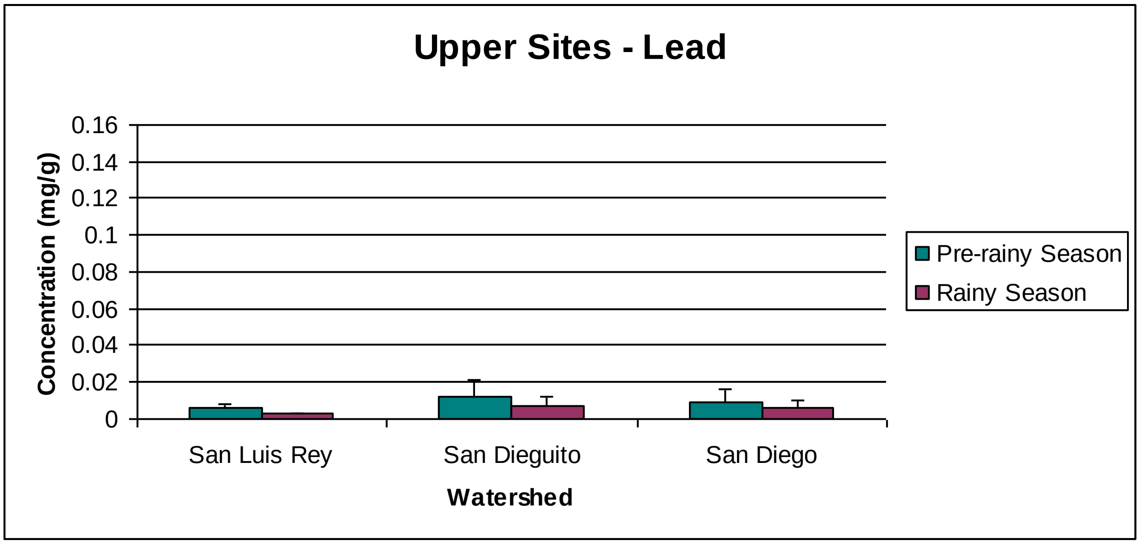

Figure 31: Concentration (mean + SD) of Lead for upper watershed sites in all three watersheds, during the pre-rainy and during rainy season.

The San Dieguito watershed coastal sites were similar in concentrations of zinc which differed from both the San Diego and San Luis Rey watersheds as both had significantly (visually) higher concentrations for the rainy season (Figure 32). Inland sites for zinc were higher during the rainy season for all three watersheds (Figure 33). Additionally, for inland sites, zinc concentrations were all similar to each other when compared to other watersheds for the same season (Figure 33). The upper watershed sites for the San Dieguito and San Diego watersheds varied slightly between seasons (Figure 34). All upper watershed sites were low compared with the overall concentrations from the coastal and inland sites (Figures 32-34).

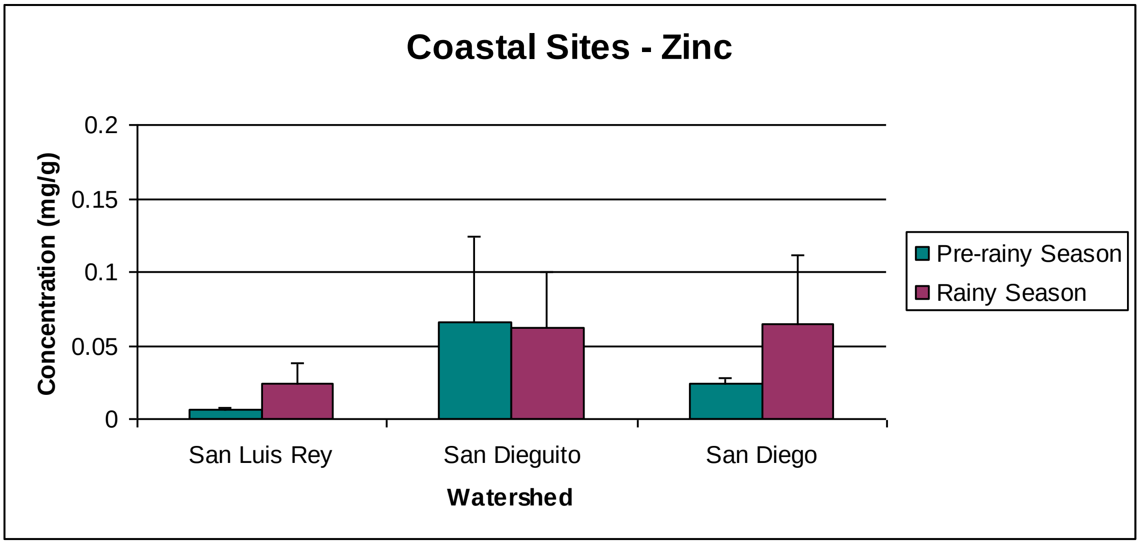

Figure 32: Concentration (mean + SD) of Zinc for coastal sites in all three watersheds, during the pre-rainy and during rainy season.

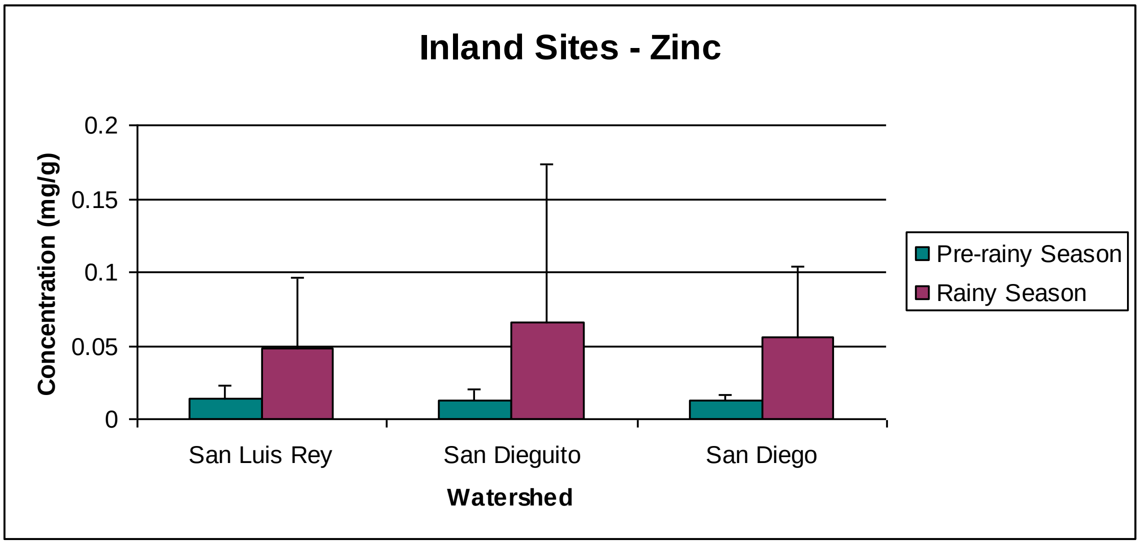

Figure 33: Concentration (mean + SD) of Zinc for inland sites in all three watersheds, during the pre-rainy and during rainy season.

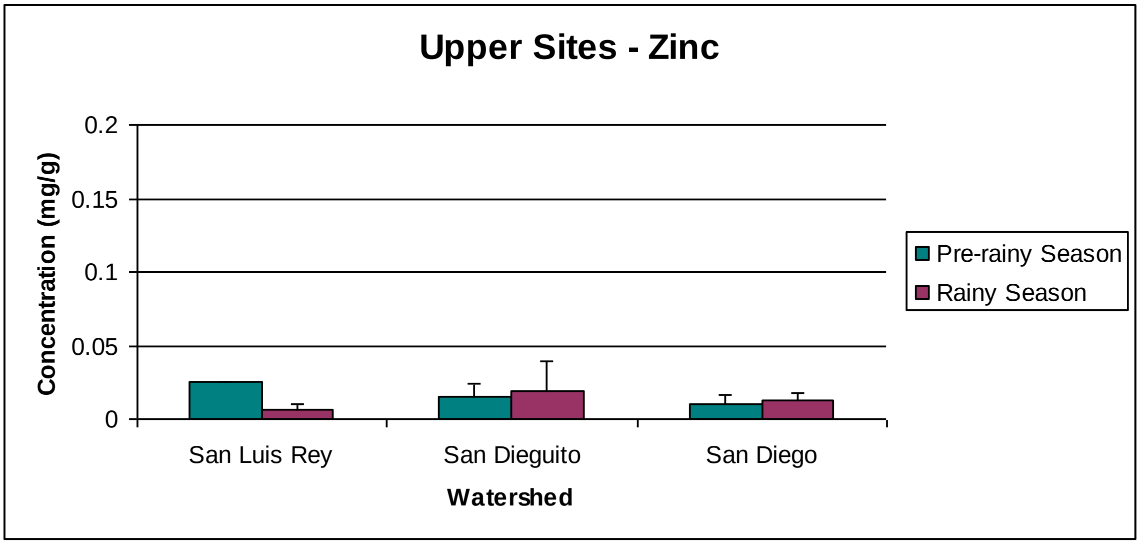

Figure 34: Concentration (mean + SD) of Zinc for upper watershed sites in all three watersheds, during the pre-rainy and during rainy season.

D. Watershed Sites – Pre-rainy and during rainy season samples

Concentrations of nickel, lead and zinc were visually similar at site 2 between the pre-rainy and during rainy season for the San Luis Rey watershed (Figures 38-40). All metals, except aluminum, were also visually similar at site 4 between the pre-rainy and during rainy season (Figures 35-40). At site 3, there was a large difference for all metals between the pre-rainy and during rainy season with the rainy season always being higher (Figures 35-40). Overall, there is no consistent pattern for any metals in the San Luis Rey watershed between the two seasons (Figures 35-40).

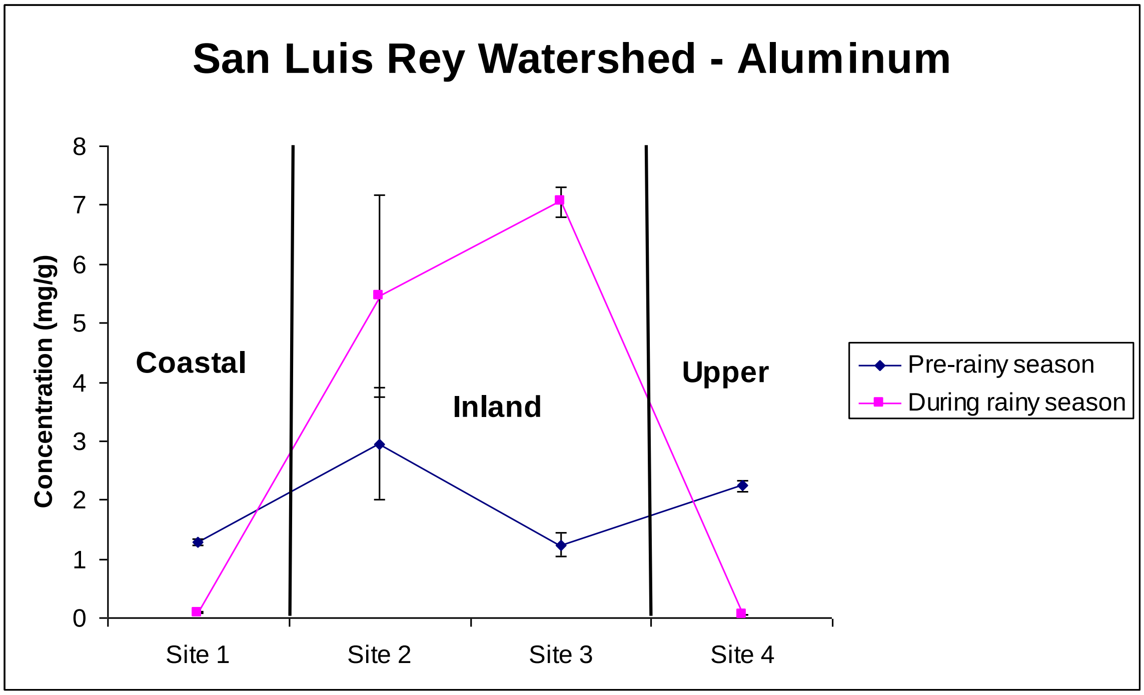

Figure 35: San Luis Rey Watershed divided into the coastal, inland and upper sample sites – Aluminum concentrations (mean ± SD) for pre-rainy and during rainy season

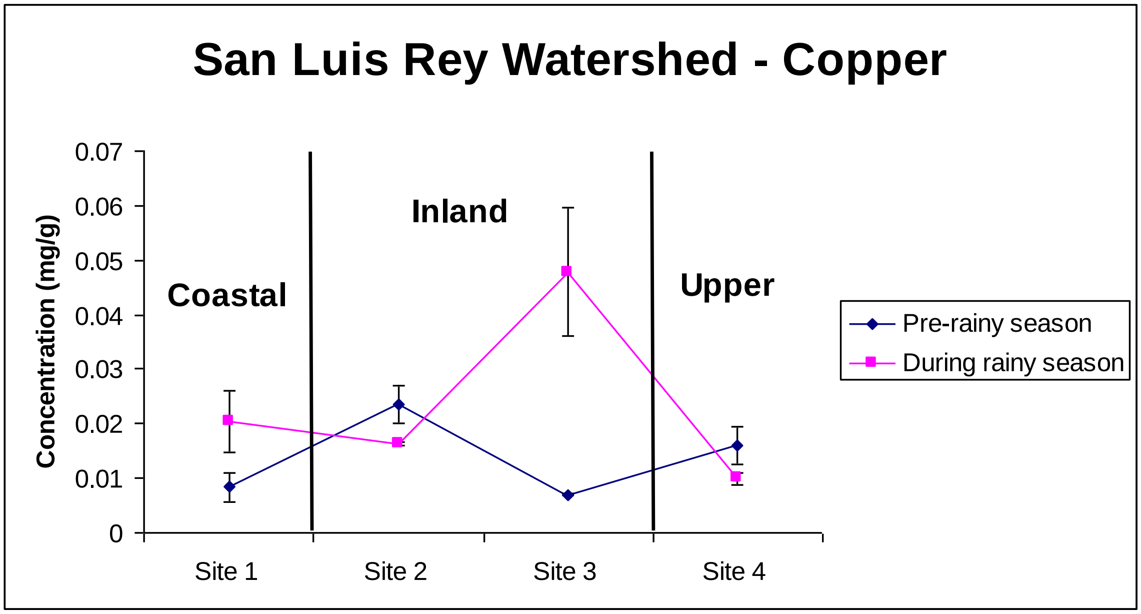

Figure 36: San Luis Rey Watershed divided into the coastal, inland and upper sample sites – Copper concentrations (mean ± SD) for pre-rainy and during rainy season

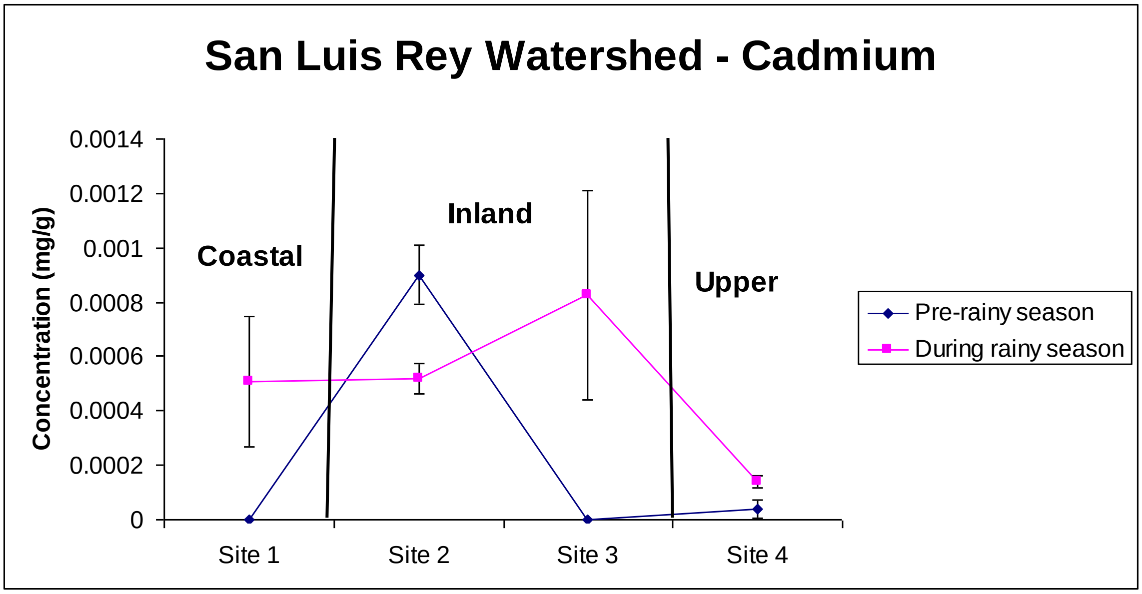

Figure 37: San Luis Rey Watershed divided into the coastal, inland and upper sample sites – Cadmium concentrations (mean ± SD) for pre-rainy and during rainy season

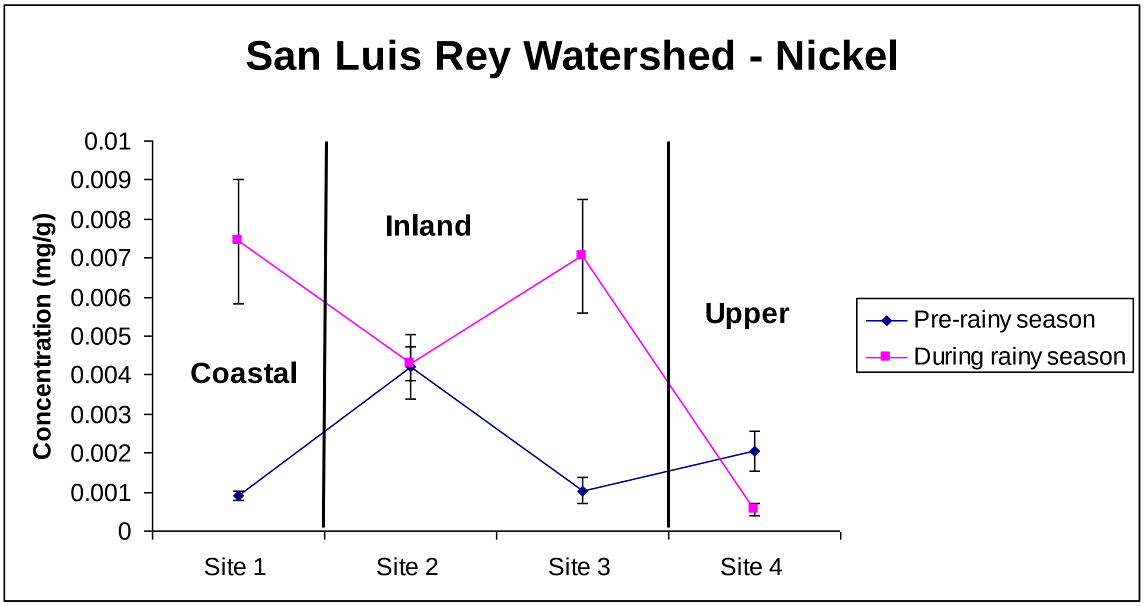

Figure 38: San Luis Rey Watershed divided into the coastal, inland and upper sample sites – Nickel concentrations (mean ± SD) for pre-rainy and during rainy season

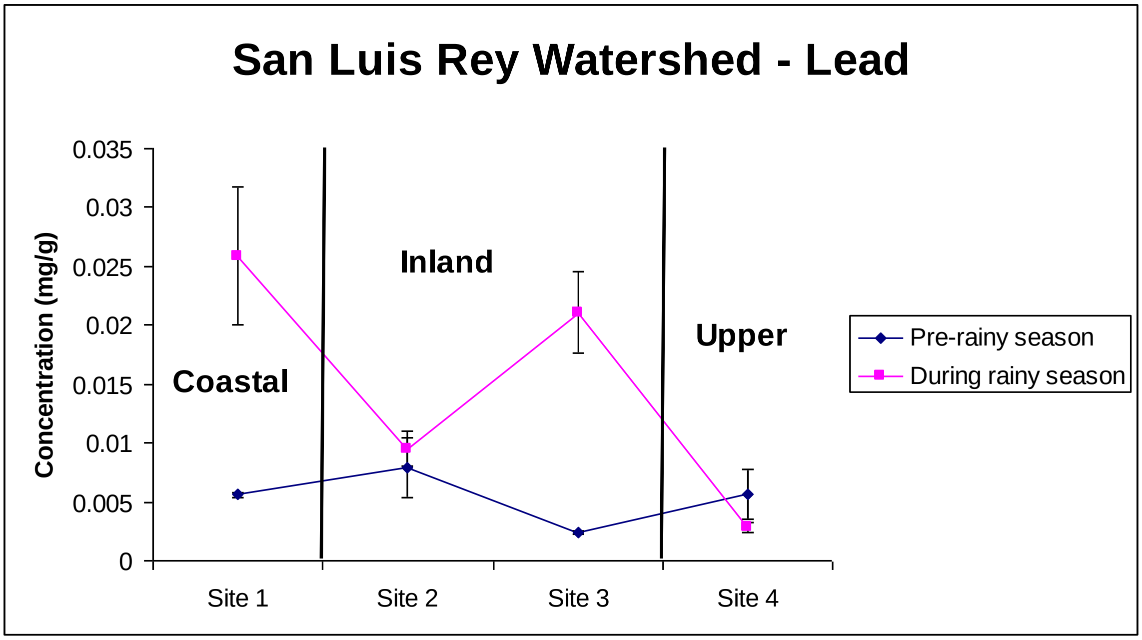

Figure 39: San Luis Rey Watershed divided into the coastal, inland and upper sample sites – Lead concentrations (mean ± SD) for pre-rainy and during rainy season

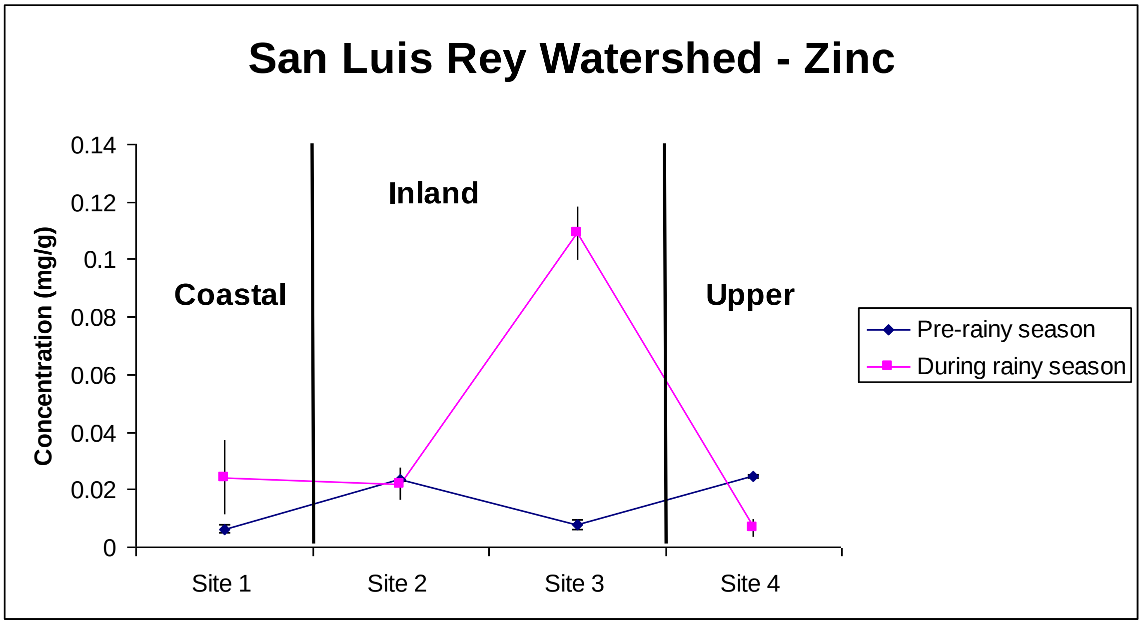

Figure 40: San Luis Rey Watershed divided into the coastal, inland and upper sample sites – Zinc concentrations (mean ± SD) for pre-rainy and during rainy season

All metals except aluminum have little to no variation between the pre-rainy and during rainy season concentrations among sites in the San Dieguito watershed (Figures 41-46). The exceptions are SCY2 for Cd, Site 1 for Pb and KCC3 for Zn (Figures 41-46).

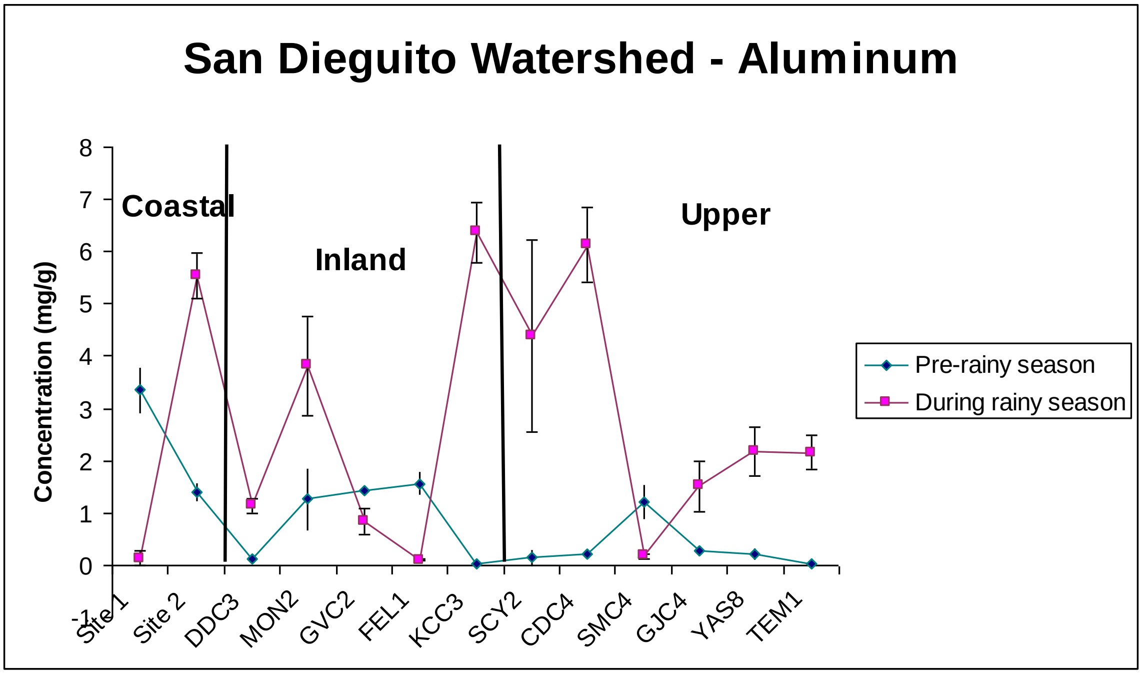

Figure 41: San Dieguito Watershed divided into the coastal, inland and upper sample sites – Aluminum concentrations (mean ± SD) for pre-rainy and during rainy season

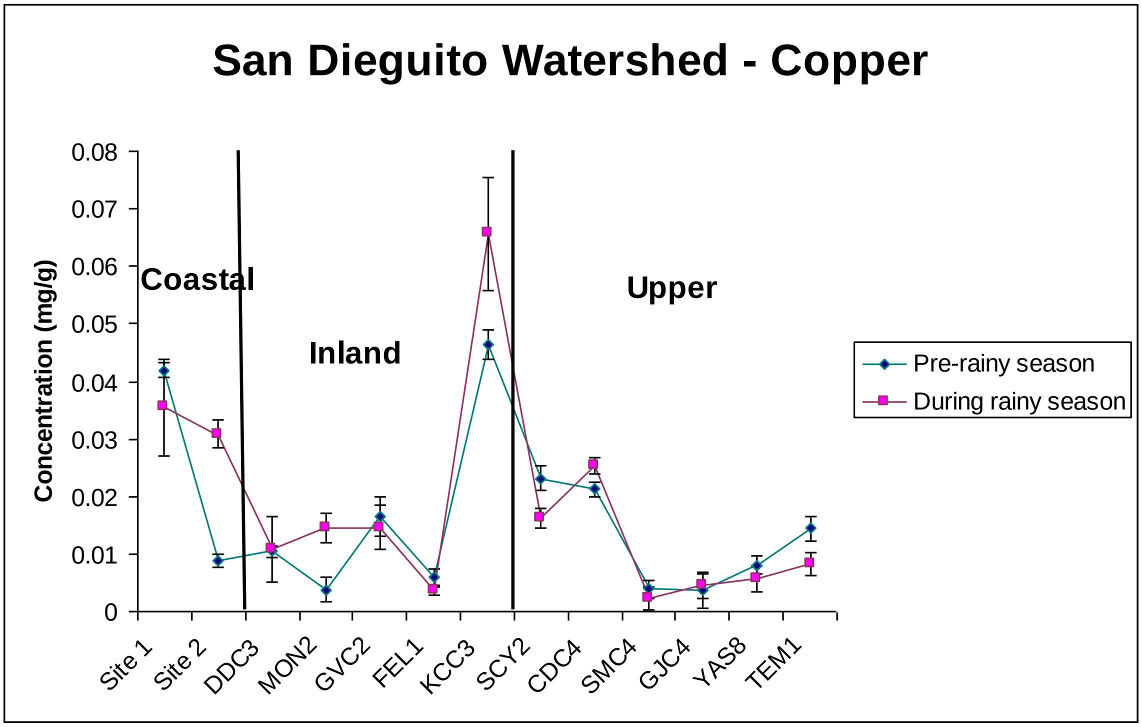

Figure 42: San Dieguito Watershed divided into the coastal, inland and upper sample sites – Copper concentrations (mean ± SD) for pre-rainy and during rainy season

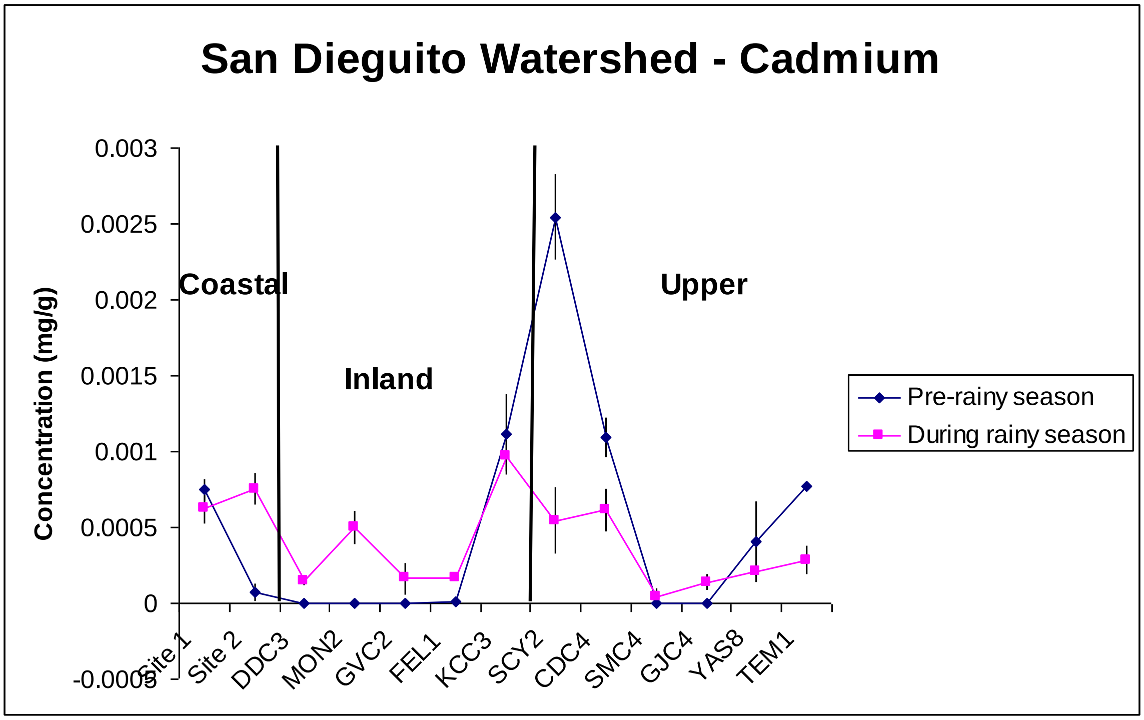

Figure 43: San Dieguito Watershed divided into the coastal, inland and upper sample sites – Cadmium concentrations (mean ± SD) for pre-rainy and during rainy season

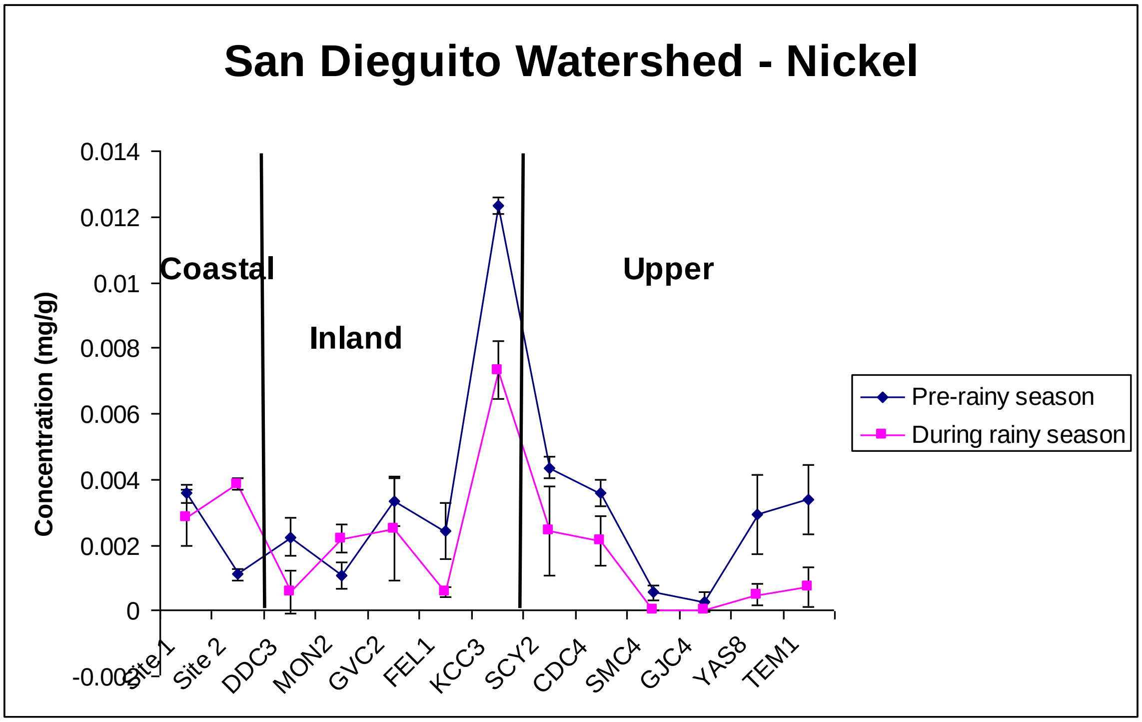

Figure 44: San Dieguito Watershed divided into the coastal, inland and upper sample sites – Nickel concentrations (mean ± SD) for pre-rainy and during rainy season

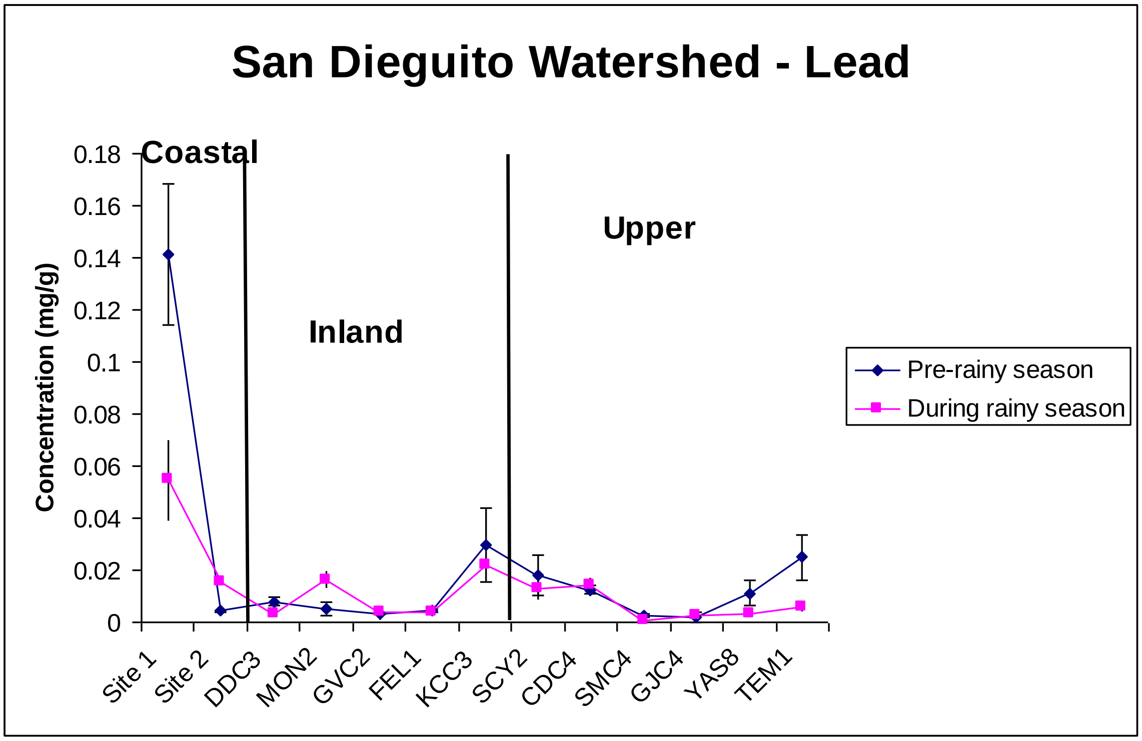

Figure 45: San Dieguito Watershed divided into the coastal, inland and upper sample sites – Lead concentrations (mean ± SD) for pre-rainy and during rainy season

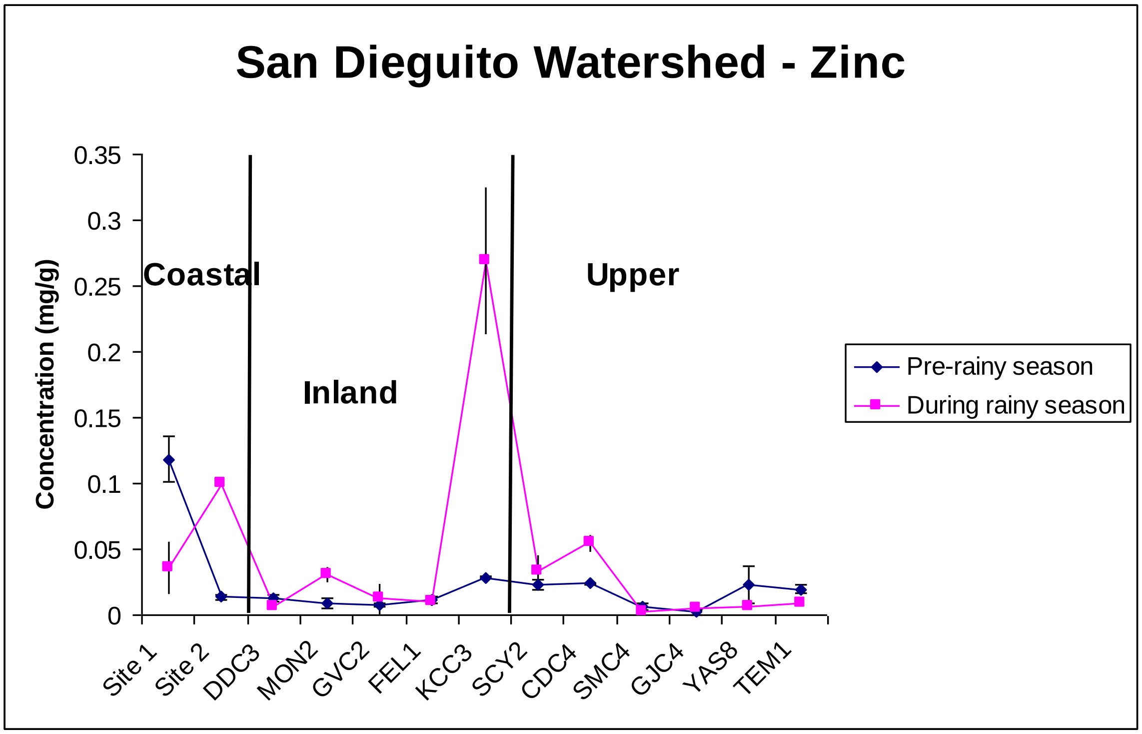

Figure 46: San Dieguito Watershed divided into the coastal, inland and upper sample sites – Zinc concentrations (mean ± SD) for pre-rainy and during rainy season

All metals except aluminum follow a similar pattern between the pre-rainy and during rainy season concentrations among sites in the San Diego watershed (Figures 47-52). The exceptions are Site 2 for Cu (which has a very large standard deviation), and Site 1, 2 and 6 for Zn (Figures 48 and 52). Aluminum concentrations in the San Diego watershed are consistently low at all sites during the pre-rainy season and then varies greatly during the rainy season (Figure 47).

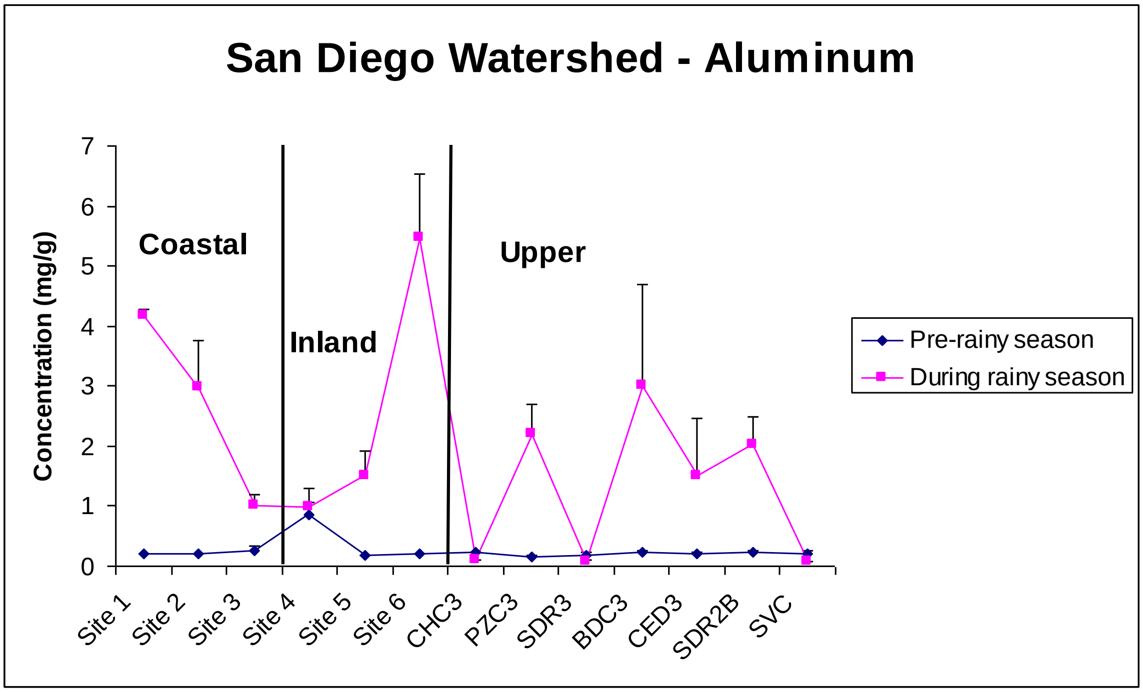

Figure 47: San Diego Watershed divided into the coastal, inland and upper sample sites – Aluminum concentrations (mean ± SD) for pre-rainy and during rainy season

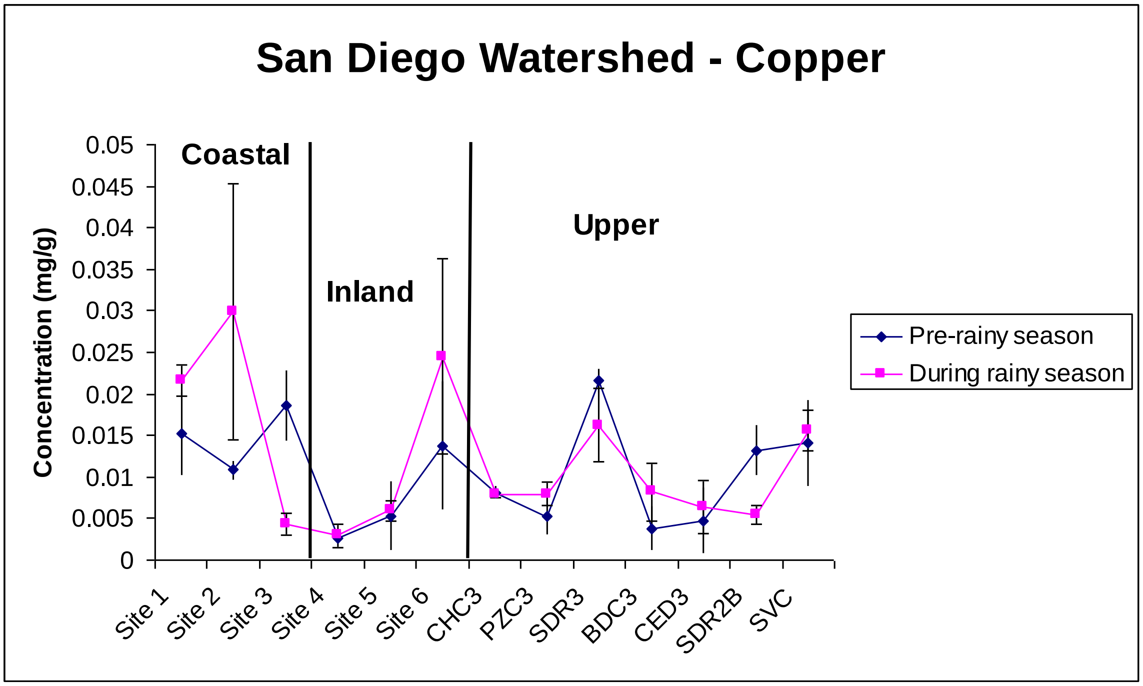

Figure 48: San Diego Watershed divided into the coastal, inland and upper sample sites – Copper concentrations (mean ± SD) for pre-rainy and during rainy season

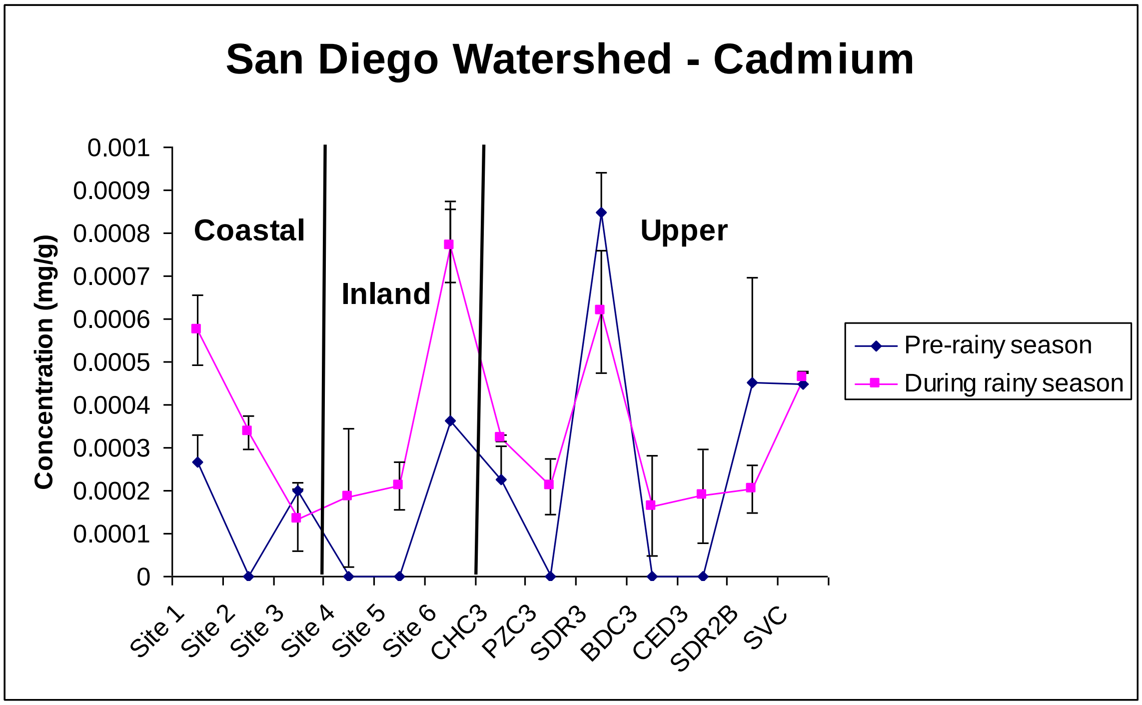

Figure 49: San Diego Watershed divided into the coastal, inland and upper sample sites – Cadmium concentrations (mean ± SD) for pre-rainy and during rainy season

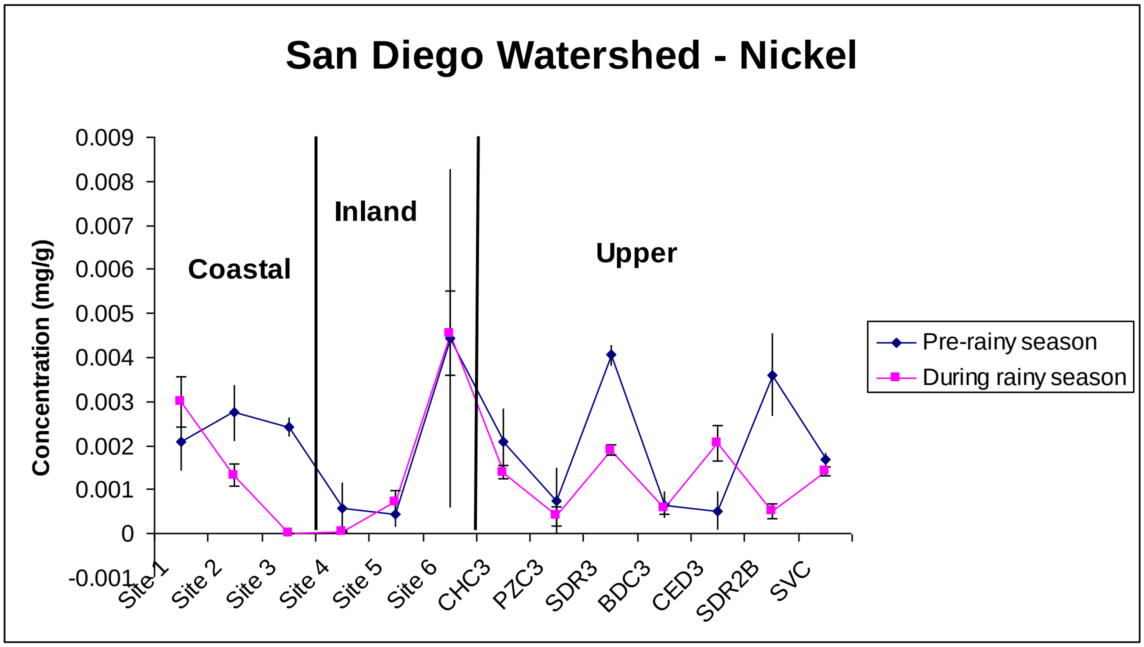

Figure 50: San Diego Watershed divided into the coastal, inland and upper sample sites – Nickel concentrations (mean ± SD) for pre-rainy and during rainy season

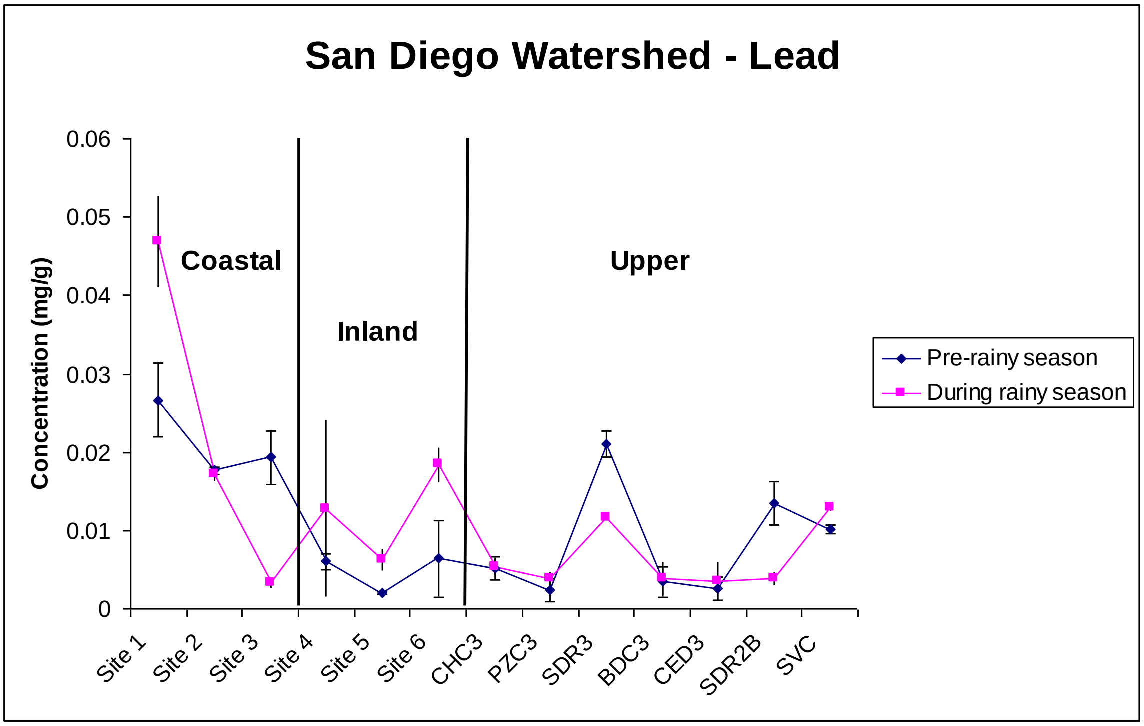

Figure 51: San Diego Watershed divided into the coastal, inland and upper sample sites – Lead concentrations (mean ± SD) for pre-rainy and during rainy season

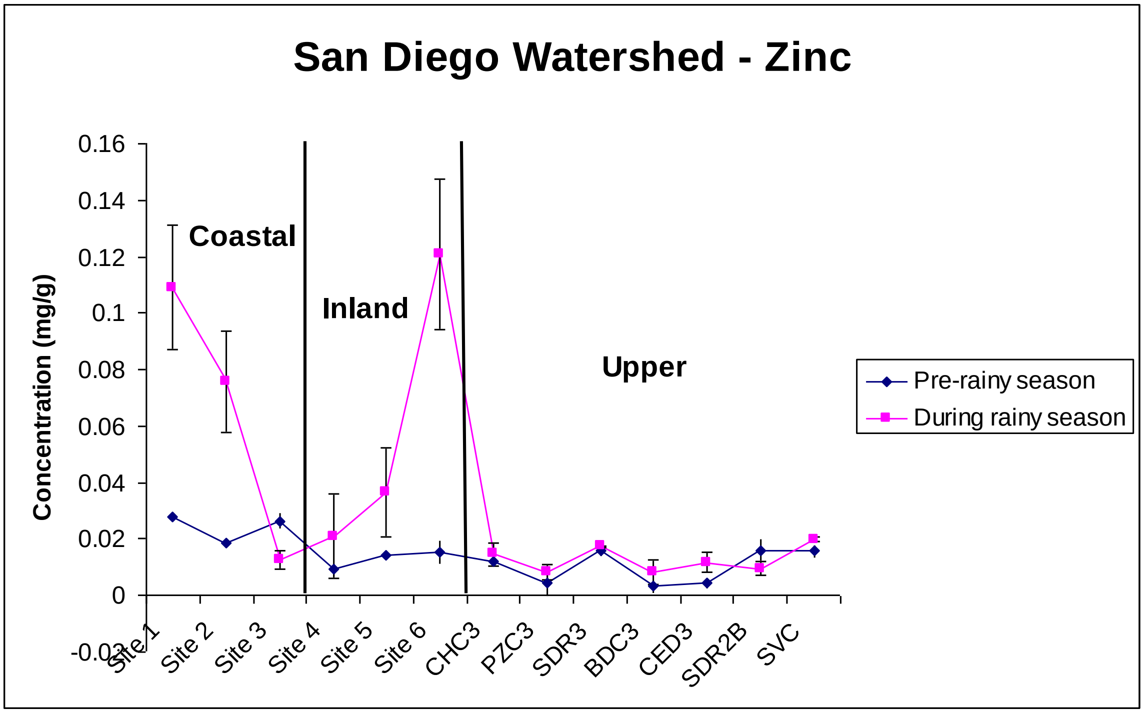

Figure 52: San Diego Watershed divided into the coastal, inland and upper sample sites – Zinc concentrations (mean ± SD) for pre-rainy and during rainy season

Survey

A total of 117 respondents started the survey and 103 respondents completed the survey. Respondents represented a wide range of age distributions as well as educational backgrounds (Figures 53 and 54). A majority of respondents were in the 20-25 age bracket (28.3%) followed by 41-50 year olds (20.5%) (Figure 53). A Bachelor's Degree (37.6%) among respondents was most common followed by a Master's Degree (28.2%) (Figure 54). A strong majority of respondents (79.4%) were aware of the increase in frequency and intensity of wildfires during the past 20 years (Figure 55) as well as the predicted increase that is expected due to climate change (67%) (Figure 56). Respondents overwhelmingly stated the priority of the environment at very high or quite high (83.3%) (Figure 57). Additionally, a majority of respondents (76.6%) were aware that contaminants can leach from a home's building material and the inhabitants belongings when burned (Figure 58). However, a significant portion of respondents (59.4%) were unaware of heavy metals being leached from organic material when burned (Figure 59). A little over half of respondents (56.2%) rated the importance of building infrastructure to examine soil and water quality after wildfires as very high or quite high (Figure 60). Furthermore, respondents favored the State of California and other environmental agencies to prioritize the integration of wildfire contamination issues into current watershed management practices (68.9%) (Figure 61).

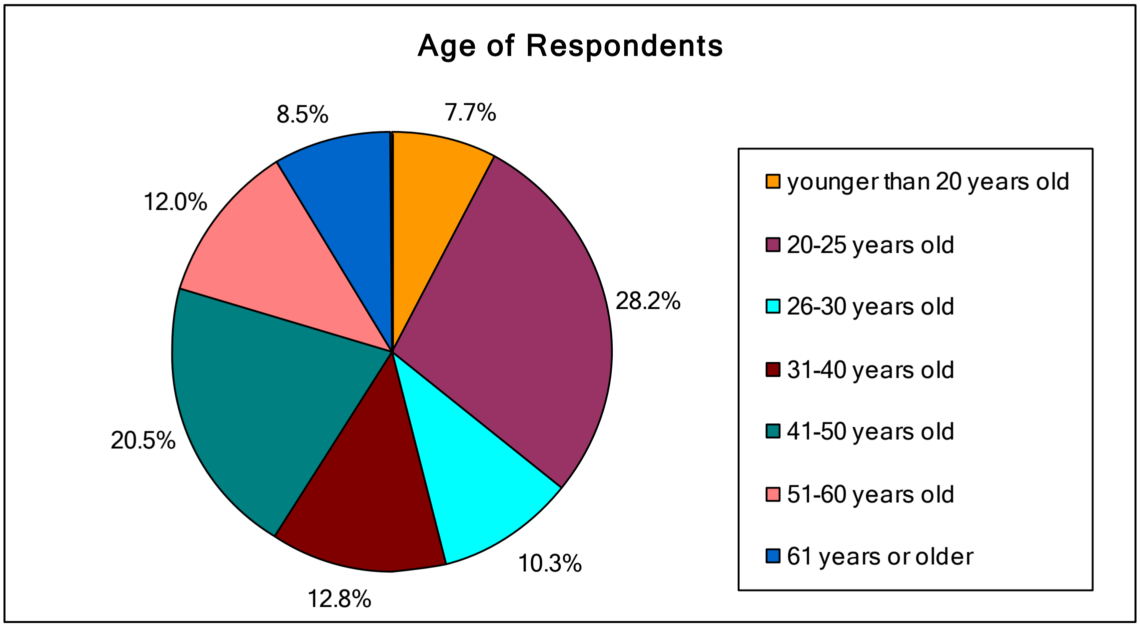

Figure 53: Age of Respondents

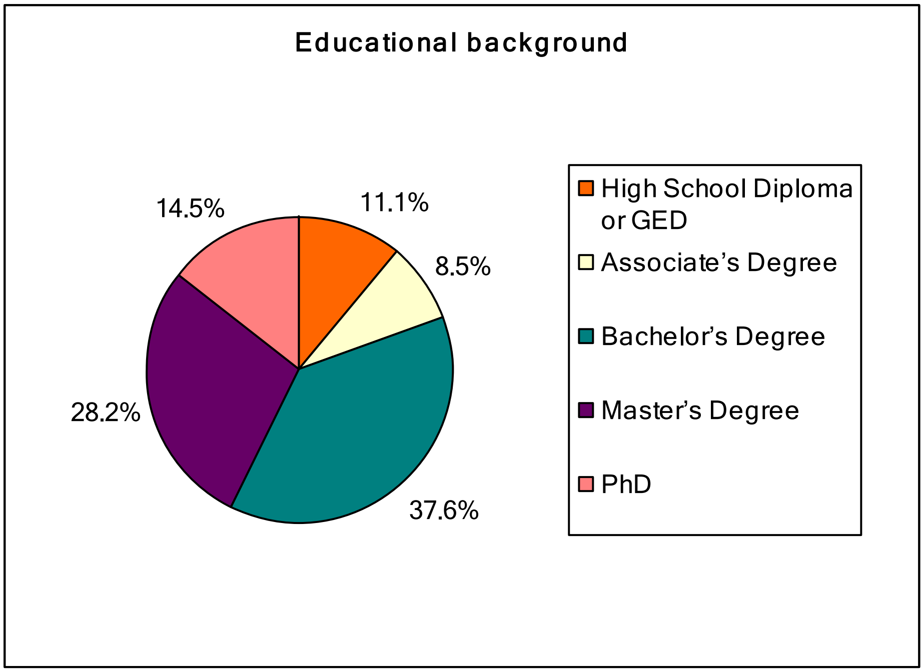

Figure 54: Educational Background of Respondents

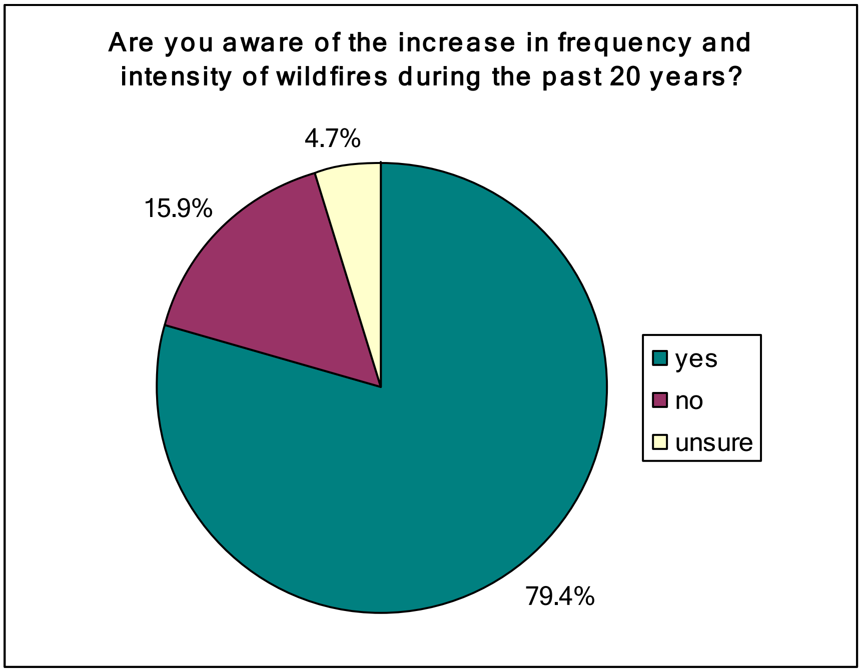

Figure 55: Awareness of the increase in frequency and intensity of wildfires

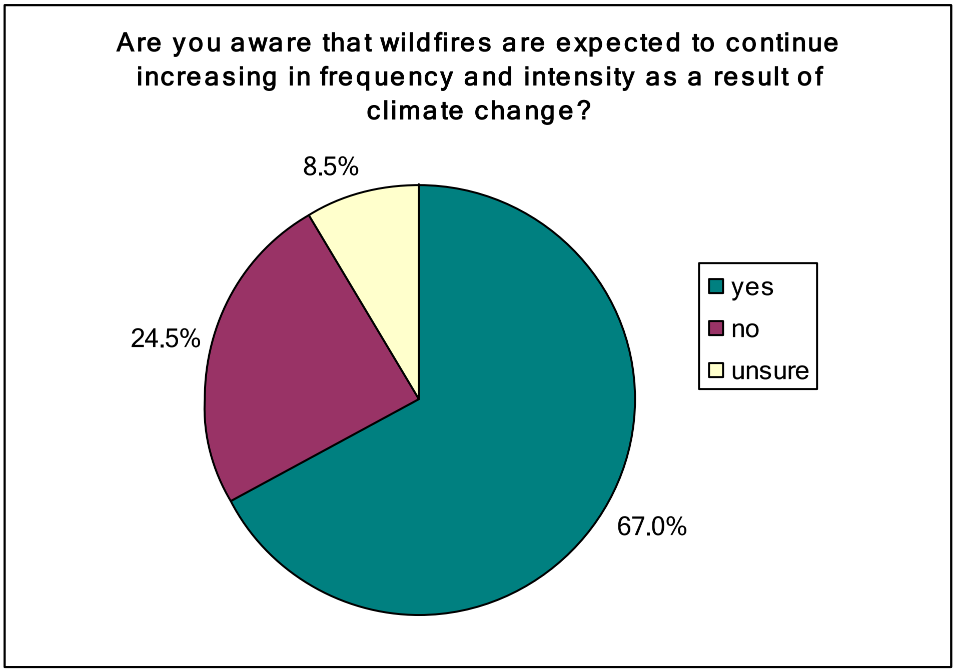

Figure 56: Awareness of the expected increase in frequency and intensity of wildfires

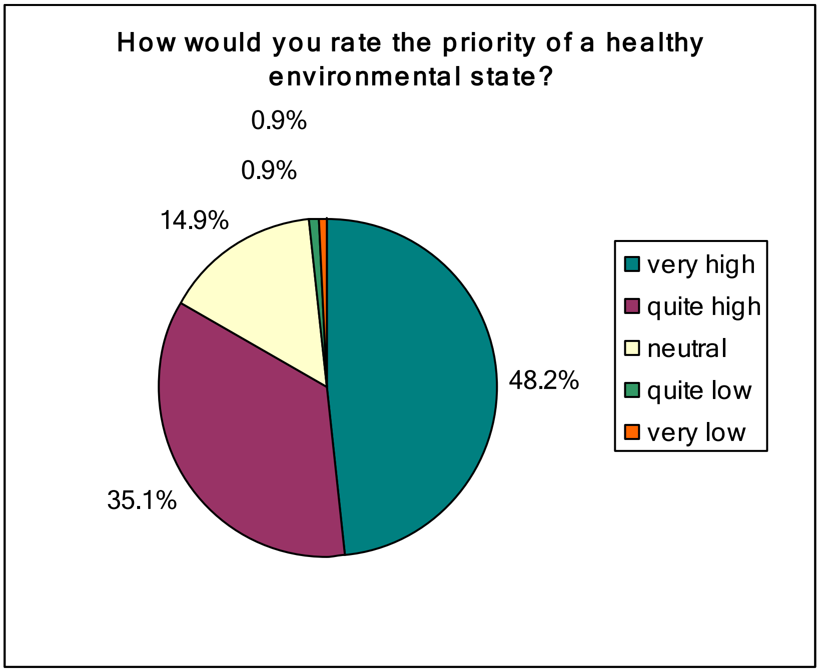

Figure 57: Respondent's priority of the environment

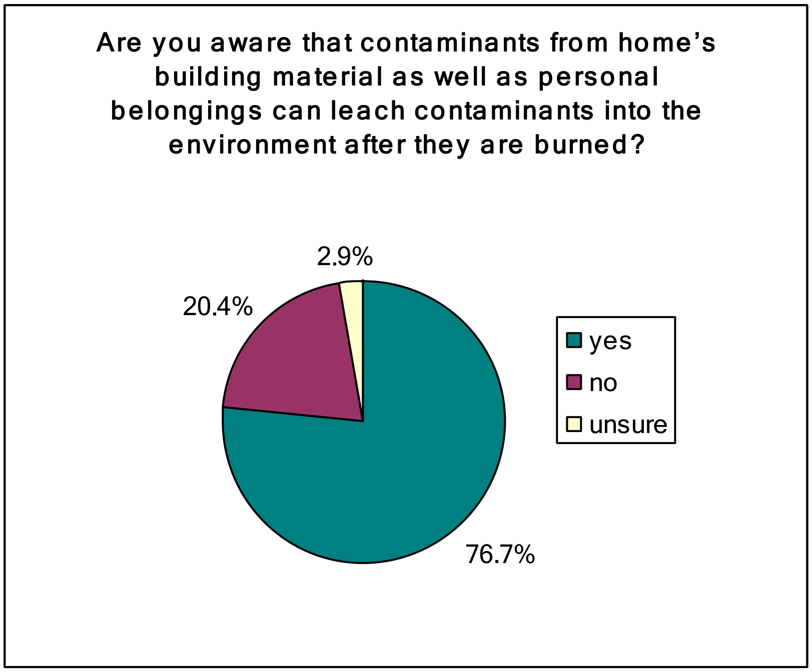

Figure 58: Awareness of possible contamination from anthropogenic sources

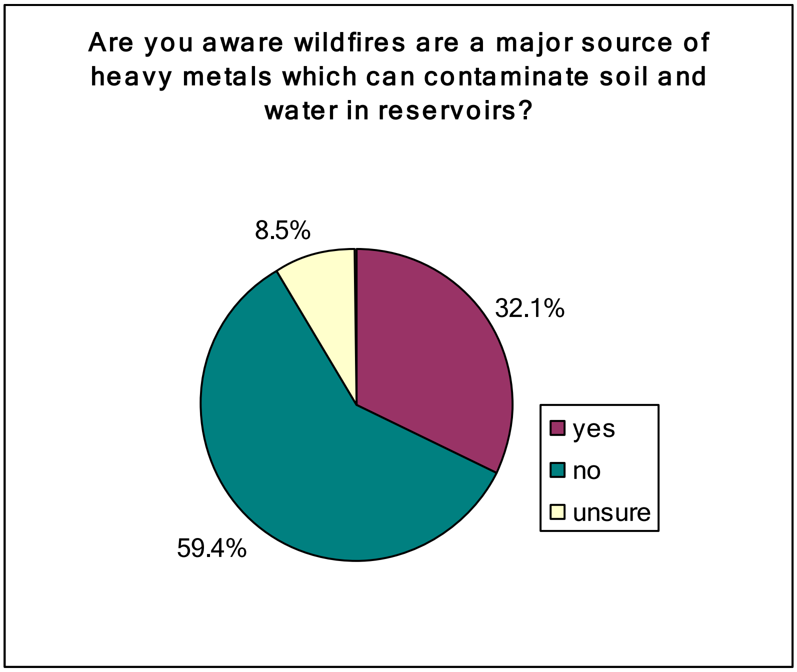

Figure 59: Awareness of wildfires as a source of heavy metal contamination

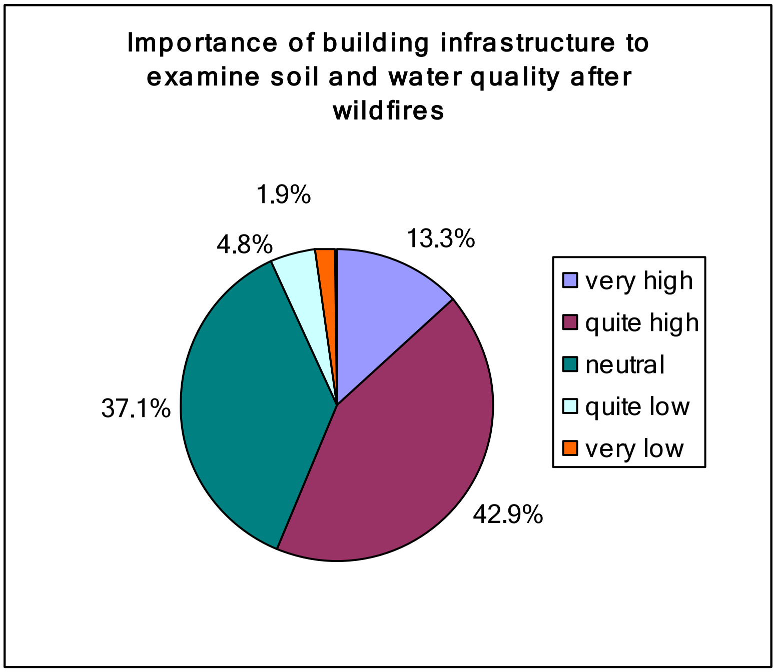

Figure 60: Respondent’s opinion on the importance of monitoring effects of wildfires

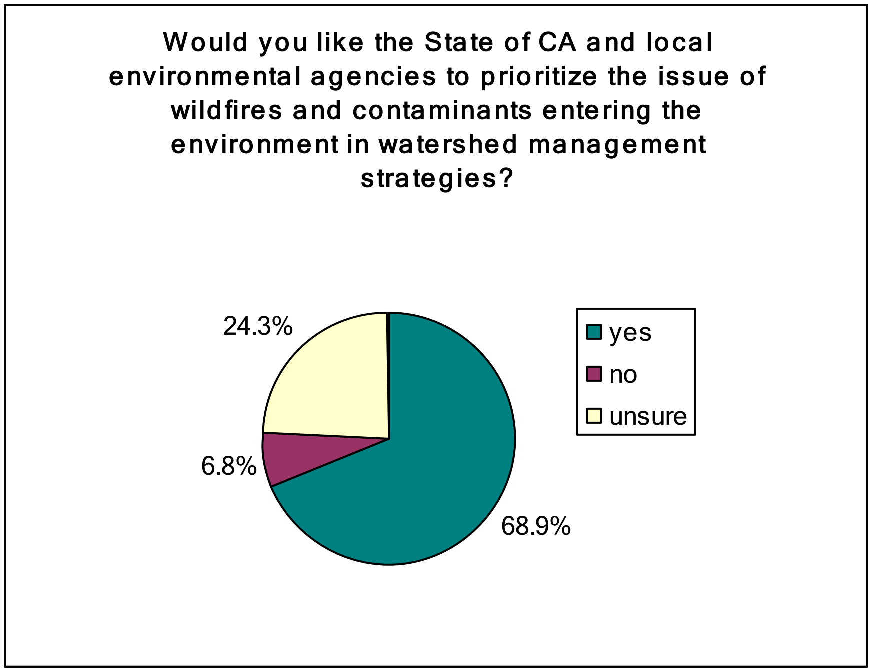

Figure 61: Respondent’s preference for the prioritization of wildfire issues into management

Discussion

Sediment Samples

Although concentrations varied between sites and metals, there was a noticeable difference between burned and unburned sites. However, there was no noticeable wildfire signature in metal concentrations. Therefore, this variation could be due to human impacts in different areas of the watershed rather than impacts from a wildfire. If a there was a wildfire signature, I would expect to see metal concentrations consistently higher at either burned areas or downstream from the burned areas. The figures do not show a pattern between burned and unburned sites which allows me concluded these metal concentrations are from various human impacts such as agriculture, industry, dumping and human presence in the watersheds.

The various human impacts vary in each watershed. The coastal and inland sites of the San Diego watershed are highly populated while the upper sites are less populated and dumping could be occurring in these remote areas contributing to some of the metal concentrations. The San Dieguito watershed’s coastal sites are surrounded by agriculture. There is a low population density in this area, but vegetation in these coastal sites are dense with very fine sediment possibly contributing to higher heavy metal concentrations as sediment is held in place well and not travelling as readily. The upper San Dieguito watershed is less populated where agriculture is dominant and dumping is not uncommon. The San Luis Rey watershed has little agriculture around the sample sites, but there is sparsely located human development around all sites.

Since this study includes burned areas as recently as 3 years ago, it can be concluded that sampling of soil and sediment should occur immediately following a wildfire. Plumlee et al. (2007) found that Zn and Cu increased significantly immediately following the 2007 wildfires in southern California. Therefore, we know that heavy metals can increase in concentration after wildfires, but there is no study to date showing how long this metal signature stays in the soil and sediment (Stein and Brown 2009). From this data, it can be concluded that the wildfire signature for this particular area is not measureable after 3 years.

An option to see a possible wildfire signature is to sample greater than 2cm below the surface. Sediment containing metals from the 2003 and 2007 wildfires could possibly be under sediment that has been transferred to the sites more recently.

This data also shows differences between pre-rainy and during rainy season concentrations. These trends differed between sites and metals. Some sites showed higher concentrations of metals during the rainy season while others showed higher concentrations of metals for the pre-rainy season. Overall, there is evidence that sediment is being moved around and transported down the watersheds during the rainy season.

Since the data shows sediment is moving around from one season to another, monitoring of heavy metal concentrations should be conducted in different seasons throughout the year. This monitoring will insure that the true metal signature in sediment is measured throughout the year.

The data also shows extensive variability of heavy metals within a given watershed. Coastal, inland and upper sites for each watershed were grouped according to the different human impacts and ecosystems within a given watershed. This variability is also shown among pre-rainy and during rainy season concentrations in addition to the variability within each watershed’s coastal, inland and upper watershed sites.

This variability in metal concentrations between burned and unburned areas justifies site or metal specific analysis. However, since not all metals showed the same signature in all sites or between seasons, it would be unnecessary to analyze all metals at all sites for every season.

There were notable differences between metals within a given watershed. Not all metals have the same signature in a watershed. Some metals (Cu, Cd, Ni, Pb and Zn) showed similar concentrations between the pre-rainy and during rainy season at a given site while aluminum varied quite drastically between seasons and sites. Therefore, it is possible that heavy metals are under a constant input source for each site except for the metal aluminum which could be variable as a result of a less constant heavy metal input such as dumping. The San Luis Rey watershed showed a lot more variation for all metals compared with the same metals in the San Dieguito and San Diego watersheds. However, this may be explained by the small number of sample sites for the watershed.

Another explanation of metal concentrations is sediment type at sample sites. The sediment influences the leachability, and therefore concentrations, of heavy metals at sample sites. Fine sediment holds onto metals better than coarse sediment which leaches metals into the environment more readily. Future studies resulting from this research include testing the different sites' granulometry for all sample sites' sediment.

Another factor to take into consideration for this study is that San Diego County experienced an El Niño year for this studies' rainy season. This may have increased the amount of sediment, and therefore metals, being transferred from one area of the watershed downstream. However, this may not be the case since most metals in the San

Dieguito and San Diego watershed showed fairly consistent concentrations across seasons for most metals.

Watershed managers have completely under-addressed the issue of heavy metal contamination from wildfires. As mentioned previously, there is evidence of increases in metal concentrations immediately following a wildfire. It is important for this topic to be integrated into management because of the possible health risk to humans.

Additionally, there are several reservoirs in remote areas of the county where the probability of a wildfire occurring are higher than in highly populated areas near the coast. Sediment travels into these reservoirs during rain events and could possibility contaminate drinking water. This poses a huge health hazard for residents all across the county. Moreover, this possible contamination of soil in areas where agriculture occurs could also transfer heavy metals from the soil to the crop adding yet another health hazard for residents. These are more reasons to monitor heavy metals in soil and sediment after a wildfire.

Recently, the Southern California Coastal Water Research Project (SCCWRP) held a workshop with other technical experts and stormwater managers in addition to experts from academia, government and the private sector. The goal of this workshop was to compile a report on the much needed research for monitoring post-fire water quality. This report focuses on three main management questions: how does post-fire runoff affect contaminant flux, what is the effect of post-fire runoff on downstream receiving waters, and what are the factors that influence how long post-fire runoff effects persist. This document also includes the implementation of a plan to address these questions and a funding strategy. The report was sent to all watershed managers of governmental agencies. Even after the report was distributed, there is and will be ongoing development in a coordinated effort through a working group that includes the US Forest Service, US Geological Survey, CAL FIRE, regional water quality control boards, major municipalities, key landowners and local researchers.

Survey

It can be inferred from the survey that a majority of southern California residents are aware of the recent increase in wildfire frequency and intensity as well as the predicted continuing increase due to climate change. Interestingly, survey respondents seemed to be aware of the effects from the burning of home building materials in regards to the leaching of contaminants into the environment. However, this survey also showed there is a large gap in southern California resident’s knowledge of the long-term effects of wildfires such as the possible leaching of heavy metals into the environment.

As a result, residents, especially remote residents, should be educated about the possible contamination of heavy metals from wildfires. Since most residents seem to be educated about the possible harmful effects from the burning of home building material and personal belongings they should be aware of this contamination issue. With the expected continuing frequency and intensity of wildfires, re-building year after year in these burned areas could prove to be harmful for humans.

It also can be concluded, from the survey, that most southern California residents would like infrastructure built to examine soil and water quality after wildfires. However, most respondents stated a high preference for environmental health, and this may not be the case for all residents in southern California. A strong majority of respondents favored the State of CA and other environmental agencies integrating wildfire contamination issues into current watershed management practices. This integration would be a lot less costly than building infrastructure and therefore more favorable among most southern California residents especially with the increase in wildfire frequency and intensity continuing into the future.

Conclusions

Sampling of soil and sediment should ideally begin immediately after a wildfire occurs. Residents need to be informed about the leaching of heavy metals from organic material after a wildfire. With the predicted continuing increase in wildfire frequency and intensity, it is extremely important to address this issue. Residents also need to be informed of the possible harmful consequences of living in frequency burned areas especially residents in remote locations of the county where wildfires are more likely to occur. If infrastructure is not built to address these issues, there needs to be some integration of wildfire contamination issues into current watershed management practices.

Acknowledgements

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Appendix I: Survey Questions

1. What is your professional background?
    - 1= Scientist/Researcher
    - 2= Student
    - 3= Law
    - 4= Business
    - 5= Other
2. Does your area of expertise involve quality of water or soil and/or watershed management?
    - 1= yes
    - 2= no
    - 3= unsure
3. What is your annual income?
    - 1= less than $30,000
    - 2= $30,000 - $50,000
    - 3= $50,000 - $70,000
    - 4= $70,000 - $100,000
    - 5= greater than $100,000
    - 6= prefer not to answer
4. What is your age?
    - 1= younger than 20 years old
    - 2= 20-25 years old
    - 3= 26-30 years old
    - 4= 31-40 years old
    - 5= 41-50 years old
    - 6= 51-60 years old
    - 7= 61 years or older
    - 8= prefer not to answer
5. What is your educational background?
    - 1= No High School diploma or GED
    - 2= High School Diploma or GED
    - 3= Associate's Degree
    - 4= Bachelor's Degree
    - 5= Master's Degree
    - 6= PhD
6. Do you live in an area which has a probability of wildfires burning your home?
    - 1= yes (answer Question #6)
    - 2= no
    - 3= unsure
7. Has your property experienced damage from a wildfire?
    - 1= yes
    - 2= no
    - 3= unsure

8. Do you consider the state of the environment a priority?
    1= very high
    2= quite high
    3= neutral
    4= quite low
    5= very low
9. Do you know the definition of a watershed?
    1= yes
    2= no
    3= unsure
10. How would you rate the importance of building infrastructure to examine soil and water quality after wildfires?
    1= very high
    2= quite high
    3= neutral
    4= quite low
    5= very low
11. Are you aware that wildfires have been increasing in frequency and intensity during the past 20 years?
    1= yes
    2= no
    3= unsure
12. Are you aware that wildfires are expected to continue increasing in frequency and intensity as a result of climate change?
    1= yes
    2= no
    3= unsure
13. Do you believe that climate change is occurring?
    1= yes
    2= no
    3= unsure
14. Are you aware that vegetation burned during wildfires can release many heavy metals into the environment?
    1= yes
    2= no
    3= unsure
15. Are you aware that wildfires are a major source of heavy metals, such as zinc and mercury, being released into the environment which in turn can contaminate soil and water in reservoirs?
    1= yes
    2= no
    3= unsure

16. Are you aware that soil burned in wildfires areas contains high levels of contaminants that can leach, even months and maybe years after the wildfire?
    1= yes
    2= no
    3= unsure
17. Are you aware that contaminants from home's building material as well as personal belongings can leach contaminants into the environment after they are burned?
    1= yes
    2= no
    3= unsure
18. Are you aware that contaminants which run into rivers and streams can reach the ocean?
    1= yes
    2= no
    3= unsure
19. Are you aware that heavy metals entering rivers and streams can transfer into fish and other wildlife?
    1= yes
    2= no
    3= unsure
20. Are you aware that erosion in recently burned areas can carry heavy metals and other contaminants into rivers and streams eventually entering into the ocean?
    1= yes
    2= no
    3= unsure
21. Would you like the State of CA and local environmental agencies to prioritize the issue of wildfires and contaminants entering the environment in watershed management strategies?
    1= yes
    2= no
    3= unsure
22. Chemicals are frequently used to help put out wildfires, in addition to water, despite their high toxicity. Do you think that the benefits of controlling the fire outweigh the costs of contaminating the environment with chemicals?
    1= yes
    2= no
    3= unsure
23. Were the questions in this survey clear and concise?
    1= yes
    2= no
    3= unsure

24. If you were aware of the impacts wildfires have on the environment, where did you get your information from?
    - 1= Internet
    - 2= Newspaper
    - 3= Television
    - 4= School
    - 5= Other
    - 6= Not aware
25. Were the questions in this survey beneficial to your understanding of the contamination occurring in the aftermath of wildfires?
    - 1= yes
    - 2= no
    - 3= unsure

Figure 1: Burned areas and sediment sample sites