Sequential extraction of metal(loids) in agricultural field soils impacted by Animas/San Juan River after the 2015 Gold King Mine Spill

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Metal laden contaminated water spilling out from the Gold King Mine on August 5, 2015

INTRODUCTION

On August 5, 2015, three million gallons of acidic, metal-laden water was accidentally released into the Animas River from the Gold King Mine (GKM). The spill impacted the cultivation of agricultural crops all across the watershed when irrigation ditches were closed for several weeks while the contamination moved downstream. While contamination from this one event may not have reached the closed irrigation ditches and fields, legacy mining that may have released metals into the watershed over the last 150 years may be affecting the soils.

The metals carried by the Animas and San Juan Rivers to the irrigation ditches and into the fields may become adsorbed or undergo various chemical reactions in the soil matrix over the course of time. Large areas of the Animas and San Juan River watershed lies in the Navajo Nation and the tribe uses soil and water not only for cultivation but for ceremonial purposes. A large number of farmers in the Animas watershed cultivate alfalfa (Medicago sativa) and cucurbitaceous vegetables using the water from irrigation ditch system. Thus, it is important to know whether these metals are toxic to plants and environment. These metal(loid)s may be present in the soil in different forms or species that have varying toxicity or bioavailability. Ion exchange, surface complexation and precipitation mechanisms all contribute to the availability and toxicity of different metal species. These mechanisms are influenced by clay and organic matter content, pH, redox and concentration. According to the study in the Animas river watershed by Rodriguez-Freire et al. in 2016 the solubility of jarosite at near-neutral pH and biogeochemical processes that occurs downstream affects the remobilization of metals in sediments. Manganese (Mn) and iron (Fe) oxides have a high adsorption affinity for heavy metals like Arsenic (As) that binds as inner-sphere mono and bi dentate surface complexes (Arcon et al.

2005). Arsenic sorption in soil is mainly controlled by the content and nature of the iron oxides and hydroxides (Alloway 2012).

This study focuses on determining the total concentration and water soluble, exchangeable fractions of arsenic in agricultural field soils irrigated by Animas and San Juan River water. Water soluble and exchangeable fractions significantly contribute to the bioavailable or plant available fractions. Thus, it is important to determine the concentrations of metals in these fractions as compared to the total concentrations.

MATERIALS AND METHODS

Site description and features

The study was conducted in agricultural fields irrigated by river water in Animas watershed of New Mexico. The Animas River flows from Colorado and enters into New Mexico where it joins the San Juan River in Farmington (NM) before entering the Navajo Nation. The geologic setting of this region is a result of multiple episodes of hydrothermal activities that produced widespread areas of pyrite alterations and quartz-pyrite-metal veins (Church *et al*, 2007). Two fields irrigated by water from Upper Animas and San Juan rivers respectively, were selected to monitor the metal contaminations. These farm fields were evaluated as part of this study in January of 2017 to reflect the growing season of 2016. One field was located in the upper region of the watershed and was irrigated by the Animas River water. The second field was located in the lower watershed area, irrigated by San Juan River water. Alfalfa is grown on the field located in the Upper Animas area and cucurbitaceous vegetables were grown on the field in the San Juan River area. Soils in the fields were classified as at an elevation between 1400 to 1700 m above sea level. In order to keep the identity of landowners anonymous, the exact coordinates of these fields are not provided in this public report.

Field Sampling

Using a random sampling scheme, 150 points (75 points X 2 fields) was established using ArcGIS (ESRI, The Redlands, CA, USA). These points were downloaded into an eTrex (Garmin, Olathe, KS, USA) handheld global positioning receiver. The in-situ analysis of metal(loid) concentration data in the field was done using the Delta Premium 6000 portable X-ray fluorescence (PXRF) spectrometer (Olympus, Waltham, MA, USA) (Weindorf and Chakraborty, 2016). The instrument was calibrated using a stainless steel alloy chip prior to the field scanning. The instrument was operated in *Soil Mode* at 30 seconds per beam for three beams completing 90 seconds for each point scanned. Any organic material, stones or pebbles or any pointed surface was scraped prior to the scan. Surface soils were scanned and the results of the instrument were validated by using a silica blank and National Institutes of Standards and Technology (NIST) certified reference materials (e.g. NIST 2711a and NIST 2710a). Additionally, soil samples were collected from the surface (0-7.5 cm) of the agricultural fields using the stainless steel auger at every 10^{th} point in the field to verify the results in laboratory using acid digest and Inductively Coupled Plasma (ICP) analysis.

Spatial and statistical analysis of total metal(loid) concentration

The spatial distribution of elemental concentrations analyzed using PXRF were mapped using Kriging interpolation in ArcGIS for those metals that showed exceedances above the Residential Screening Level (RSL) in the samples analyzed. Statistical analyses were done using SAS Version 9.4 software (SAS Institute, Cary, NC). Correlation function was performed to determine the strength of relationship (correlation coefficient) between pXRF and ICP based analysis of metal(loid)s in validation samples (n=104) collected in the agricultural fields all across Animas and San Juan watershed.

Laboratory analysis

The laboratory study was facilitated (a) to determine the total concentrations of metal(loid)s of interest and compare with PXRF results and (b) to determine the plant available fraction (assumed to be represented by water soluble and exchangeable fractions) in soils using partial sequential extraction methods (reference).

Total metal concentrations of soil samples were analyzed using EPA Method 3051A (microwave assisted acid digestion of sediments, sludges, soils, and oils). Briefly, 0.5 grams of air-dried sediment were mixed with nine milliliters (mL) of concentrated nitric acid and three mL of concentrated hydrochloric acid within Teflon reaction vessels and digested using a Microwave Accelerated Reaction System at 90 bars of pressure and 200 degrees Celsius temperature (USEPA, 2007). A quality control (NIST 8704 or 2711) and blank were included in each batch of samples digested. All quality control samples fell within the 90-110% acceptance range of the known value for total metal concentration. Digested solutions were filtered through Whatman #2V filter paper, triple-rinsed with deionized (DI) water, then brought to 100 mL volume with DI water for analysis of total metals. Soil digests were analyzed for nine elements of interest (Al, As, Ca, Cr, Cu, Fe, Mn, Pb, Zn) using SW-846 Method 6010D Inductively Coupled Plasma (ICP) technology. It was also determined that As would be analyzed using ICP-MS for better accuracy and detection of lower concentrations of As in samples. All but As was analyzed using an Optima 4300 Dual View Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES; Perkins-Elmer, Waltham, MA), also referred to as Inductively Coupled Plasma/Optical Emission Spectrometry (ICP-OES). Total As was analyzed using a Perkin Elmer Elan DRC-e ICP-Mass Spectroscopy (ICP-MS; Perkin Elmer, Waltham, MA). Because As was the only metal(oid) in excess of regulatory limits, the soil samples were analyzed using the first steps of the partial sequential extraction procedure developed by Tessier *et al.* (1979) to determine As concentrations in the water soluble and exchangeable fractions of the soil. Triplicates of 2 g of soil samples were weighed into the Falcon centrifuge tubes. Ten mL of deionized water was added to the samples and was shaken in the mechanical shaker for 1.5 hours. The samples were then centrifuged in centrifuge machine (diameter 254 mm) at 6000 rpm (12,000 g) for 30 minutes. The supernatant was decanted and analyzed for As using the ELAN DRC-e ICP-MS by following the EPA Method 200.8. This determined the water soluble fraction in soil samples. In the next step, 16 mL of 1 M magnesium chloride (pH 7.0) were added to the soil residue, shaken and centrifuged at 6000 rpm for 30 minutes. The supernatant was analyzed as in the first step providing the. exchangeable fraction of As in the soil.

RESULTS AND DISCUSSIONS

Soil properties

Soils in the two fields were classified as Fruitland sandy loam (Coarse-loamy, mixed, superactive, calcareous, mesic Typic Torriorthents) and Fruitland sandy clay loam (Coarse-loamy, mixed, superactive, calcareous, mesic Typic Torriorthents) soil series, respectively for alfalfa field irrigated by Animas river water and vegetable field irrigated by San Juan river water. The soil properties measured in the laboratories for reference are shown in *Table 1*. The soil pH in alfalfa field was neutral while that in the vegetable field was alkaline. Organic matter (OM), potassium (K) and phosphorus (P) content were higher in alfalfa field compared to vegetable field. However, electrical conductivity (EC), sodium adsorption ratio (SAR) and nitrate-nitrogen (N) content were higher in vegetable field.

Table 1. Basic soil properties of alfalfa (A) and vegetable (V) fields

Field	pH	EC (dSm^{-1})	OM (%)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	SAR
A	7.0	0.49	2.02	10.2	48.0	47.3	0.38
V	8.1	3.30	0.99	32.6	5.22	37.3	1.12

Validation of PXRF in-situ field scans vs. laboratory analysis

PXRF is a rapid and in-situ analysis of metal contaminants (USEPA 6200). Therefore, it is always important to validate the results using laboratory analysis of representative samples specific to the region. The samples analyzed in the laboratory using the ICP showed moderate to strong correlation with in-situ field scanned PXRF metal concentration results. The correlation coefficient depicting the strength of linear relationships between two methods used to analyze the samples are shown in Table 2. Calcium concentration measured by both the methods shows strongest correlation with a coefficient of 0.96 while lowest coefficient 0.80 for manganese shows moderate correlation. The PXRF vs. ICP correlation coefficient for arsenic (0.88) and lead (0.89) were fairly strong, while the correlation coefficient for iron (0.82), zinc (0.82) and copper (0.81) were moderately strong.

The strength of correlation obtained for validating PXRF results with ICP analyzed samples for Animas watershed affirms the use of PXRF for in-situ analysis in field soils. Other researchers have reported higher correlations between ICP-OES and PXRF measurements but they had prepared the samples similarly including air drying, grinding and sieving to a uniform particle size (Rouillon and Taylor, 2016). Field scanning is not as accurate, but still provides a robust, low-cost estimate of metal concentration and distribution (Weindorf et al., 2013). The sample results from PXRF were also within 20 percent of the NIST 2710a and 2711b standards, measured at the end of each field study.

Table 2. Validation of metal concentration data analyzed using PXRF and ICP (n=104 points) across Animas watershed

Element	Instrument	Correlation coefficient (r^2)	Minimum	Maximum
Arsenic	ICP-MS	0.87945	2.75	14.79
	PXRF		2.70	13.00
Iron	ICP-OES	0.82335	7577	27320
	PXRF		5585	32683
Manganese	ICP-OES	0.80524	135	746
	PXRF		132	1005
Lead	ICP-OES	0.89598	6.23	124.8
	PXRF		7.90	121.0
Zinc	ICP-OES	0.81941	30.84	323.7
	PXRF		36.90	401.0
Calcium	ICP-OES	0.96076	2198	37770
	PXRF		2110	45330
Copper	ICP-OES	0.80864	8.52	51.01
	PXRF		8.30	65.00

Total metal(loid) concentrations in agricultural fields

The descriptive statistics (mean, standard deviation, minimum and maximum) of heavy metal(loids) analyzed using PXRF by scanning 150 points in two fields are shown in table 3. The mean metal concentrations (mg kg^{-1}) of respective metal(loids) of interest in the two fields averaged can be ranked in the order calcium > iron > manganese > zinc > lead > copper > arsenic. The soils in the two fields appear to be calcareous meaning they contain calcium carbonate. The average concentration of calcium in field soils irrigated with San Juan river water is comparatively seven-folds higher than the soils collected and analyzed from agriculture field irrigated by Animas river water. This can be attributed to the fact that the location of field further downstream tends to accumulate higher amounts of calcium carbonate that come along with the river water. As the soils erode into the rivers or irrigation channels they release some calcium (Briggs and Ficke, 1977).

Historically, the high concentrations of iron and manganese in the region have also been reported by the geologists in several other studies. Iron-rich groundwater deposits have infiltrated after pyritic weathering (Yager et al., 2003; Yager and Bove, 2007; Wirt et al., 2007) through the mineral deposits with polymetallic base (copper-lead-zinc and copper-arsenic-antimony) predominant in Silverton and San Juan calderas in the Animas watershed (Varnes, 1963; Casadevall and Ohmoto, 1977). According to Church and coworkers (2007), the geologic alterations of quartz-serite-pyrite deposits have substantially contributed to the loads of manganese and zinc across the Animas watershed. These metal loads moved downstream with the flow of river water.

Table 3. Descriptive statistics (mean, standard deviation, minimum and maximum concentrations) of metal concentration (in mg kg^{-1}) in alfalfa field (A) and vegetable field (V) scanned at 75 points per field using PXRF

Field		Ca	Mn	Fe	Cu	Zn	As	Pb
	RSSL*	N/A	1800	55000	3100	23000	7.07**	400
A	M	5399	313.65	15886	14.10	56.51	4.09	24.79
	SD	2259	65.64	2724	3.70	14.92	1.30	9.90
	Min	3317	218.00	11058	7.00	25.60	2.50	12.40
	Max	18049	569.00	27721	27.80	106.00	8.60	59.70
V	M	36926	305.00	21824	20.63	70.09	7.36	17.04
	SD	6602	50.19	3809	3.75	9.73	1.51	3.10
	Min	23106	162.00	9468	11.00	46.00	4.70	9.00
	Max	59583	412.00	27245	28.00	99.00	11.3	25.00

*RSSL-Residential Soil Screening Level (US Environmental Protection Agency recommendations except Arsenic); **As per New Mexico Environment Department (2017)

The mean values of PXRF scanned metal(loid) concentrations (Table 3.) for the two fields were below the EPA or NMED residential soil screening level (RSSL) values. However, on monitoring the range for each metal(loid), the maximum value for arsenic exceeded the NMED RSSL of 7.07 mg kg^{-1}. These regions of exceedances or hotspots indicates the presence of at least one or more sampling point(s) where the arsenic concentrations are above the RSSL value.

Spatial distribution of total arsenic in agricultural fields

The apportionment of arsenic distribution in the studied areas were analyzed by the spatial distribution of total arsenic (mg kg^{-1}). The spatial maps interpolated by Kriging interpolation technique using known concentration values of arsenic at 75 points scanned using PXRF are shown in figure 1 (A.) and (B.) for the two fields irrigated using Animas and San Juan river waters respectively. The Kriging maps are indication of estimated concentration of arsenic in fields based on interpolation of scanned points in close proximities. It is based on the prediction of concentrations at unknown locations in the field based on interpolating the known values from scanned points by in-situ field analysis.

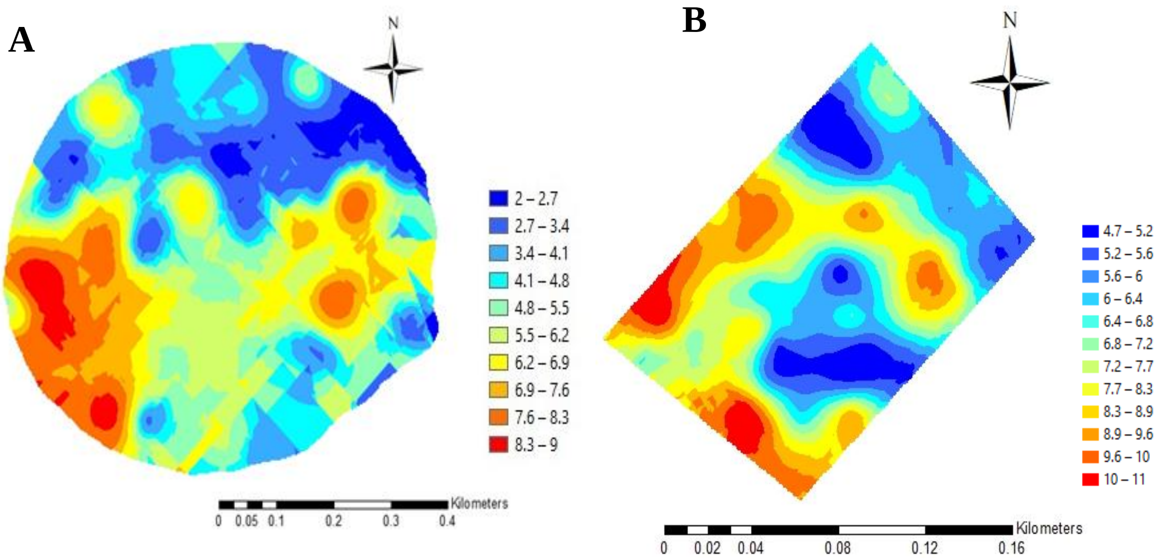

Figure 1. Spatial Distribution of As (in mg kg^{-1}) in agricultural fields irrigated by (A.) Animas and (B.) San Juan river waters respectively

In figure 1. spatial map A. reflects the spatial distribution of arsenic in field irrigated by Animas river under pivot irrigation system. However, spatial map B. demonstrates the distribution of arsenic in field irrigated by San Juan river water under furrow irrigation system with water entering the field from north east direction towards the south west direction. The distribution indicates the accumulation of arsenic in regions of lower elevation in the two fields. In map B. the furrow irrigation system may tend to mobilize the metalloid towards the rear end of the field. These hotspots of arsenic were not evenly spread in the fields, but located to specific regions in the two fields. On closely observing the range values in the legends of figure 1. (A.) and (B.) they differ in their extent. Hotspots of map (A.) ranges from 7.07 mg kg^{-1} to 9 mg kg^{-1}. However, for map (B.) the maximum value exceeds to 11 mg kg^{-1}.

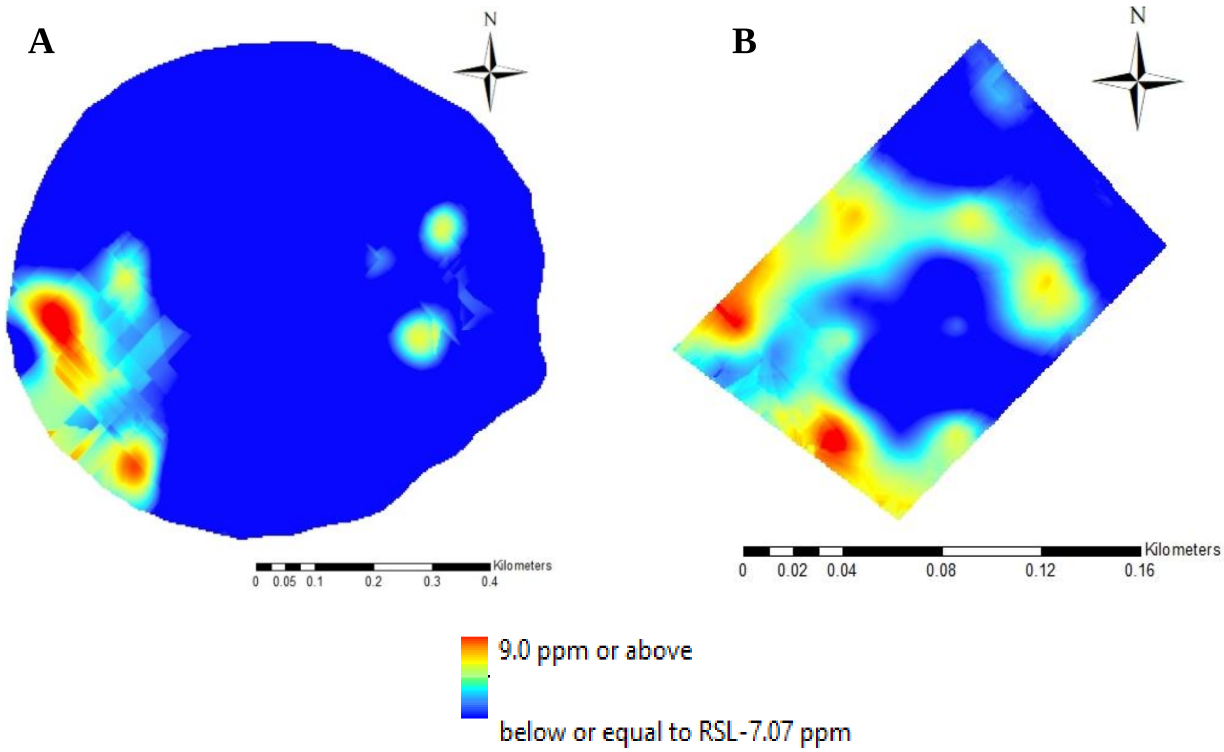

Figure 2. Comparison of hotspots between alfalfa field (A) and vegetable field (B)

In order to more effectively display the hotspots of arsenic in the two fields, the spatial maps were *stretched* to the same scale of concentrations and the range values were simplified as shown in figure 2. Any concentration below or equal to 7.07 mg kg^{-1} were shown in dark blue color. Any concentration above this value but below 9 mg kg^{-1} were shown in range of color legend from light blue to orange. The region predominantly shown with red were concentration of higher arsenic in fields and exceeding the value of 9 mg kg^{-1}. The range 9 mg kg^{-1} was selected in the *stretch* because the maximum value of total arsenic concentration in field irrigated with Animas river water is 8.6 mg kg^{-1}.

Bioavailable fractions of metal(loids) in agricultural fields

The total concentrations of arsenic observed to exceed the RSSL value can be dangerous if the plants grown in the fields uptake the available arsenic in high amounts. Arsenic accumulated in leaf tissues of alfalfa can be dangerous for cattle, while those accumulated in vegetable leaf tissue possess risk of being translocated to the edible parts. However, the plants uptake nutrients from soil in their available forms. The bioavailability of metal(loid)s refers to water-soluble and exchangeable fractions. These fractions can be mobilized easily and can be taken up by plant roots (Intawongse and Dean, 2006; Peralta-Videa et al. 2009).

Table 4. Total, water soluble and exchangeable arsenic concentrations (mg kg^{-1}) in sequentially extracted soil samples in field A irrigated by Animas river water and field V irrigated by San Juan river water.

Field		Total As (ICP-MS)	Water soluble As	Exchangeable As
A	M	7.35	0.054	0.224
	SD	1.09	0.013	0.107
	Min	5.62	0.032	0.144
	Max	8.64	0.074	0.450
V	M	11.42	0.018	0.176
	SD	1.74	0.002	0.037
	Min	9.65	0.014	0.135
	Max	14.79	0.021	0.248

The descriptive statistics (mean, standard deviation, minimum and maximum) for total, water soluble and exchangeable arsenic analyzed in randomly collected field samples from two fields are shown in table 4. The mean value of total arsenic in 14 representative samples from two fields exceed the RSSL value of 7.07 mg kg^{-1} for both the fields.

Contrary to the total concentration, water-soluble and exchangeable fractions are significantly lower. The order of metal concentrations includes total > exchangeable > water-soluble. These concentrations are very low for accumulation to the plant tissue. Therefore, extremely small fraction of total metal concentration contributes to water soluble and exchangeable fractions (figure 3). Other fractions that are bound to carbonates, organic-matter, silicate etc. present in the soil matrix are transformed to water-soluble or exchangeable forms under favorable physicochemical conditions (Brallier et al.1996).

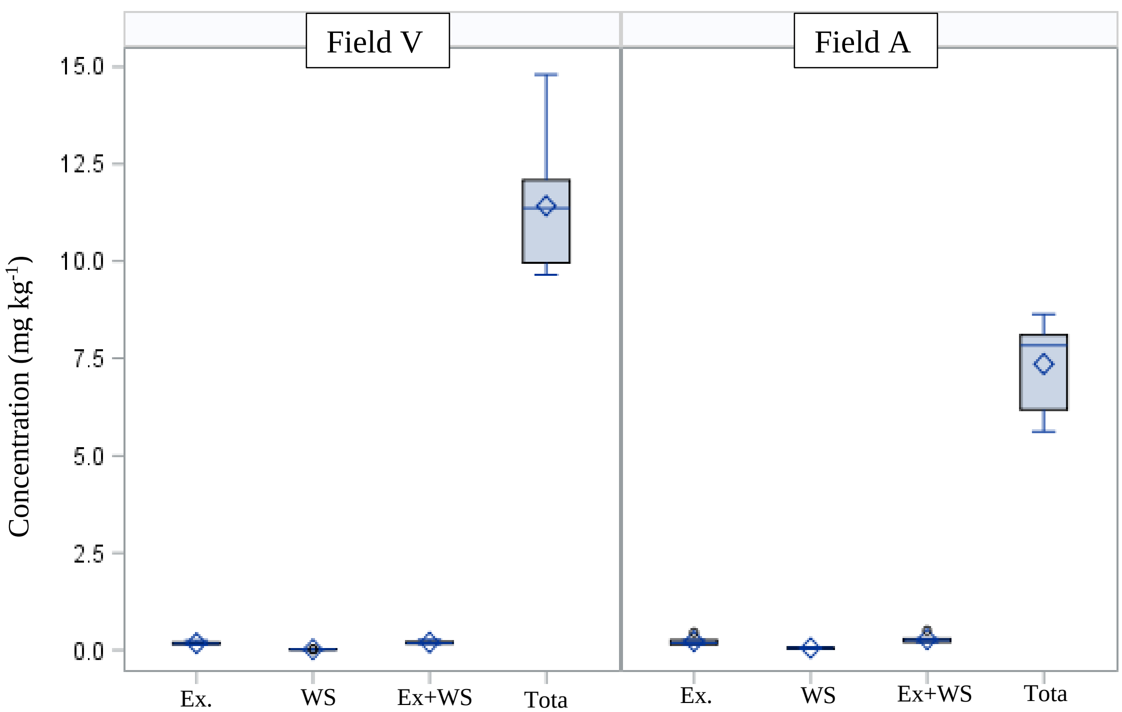

Figure 3. Box plot representation of total, water soluble (WS) and exchangeable (Ex.) arsenic in sequentially extracted soil samples from field V irrigated by San Juan river water and field A irrigated by Animas river water.

The water soluble and exchangeable fractions compared between two fields (figure 4) shows similar trend. Exchangeable fraction, however being more than water soluble fractions in both the fields, shows higher range in field in Animas region than the field in San Juan region. Also, water soluble fraction tends to be higher in this region. Therefore, more the exchangeable fraction, more will be the water soluble fractions. However, according to the results shown in figure 4, the total concentration does not play any role in determining the exchangeable or water soluble fraction. These fractions depend on many other factors like soil pH, organic matter, EC and soil texture etc.

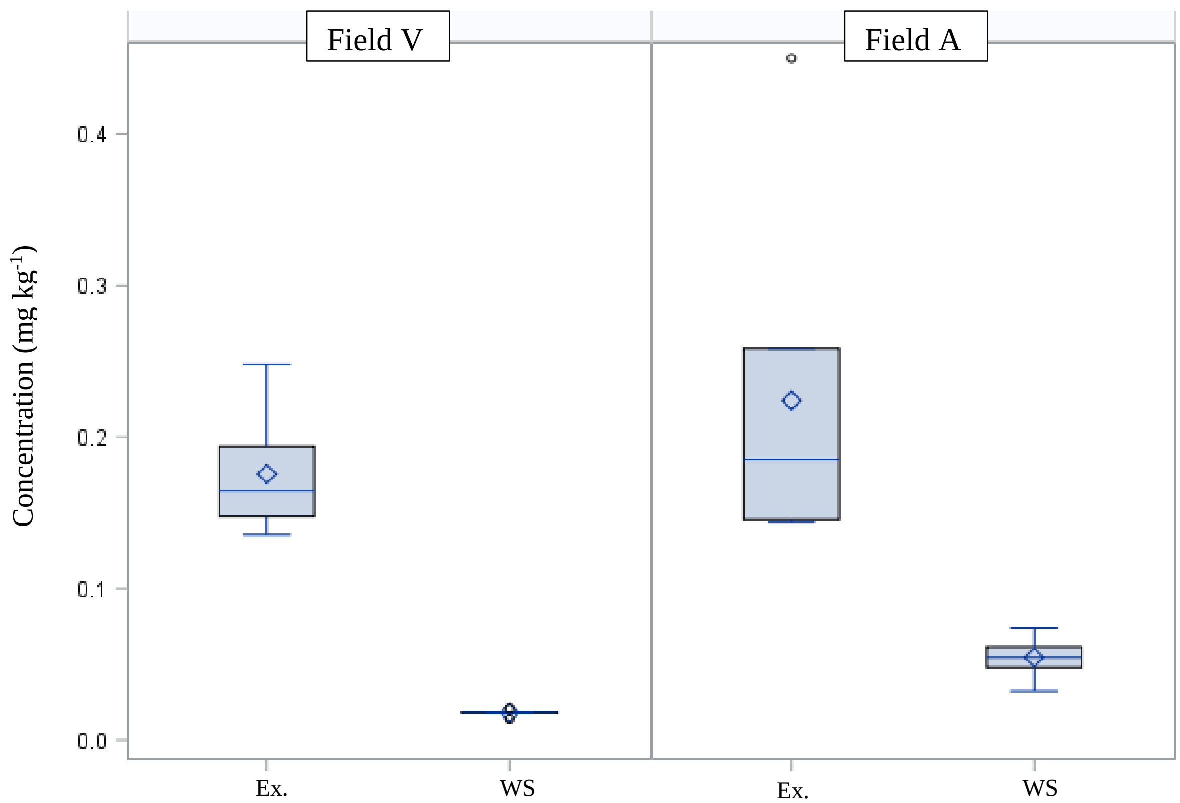

Figure 4. Box plot representation of exchangeable and water soluble fractions in sequentially extracted soil samples from field V irrigated by San Juan river water and field A irrigated by Animas river water.

CONCLUSIONS AND RECOMMENDATIONS

This study has monitored the metal(loid)s of concern that moved downstream with the Animas and San Juan river water as a result of the Gold King Mine Spill and also due to legacy mining activities. These metals in the two agricultural fields of study were below the residential screening level of EPA or NMED except arsenic (As). On spatial analysis, As was found to be increasing at many sampling points analyzed using in-situ PXRF scans for multi-elemental analysis and therefore the hotspots in the field maps showed exceedances in As beyond 7.07 mg kg^{-1}. The water soluble and exchangeable fraction that contributes to the bioavailable forms were monitored in this study to determine the available fraction to the plants with respect to the total concentrations monitored. The bioavailable fractions were significantly lower and therefore possess no threat to the plants growing in the fields as a very small part of this fraction will be taken up by the plants.

Future studies need to be done to monitor the sequential extraction methods using single or multiple extractants suitable for analyzing the plant available fractions. Extensive analysis of vegetable leaf tissues and produce samples should be further analyzed to affirm the conclusions made in this study. Overall, we believe this study is a valuable addition in environmental monitoring of soil contaminations after the mine spill and legacy events to help make the buyers and growers aware of the field soils used for growing important crops like alfalfa, corn and cucurbits.

RESEARCH IMPACT

The outcome of this research has helped the researchers to clearly understand if the total metal concentrations that exceeded the USEPA guideline values are in available or non-available form and also understand how the water from the river is affecting the metal content in crop fields irrigated by Animas river water. Overall goal of this project aims to educate and inform multiple stakeholders in assessing the safety of their agricultural fields and resume to normal cultivation methods as they did before the 2015 GKM acid mine spill. The farmers and ranchers cultivating across the Animas and San Juan watershed need to know whether the concentration of that exceed recommended levels in soils are available for plant growth and potentially toxic. This research has answered some of the questions and concerns raised in "Teach-ins" at various Navajo Nation Chapterhouses and by farmers in Aztec and Farmington area. It has helped the people in Navajo Nation to make decisions about the safety of the soils to resume the ceremonial uses of soil and the cultivation of agricultural crops. The results can be used by NM WRRI for further research and extension.

The results from this research were shared in following outreach events-

- Shiprock Agricultural Days Teach-in presentation on Gold King Mine Exposure to Navajo Nation: Long term monitoring of soil, plants and water in the Animas and San Juan watershed (March 20, 2019)
- Radio Forum in Navajo Nation on Gold King Mine Spill Updates on KNDN 960 AM (March 18, 2019) and KTNN 660 AM (March 19, 2019)
- Monthly Teach-in presentations in collaboration with University of Arizona and Navajo EPA in Shiprock, Upper Fruitland and Aneth Chapterhouses in 2017-2018 to update on the results of contaminants concentrations after the Gold King Mine Spill (2015)

Radio Forum with KNDN 960 AM in Navajo Nation (March 18, 2019)

Radio Forum with KTNN 660 AM in Navajo Nation with more than 29000 listeners reported

(March 19, 2019)

Shiprock Ag.Days Teach-in attended by farmers and buyers in Navajo Nation
(March 20, 2019)

Panel discussion at Shiprock Ag.days teach in (March 20, 2019)

PRESENTATIONS

Oral presentations-

- Jha, G., Ulery, A. L., & Lombard, K.A., (2019*) "Metal Contaminants in the Animas and San Juan Watershed after the Gold King Mine Spill (2015)".. Presented Data blitz talk at NMSU 6th Annual Graduate Research and Arts Symposium from April 4-6, 2019*
- Jha, G., Ulery, A. L., Lombard, K.A., & Weindorf, D.W., (2019). *Metal Contaminants in the Animas and San Juan Watershed after the Gold King Mine Spill (2015)*. Presented at Soil Science Society of America 2019 International Soils Meeting "Soils Across Latitudes", San Diego, CA
- Jha, G., Ulery, A. L., & Lombard, K.A., (2019*). Rapid and in-Situ Analysis of Metal Concentrations after the Gold King Mine Spill Using Portable X-Ray Fluorescence (PXRF)*. Presented at Soil Science Society of America 2019 International Soils Meeting "Soils Across Latitudes", San Diego, CA.
- Jha, G., Ulery, A. L., & Lombard, K.A., (2018*). Spatial and Temporal Variability of Metal Concentration in Agricultural Fields Downstream from the 2015 Gold King Mine Spill.* Presented at 73rd International Annual Conference of Soil Water Conservation Society, Albuquerque, NM.
- Jha, G., Ulery, A. L., & Lombard, K.A., (2018). *Rapid and in-situ analysis of metal concentrations in agricultural fields in San Juan County using Portable X-Ray Fluoresence.* Presented at New Mexico Water Resources Research Institute's 2018 Annual Conference on Environmental Conditions of the Animas and San Juan Watersheds, Farmington, NM.

- Mathews, A., Jha, G., Ulery, A. L., Lombard, K.A., & Francis, B., (2018). *Metal Contaminants in the Animas and San Juan Watershed.* Presented at New Mexico Water Resources Research Institute's 2018 Annual Conference on Environmental Conditions of the Animas and San Juan Watersheds, Farmington, NM.

Poster presentations-

- Jha, G., Ulery, A. L., Lombard, K.A., & Weindorf, D.W., (2019). *Metal Contaminants in the Animas and San Juan Watershed after the Gold King Mine Spill (2015)*. Presented at Soil Science Society of America 2019 International Soils Meeting "Soils Across Latitudes", San Diego, CA.
- Jha, G., Ulery, A. L., & Lombard, K.A., (2018). *Spatial and Temporal Variability of Metal Contaminants in the Animas and San Juan Watershed Downstream from Legacy Mining..* Presented at Joint Annual Meeting of the International Society of Exposure Science and the International Society for Environmental Epidemiology (ISES-ISEE 2018), Ottawa, Canada.
- Jha, G., Ulery, A. L., Lombard, K.A., & Holguin, O. (2018). *Speciation of metal(loids) in agricultural field soils impacted by Animas/San Juan River after the 2015 Gold King Mine Spill.* Presented at 63rd Annual New Mexico water Conference by New Mexico Water resources research Institute, Las Cruces, NM.
- Jha, G., Ulery, A. L., Lombard, K.A., Weindorf, D.C., Fullen, S., Francis, B.,(2018).*Metal Concentration in Agricultural Fields Downstream from the Gold King Mine Spill (2015).* Presented at The College of Agricultural, Consumer, and Environmental Sciences (ACES) Open House 2018.

AWARDS AND RECOGNITIONS

Awards and recognition related to the project-

- Recognition by Soil Science Society of America for scholarly excellence and academic achievement as a finalist in the 2019 SSSA Society-Wide Student Competition.
- First place in the 2019 Graduate student poster presentation in the Soils and Environmental Quality division of SSSA 2018-2019 International Soils Meeting.
- Award to present and moderate at the Joint Annual Meeting of the International Society of Exposure Science and the International Society for Environmental Epidemiology (ISES-ISEE 2018) in Ottawa, Canada
- NMWRRI article for the project- https://nmwrri.nmsu.edu/nmsu-graduate-student-studying-metal-contaminated-sediment-in-irrigation-ditches-and-agriculture-fields-along-the-animas-and-san-juan-rivers/

PUBLICATIONS AND REPORTS

- Final report for the NM WRRI grant entitled *Speciation of metal(loids) in agricultural field soils impacted by Animas/San Juan River after the 2015 Gold King Mine Spill.*
- Manuscript entitled *Bioavailability of heavy metals in field soils irrigated by Animas and San Juan river after the Gold King Mine Spill (2015).* [In progress]

GRANT FUNDS BREAKDOWN

S.No.	Account title	Amount used
1.	Graduate Assistance	1447.50
2.	Fringe Rate (Students)	16.08
3.	Travel for conference (1) and sample Collections (2 trips)	1080.00 557.14 299.59
4.	Office Supplies	29.27
5.	Lab Supplies/Education	1199.87
6.	Printing Reproduction	107.26
7.	Lab analysis	850.00
	Amount Spent	**5586.71**
	Amount left	**18.23**

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