Quantifying the Effects of Frac Sand Waste Fines on Subsurface Water Quality

E.D. Sorenson, H.A.S. Dolliver, and P.T. Kivlin
University of Wisconsin-River Falls

ABSTRACT

Silica sand mining for frac sand production has increased substantially in the United States over the last five years. Since only a certain size range of sand is desirable for fracking operations, the processing of sand generates large volumes of waste material, which consists mostly of silt and clay. 'Waste fines' are typically incorporated with overburden and used to fill in the mined area during reclamation. A long-term field study is being conducted in Chippewa County, Wisconsin to evaluate the effects of using waste fines as a soil amendment during reclamation. Frac sand mines are generally located on sandy, shallow soils. While the waste fines have the ability to improve moisture retention and soil physical properties, they are known to contain heavy metals and nutrients that could pose environmental concerns. A 5 acre- reclamation site was established in 2015 using a randomized complete block design in a split-plot arrangement with application of waste fines as the main treatment. Waste fines were applied as a 30 cm layer below the subsoil and topsoil. Total thickness of soil layers was an average of 32 cm. For this particular study, subsurface water quality was monitored using suction cup lysimeters. Leachate samples were collected bimonthly during the growing season and analyzed for heavy metals using ICP-MS.

INTRODUCTION & OBJECTIVE

The demand for silica sand in the United States has increased substantially over the past five years. Silica sand is used for hydraulic fracturing which fractures and props open tight oil and gas formations. The state of Wisconsin is the nation's largest supplier of frac sand.

During the frac sand mining process, sandstone is disaggregated and sieved into different size classes. The cementing agent that holds the sand grains together contains significant silt and clay. The fine fraction is washed away from the usable sand generating what is referred to in the industry as 'muds'. The 'muds' are belt pressed to remove the excess water and generally mixed with overburden material to fill in excavated areas.

Wisconsin Administrative Code (NR 135) requires reclamation of sand mines once material has been removed or a mine closes. Reclamation of sand mines is especially challenging because the soils are naturally thin, nutrient-poor, and are sandy. This make establishment of vegetation difficult. The waste 'muds' material has the potential to improve reclamation success. When mixed with the top and subsoil, the muds may improve moisture retention. The muds also contain naturally adsorbed metals such as calcium and magnesium and may be a source of essential nutrients that could augment plant growth. However, they also have the potential to introduce heavy metals into groundwater.

The objective of this study was to evaluate the use of the waste fine material in a reclamation site. The specific focus of this research was to measure the background metal content in the muds and soil used for reclamation as well as the transport of metals in leachate.

METHODS

Solid Sample Collection

Four replicate mud samples were collected from below the belt press (Fig. 3). Two 100 cm soil cores were collected from each background site and reclamation site treatment (Fig. 4-5). Soil cores were subsampled at the following intervals: 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm. Mud and soil samples were air dried and ground. Samples were submitted to the University of Minnesota's Research and Analytical Laboratory for analysis. Samples were digested in a microwave digester with nitric acid and analyzed for 27 metals using ICP-MS analysis.

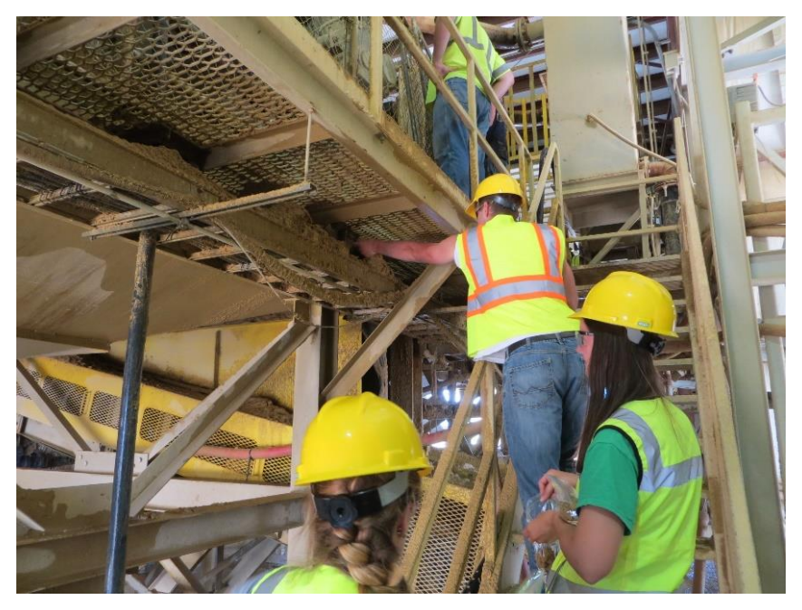
Figure 3: Collecting mud samples below belt press.

Lysimeter Samples

Suction cup lysimeters (Irrometer, Inc) were installed in background sites and each reclamation treatment (Fig. 4-6). A total of three lysimeters were installed in each site/treatment. In total, 21 lysimeters were installed in Summer 2015. The lysimeters were installed at a depth of 45 cm to ensure sampling below the muds layer. Lysimeters were pressurized and water samples were collected in two-week intervals (Fig. 7-8). The samples were analyzed for 27 different metals using ICP-MS analysis.


Figure 4: Installation of lysimeter.


Figure 5: Suction cup lysimeter.


Figure 6: Installed lysimeter.

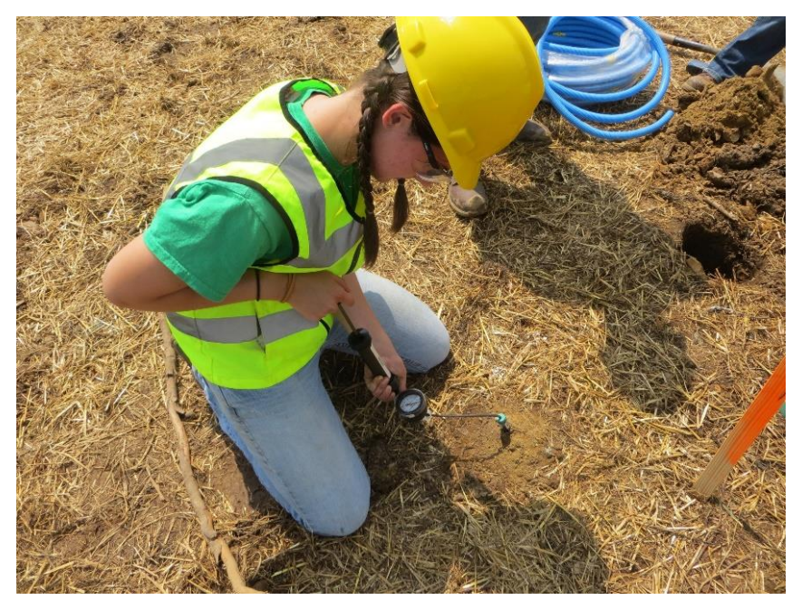
Figure 7: Vacuuming lysimeter with hand pump.


Figure 8: Sampling leachate with syringe.

CONCLUSION

Belt press muds may be a valuable source of essential plant nutrients that could improve the success of vegetation establishment during mine reclamation. However, the application of a muds amendment could lead to leaching losses of problematic heavy metals. More research is needed to quantify the ability of plants to uptake metals from the muds material and the environmental fate and transport of metals.

ACKNOWLEDGEMENTS

A special thanks to the mine company, Superior Silica Sands, and mine operators for all of their assistance in preparing the reclamation site and their willingness to explore potentially novel uses of the muds material, despite significant challenges both with weather and working with the muds material. Thank you also to the Chippewa County Land Conservation and Forest Management for their management and oversight of the project objectives and field activities. Finally, thank you to my advisors Dr. Holly Dolliver and Paul Kivlin and fellow interns Amanda French and Logan Ahlers for assisting with equipment installation, sampling, and research advice.

RESEARCH SITE & STUDY DESIGN

The mine site is located in Chippewa County, Wisconsin (Fig. 1). The active industrial sand mine is 100 acres in size. Three background sites represented various pre-mining soil conditions (shallow vs. deep and sandy vs. silty soil) (Fig. 2). The background site conditions included both undisturbed and disturbed soils. In the summer of 2015, a 5 acre reclamation site was completed. The reclamation site was split into two treatments no muds (control) and muds applied as an amendment 30 cm below the topsoil and subsoil.

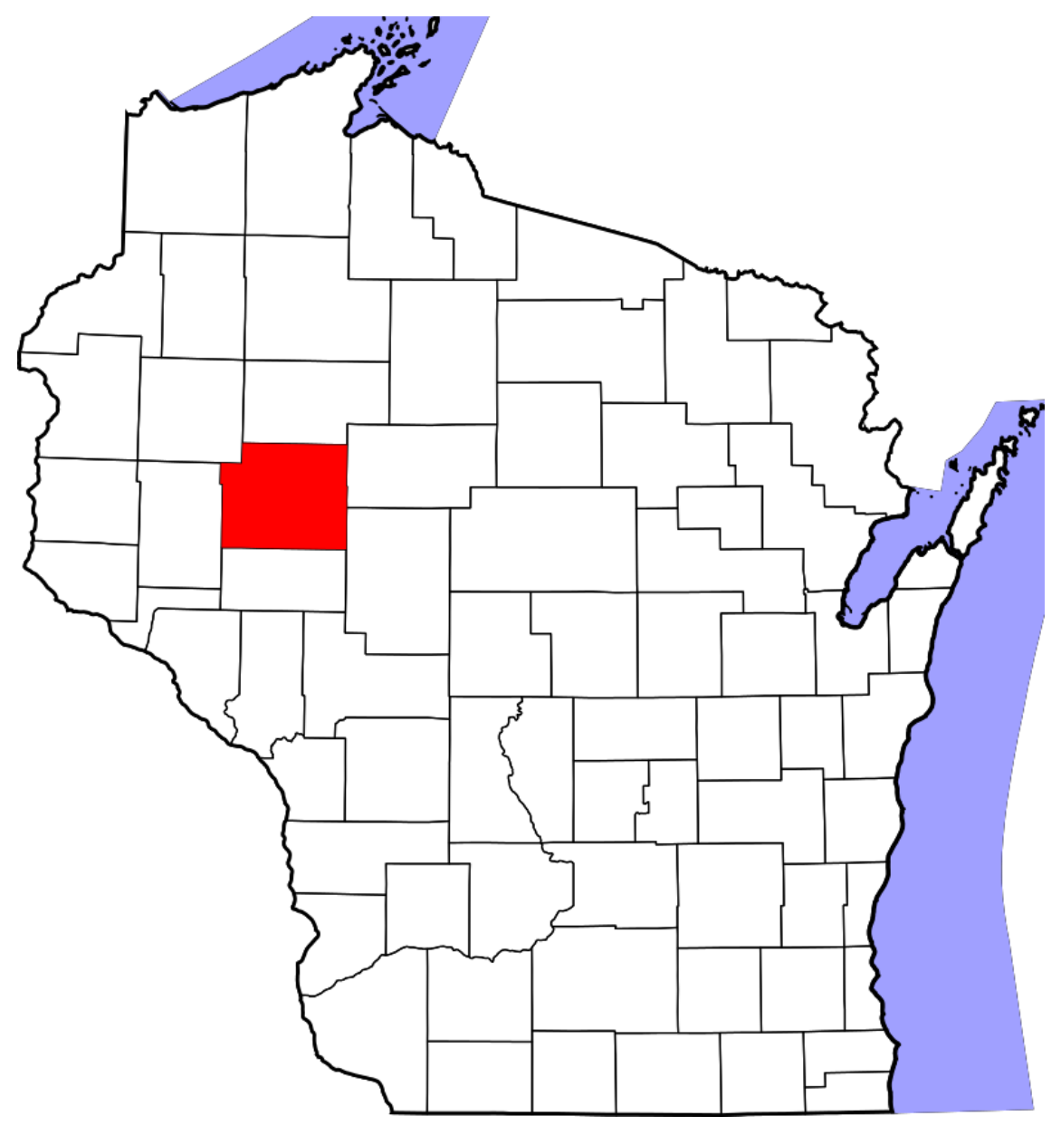
Figure 1: Map of Wisconsin with Chippewa County shaded in red.

Figure 2: Map of the sand mine including background and reclamation site locations and descriptions.

RESULTS

Of the 27 metals analyzed, 19 metals had a higher metals concentration in the muds material compared to the reclaimed site soil (Table 1). Specifically copper (+93%), sulfur (+92%), arsenic (+81%), lead (+77%), and cadmium (+77%) had the largest percentage increase between the reclaimed site soil and muds materials.

Several essential plant nutrients such as calcium, magnesium, phosphorus, and potassium were significantly enriched in the muds material (>30% above the background soil concentration). This suggests that the muds material may be used as a soil amendment to augment plant growth; however, more research is needed to determine whether the metals are available and in a form that can be up taken by plants.

While the muds material may be a source of important plant nutrients, it may also be a source of toxic heavy metals to the environment. Metals such as cadmium, arsenic, chromium, and lead are all known to be toxic at low levels and are enriched in the muds material (Table 1). These metals may bioaccumulate in plants or move with leachate into groundwater; however, more research is needed to determine the fate and transport of these metals since their mobility in the environment depends on many factors such as pH, soil texture, clay mineralogy, redox state, etc.

Lysimeters were installed but metals data is limited at this point due to a short first year sampling season. As an illustration, copper, had the largest percent increase between the reclamation site soil and muds material (+93%). Adding the muds material to the reclamation soil, increased copper concentration in the soil by 50% (Fig. 9). Consequently, the reclaimed site soil with the muds also showed higher levels of copper in pore water, although not statistically different due to high variability (Fig. 10). Interestingly, the copper concentration in pore waters from the background sites (pre-mining condition) were significantly higher than the reclaimed sites (with or without muds). This could be because of higher natural levels of metals or differences in their ability to transport metals (texture, pH, mineralogy, etc.). More research is needed to quantify losses and relevant factors for both the background (pre-mining) and reclaimed site to understand the environmental significance and concerns associated with metals.

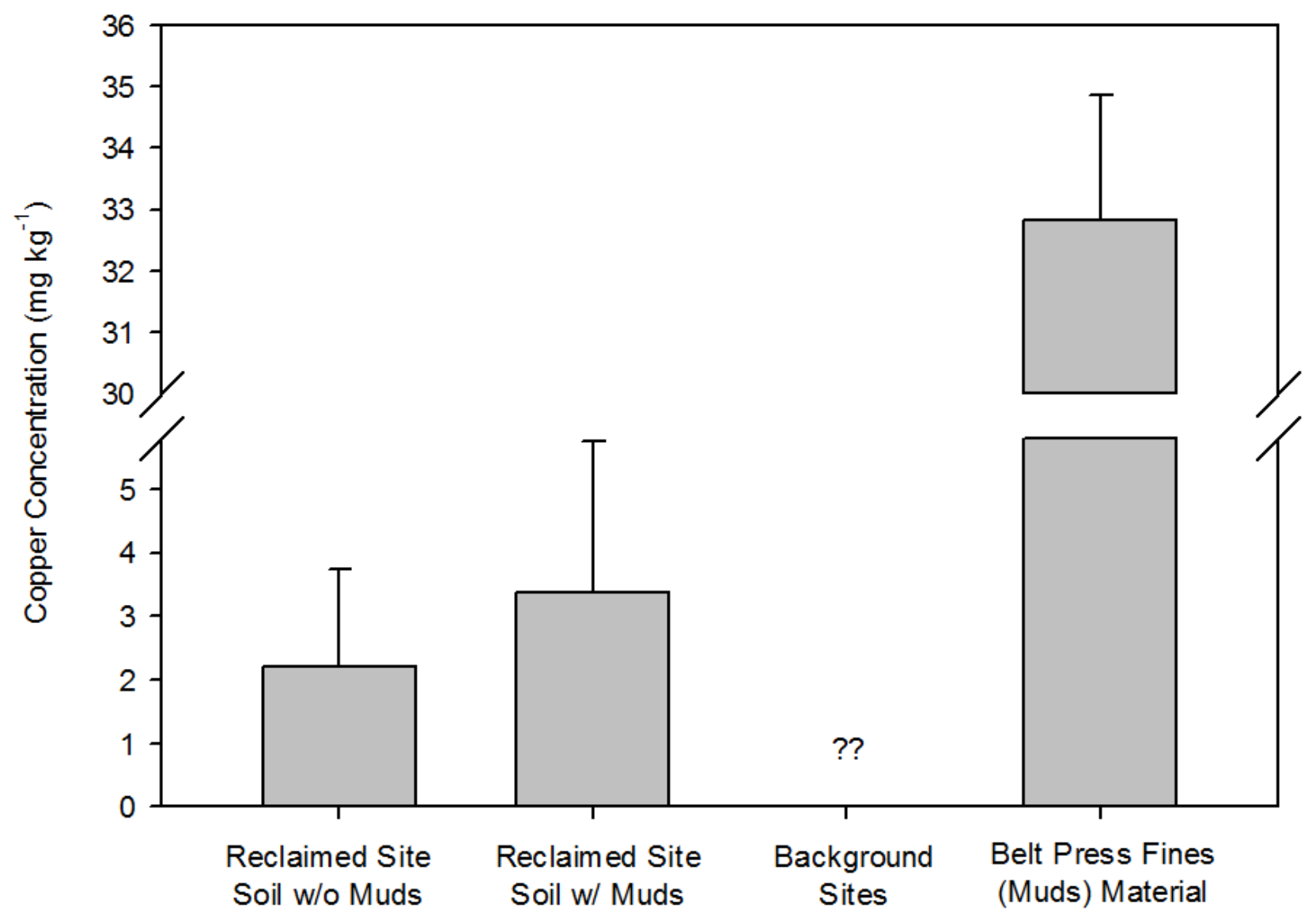

Figure 9: Concentration of copper in solid soil samples.

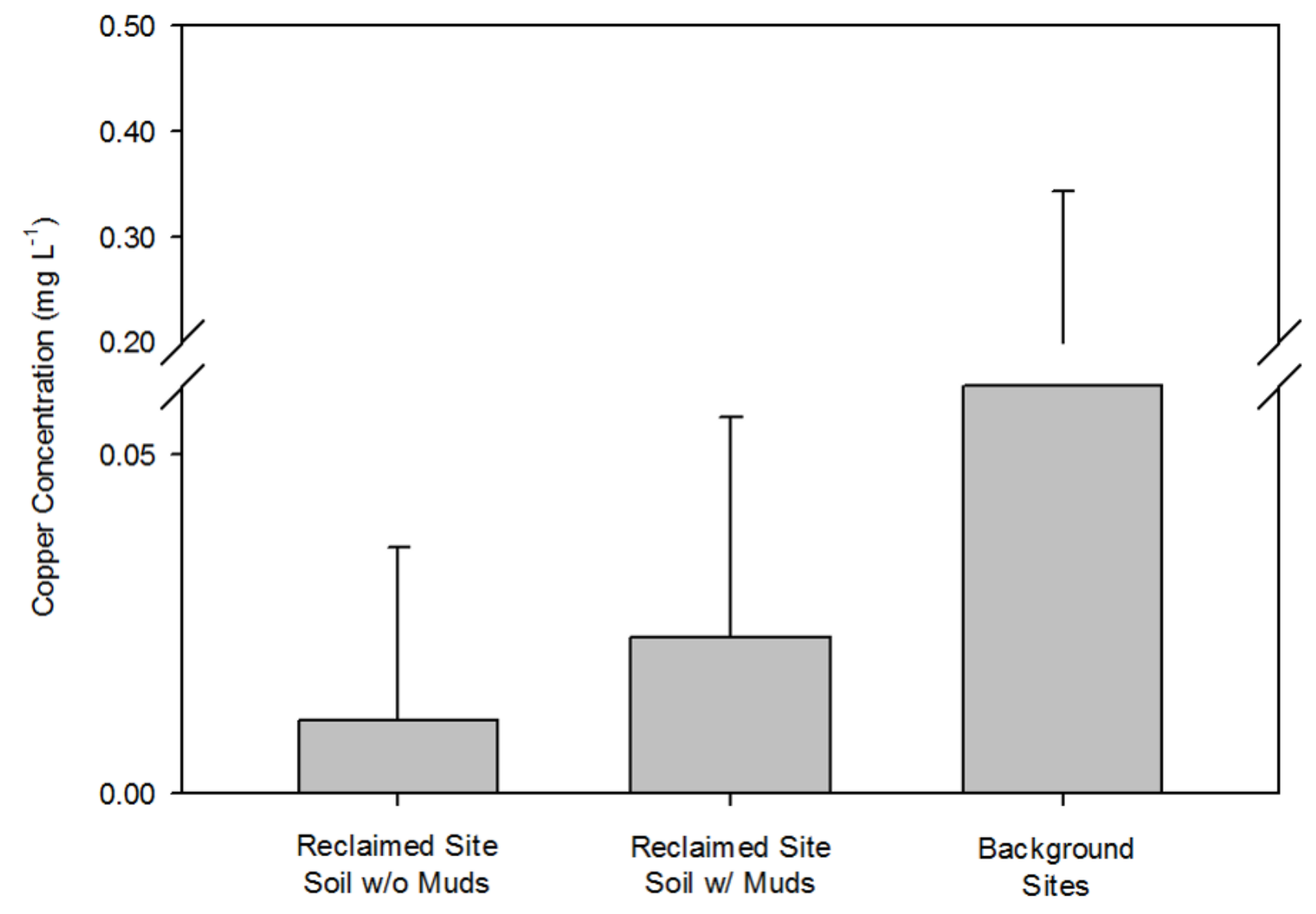

Figure 10: Concentration of copper in lysimeter leachate samples.

Metal	Reclaimed Site Soil mg kg^{-1} or ppm	Belt Press Fines (Muds) Material mg kg^{-1} or ppm	% Difference
Al	6232.11	6936.93	+10.16
As	3.37	17.85	+81.11
B	10.05	19.33	+48.00
Ba	52.98	31.74	-66.92
Be	0.59	0.33	-77.98
Ca	1011.00	2984.80	+66.13
Cd	0.09	0.39	+76.69
Co	6.39	12.68	+49.57
Cr	12.33	36.23	+65.97
Cu	2.21	32.83	+93.28
Fe	27501.65	20431.75	-34.60
K	985.05	4059.50	+75.73
Li	4.03	3.83	-5.15
Mg	1330.29	2188.24	+39.21
Mn	442.70	441.39	-0.30
Mo	0.12	0.00	NA
Na	33.70	94.61	+64.38
Ni	10.38	29.48	+64.77
P	464.77	1335.89	+65.21
Pb	9.13	39.61	+76.95
Rb	148.40	139.88	-6.09
S	53.52	667.63	+91.98
Si	377.35	870.75	+56.66
Sr	37.04	91.59	+59.56
Ti	107.32	75.13	-42.86
V	11.50	20.15	+42.91
Zn	27.42	53.26	+48.52

Table 1: Concentration of 27 different metals in the reclamation site soil without muds, muds material, and the percent difference between them.