

CHARACTERIZING TEMPORAL AND SPATIAL TRENDS
IN SOIL GEOCHEMISTRY ON POLDER 32,
SOUTHWEST BANGLADESH

By

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CHAPTER I

INTRODUCTION

This research is aimed to characterize the soil properties on Polder 32 located in the coastal area of Southwest Bangladesh and potential soil-related risks to agricultural productivity and human health, including salinization, soil acidification and arsenic contamination. Polders, or land masses enclosed by embankments, are surrounded by tidal channels filled with brackish water. Polders are primarily used for agricultural purposes in coastal Bangladesh. Much of Polder 32 uses a farming system in which rice is farmed during the wet season and brine shrimp is farmed during the dry season. During the wet season, farmers create controlled openings in the embankments in order to irrigate rice paddies. In the dry season, farmers do the same to create shrimp ponds. Continued use of brine shrimp farming can increase the salinity of soil, resulting in a decrease in soil fertility and reduction in crop yields (Ali, 2006; Barmon et al., 2010; Chowdhury et al., 2011, Clarke et al., 2015).

The Sunderbans National Park, the largest mangrove forest in the world, is located directly south of Polder 32. It is home to 40 species of mammals, 260 species of birds and 35 species of reptiles (UNESCO, 1997). Polder 32 was originally part of the Sunderbans, but deforestation has led to the establishment of farmland. The mangrove forest is now a UNESCO World Heritage Site, helping to protect from further deforestation. Converting an area to farmland from a mangrove forest could impact soil salinity and acidity.

Potential Causes and Effects of Salination on Land Use

Soil salination is a process in which soil becomes enriched in salts. It often results from improper irrigation practices. Salts dissolved in irrigation water precipitate in the soil during evaporation, and unless flushed out continue to accumulate over many years. Salts can also be deposited by tidal inundation and subsequent evaporation. Since Polder 32 is surrounded by embankments (Figure 1) this is not a problem, unless the embankments are breached by events such as cyclones. Additionally, salts can enter plant roots if irrigation water causes the water table to rise up to the root zone. Transpiration can cause salts to accumulate in plants (Postel, 1999). Over time increased salt build-up will cause crop yields to decrease, and can eventually lead to agricultural abandonment (Postel, 1999).

Rice is a staple food in the Bangladeshi diet, and reducing the yield of rice could lead to food shortages. Nearly all varieties of rice are sensitive to salinity, which can reduce the seed yield of plants and growth of seedlings, and increase plant susceptibility to insect pests (Flaherty et al., 1999; Welfare et al., 1996). Methods to increase yields, such as using modern varieties of rice, are being exhausted, which leaves soil fertility, one of the main limiting factors in rice production, to be improved (Rahman, 2003).

In southwest Bangladesh, a rotation between shrimp farming in the dry season and rice cultivation in the wet season is common (Azad et al., 2009). The majority of shrimp farms in coastal Bangladesh were established in the 1980s due to the large demand and high prices of shrimp on the international market (Hossain et al., 2004). Shrimp farming produces a profit that is 12 times higher than that of high yielding variety rice (Shang et al., 1998). In 2000 -2001



Figure 1. . Pictures showing embankments on Polder 32 from the embankment (top) and from the tidal channel (bottom).

Bangladesh exported about 364 million USD worth of shrimp, which grew to 403.5 million USD in 2005-2006 (Azad et al., 2009), making shrimp the third largest exported product after garments and tea (Hossain et al., 2004). While these economic figures are notable, shrimp farming can have negative effects on its surrounding environment, such as soil salinization and a reduction in land productivity.

Prolonged inundation of soil in saline shrimp ponds may accelerate leaching of base minerals and increase soil salinity (Ali, 2006; Flaherty et al., 1999). Most shrimp ponds on Polder 32 are located alongside tidal channels, making it easier to exchange saline water in and out of the ponds. Introducing saline water to the soil causes salinization. Additionally, discharge of saltwater from brine shrimp ponds can cause salinization of adjoining rice paddies (Azad et al., 2009). Ali (2006) determined over 5, 10, and 15 year periods that soil salinity increased 33%, 36%, and 39%, respectively, when rice paddies were converted to shrimp farms during the dry season.

Soil Acidification and Arsenic Contamination

Soil acidification is another problem potentially caused by shrimp farming. Soil submerged for long periods of time will become anaerobic, causing the precipitation of sulfides such as pyrite (FeS_2). As the land used for shrimp farming dries out and is tilled for rice cultivation, the exposed sulfide deposits are oxidized, releasing sulfuric acid which increases acidity (Ali, 2006). Excessive acidity ($\text{pH} < 4$) can lead to a reduction in rice growth and yield, in addition to adversely affecting the aquatic species living in the water (Ali, 2006).

Arsenic contamination in soil is another potential risk in the area. Groundwater and tidal channel water in the area have elevated arsenic concentrations (George, 2013), which rice plants could uptake. Tidal channel water is of particular concern, as it is used to irrigate rice paddies. Rice could significantly contribute to dietary arsenic intake. In areas where populations are not drinking water with elevated arsenic, rice is the largest dietary source of arsenic by a large margin (Zhu et al., 2008). In an area such as coastal Bangladesh where irrigation water is contaminated with arsenic that can accumulate in rice plants, ingestion of arsenic contaminated rice could increase the risk of arsenicosis.

Primary Research Questions

This research explores the hypotheses saline tidal channel water is the source of salts. The alternate hypotheses are that saline groundwater is the salt's source, either due to its use for irrigation or through natural groundwater seepage. Salinity of soil from polder 32 (post-development) and the Sunderbans (pre-development) have also been compared to evaluate the effects deforestation and polderization. The problems of soil acidification stemming from increased shrimp farming and arsenic contamination from groundwater and tidal channel water have also been investigated.

CHAPTER II

SITE DESCRIPTION

Location & Climate

Polder 32 is located within the Ganges-Brahmaputra Delta System in the Bengal Basin. Figure 2 shows the general area of the research site located about 30 km southwest of Khulna, Bangladesh. Polder 32 is approximately 18 km long and 7 km wide, with an area of roughly 68 km², as shown in Figure 3.

Southwest Bangladesh has a humid, biseasonal climate (Nobi & Gupta, 1997). The South Asian Monsoon occurs from June to October, Southwest Bangladesh's wet season, in which 90% of annual rainfall, which ranges from 1,500 to 2,100 mm, takes place (Michael & Voss, 2009; Nobi & Gupta, 1997). This precipitation floods approximately 30% of the land surface during the wet season, covering croplands (Michael & Voss, 2009). The dry season occurs from November to May. The area is subject to tropical cyclones that form over the North Indian Ocean typically during the transitional months of November and May (Singh et al., 2000). On average, a severe cyclone strikes Bangladesh every three years (Dasgupta et al., 2011).

On May 25, 2009 Cyclone Aila made landfall over Bangladesh. Aila struck Bangladesh during high tide, causing tidal surges of up to 6.5 meters (United Nations, 2010). Eleven coastal

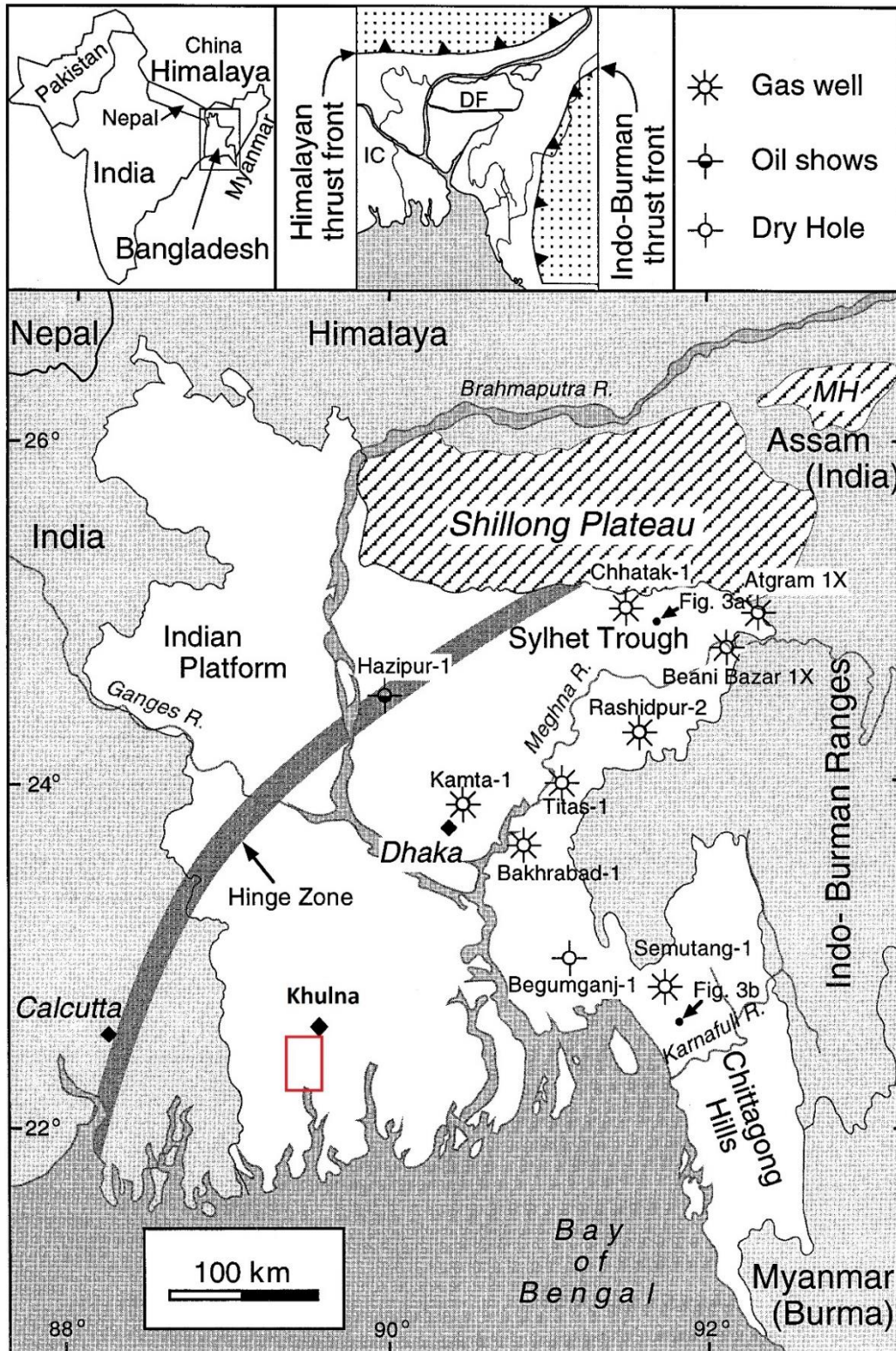


Figure 2. Map showing the research location (red square) and of geologic features surrounding the Bengal Basin including the Shillong Plateau, Himalayas, Indian Platform, Bay of Bengal, and the Indo-Burman Ranges (Uddin and Lundberg, 1999).



Figure 3. Image of Polder 32 (Google Earth, 2015).

districts were affected, and over 1,742 kilometers of embankments were washed away, including embankments protecting Polder 32 (United Nations, 2010). Satellite imagery shows that the majority of Polder 32 was inundated through February 2011. This long period of inundation could have caused an increase in soil salinity.

Geology

Polder 32 is located in the Bengal Basin, which is constrained by the Bay of Bengal to the South, the Himalayas and Shillong Plateau to the North, the Indo-Burman Ranges to the East, and the Indian Platform to the West. It lies within the Ganges-Brahmaputra-Meghna (GBM) delta system, which is the world's largest river delta, being approximately 400 km long and 450 km wide with a volume of $5.4 \times 10^6 \text{ km}^3$ (Johnson, 1994). This delta sequesters approximately 1×10^9 tons of sediment per year, primarily from the Himalaya Mountains and the Shillong Plateau (Goodbred and Kuehl, 1999). The region is tectonically active, with the delta at the junction of three converging tectonic plates: the Indian, Burma, and Eurasian Plates. Polder 32 is in a part of the GBM delta that is currently not constructing or destroying land due to subsidence rates and accretion rates being comparable, and is located in the "Bengal foredeep", which has much thicker sediment accumulation than the rest of the Bengal Basin (Uddin and Lundberg, 1998). Subsidence and tectonic activity can explain the large thickness and depth extent of sediments, which were originally deposited at the surface (Michael and Voss, 2009). The surficial geology of Polder 32 can be described as tidal deltaic deposits (see Figure 4), with an upper silt and clay thickness of approximately 20 to 30 meters (Shamsudduha et al., 2011).

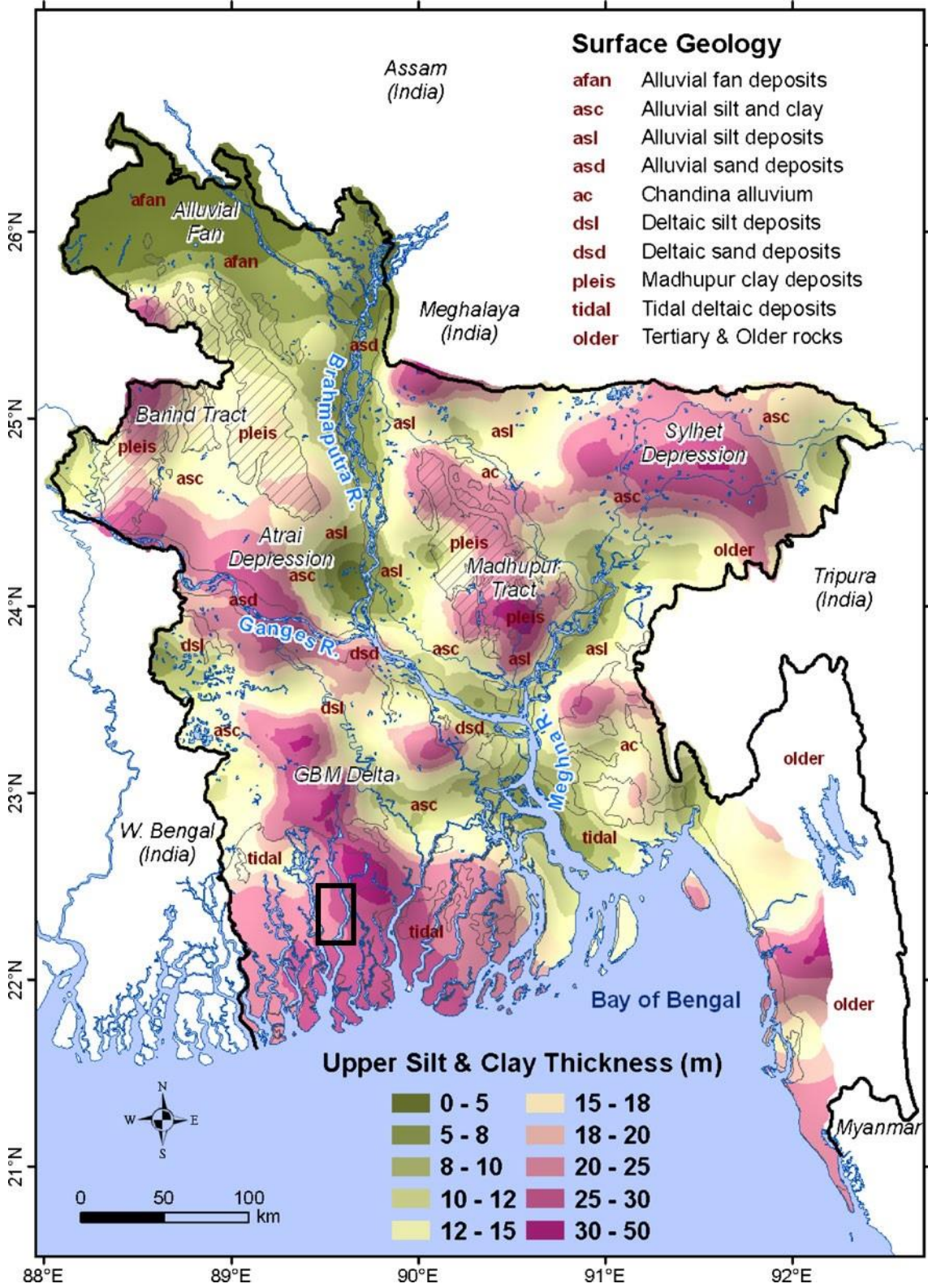


Figure 4. Surficial geology of Bangladesh, with research area highlighted in black box (Shamsudduha et al., 2011).

CHAPTER III

METHODS

Sampling Plan

Soil samples from rice paddies on Polder 32, soil samples from the Sunderbans and sediment samples from adjacent tidal channels were collected in order to completely describe soil salinity. Soil samples were collected in May 2013, October 2013 and May 2014. Samples were collected from the uppermost 15 centimeters, which represents the cultivated topsoil (Barmon et al., 2010). Sample site locations were recorded using a Trimble GeoXT 6000, with a horizontal accuracy of 50cm. Collected soil samples were analyzed using the methods described below.

Analytical Methods (Solid Soil)

Apart from particle size analysis, all soil samples were air dried and then sieved using a No. 10 (2 mm) sieve prior to performing analyses.

X-Ray Fluorescence (XRF)

Soil samples were measured for bulk chemical composition using a Thermo Scientific Niton XL3t handheld XRF analyzer. Samples were heated to 105°C overnight and then packed into a XRF detector cup for analysis. Two standards, NIST 2709a and TILL-4PP, were used for calibration.

Loss on Ignition (LOI)

Following Pansu and Gautheyrou (2007), loss on ignition was conducted at 105°C for H₂O⁻ (“free” form water) content and 1000°C for H₂O⁺ (structural water) content. For free form water content analysis, approximately 2 to 3 grams of soil sample was heated overnight at 105°C and then reweighed. The following equation was applied to determine the percent of mass lost:

$$\text{H}_2\text{O}^- \% = 100 \times \frac{m_1 - m_2}{m_1 - m_0} \quad (1)$$

where m_0 is the mass of the crucible holding the sample, m_1 is the mass of the sample before drying and m_2 is the mass of the sample after drying. For structural water content, the same soil sample from 105°C drying was used. The sample was heated at a rate of 6°C per minute, held at 300°C for 20 minutes, then heated rapidly to 1000°C, where it stayed for 4 hours. The sample was then reweighed and the following equation was applied:

$$\text{H}_2\text{O}^+ \% = 100 \times \frac{m_2 - m_3}{m_2 - m_0} \quad (2)$$

where m_3 is the mass of the sample after 1000°C drying.

Total Carbon

Analyses of total carbon (TC) were performed on a Shimadzu model TOC-V CPH/CPN combined with a SSM-5000A unit for solid samples. The TC furnace ran at 900°C, and zero air at 150 mL/min was used as the carrier gas. Five-point calibration curves using a glucose standard were generated for an analytical range between 10% carbon and 100% carbon and were accepted with a correlation coefficient of at least 0.995. A glucose standard was run every 20 samples.

The standard was required to be within 15% of the specified value. A mass of approximately 50 mg of sample was loaded for analysis.

Particle Size Analysis

Soil samples were analyzed for particle size using a Malvern Mastersizer 2000. Samples were washed through a No. 18 (1 mm) sieve with deionized water, homogenized and then rinsed into a 100 mL beaker with additional deionized water. Samples were then deflocculated while suspended in deionized water via sonication before analysis.

Analytical Methods (Soil Extracts)

Soil samples were dried overnight at 105°C, and then sieved using a No. 10 sieve. Deionized water (DI) extracts were prepared and analyzed used to estimate bioavailability of elements in soil. First, saturated pastes were made by adding deionized water to the samples in a 1:5 (soil:water) ratio, and then measured for pH using an Accumet pH meter and specific conductance (SpC) using a HANNA Portable Solution Conductivity Measurement Meter. The saturated pastes were then filtered using a vacuum pump, coarse porosity/fast flow filter paper, a vacuum flask and a Büchner funnel. The DI extracts were obtained by filtering a second time through a 0.45 µM syringe filter and then refrigerating for analysis via the methods described below.

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

Soil extracts were analyzed for aluminum, barium, boron, calcium, copper, iron, magnesium, phosphorus, potassium, silicon, sodium, strontium, sulfur and zinc using a Varian ICP Model

720-ES ICP-OES utilizing Environmental Protection Agency (EPA) Method 6010B. Instrument settings included plasma gas flow at 15 liters per minute (L/min), radio frequency power at 1.2 kilowatts (kW), and nebulizer flow of 0.75 L/min. Five-point standard curves were used for an analytical range between approximately 0.1 milligrams per liter (mg/L) and 25 mg/L for trace metals and approximately 0.1 mg/L and 500 mg/L for major elements. Analytical blanks and analytical check standards at approximately 0.5 mg/L were run every 20 samples and required to be within 15% of the specified value. Samples for analysis were diluted gravimetrically to within the targeted analytical range using 1% volume-volume (v/v) Optima grade nitric acid (Fisher Scientific) if the maximum calibration was exceeded. Yttrium at 10 mg/L was used as the internal standard.

Inductively Coupled Plasma Mass Spectroscopy (ICP-MS)

Soil extracts were analyzed for antimony, arsenic, beryllium, cadmium, cobalt, chromium, lead molybdenum, nickel, selenium, thallium and vanadium using a Perkin Elmer model ELAN DRC II in both standard and dynamic reaction chamber (DRC) modes. Standard analysis mode was used for all analytes except for As and Se, which were run in DRC mode with 0.5 mL/min of oxygen as the reaction gas. Seven-point standard curves were used for an analytical range between approximately 0.5 µg/L and 250 µg/L and completed before each analysis. Analytical blanks and analytical check standards at approximately 50 µg/L were run every 10 to 20 samples and required to be within 15% of the specified value. Samples for analysis were diluted gravimetrically to within the targeted analytical range using 1% v/v Optima grade nitric acid (Fisher Scientific). Initially, analyses for 10:1 dilutions were performed to minimize total

dissolved loading to the instrument. Additional dilutions at 100:1 and 1000:1 were analyzed if the calibration range was exceeded for the 10:1 dilution. 50 µL of a 10 mg/L internal standard consisting of indium (In) (for mass range below 150) and bismuth (Bi) (for mass range over 150) was added to 10 mL of sample aliquot prior to analysis. Analyte concentrations measured that are less than the minimum level of quantitation (ML) and greater than the method detection limit (MDL) are reported as estimated value using the instrument response.

Ion Chromatography (IC)

Analyses of anions were performed on a Metrohm 881 Compact IC pro employing American Society for Testing and Materials (ASTM) Method D-4327-03. Seven-point calibration curves were generated by dilution of a multi-anion standard at 500x, 200x, 100x, 50x, 10x, 2x, and 1x and were accepted with a correlation coefficient of at least 0.995. An analytical blank and check standard at approximately 10 times the dilution of the standard was run every 20 samples. The standard was required to be within 15% of the specified value. A volume of approximately 10 milliliters (mL) of undiluted sample was loaded for analysis. Samples for analysis were run at 0.7 milliliters per minute 18 (mL/min) using an eluent of 3.2 millimoles (mmol) sodium carbonate per 1.0 mmol sodium bicarbonate. Samples were diluted automatically to within the targeted analytical range using Milli-Q water if the maximum calibration was exceeded.

Total Organic Carbon (TOC) Analyzer

Analyses of organic and inorganic carbon were performed on a Shimadzu model TOC-V CPH/CPN using ASTM Method D-7573-09. The TOC furnace was run at 680 °C and zero air, at

150 mL/min, was used as the carrier gas. Five-point calibration curves, for both dissolved inorganic carbon (DIC) and non-purgeable dissolved organic carbon (DOC) analyses, were generated for an analytical range between 5 parts per million (ppm) and 100 ppm and were accepted with a correlation coefficient of at least 0.995. An analytical blank and check standard at approximately 10 ppm was run every 20 samples. The standard was required to be within 15% of the specified value. A volume of approximately 20 mL of undiluted sample was loaded for analysis. DIC analysis was performed first for the analytical blank and standard and then the samples. DOC analysis was carried out separately after completion of DIC analysis. DOC analysis started with addition of 2 Molar (M) hydrochloric acid to achieve a pH of 2 along with a sparge gas flow rate of 50 mL/min to purge inorganic carbon prior to analysis. Samples for analysis were diluted automatically to within the targeted analytical range using Milli-Q water if the maximum calibration was exceeded.

CHAPTER IV

RESULTS

Field Observations

Sample collection took place during three trips. A sample location map is given (Figure 5). May 2013 and May 2014 represent the dry season, and October 2013 represents the wet season. Since climactic conditions change dramatically in the region between these seasons, it was imperative to collect samples in each season to fully characterize the variability of soil composition. Figures 6 & 7 show how the landscape changes from season to season, with abundant rice paddies present in the wet season being replaced with fallow land with shrimp ponds present near the tidal channel in the dry season.

Physical Analyses

Two soil profiles (Figure 8) taken from May 2014 show that the soils on Polder 32 are entisols, having no horizons developed yet. This suggests that the soil is essentially recently deposited unaltered sediment from the tidal channels. Total carbon measurements taken from October 2013 indicate very low carbon in the soil, around 1.2% - 2.6%. Figure 9 shows results of particle size analysis on select samples. Samples are dominated by silt-sized material, which is similar to additional particle size analyses done on surface samples from the polder and sediments in the tidal channels (Wilson & Goodbred, personal communication, June 23, 2015). This also shows that samples from Polder 32 and the Sunderbans have similar grain size distributions.



Figure 6. Picture of fallow rice paddy field in May 2014.



Figure 7. Picture of rice paddy field in October 2013.



Figure 8. Pictures of two soil profiles taken in May 2014.

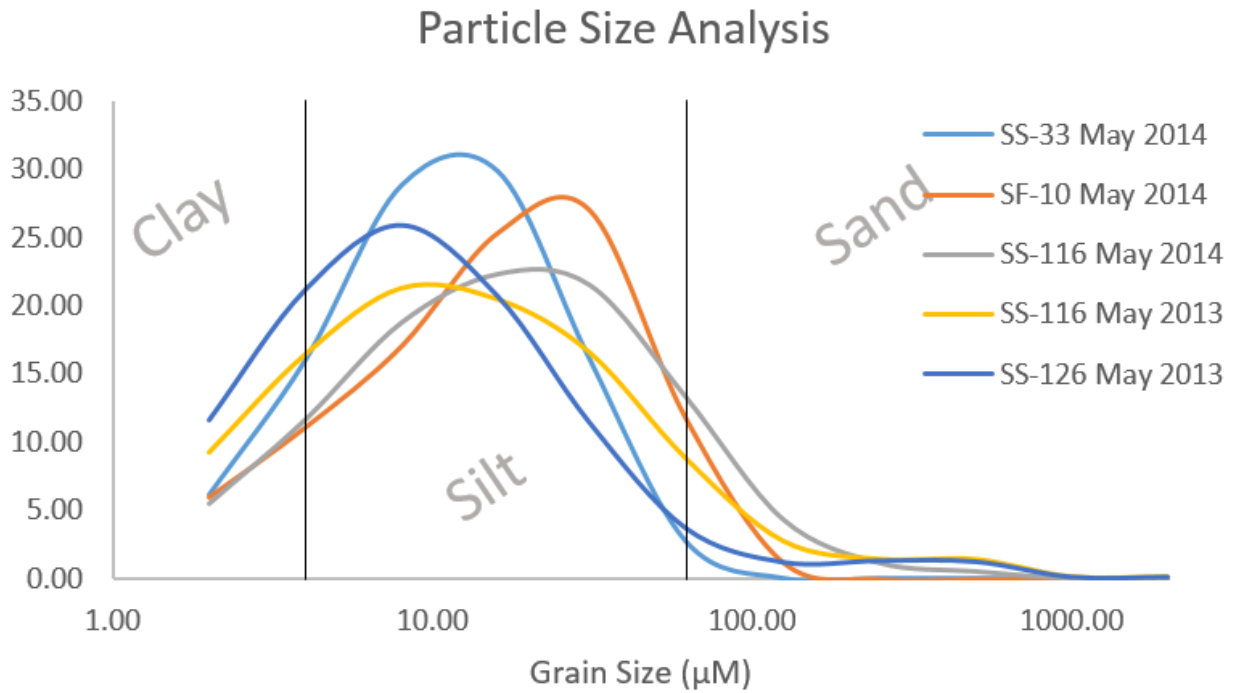


Figure 9. Particle size analysis histogram of select samples showing dominant grain sizes. SS-33, SS-116 and SS-126 are fallow rice paddies. SF-10 is a Sunderbans sample.

Geochemical Analyses

Analytical results include physical parameters of deionized water (DI) extracts (Table 1), major cation concentrations in DI extracts (Table 2), major anion concentrations in DI extracts (Table 3), bulk chemical concentrations in soil samples (Table 4), and water content, organic carbon and inorganic carbon of select soil samples (Table 5).

Figures 10 & 11 compare As and S concentrations in bulk soil against deionized water extracts. Arsenic concentrations in bulk soil and deionized extracts show little correlation, and As concentrations in deionized extracts are much lower than in bulk soils. Both of these observations indicate that most As is not bioavailable, however it is important to note that most soil soluble As concentrations exceed the World Health Organization of 10 parts per billion.

Temporal Correlations

Scatter plot matrices for major cations, anions, pH and specific conductance are shown for October 2013 (Figure 12) and May 2014 (Figure 13). In October 2013 Na-Cl and Ca-SO₄ from DI extracts show positive correlations, which indicates that salts in soil samples most likely occur as halite (NaCl) and gypsum (CaSO₄). There is also a weak negative correlation between pH-SO₄, which could indicate that SO₄ and H⁺ are added to soil by oxidation of sulfide minerals such as pyrite (FeS₂). Similar trends are shown by samples from May 2014 (Figure 13), with the additional positive correlation between K and Cl, suggesting the presence of sylvite (KCl).

Table 1. Physical properties of soil samples. DRP - Dry Rice Paddy, RP - Rice Paddy, TC - Tidal Channel, SF - Sunderban Forest

ID	DATE	LATITUDE	LONGITUDE	TYPE	PH	SPC (SLURRY) ($\mu\text{S}/\text{CM}$)
SS-11	5/4/2013	22.54291	89.45233	DRP	7.68	4.03
SS-12	5/7/2013	22.50682	89.47332	DRP	7.83	4.00
SS-14	5/7/2013	22.50625	89.47649	DRP	7.55	3.90
SS-15	5/7/2013	22.503	89.47941	DRP	7.70	3.26
SS-16	5/7/2013	22.50538	89.48306	DRP	6.95	2.81
SS-17	5/7/2013	22.5063	89.48746	DRP	7.82	2.96
SS-18	5/7/2013	22.53543	89.47053	DRP	7.19	3.07
SS-19	5/7/2013	22.53671	89.47283	DRP	7.55	2.27
SS-110	5/7/2013	22.53606	89.47637	DRP	7.95	1.25
SS-111	5/7/2013	22.53475	89.47936	DRP	7.53	1.42
SS-13	5/7/2013	22.5067	89.47652	DRP	8.10	1.20
SS-112	5/8/2013	22.45827	89.46217	DRP	7.33	2.55
SS-113	5/8/2013	22.45995	89.45743	DRP	7.80	2.72
SS-114	5/8/2013	22.46185	89.45329	DRP	7.61	3.17
SS-115	5/8/2013	22.46308	89.4472	DRP	7.69	2.48
SS-116	5/8/2013	22.46499	89.44318	DRP	7.76	3.95
SS-117	5/8/2013	22.46637	89.43948	DRP	7.72	3.25
SS-118	5/8/2013	22.43777	89.4352	DRP	6.89	4.97
SS-119	5/8/2013	22.43639	89.43863	DRP	7.34	6.05
SS-120	5/10/2013	22.53236	89.45859	DRP	7.63	2.37
SS-122	5/10/2013	22.53713	89.45946	DRP	7.75	2.29
SS-121	5/10/2013	22.53617	89.46804	DRP	8.16	1.33
SS-123	5/10/2013	22.53813	89.45039	DRP	7.68	1.28
SS-124	5/10/2013	22.57009	89.48026	DRP	7.31	1.10
SS-125	5/10/2013	22.57064	89.48743	DRP	6.62	1.05
SS-126	5/10/2013	22.57044	89.49204	DRP	6.09	1.25
SS-05	10/26/2013	22.50629	89.48983	RP	6.81	3.3
SS-08	10/27/2013	22.43033	89.45135	SP	5.16	1.34
SS-30	10/22/2013	22.45902	89.46314	SF	8.26	0.46
SS-32	10/22/2013	22.57322	89.48357	RP	7.58	0.03
SS-33	10/23/2013	22.57224	89.48987	RP	6.62	1.09
SS-34	10/24/2013	22.50076	89.43239	RP	6.88	2.92
SS-35	10/24/2013	22.50629	89.43812	RP	8.15	5.1
SS-36	10/24/2013	22.53279	89.45673	RP	8.12	0.56
SS-37	10/25/2013	22.53221	89.48728	RP	7.26	1.78
SS-38	10/26/2013	22.46737	89.45774	RP	7.10	1.04
SS-39	10/26/2013	22.4798	89.48141	RP	6.41	2.29

ID	DATE	LATITUDE	LONGITUDE	TYPE	PH	SPC (SLURRY) ($\mu\text{S}/\text{CM}$)
SS-40	10/27/2013	22.48018	89.44815	RP	7.04	0.61
SS-41	10/28/2013	22.56363	89.45819	RP	7.31	1.48
SS-110	10/25/2013	22.53606	89.47637	RP	7.72	0.34
SS-111	10/25/2013	22.53475	89.47936	RP	7.78	0.74
SS-112	10/22/2013	22.45827	89.46217	RP	7.15	1.3
SS-122	10/24/2013	22.53713	89.45946	RP	7.80	0.57
SS-126	10/23/2013	22.57044	89.49204	RP	7.47	0.35
TSS-01	10/23/2013	22.55039	89.48928	TC	7.45	0.53
TSS-02	10/24/2013	22.5174	89.4436	TC	7.07	0.85
TSS-03	10/24/2013	22.51476	89.4478	TC	7.82	0.29
TSS-04	10/25/2013	22.53382	89.48684	TC	8.15	0.14
SS-34	5/9/2014	22.50076	89.43239	DRP	7.75	4.53
SS-35	5/9/2014	22.50629	89.43812	DRP	8.1	4.75
SS-115	5/10/2014	22.46308	89.4472	DRP	7.89	3.12
SS-116	5/10/2014	22.46499	89.44318	DRP	7.74	4.23
SS-117	5/10/2014	22.46637	89.43948	DRP	7.76	2.1
SS-200	5/10/2014	22.47492	89.43869	DRP	8.05	3.2
SS-201	5/10/2014	22.47684	89.43841	DRP	8.25	1.81
TSS-20	5/10/2014	22.47097	89.43876	TC	8.39	2.89
SS-202	5/11/2014	22.48796	89.43201	DRP	7.79	6.61
TSS-21	5/11/2014	22.46453	89.43459	TC	8.15	3.50
SS-04	5/12/2014	22.52246	89.49187	DRP	7.95	1.69
SS-32	5/12/2014	22.57322	89.48357	DRP	7.31	2.19
SS-33	5/12/2014	22.57224	89.48987	DRP	8.23	1.22
TSS-22	5/12/2014	22.51992	89.49322	TC	7.91	2.90
TSS-25	5/12/2014	22.5717	89.4914	TC	8.28	2.29
SF-10	5/13/2014	22.45812	89.46827	SF	8.29	5.01
SS-05	5/13/2014	22.50629	89.48983	DRP	7.74	2.94
SS-12	5/13/2014	22.50682	89.47332	DRP	7.94	3.58
SS-13	5/13/2014	22.5067	89.47652	DRP	7.86	3.42
SS-16	5/13/2014	22.50538	89.48306	DRP	7.87	7.17
SS-17	5/13/2014	22.5063	89.48746	DRP	7.77	2.48
TSS-23	5/13/2014	22.49916	89.48933	TC	7.92	2.36
SS-37	5/14/2014	22.53221	89.48728	DRP	7.74	4.74
SS-111	5/14/2014	22.53475	89.47936	DRP	7.76	4.15
SS-203	5/14/2014	22.51955	89.49197	DRP	7.95	3.32
TSS-04	5/14/2014	22.53382	89.48684	TC	8.15	3.23
SS-38	5/15/2014	22.46737	89.45774	DRP	7.4	8.29
SS-204	5/15/2014	22.56395	89.49018	DRP	7.25	2.08
TSS-24	5/15/2014	22.4728	89.4611	TC	7.96	2.45
SS-08	5/16/2014	22.43132	89.45049	DRP	7.22	6.18

Table 2. Cation concentrations of soil samples obtained from deionized water extracts. Values are normalized to reflect concentration in soil. Values are shown in logbase 10.

ID	DATE	AL (PPM SOIL)	AS (PPM SOIL)	B (PPM SOIL)	BA (PPM SOIL)	CA (PPM SOIL)	FE (PPM SOIL)	K (PPM SOIL)	MG (PPM SOIL)	MN (PPM SOIL)	NA (PPM SOIL)	P (PPM SOIL)	S (PPM SOIL)	SI (PPM SOIL)	SR (PPM SOIL)
SS-11	5/4/2013	-0.47	-1.94	-1.23	-0.70	3.34	-1.97	2.20	2.77	--	3.35	-0.22	3.26	1.00	0.87
SS-12	5/7/2013	-0.50	-1.95	-0.54	-0.71	3.34	--	2.25	2.72	--	3.22	-0.47	3.48	1.02	0.97
SS-14	5/7/2013	-0.48	-2.02	-0.59	-0.62	3.47	--	2.28	2.75	--	3.30	-0.44	3.52	1.06	1.07
SS-15	5/7/2013	-0.49	-2.04	-0.51	-0.72	3.24	-1.73	2.27	2.64	--	3.24	-0.41	3.34	0.97	0.84
SS-16	5/7/2013	-0.67	-1.90	-0.02	-0.61	2.78	-1.98	2.21	2.51	--	3.23	0.03	3.01	1.25	0.55
SS-17	5/7/2013	-0.58	-2.05	-0.68	-0.78	2.98	--	2.30	2.62	--	3.23	-0.56	3.26	0.86	0.62
SS-18	5/7/2013	-0.53	-1.74	-0.34	-0.59	3.15	--	2.26	2.61	--	3.23	0.05	3.27	1.22	0.78
SS-19	5/7/2013	-0.89	-2.11	-0.88	-0.81	2.57	--	2.04	2.23	--	3.13	-0.32	2.80	0.99	0.26
SS-110	5/7/2013	--	-2.22	-0.16	-1.25	2.27	-1.97	1.91	1.83	-0.44	2.94	-0.15	2.66	0.91	-0.10
SS-111	5/7/2013	--	-2.17	-0.16	-1.13	2.41	--	1.96	2.03	-0.14	2.97	-0.14	2.72	1.04	0.06
SS-13	5/7/2013	-1.34	--	-1.53		-0.40	--	-0.11	-0.32	-2.53	1.03	-0.61	0.44		
SS-112	5/8/2013	-0.76	-2.14	-0.38	-0.84	2.68	--	2.15	2.52	--	3.17	-0.43	3.09	1.04	0.43
SS-113	5/8/2013	-0.54	-2.03	-1.61	-0.86	3.15	--	2.15	2.57	--	3.13	-0.52	3.29	0.96	0.77
SS-114	5/8/2013	-0.54	-1.93	-0.83	-0.72	3.08	--	2.13	2.60	--	3.22	-0.23	3.17	1.06	0.72
SS-115	5/8/2013	-0.55	-1.96	-1.05	-0.87	3.15	--	2.11	2.47	--	3.11	-0.27	3.28	1.02	0.74
SS-116	5/8/2013	-0.53	-1.79	-0.73	-0.78	3.32	--	2.17	2.68	--	3.28	-0.27	3.39	0.93	0.93
SS-117	5/8/2013	-0.52	-1.86	-1.69	-0.69	3.13	--	2.25	2.69	--	3.18	-0.21	3.26	0.97	0.76
SS-118	5/8/2013	-0.46	-1.61	0.29	-0.34	3.44	-1.97	2.54	2.99	--	3.33	0.19	3.64	1.24	1.16
SS-119	5/8/2013	-0.50	-1.86	-0.24	-0.65	3.20	--	2.42	3.00	--	3.41	-0.27	3.31	0.92	0.81
SS-120	5/10/2013	-0.70	-1.50	-0.55	-0.68	2.79	-1.82	2.13	2.33	--	3.12	0.38	2.87	1.51	0.40
SS-122	5/10/2013	-0.72	-2.11	-1.28	-0.91	2.70	--	2.03	2.25	--	3.11	-0.42	2.90	0.96	0.32
SS-121	5/10/2013	--	-2.32	-0.16	-1.49	1.96	-1.91	1.74	1.71	-1.03	2.98	-0.21	2.41	1.03	-0.32
SS-123	5/10/2013	--	-1.88	-0.10	-1.11	2.65	-1.42	2.04	2.13	0.25	3.00	0.24	2.82	1.19	0.25

ID	DATE	AL (PPM SOIL)	AS (PPM SOIL)	B (PPM SOIL)	BA (PPM SOIL)	CA (PPM SOIL)	FE (PPM SOIL)	K (PPM SOIL)	MG (PPM SOIL)	MN (PPM SOIL)	NA (PPM SOIL)	P (PPM SOIL)	S (PPM SOIL)	SI (PPM SOIL)	SR (PPM SOIL)
SS-124	5/10/2013	--	-2.28	-0.38	-1.14	2.40	--	1.85	2.03	-0.32	2.86	-0.16	2.61	0.98	-0.06
SS-125	5/10/2013	--	-2.27	-0.27	-0.94	2.16	-1.57	1.89	2.01	-0.17	2.87	-0.02	2.35	1.25	-0.13
SS-126	5/10/2013	-1.16	-2.06	-0.06	-0.91	2.51	-0.84	1.98	2.28	0.51	2.92	0.16	2.72	1.34	0.14
SS-05	10/26/2013	--	-1.84	--	-1.14	2.93	0.24	2.08	2.60	--	3.31	0.86	3.07	--	0.57
SS-08	10/27/2013	0.59	-1.71	0.27	-0.66	2.41	0.35	2.11	2.47	--	2.74	-0.23	2.90	1.27	0.40
SS-30	10/22/2013	--	-1.80	-0.36	-1.12	1.84	-0.89	1.67	1.49	--	2.62	-0.55	2.19	0.76	-0.43
SS-32	10/22/2013	-0.07	-2.08	-0.78	-1.40	1.43	-0.01	1.35	1.13	--	2.09	-0.36	1.55	1.01	-0.92
SS-33	10/23/2013	-1.04	-1.69	-0.05	-0.36	2.60	0.30	1.82	2.17	--	2.70	0.70	2.57	1.13	0.20
SS-34	10/24/2013	--	-1.73	--	-1.35	2.96	0.13	1.89	2.60	--	3.23	0.28	3.03	-0.26	0.56
SS-35	10/24/2013	--	--	--	-1.58	2.58	-0.57	1.89	2.41	--	3.63	0.22	2.66	--	0.23
SS-36	10/24/2013	--	-1.81	-0.53	-0.95	2.09	-1.05	1.65	1.73	--	2.65	-0.32	2.28	0.98	-0.24
SS-37	10/25/2013	--	-1.63	0.00	-0.58	2.59	-0.64	2.04	2.36	--	2.94	0.16	2.85	1.19	0.38
SS-38	10/26/2013	--	-1.82	-0.34	-0.51	2.71	-0.50	1.84	2.19	--	2.61	-0.38	2.71	1.06	0.32
SS-39	10/26/2013	--	--	--	-1.20	2.27	--	1.80	2.21	--	3.30	0.27	2.50	0.05	-0.01
SS-40	10/27/2013	--	-1.83	-0.25	-1.02	2.23	-0.11	1.78	1.89	--	2.65	-0.27	2.34	1.16	-0.10
SS-41	10/28/2013	--	-1.58	-0.01	-0.67	2.68	-0.56	2.06	2.30	--	2.90	0.25	2.91	1.06	0.34
SS-110	10/25/2013	--	-1.99	-0.51	-1.04	2.10	-0.36	1.69	1.67	--	2.47	0.15	2.10	0.95	-0.23
SS-111	10/25/2013	--	-2.00	-0.45	-0.96	2.16	-0.94	1.77	1.74	--	2.66	-0.37	2.48	0.86	-0.19
SS-112	10/22/2013	--	-1.61	0.02	-1.08	2.20	0.33	1.83	2.05	--	2.90	0.58	2.51	1.14	-0.02
SS-122	10/24/2013	--	-1.84	-0.31	-1.37	1.75	0.19	1.66	1.53	--	2.69	0.33	2.28	1.14	-0.53
SS-126	10/23/2013	--	-2.04	-0.72	-0.64	2.34	-0.84	1.65	1.79	--	2.24	-0.34	2.34	0.92	-0.06
TSS-01	10/23/2013	--	-1.93	-0.70	-0.74	2.63	-1.37	1.73	1.83	--	2.13	-0.39	2.49	1.02	0.09
TSS-02	10/24/2013	--	-1.77	-0.69	-0.67	2.83	-0.78	1.80	2.14	--	2.13	-0.31	2.72	0.89	0.32
TSS-03	10/24/2013	--	-1.89	-0.71	-0.68	2.32	-1.33	1.62	1.65	--	2.14	0.05	2.10	1.03	-0.10
TSS-04	10/25/2013	--	-1.99	-0.91	-0.40	2.28	-1.68	2.54	1.52	--	1.86	1.25	2.09	0.87	-0.15
SS-34	5/9/2014	-0.54	-2.00	-0.12	-0.87	3.03	-2.00	2.28	2.75	--	3.56	-0.19	3.24	1.03	0.68
SS-35	5/9/2014	-0.76	-2.15	-0.16	-0.94	2.61	-1.70	2.24	2.54	--	3.67	-0.18	2.95	0.93	0.29

ID	DATE	AL (PPM SOIL)	AS (PPM SOIL)	B (PPM SOIL)	BA (PPM SOIL)	CA (PPM SOIL)	FE (PPM SOIL)	K (PPM SOIL)	MG (PPM SOIL)	MN (PPM SOIL)	NA (PPM SOIL)	P (PPM SOIL)	S (PPM SOIL)	SI (PPM SOIL)	SR (PPM SOIL)
SS-115	5/10/2014	-0.55	-2.04	-0.17	-1.01	3.02	--	2.16	2.51	--	3.20	-0.32	3.20	0.93	0.63
SS-116	5/10/2014	-0.51	-1.92	-0.28	-0.99	3.21	--	2.18	2.57	--	3.37	-0.24	3.30	0.92	0.71
SS-117	5/10/2014	-0.57	-1.98	-0.25	-0.87	3.08	--	2.12	2.44	--	2.77	-0.47	3.21	1.01	0.65
SS-200	5/10/2014	-0.67	-2.24	0.01	-1.08	2.79	--	2.18	2.42	--	3.36	-0.53	2.98	0.92	0.45
SS-201	5/10/2014	-0.91	-2.15	-0.34	-1.02	2.46	--	2.11	2.17	--	3.13	-0.48	2.74	0.86	0.06
TSS-20	5/10/2014	-1.21	-1.82	0.09	-1.08	2.11	-1.78	2.15	2.10	--	3.43	-0.38	2.58	0.93	0.05
SS-202	5/11/2014	-0.56	-2.04	-0.04	-0.70	2.91	-1.56	2.32	2.78	--	3.75	0.03	3.12	1.06	0.63
TSS-21	5/11/2014	-0.86	-1.99	-0.24	-0.83	2.53	-1.85	2.07	2.16	--	3.51	-0.15	2.56	0.96	0.20
SS-04	5/12/2014	-0.91	-1.98	-0.25	-0.89	2.47	-1.92	2.13	2.03	--	-0.06	-0.04	2.75	1.02	0.09
SS-32	5/12/2014	-0.75	-1.91	-0.31	-0.95	2.73	-1.29	2.10	2.37	--	-0.02	0.22	2.85	1.18	0.28
SS-33	5/12/2014	-1.04	-2.49	-0.61	-0.96	2.29	--	1.82	1.80	--	2.98	-0.45	2.14	0.90	-0.13
TSS-22	5/12/2014	-0.81	-1.84	0.11	-0.66	2.54	-1.92	2.85	2.41	--	3.54	-0.24	2.85	0.92	0.38
TSS-25	5/12/2014	-1.17	-1.89	-0.04	-1.00	2.22	-1.91	2.06	2.10	--	3.26	-0.34	2.61	0.86	0.05
SF-10	5/13/2014	-0.95	-1.78	0.01	-0.76	2.37	-1.53	2.19	2.40	--	0.65	-0.08	2.57	0.86	0.29
SS-05	5/13/2014	-0.68	-1.94	-0.08	-0.77	2.78	-1.75	2.13	2.48	--	0.33	-0.04	3.02	1.19	0.44
SS-12	5/13/2014	-0.76	-2.18	-0.21	-0.89	2.67	--	2.19	2.37	--	0.47	-0.73	2.76	0.91	0.30
SS-13	5/13/2014	-0.63	-2.02	-0.24	-0.84	2.87	--	2.28	2.48	--	0.34	-0.23	3.04	1.07	0.49
SS-16	5/13/2014	-0.60	-1.98	0.19	-0.51	2.89	-1.92	2.42	2.79	--	0.85	-0.19	2.94	1.08	0.70
SS-17	5/13/2014	-0.81	-2.07	-0.30	-0.74	2.58	-1.73	2.11	2.35	--	0.41	-0.11	2.55	1.05	0.28
TSS-23	5/13/2014	-0.80	-1.96	-0.14	-0.82	2.56	-1.78	2.11	2.18	--	3.21	-0.25	2.81	0.89	0.18
SS-37	5/14/2014	-0.55	-2.05	-0.15	-0.78	3.01	-1.81	2.30	2.60	--	3.50	-0.11	3.16	1.00	0.66
SS-111	5/14/2014	-0.61	-2.02	-0.08	-0.78	2.90	-1.85	2.25	2.54	--	3.53	-0.05	2.98	1.02	0.52
SS-203	5/14/2014	-0.72	-2.12	-0.18	-0.80	2.67	--	2.20	2.46	--	3.39	-0.61	2.92	0.95	0.37

ID	DATE	AL (PPM SOIL)	AS (PPM SOIL)	B (PPM SOIL)	BA (PPM SOIL)	CA (PPM SOIL)	FE (PPM SOIL)	K (PPM SOIL)	MG (PPM SOIL)	MN (PPM SOIL)	NA (PPM SOIL)	P (PPM SOIL)	S (PPM SOIL)	SI (PPM SOIL)	SR (PPM SOIL)
TSS-04	5/14/2014	-0.82	-1.80	0.07	-0.65	2.54	--	2.20	2.32	--	3.44	0.02	2.85	0.96	0.26
SS-38	5/15/2014	-0.48	-2.01	0.34	-0.74	3.17	-1.41	2.57	3.08	--	3.91	-0.01	3.45	1.03	0.96
SS-204	5/15/2014	-0.76	-2.11	-0.66	-0.90	2.67	-1.91	1.96	2.33	--	3.14	-0.01	2.71	0.99	0.14
TSS-24	5/15/2014	--	--	--	-2.16	0.49	--	0.20	0.33	--	1.33	--	1.00	--	-1.84
SS-08	5/16/2014	-0.94	-1.96	0.36	-0.46	2.44	-1.61	2.39	2.62	--	0.76	-0.24	2.87	1.01	0.45

Table 3. Anion concentrations of soil samples obtained from deionized water extracts. Values are normalized to reflect concentration in soil. Values are shown in log base 10.

ID	DATE	CL (PPM SOIL)	NO₃ (PPM SOIL)	SO₄ (PPM SOIL)
SS-11	5/4/2013	3.53	-0.05	3.68
SS-12	5/7/2013	1.69	0.09	1.82
SS-14	5/7/2013	1.77	0.11	1.86
SS-15	5/7/2013	1.66	0.08	1.67
SS-16	5/7/2013	1.61	-0.22	1.31
SS-17	5/7/2013	1.61	0.02	1.60
SS-18	5/7/2013	1.61	-0.15	1.60
SS-19	5/7/2013	1.48	0.21	1.08
SS-110	5/7/2013	2.11	-0.84	2.16
SS-111	5/7/2013	2.17	-0.79	2.20
SS-13	5/7/2013	0.23	-0.84	-0.12
SS-112	5/8/2013	1.57	0.16	1.49
SS-113	5/8/2013	1.48	0.04	1.65
SS-114	5/8/2013	1.66	0.32	1.51
SS-115	5/8/2013	1.41	0.13	1.63
SS-116	5/8/2013	1.74	0.16	1.74
SS-117	5/8/2013	1.57	0.24	1.61
SS-118	5/8/2013	1.80	-0.24	1.99
SS-119	5/8/2013	2.00	0.33	1.64
SS-120	5/10/2013	1.43	0.52	1.21
SS-122	5/10/2013	1.43	0.20	1.24
SS-121	5/10/2013	2.15	-0.75	1.88
SS-123	5/10/2013	2.19	-0.93	2.27
SS-124	5/10/2013	2.06	-0.75	2.07
SS-125	5/10/2013	2.05	-0.75	1.82
SS-126	5/10/2013	2.10	-0.91	2.18
SS-05	10/26/2013	3.47	0.30	3.55
SS-08	10/27/2013	2.88	0.32	3.37
SS-30	10/22/2013	2.75	0.29	2.53
SS-32	10/22/2013	2.21	0.99	2.04
SS-33	10/23/2013	2.87	0.64	3.00
SS-34	10/24/2013	3.37	0.27	3.40
SS-35	10/24/2013	3.75	0.28	3.01
SS-36	10/24/2013	2.83	0.33	2.73
SS-37	10/25/2013	3.11	0.28	3.23
SS-38	10/26/2013	2.80	0.93	3.13
SS-39	10/26/2013	3.44	0.29	2.92
SS-40	10/27/2013	2.80	0.32	2.70

ID	DATE	CL (PPM SOIL)	NO ₃ (PPM SOIL)	SO ₄ (PPM SOIL)
SS-41	10/28/2013	3.04	0.30	3.28
SS-110	10/25/2013	2.63	0.28	2.48
SS-111	10/25/2013	2.81	0.29	2.87
SS-112	10/22/2013	3.03	0.31	2.89
SS-122	10/24/2013	2.84	0.30	2.66
SS-126	10/23/2013	2.42	0.32	2.74
TSS-01	10/23/2013	2.26	0.34	2.92
TSS-02	10/24/2013	2.26	0.33	3.14
TSS-03	10/24/2013	2.27	0.31	2.48
TSS-04	10/25/2013	2.06	0.29	2.48
SS-34	5/9/2014	3.68	1.41	3.67
SS-35	5/9/2014	3.79	0.99	3.41
SS-115	5/10/2014	3.34	1.13	3.64
SS-116	5/10/2014	3.50	1.43	3.74
SS-117	5/10/2014	2.88	1.59	3.64
SS-200	5/10/2014	3.48	1.09	3.41
SS-201	5/10/2014	3.25	1.19	3.20
TSS-20	5/10/2014	3.57	--	3.02
SS-202	5/11/2014	3.88	1.20	3.55
TSS-21	5/11/2014	3.63	0.51	3.03
SS-04	5/12/2014	3.07	1.28	3.17
SS-32	5/12/2014	3.15	2.14	3.31
SS-33	5/12/2014	3.09	1.41	2.61
TSS-22	5/12/2014	3.67	--	3.28
TSS-25	5/12/2014	3.41	--	3.04
SF-10	5/13/2014	3.81	--	3.01
SS-05	5/13/2014	3.43	1.14	3.44
SS-12	5/13/2014	3.59	1.14	3.18
SS-13	5/13/2014	3.47	1.43	3.47
SS-16	5/13/2014	3.96	1.27	3.37
SS-17	5/13/2014	3.52	1.28	3.00
TSS-23	5/13/2014	3.32	0.30	3.23
SS-37	5/14/2014	3.64	1.19	3.60
SS-111	5/14/2014	3.63	1.41	3.40
SS-203	5/14/2014	3.56	--	3.35
TSS-04	5/14/2014	3.56	--	3.28
SS-38	5/15/2014	4.01	1.29	3.89
SS-204	5/15/2014	3.31	0.95	3.17
TSS-24	5/15/2014	3.49	--	3.22
SS-08	5/16/2014	3.91	--	3.29

Table 4. Bulk chemical concentrations of soil samples obtained from bulk soil analyses. Values are shown in log base 10.

ID	DATE	AL (PPM)	AS (PPM)	BA (PPM)	CA (PPM)	CL (PPM)	CU (PPM)	FE (PPM)	K (PPM)	MG (PPM)	MN (PPM)	S (PPM)	SI (PPM)	SR (PPM)
SS-11	5/4/2013	4.71	0.90	2.74	4.08	3.73	1.48	4.69	4.46	3.85	2.84	3.49	5.33	1.96
SS-12	5/7/2013	4.69	1.11	2.70	4.02	3.45	1.52	4.67	4.44	3.87	2.81	3.65	5.34	1.97
SS-14	5/7/2013	4.68	0.85	2.63	4.05	3.54	1.56	4.64	4.41	3.92	2.79	3.66	5.35	2.00
SS-15	5/7/2013	4.69	1.00	2.65	4.06	3.52	1.36	4.67	4.44	3.93	2.73	3.51	5.34	1.96
SS-16	5/7/2013	4.73	1.04	2.76	3.75	3.51	1.62	4.73	4.46	3.74	2.74	3.30	5.33	1.92
SS-17	5/7/2013	4.68	0.95	2.70	3.90	3.48	1.46	4.69	4.43	3.40	2.75	3.45	5.31	1.89
SS-18	5/7/2013	4.71	0.95	2.68	4.02	3.53	--	4.68	4.44	3.66	2.77	3.46	5.34	1.96
SS-19	5/7/2013	4.71	1.00	2.68	3.85	3.38	1.41	4.68	4.44	3.80	2.68	3.20	5.34	1.91
SS-110	5/7/2013	4.71	1.00	2.73	3.86	2.96	1.52	4.71	4.45	3.73	2.78	3.15	5.32	1.91
SS-111	5/7/2013	4.74	0.95	2.76	3.76	3.04	1.67	4.74	4.46	3.91	2.74	3.11	5.33	1.88
SS-113	5/7/2013	4.70	0.90	2.73	3.93	3.00	1.53	4.67	4.44		2.69	3.15	5.35	1.91
SS-112	5/8/2013	4.74	0.90	2.71	3.77	3.41	1.66	4.70	4.46	3.78	2.77	3.45	5.35	1.91
SS-113	5/8/2013	4.70	1.04	2.68	4.13	3.32	1.43	4.66	4.42	3.74	2.81	3.54	5.35	1.97
SS-114	5/8/2013	4.67	1.04	2.65	4.07	3.53	--	4.64	4.40	3.81	2.85	3.58	5.36	1.98
SS-115	5/8/2013	4.72	0.90	2.68	4.07	3.30	--	4.65	4.43	4.05	2.80	3.62	5.35	2.00
SS-116	5/8/2013	4.67	0.95	2.67	4.12	3.54	--	4.61	4.38	3.91	2.82	3.64	5.37	2.03
SS-117	5/8/2013	4.72	1.08	2.67	4.09	3.52	1.58	4.65	4.44	3.80	2.79	3.57	5.37	1.98
SS-118	5/8/2013	4.72	0.85	2.69	3.99	3.62	1.38	4.67	4.44	4.07	2.78	3.78	5.35	2.00
SS-119	5/8/2013	4.73	1.00	2.66	4.02	3.82	--	4.66	4.44	3.76	2.80	3.54	5.37	1.95
SS-120	5/10/2013	4.70	0.90	2.71	4.04	3.40	1.46	4.68	4.44	4.02	2.83	3.38	5.34	1.95
SS-122	5/10/2013	4.73	0.95	2.75	3.99	3.32	1.40	4.68	4.45	3.96	2.80	3.26	5.34	1.93
SS-121	5/10/2013	4.71	1.00	2.72	3.88	3.08	1.46	4.69	4.43	3.79	2.96	2.76	5.36	1.92
SS-123	5/10/2013	4.79	1.23	2.77	4.11	3.08	1.66	4.75	4.48	3.98	2.96	3.18	5.33	1.93

ID	DATE	AL (PPM)	AS (PPM)	BA (PPM)	CA (PPM)	CL (PPM)	CU (PPM)	FE (PPM)	K (PPM)	MG (PPM)	MN (PPM)	S (PPM)	SI (PPM)	SR (PPM)
SS-124	5/10/2013	4.76	1.11	2.75	3.76	2.98	1.51	4.73	4.47	3.90	2.76	3.08	5.35	1.89
SS-125	5/10/2013	4.76	1.00	2.75	3.63	3.04	1.67	4.75	4.46	3.91	2.72	2.89	5.33	1.86
SS-126	5/10/2013	4.77	1.04	2.75	3.65	2.92	1.57	4.74	4.46	3.90	2.75	3.18	5.35	1.88
SS-05	10/26/2013	4.55	0.94	2.68	3.93	3.08	1.66	4.67	4.43	3.54	2.68	3.55	5.25	1.92
SS-08	10/27/2013	4.59	1.04	2.68	3.65	1.65	1.54	4.68	4.42	--	2.54	3.37	5.32	1.98
SS-30	10/22/2013	4.52	--	2.61	4.14	2.05	1.39	4.56	4.37	--	2.65	3.07	5.33	1.99
SS-32	10/22/2013	4.59	1.10	2.66	3.78	--	1.55	4.68	4.42	3.70	2.81	2.92	5.29	1.89
SS-33	10/23/2013	4.55	1.13	2.66	3.91	2.63	1.56	4.67	4.42	3.72	2.66	3.20	5.26	1.91
SS-34	10/24/2013	4.50	0.96	2.72	4.19	3.49	1.48	4.57	4.37	--	2.73	2.94	5.31	1.99
SS-36	10/24/2013	4.64	1.04	2.63	4.12	2.27	1.60	4.68	4.45	3.85	2.82	3.16	5.31	1.93
SS-37	10/25/2013	4.59	1.08	2.62	4.03	2.92	1.69	4.69	4.43	3.78	2.86	3.45	5.27	1.94
SS-38	10/26/2013	4.60	0.98	2.60	4.03	2.25	1.53	4.63	4.42	3.77	2.75	3.26	5.32	1.95
SS-39	10/26/2013	4.61	--	2.67	3.61	3.31	1.66	4.71	4.44	--	2.67	3.10	5.27	1.90
SS-40	10/27/2013	4.57	0.84	2.69	3.92	2.67	1.58	4.65	4.42	--	2.66	3.04	5.29	1.92
SS-41	10/28/2013	4.58	1.11	2.62	4.00	2.97	1.55	4.66	4.43	3.51	2.75	3.67	5.28	1.95
SS-110	10/25/2013	4.55	0.92	2.73	3.91	--	1.61	4.70	4.43	--	2.83	2.84	5.25	1.92
SS-111	10/25/2013	4.64	1.15	2.67	3.96	2.00	1.67	4.71	4.45	3.73	2.78	3.34	5.29	1.89
SS-112	10/22/2013	4.57	0.80	2.70	3.81	2.72	1.63	4.69	4.44	3.58	2.68	3.02	5.28	1.91
SS-122	10/24/2013	4.59	1.14	2.69	3.78	2.14	1.60	4.69	4.43	3.69	2.68	2.95	5.28	1.90
SS-126	10/23/2013	4.56	0.93	2.67	4.07	2.45	--	4.63	4.41	3.73	2.63	3.06	5.29	1.93
TSS-01	10/23/2013	4.56	0.87	2.67	4.26	--	1.57	4.59	4.39	--	2.80	3.07	5.31	2.02
TSS-02	10/24/2013	4.51	1.05	2.66	4.20	--	--	4.58	4.36	3.60	2.73	3.23	5.31	2.01
TSS-03	10/24/2013	4.61	1.01	2.67	4.13	--	1.60	4.68	4.44	--	2.82	2.98	5.28	1.96
TSS-04	10/25/2013	4.56	1.04	2.67	4.22	--	1.43	4.62	4.39	3.60	2.83	3.06	5.30	1.98
SS-34	5/9/2014	4.60	1.04	2.67	3.92	3.42	1.50	4.67	4.44	3.75	2.68	3.62	5.28	1.93
SS-35	5/9/2014	4.53	0.97	2.68	4.19	3.34	--	4.59	4.37	--	2.76	3.03	5.32	1.99
SS-115	5/10/2014	4.57	1.04	2.65	4.08	3.29	--	4.65	4.41	3.63	2.80	3.58	5.28	1.99
SS-116	5/10/2014	4.56	1.06	2.59	4.04	3.40	1.55	4.61	4.39	3.64	2.79	3.64	5.29	1.95
SS-117	5/10/2014	4.58	1.03	2.68	4.02	2.73	1.52	4.67	4.43	3.61	2.83	3.63	5.27	1.98

ID	DATE	AL (PPM)	AS (PPM)	BA (PPM)	CA (PPM)	CL (PPM)	CU (PPM)	FE (PPM)	K (PPM)	MG (PPM)	MN (PPM)	S (PPM)	SI (PPM)	SR (PPM)
SS-200	5/10/2014	4.54	0.97	2.64	4.06	3.29	1.46	4.59	4.38	3.59	2.71	3.23	5.31	1.97
SS-201	5/10/2014	4.52	0.92	2.67	4.11	3.14	1.36	4.59	4.37	--	2.72	3.13	5.32	1.98
TSS-20	5/10/2014	4.56	1.03	2.63	4.02	3.37	1.40	4.61	4.39	3.87	2.78	3.09	5.29	1.97
SS-202	5/11/2014	4.60	1.05	2.74	4.11	3.54	1.64	4.69	4.45	3.65	2.85	3.42	5.28	1.94
TSS-21	5/11/2014	4.58	0.99	2.69	4.21	3.49	1.50	4.61	4.40	3.80	2.78	2.95	5.31	2.00
SS-04	5/12/2014	4.63	1.09	2.76	3.89	2.92	1.46	4.73	4.46	3.78	2.83	3.18	5.26	1.91
SS-32	5/12/2014	4.58	1.07	2.72	3.89	2.98	--	4.71	4.42	3.54	2.69	3.34	5.24	1.93
SS-33	5/12/2014	4.59	0.89	2.79	4.10	2.94	1.56	4.68	4.42	3.58	2.72	2.64	5.28	1.93
TSS-22	5/12/2014	4.56	0.96	2.56	4.12	3.38	1.55	4.63	4.39	3.66	2.83	3.33	5.29	1.99
TSS-25	5/12/2014	4.56	0.88	2.62	4.11	3.20	--	4.61	4.38	--	2.75	3.24	5.31	1.98
SF-10	5/13/2014	4.53	0.97	2.65	4.15	3.59	1.43	4.58	4.37	3.79	2.73	3.05	5.32	2.00
SS-05	5/13/2014	4.64	1.19	2.74	3.95	3.29	1.61	4.74	4.47	3.81	2.86	3.48	5.27	1.92
SS-12	5/13/2014	4.56	1.04	2.67	4.03	3.38	1.45	4.62	4.40	3.56	2.75	3.14	5.29	1.95
SS-13	5/13/2014	4.57	0.93	2.65	4.03	3.32	1.59	4.65	4.42	3.68	2.72	3.49	5.29	1.94
SS-16	5/13/2014	4.62	1.09	2.67	3.93	3.66	1.52	4.71	4.46	--	2.80	3.26	5.27	1.94
SS-17	5/13/2014	4.60	0.90	2.70	3.76	3.39	--	4.68	4.44	3.58	2.73	3.11	5.27	1.90
TSS-23	5/13/2014	4.56	0.78	2.64	4.15	3.22	1.34	4.60	4.38	--	2.75	3.20	5.31	2.00
SS-37	5/14/2014	4.61	1.04	2.69	4.08	3.49	1.41	4.71	4.43	3.82	2.84	3.56	5.27	1.96
SS-111	5/14/2014	4.62	1.11	2.69	3.96	3.49	1.53	4.72	4.45	3.68	2.80	3.25	5.26	1.90
SS-203	5/14/2014	4.61	1.05	2.71	3.96	3.35	1.50	4.71	4.45	3.55	2.83	3.26	5.27	1.92
TSS-04	5/14/2014	4.58	1.09	2.61	4.14	3.41	1.45	4.64	4.40	3.69	2.83	3.25	5.29	2.00
SS-38	5/15/2014	4.58	0.97	2.68	3.80	3.64	1.56	4.69	4.44	3.70	2.63	3.60	5.27	1.96
SS-204	5/15/2014	4.61	1.15	2.74	3.82	3.17	1.63	4.71	4.44	3.83	2.72	3.30	5.26	1.88
TSS-24	5/15/2014	4.58	0.82	2.62	4.04	3.23	1.48	4.58	4.39	3.68	2.66	3.42	5.31	1.96
SS-08	5/16/2014	4.60	1.11	2.63	3.54	3.72	1.61	4.69	4.44	3.88	2.48	3.22	5.27	1.92

Table 5. Dissolved organic and inorganic carbon, % organic and total carbon, and water contents of select soil samples. DOC and DIC values obtained from deionized extracts. % carbon and water content obtained from bulk soil.

ID	DATE	DOC (PPM SOIL)	DIC (PPM SOIL)	% ORGANIC CARBON	% CARBON	H ₂ O+ %	H ₂ O- %
SS-05	10/26/2013	20.01	308.40	1.44	1.44	6.78	1.96
SS-08	10/27/2013	11.66	164.52	1.54	2.2	6.11	2.08
SS-30	10/22/2013	9.61	33.08	0.83	1.32	5.77	1.28
SS-33	10/23/2013	20.30	228.60	2.40	2.29	8.28	2.00
SS-35	10/24/2013	8.28	33.43	0.57	1.16	6.63	1.53
SS-38	10/26/2013	28.32	159.24	1.21	1.43	5.90	2.10
SS-39	10/26/2013	0.97	53.69	1.43	1.2	6.18	3.26
SS-40	10/27/2013	2.87	0.36	0.98	1.22	5.50	3.34
SS-41	10/28/2013	1.81	146.76	2.12	2.6	8.89	2.05
SS-111	10/25/2013	0.82	42.56	1.19	1.26	6.76	2.53
SS-112	10/22/2013	2.19	233.04	2.11	1.78	7.20	1.94
TSS-01	10/23/2013	21.33	54.44	1.06	1.43	6.19	1.39
TSS-02	10/24/2013	16.88	116.04	0.90	1.64	5.98	1.83
TSS-03	10/24/2013	17.67	58.42	1.14	1.33	6.89	1.79
TSS-04	10/25/2013	7.74	21.73	1.17	1.45	6.42	1.50
SS-05	5/13/2014	31.56	10.62	1.28	--	7.12	2.23
SS-08	5/16/2014	38.79	1.09	1.91	--	7.01	2.98
SS-12	5/13/2014	10.96	10.46	1.25	--	6.26	1.85
SS-33	5/12/2014	13.30	10.13	0.57	--	5.99	2.71
SS-35	5/9/2014	24.90	9.35	1.19	--	6.23	1.38
SS-38	5/15/2014	54.92	0.71	2.76	--	6.28	2.30
SS-111	5/14/2014	38.12	6.27	1.36	--	7.11	2.46
SS-115	5/10/2014	19.35	4.87	1.28	--	6.50	1.91
SS-116	5/10/2014	18.18	6.01	1.32	--	6.49	1.83
SS-202	5/11/2014	43.20	9.19	1.93	--	7.47	2.14
SS-204	5/15/2014	29.21	5.07	1.06	--	7.56	2.19
SF-10	5/13/2014	31.92	7.05	1.21	--	6.40	1.54
TSS-21	5/11/2014	21.07	10.82	1.22	--	5.90	1.77
TSS-22	5/12/2014	30.43	7.64	1.33	--	6.75	1.91
TSS-24	5/15/2014	18.39	12.38	1.23	--	5.31	1.64
TSS-25	5/12/2014	15.90	9.68	1.22	--	6.79	2.01

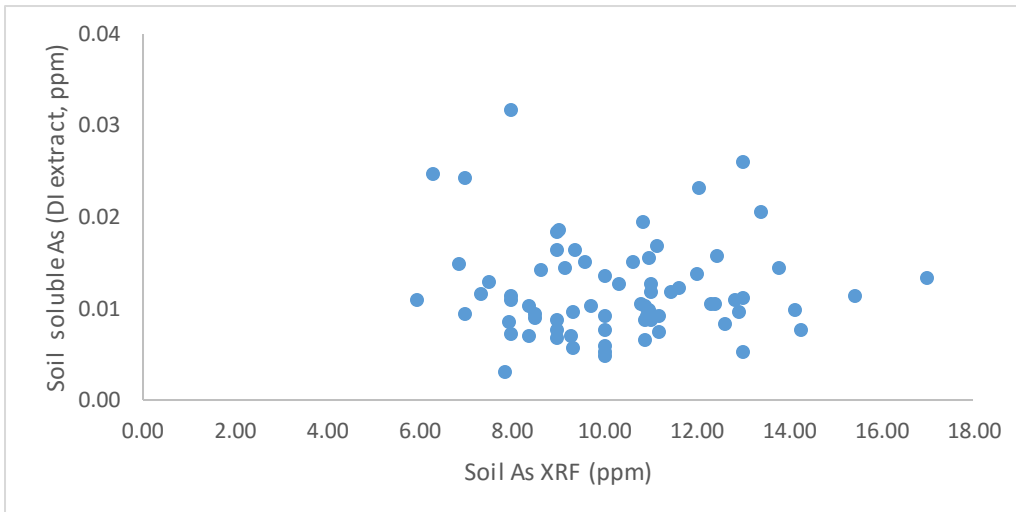


Figure 10. Arsenic bulk soil concentrations vs. soil soluble arsenic from ICP measurements.

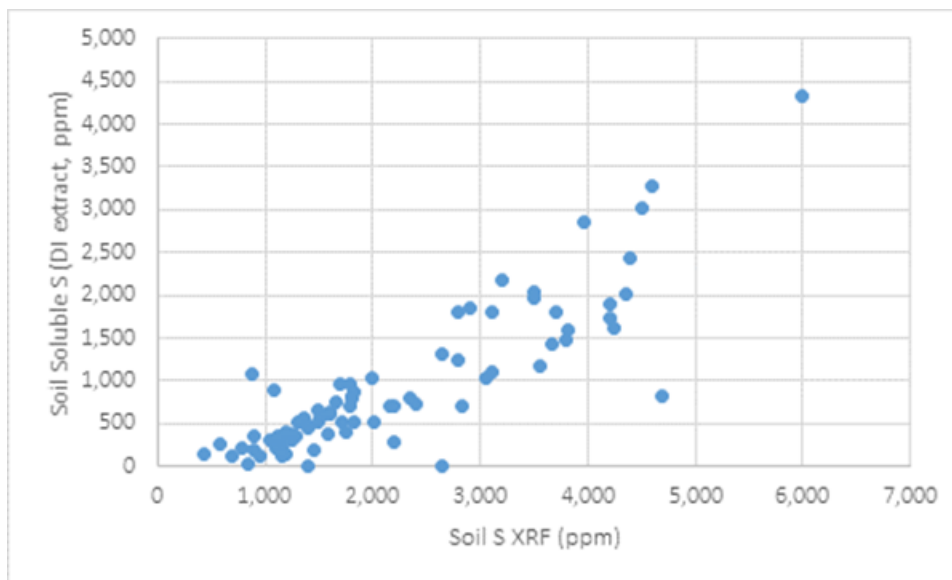


Figure 11. Sulfur bulk soil concentrations vs. soil soluble sulfur from ICP measurements.

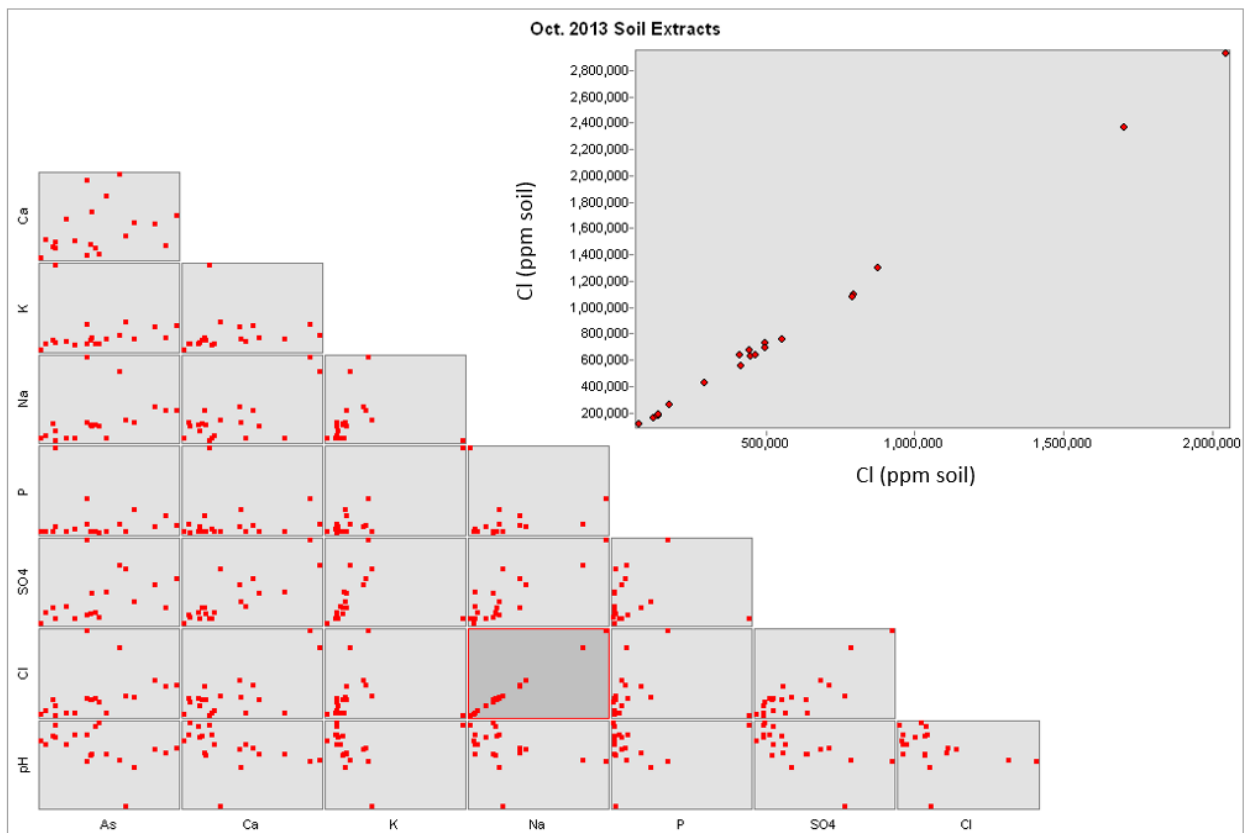


Figure 12. Scatter plot matrix of major cations, anions and pH of soil extracts from Oct. 2013.

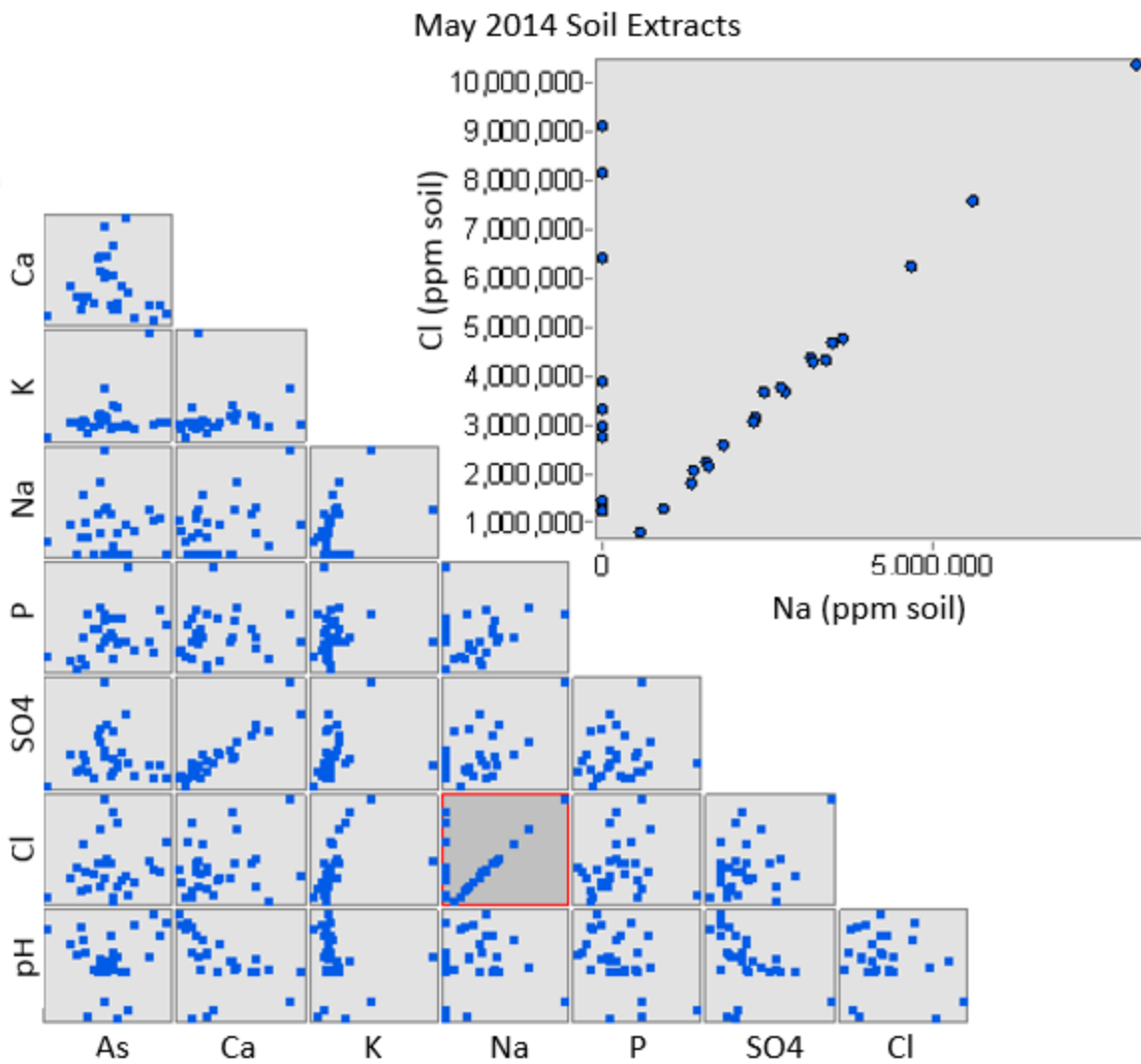


Figure 13. Scatter plot matrix of major cations, anions and pH of soil extracts from May 2014.

Figures 14 & 15 show scatter plot matrices for major element concentrations in bulk soil from XRF data for Oct. 2013 and May 2014. In May 2014, a negative correlation is observed between S obtained from XRF and pH obtained from soil slurries which, similar to the correlations between SO₄ and pH in Figures 12 & 13, could indicate that sulfide oxidation is causing sulfate precipitation and mild acidification of soil. There is also a positive correlation between As and Fe in May 2014, which could show that As is adsorbed on to hydrous ferric oxyhydroxide (HFO) minerals during the dry season. In Oct. 2013, the same correlation between As and Fe does not exist, or is not as strong.

There is a positive correlation between bulk soil S and extract S, with concentrations in bulk soil being slightly higher. The similar concentrations indicate that most S is bioavailable. Extract SO₄ measured by IC is also positively correlated with bulk soil S except for a subset of samples that show anomalously low SO₄ concentration. For this reason for the extract solutions S measured using ICP is preferred over SO₄ measured using IC as an estimate of soluble S in the soil.

Soil Salinity

Figure 16 shows a box plot of total salt concentrations in soil from various sample types, calculated from concentrations in deionized water extracts using the following equation:

$$\text{Total Salt} = \text{Ba} + \text{B} + \text{Ca} + \text{Fe} + \text{K} + \text{Mg} + \text{Mn} + \text{Na} + \text{P} + \text{S} + \text{Si} + \text{Sr} + \text{Cl} + \text{NO}_3 \quad (3)$$

. Figure 17 shows a box plot of specific conductance obtained from soil-DI slurries just before they were filtered to form deionized water extracts, which is a measure of soil salinity. There is

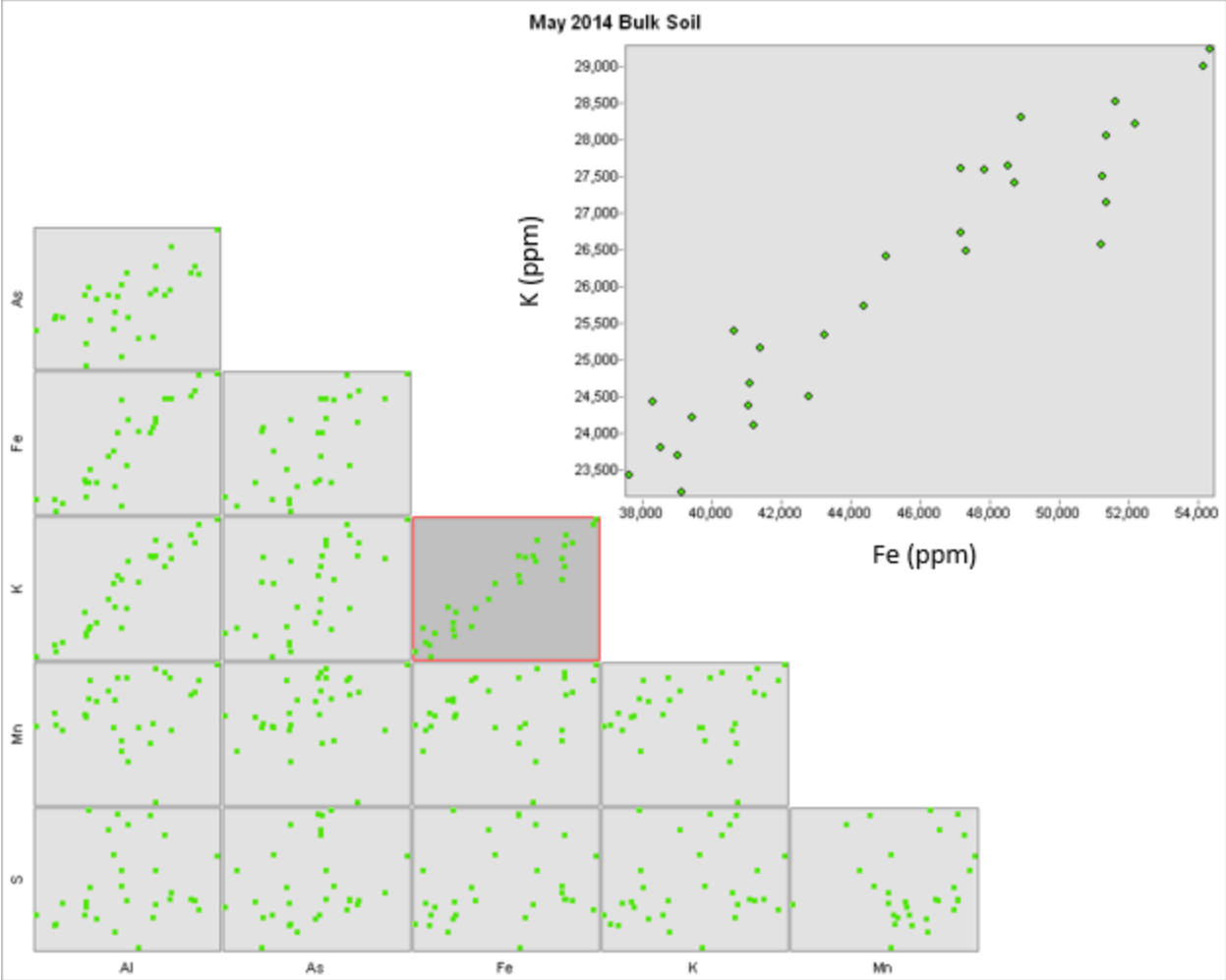


Figure 14. Scatter plot matrix of major elemental concentrations of soils from May 2014.

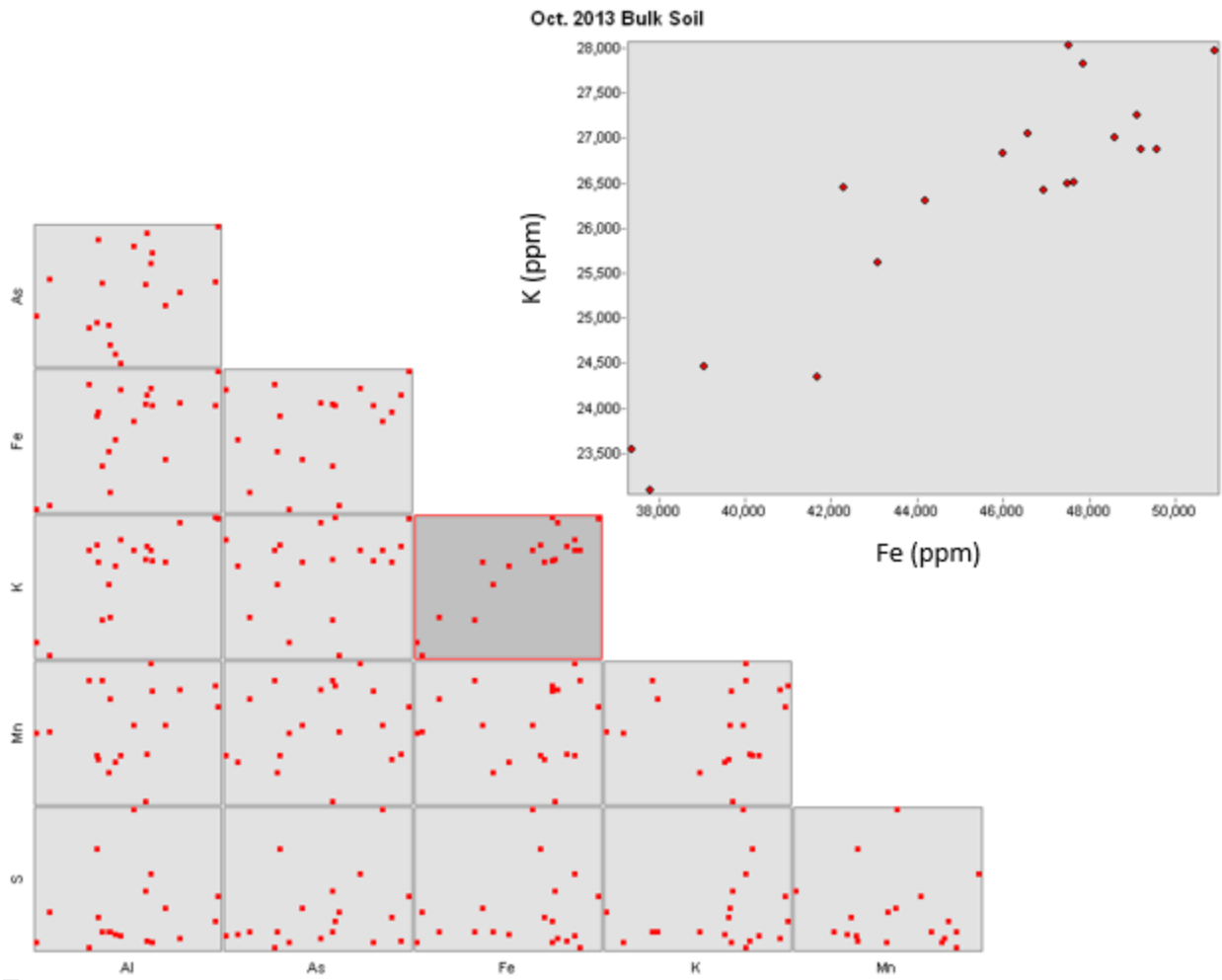


Figure 15. Scatter plot matrix of major elemental concentrations of soils from October 2013.

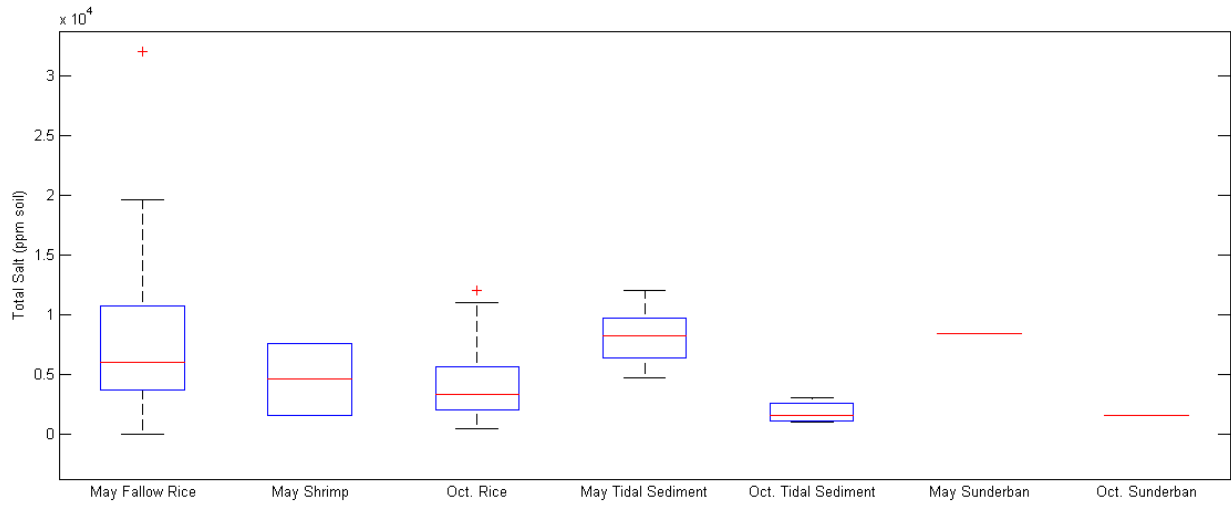


Figure 16. Box-plot analysis of total salt concentrations of various soil samples collected.

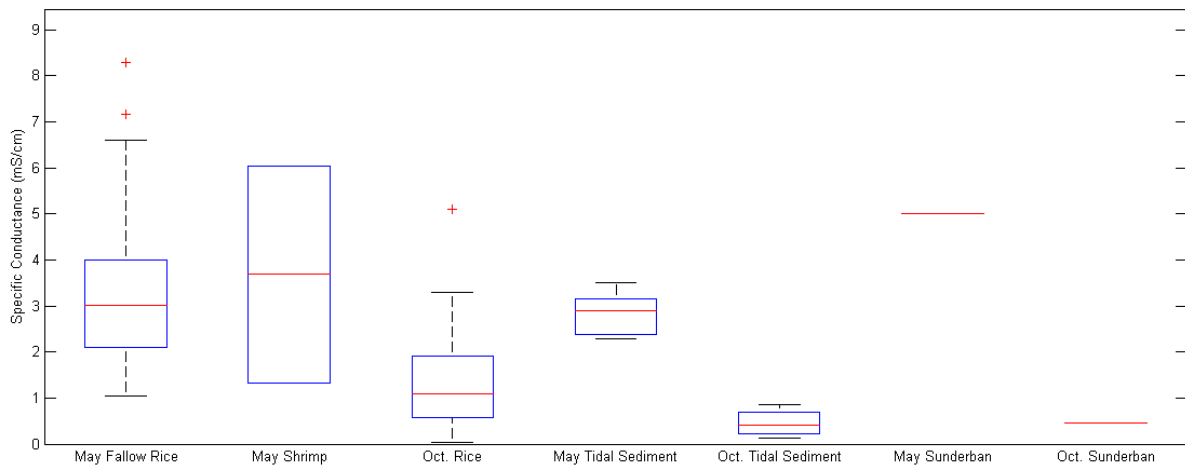
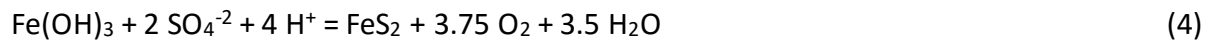


Figure 17. Box-plot analysis of specific conductance of various soil samples collected.

agreement in both box plots showing higher soil salinity during the dry season in all types of samples (rice paddies, tidal channels, Sunderbans). Note that rice paddies in the wet season split into two separate categories during the dry season, fallow rice paddies and shrimp ponds. This increase in dry season salinity can be attributed to evaporative concentration and precipitation of salts in the dry season caused by higher temperatures and less rainfall.

Soil Acidity

Figure 18 shows a box plot of pH from various soil types. The majority of rice paddies in the wet season have a lower pH than the fallow rice paddies and shrimp ponds in the dry season. Tidal channel sediment samples also show a lower pH in the wet season. Equation (4) shows that high pH in the dry season could be caused by consumption of H⁺ during reduction of (Fe(OH)₃), a form of HFO, and SO₄ and resulting precipitation of pyrite (forward reaction). This reaction could be caused by evaporative concentration, which would cause an increase in SO₄ concentration, promoting the forward reaction according to Le'Chatlier's Principle. In the wet season oxygenated water is added, promoting pyrite oxidation and HFO precipitation as represented by the reverse reaction.



Wet season

Dry season

At the beginning of the wet season when the farm land is tilled pyrite is oxidized, producing sulfuric acid. The increase in acidity during the wet season is not seen in the Sunderbans.

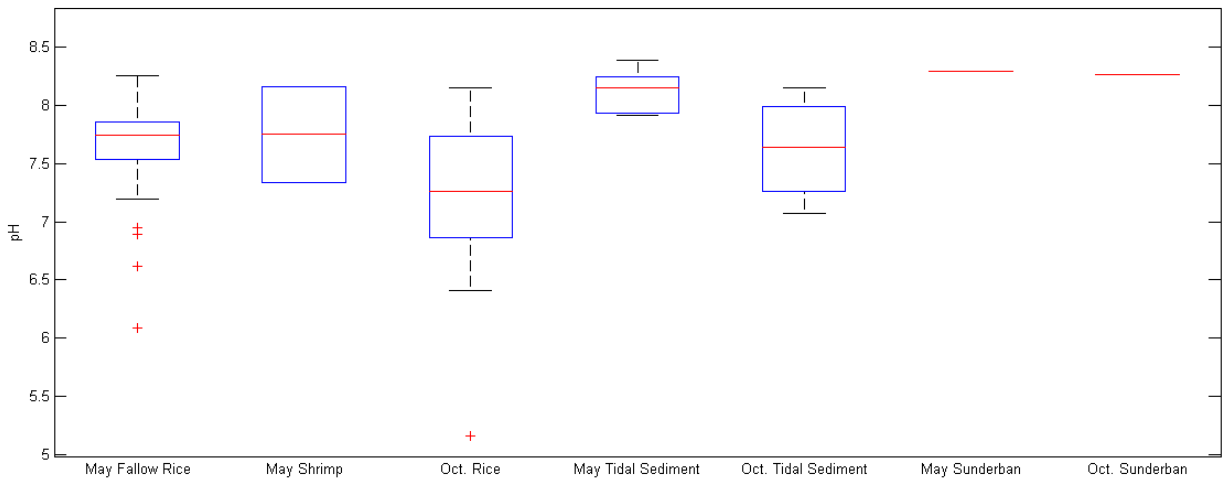


Figure 18. Box-plot analysis of pH of various soil samples collected.

Arsenic

Figure 19 shows a box plot of arsenic concentrations measured from the soil deionized extracts, which are assumed to represent soil water. There is no change in concentration seasonally in tidal channels nor Sunderbans samples, however in rice paddies soluble arsenic is

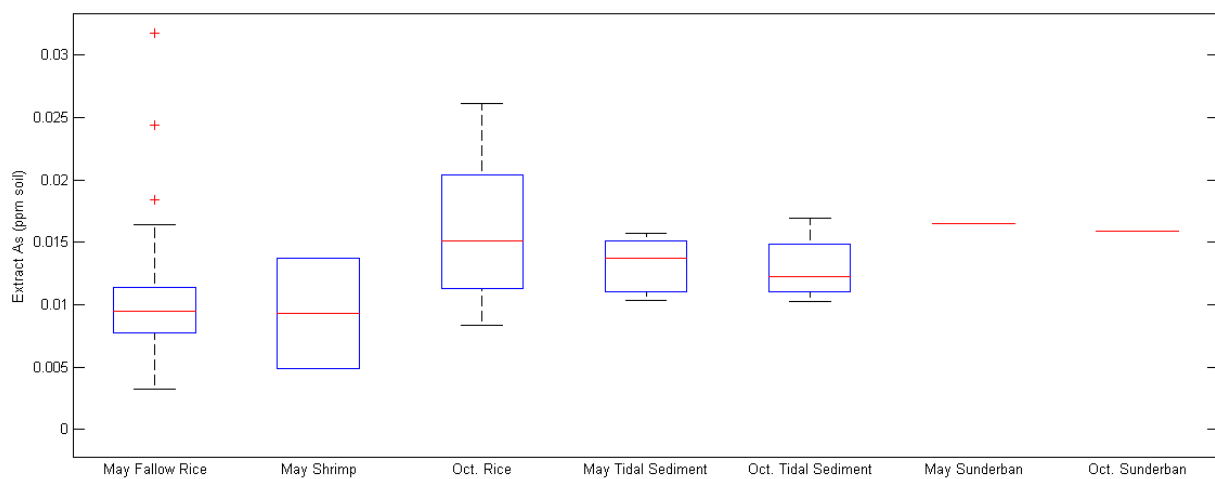


Figure 19. Box-plot analysis of extract arsenic of various soil samples collected.

slightly elevated in the wet season compared to fallow rice paddies and shrimp ponds. Bulk soil analysis by XRF shows no significant difference in As concentration between wet and dry season samples, so As must occur in a more soluble form during the wet season. Figure 20 is a boxplot of soil sulfur concentrations from DI extracts. Soluble S and bulk S concentrations are lower in the wet season in rice paddies because pyrite is oxidized and soluble SO_4 is removed from the soil by fresh water, however S in tidal channels do not vary with season. The Fe concentration in the DI extract is likely not representative of Fe concentration in the soil, as HFO is relatively insoluble under the oxidizing conditions in which the DI extracts were prepared.

DOC, DIC and H₂O content

For all soil types dissolved organic content appears to be elevated in the dry season, while dissolved inorganic content is higher in the wet season (Table 5). This may be explained by accelerated decomposition of organic matter in the wet season, resulting in the conversion of

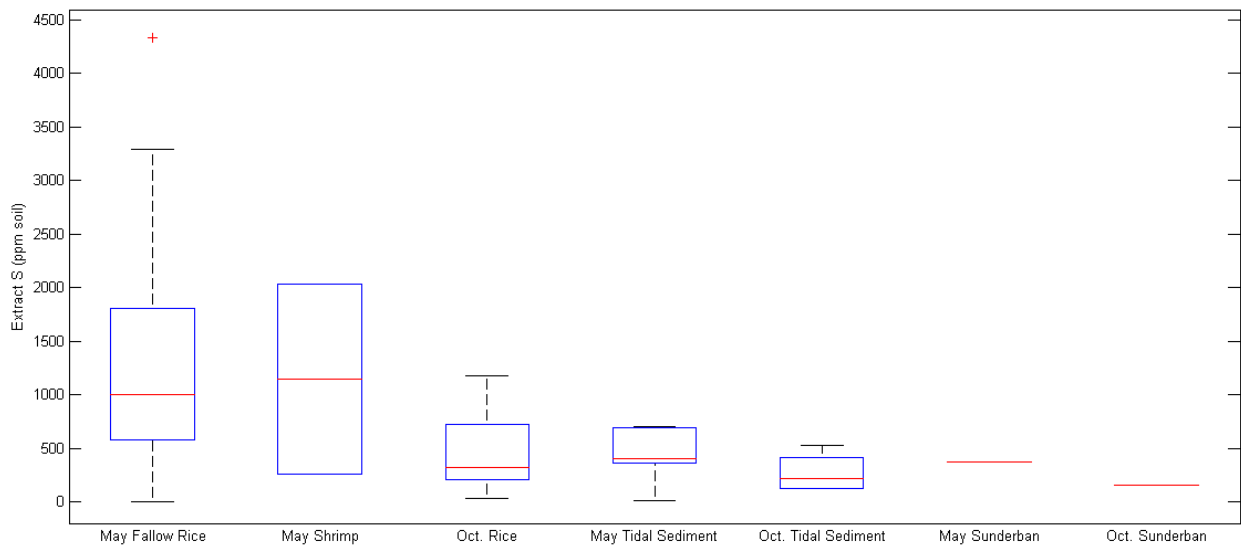


Figure 20. Box-plot analysis of extract sulfur of various soil samples collected.

organic carbon to inorganic carbon. It could also be explained by higher rates of evaporation in the dry season, which could concentrate DOC. Similarly in the wet season, lower DOC values could be due to dilution from meteoric water. H₂O content, both structural and “free-form”, do not appear to vary seasonally.

CHAPTER V

DISCUSSION

Spatial Correlations

Concentrations of major cations and anions, pH and specific conductance were plotted using ArcGIS 10.3 to determine if any spatial patterns exist.

Soil Salinity

Specific conductance of May 2014 soil sample DI extracts was plotted against distance to closest salinity source (Figure 21) to determine if tidal channels and inland streams could be the source of salinity on Polder 32. Inland streams are lumped together with tidal channels because

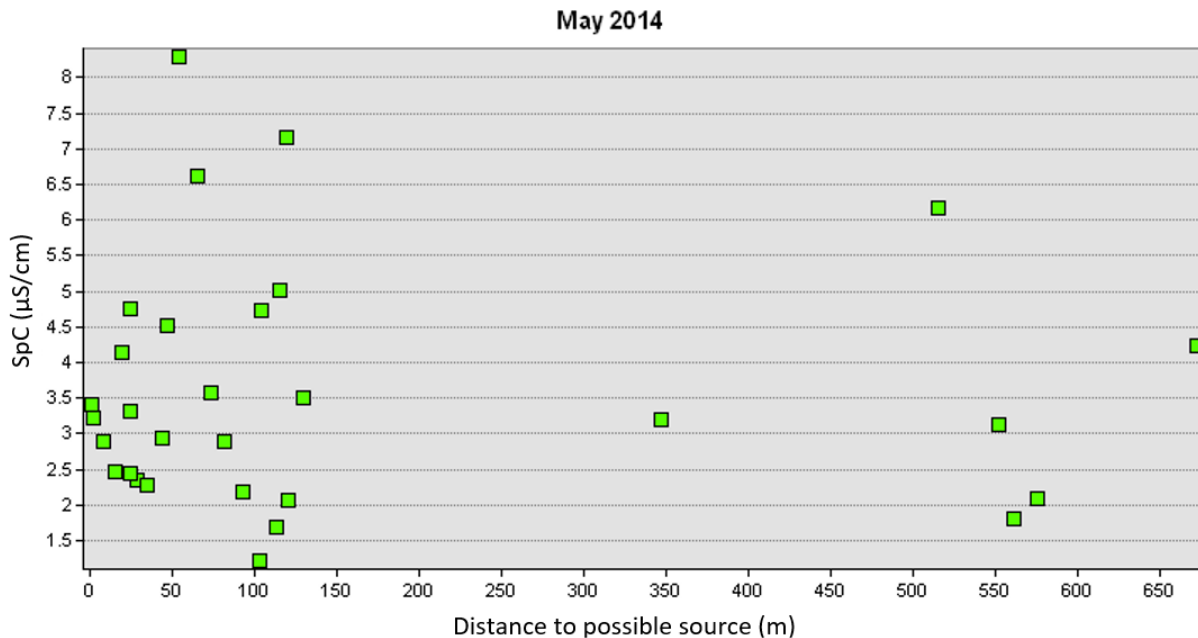


Figure 21. Graph of specific conductance plotted against distance to source in meters for May 2014 samples. Possible sources are tidal channels and inland streams connected to tidal channels.

they are connected to tidal channels and have similar compositions (George, 2013). There appears to be no spatial trend. However, this analysis, in addition to the subsequent analyses of soil acidity and arsenic concentrations, did not take into account that groundwater could be a potential source of salts. Figure 22 shows the total salt concentrations of all soil samples from every season sampled plotted as graduated symbols using ArcGIS. The graduated symbols for each season were normalized to the same scale to allow comparison and evaluation of the seasonal variations in total salt concentrations. Figure 23 shows graphs of salt content obtained from deionized extracts versus latitude during each season sampled. In every season, the south of Polder 32 has higher salt concentrations. Although there is variation and the correlations are weak, the results are consistent through every season, which could suggest that Polder 32 is located near the salinity front, the interface between fresh and salt water in the estuary, however it is important to note that the tides in the area have tens of kilometers of excursion and are well mixed. Soil salinity is higher in the Sunderbans in the dry season than the wet season, and has similar salt concentrations as Polder 32 soils during that season.

Soil Acidity

Figure 24 shows soil sample acidity plotted as graduated symbols on Polder 32. It appears as if soil acidity is not a function of its location on Polder 32.

Inundation during the wet season is supposed to cause sulfide precipitation, however this is not what is observed in our samples. Perhaps sulfide precipitation occurs at the end of the wet season when there are reducing conditions and the beginning of the dry season when

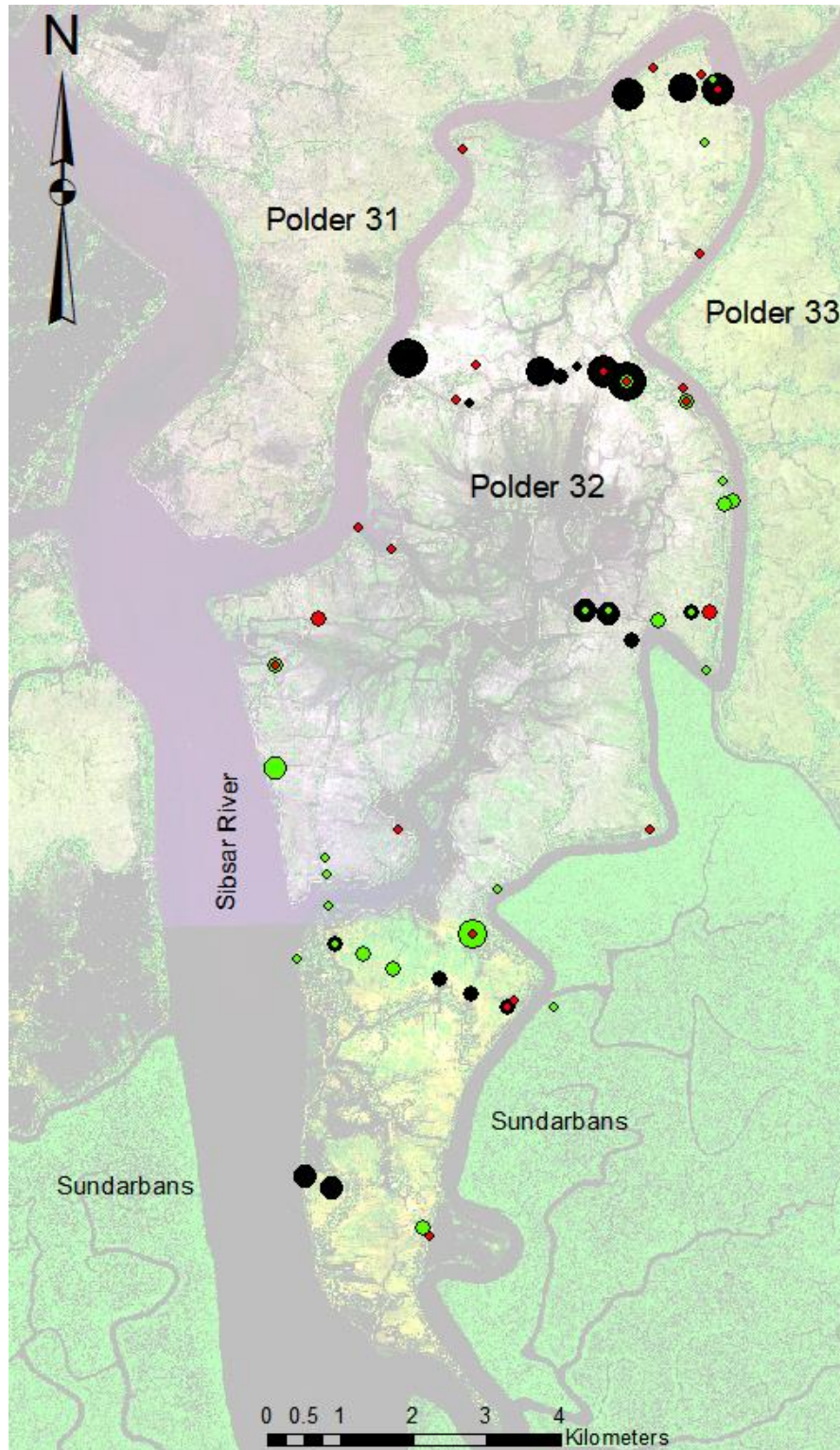


Figure 22. Map of graduated symbols of total salt concentrations of all soil samples collected. Black - May 2013, Red - Oct. 2013, Green - May 2014. Symbol size represents concentration amount.

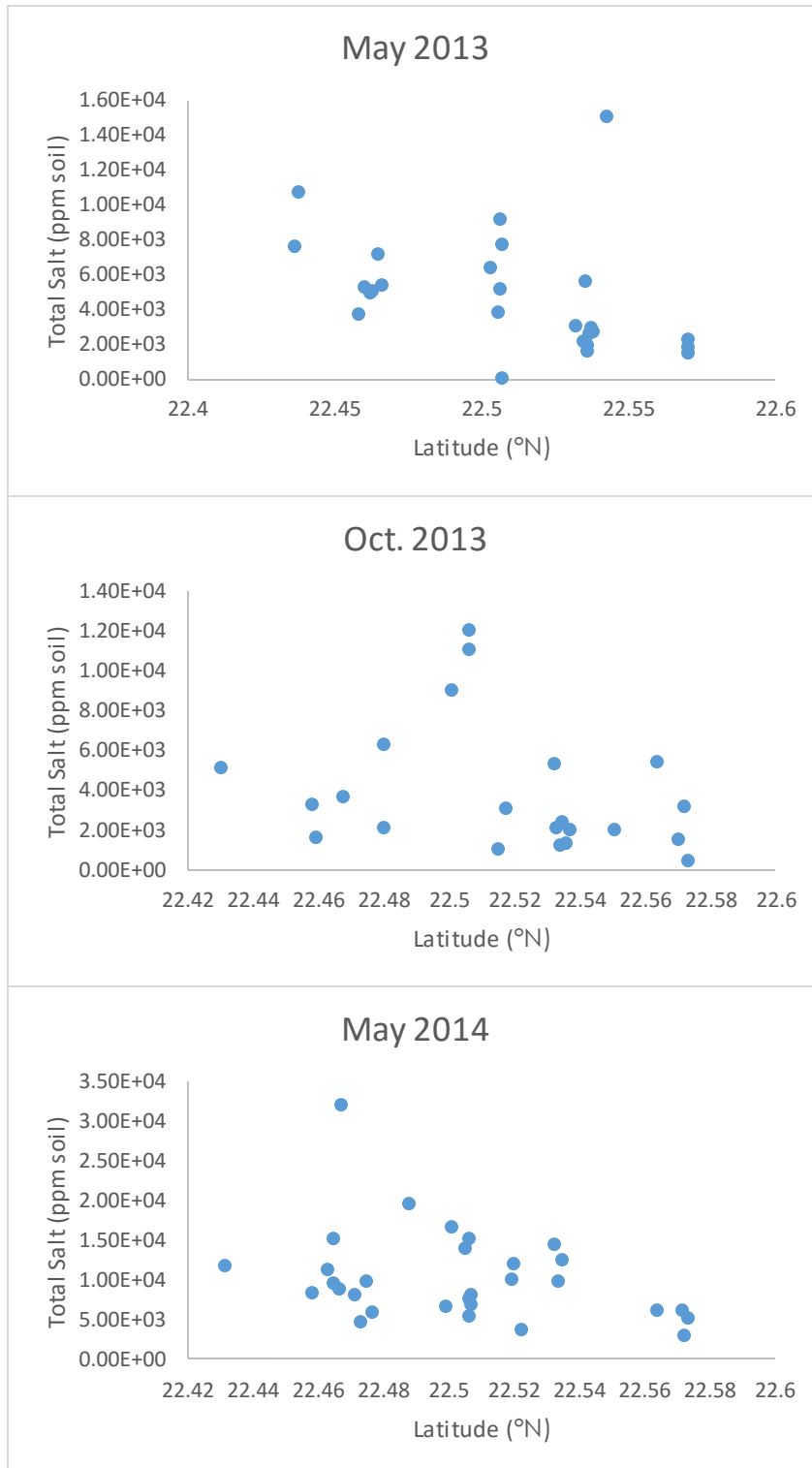


Figure 23. Graphs of total salt content versus latitude.

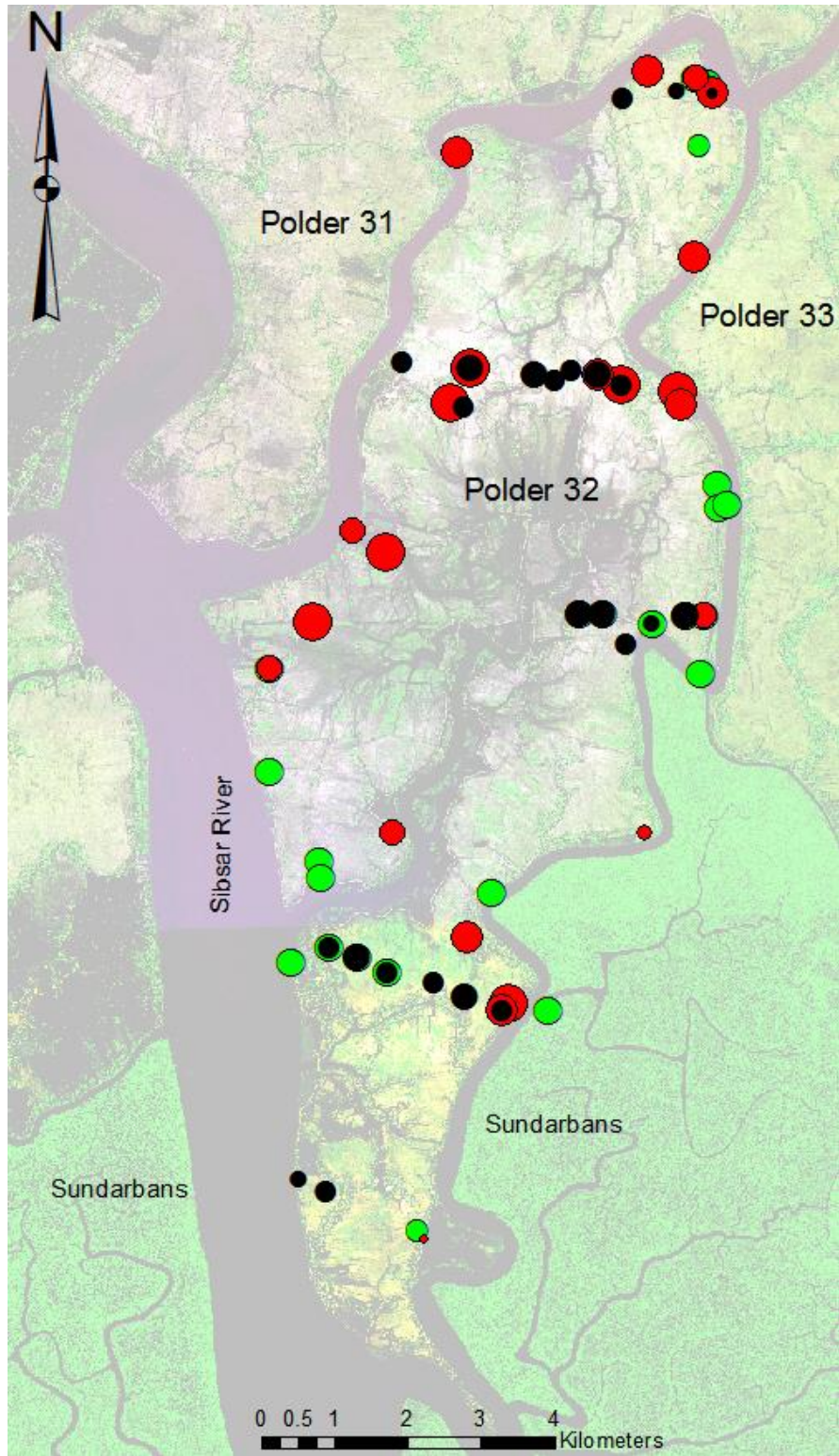


Figure 24. Map of graduated symbols of pH of all soil samples collected. Black - May 2013, Red - Oct. 2013, Green - May 2014. Symbol size represents concentration amount.

evaporation concentrates sulfur, thus leading to sulfide precipitation. Since our samples were taken at the end of the dry season and in the middle of the wet season, these processes were not observed. Soil slurry pH does not change with season, unlike pH of Polder 32 soils.

Arsenic

Similar analyses were performed on soil salinity and acidity to see if arsenic extract concentrations are a function of location (Figure 25). No spatial trends were observed.

Arsenic appears to be slightly more mobile in the wet season than in the dry season. This suggests that As is more effectively sequestered by co-precipitation in sulfides than by adsorption onto HFOs. Arsenic concentrations do not vary seasonal unlike Polder 32 soils. This could be due to the constant inundation from tidal channel water in the Sunderbans, which does not have a fluctuating concentration of As.

Health Limits & Crop Yields

Table 6 classifies the salinity of measured samples using a soil salinity classification developed by the Food and Agriculture Organization. While many samples in both May 2013 & 2014 are slightly to moderately saline, the majority of samples in October 2013 are classified as non-saline. This indicates that during the wet season, the season in which rice is grown, the majority of sampled soils' salinity have a negligible effect on rice growth. It is also worth noting that May 2014 has a higher proportion of moderately saline samples than May 2013. This could be due to

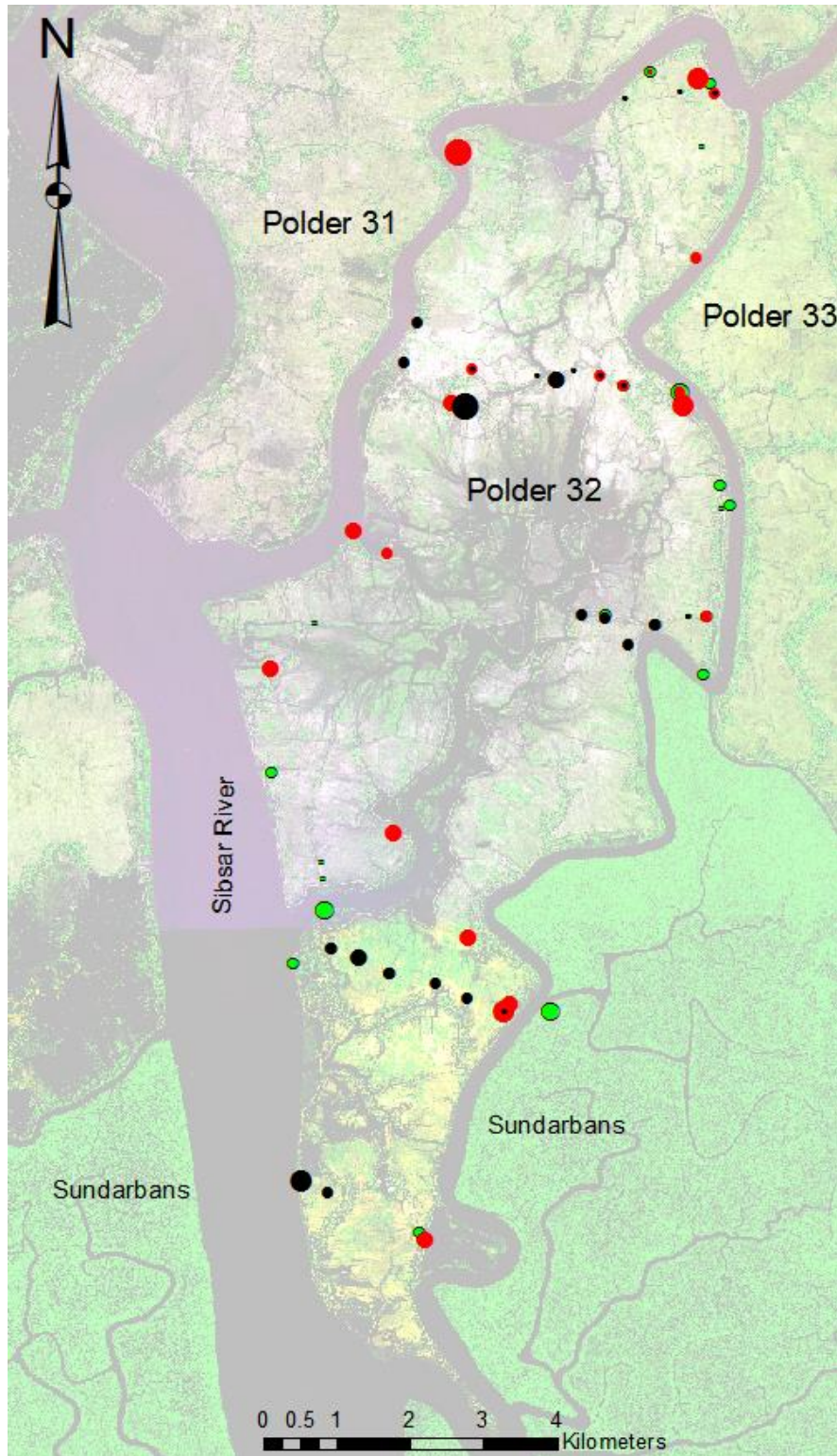


Figure 25. Map of graduated symbols of extract arsenic concentrations of all soil samples collected. Black - May 2013, Red - Oct. 2013, Green - May 2014. Symbol size represents concentration amount.

Table 6. FAO soil salinity classifications with samples classified (modified from Ayers and Westcot, 1994).

SOIL SALINITY CLASS	CONDUCTIVITY OF THE SATURATION EXTRACT (DS/M)	EFFECT ON CROP PLANTS	MAY 2013	OCT. 2013	MAY 2014
NON SALINE	0 - 2	Salinity effects negligible	8	15	3
SLIGHTLY SALINE	2 - 4	Yields of sensitive crops may be restricted	14	1	10
MODERATELY SALINE	4 - 8	Yields of many crops are restricted	3	1	9
STRONGLY SALINE	8 - 16	Only tolerant crops yield satisfactorily	0	0	0
VERY STRONGLY SALINE	> 16	Only a few very tolerant crops yield satisfactorily	0	0	0

an overall increase in salinity through time. However, more data would be needed to determine whether that is the case.

Unfortunately, no health guidelines have been established for arsenic concentration in soil. There are health limits for arsenic in water, most likely because water is a primary source while soil is a secondary source of arsenic for human consumption. Zhu et al. (2008) determined that grain concentrations of arsenic in rice would have to be as low as 50 µg/kg if consumed at 200 grams per day to equate to similar exposures from drinking water at 10 µg/L, the maximum contaminant level of arsenic in water in most countries. Heikens (2006) has shown that rice worldwide can commonly exceed inorganic arsenic concentrations of 50 µg/kg and can reach

concentrations up to approximately 400 $\mu\text{g}/\text{kg}$. Further research will need to be performed to develop standards for arsenic in soil that is used for crop cultivation.

When comparing deionized water extract arsenic concentrations to the World Health Organization (WHO) limit for drinking water (10 parts per billion), all but one rice paddy measurement is below the limit. Since DI water extracts should have a similar composition to soil water, it can be inferred that most soil water contains measureable values of arsenic but those are lower than WHO guideline limits.

Contrary to the study of Ali (2006) that motivated this research, pH values of soil DI extracts was not very acidic, even for samples from shrimp ponds. Either the measurements of Ali (2006) were erroneous, or something is happening to Polder 32 that has not happened in Ali's study area. Perhaps Cyclone Aila in 2009 and the subsequent inundation of Polder 32 for over one year resulted in deposition of sediments with enough carbonate material to buffer pH to near-neutral values. Since our samples contained measurable values of carbonate (Table 4), enough would have been present to prevent the development of acidic soils.

Soil salinities measured in this study are lower than those reported by Ali (2006), who measured specific conductance values of soils that alternated between rice and shrimp cultivation between 12.0 and 18.7 $\mu\text{S}/\text{cm}$, while values from Polder 32 measured between 0.03 and 8.29 $\mu\text{S}/\text{cm}$. In samples that alternated between rice paddy and shrimp farm, salinities were comparable to samples that were fallow during the dry season and rice paddies during the wet season. In fact, one sample (SS-121) from a rice-shrimp field had one of the lowest salinities

observed in May 2013. Deposition of fresh sediments on Polder 32 during the post-Aila tidal inundation might explain why our measured soil salinities were lower than those measured by Ali (2006). If land used for rice and shrimp cultivation were set back to the natural order of the landscape, where they were inundated regularly due to tides, then salts that have accumulated in the soil could be washed away, ultimately lowering salinity. Unfortunately no soil measurements were taken on Polder 32 before cyclone Aila. However, future studies could look at this phenomenon to determine if this is why soil is only slightly to moderately saline and pH values for soil are close to neutral.

CHAPTER VI

CONCLUSION

Soil composition on Polder 32 appears to have compositional variation in both space and time. All samples analyzed appear to be entisols that have recently been deposited by the adjacent tidal channels. Soils on Polder 32 are predominantly silt-sized with a carbon concentration typical of mangrove forests.

While not able to determine whether or not soil salinity changed on a yearly basis, a seasonal component was discovered. Soil salinities are higher in May (dry season) than in October (wet season). This is attributed to higher temperatures in the dry season that result in higher rates of evaporation coupled with lower rates of meteoric water input. Shrimp pond, tidal channel, and Sunderbans soil samples have an added input of brackish water resulting from exposure to tidal channel water which has higher salt concentrations in the dry season. Salinity was found to be elevated in the south, which could indicate that Polder 32 is located in the salinity front.

Soil acidity in certain soil types shows a seasonal trend. Rice paddies in the wet season are more acidic than fallow rice paddies and shrimp ponds in the dry season, tidal channel samples in the wet season are more acidic than in the dry season, and Sunderbans samples have roughly the same pH regardless of season. The decrease in pH in the wet season samples is likely due to oxidation of Fe sulfides exposed to rainwater by tillage.

Arsenic concentrations in tidal channel and Sunderbans samples show no seasonal variations, but are elevated in wet season rice paddies compared to dry season shrimp ponds and fallow rice paddies. A positive correlation between As and Fe concentrations in DI extracts suggests that Fe minerals control soil As concentrations. When HFOs are deposited in the wet season, arsenic from the water used to irrigate the rice paddies can adsorb on to them, while in the dry season As must co-precipitate with Fe-sulfides.

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