Salinity and Arsenic Threat in the irrigated fields of Mekelle Plateau of the northern Highlands of Ethiopia

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Abstract: Due to its semi arid climate, the Tigray Plateau suffers from chronic water shortage. In a country where agriculture represents the major form of income, ensuring adequate water becomes especially important. This concern was addressed historically by the construction of above 60 community dams throughout Tigray. This study was conducted to evaluate the impact of the recently constructed community dams on soil salinisation and arsenic accumulation in Mekelle Plateau. Hence, a total of twenty seven soil samples and nine water samples were collected and sent to the Analytical Services Laboratory of the International Livestock Research Institute (ILRI-Ethiopia) for examining the magnitude and severity of soil salinity and arsenic concentration. Accordingly, all the water samples in these dams contain salts, which the TDS varied as little as 147 µg ml^{-1} in *Adigudom dam* to 236.8 µg ml^{-1} in *Gerebsegen dam*. Based on the ratio of soluble sodium percentage to salt concentrations, *May Gasa* and *Gum Selasa* dams were the most salted dams with the amounts of 34.6 and 30%, respectively. Fifty nine percent of the studied soils were saline with the salt level greater than 2 dSm^{-1} at which the growth of major cereal crops can be impaired and the remaining 49 % were greater than 1.25 dSm^{-1}, which are potentially hazardous. The arsenic concentrations in all the soil samples were extremely high and were varied from 260-440, 260-300 and 260-460 ppm in soils of Korer, Gum Selasa and Kelamino irrigated fields, respectively. [Report and Opinion 2009;1(6):96-102].(ISSN:1553-9873).

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1. Introduction

Successful agricultural development will result in a significant reduction of poverty and an improvement in food security. However, in Ethiopia, despite numerous macroeconomic, political, and sectoral reforms, poverty, environmental degradation and food insecurity appear to be on the rise. There is a pressing need for Ethiopia to increase agricultural productivity while pursuing sustainable management of their natural resource base on which food production depends. Such development efforts require significant public investments in agricultural and environmental resources development. Agriculture is the mainstay of Ethiopia's economy, providing the livelihood base for nearly 85% of the population, contributing over 50% of gross domestic product, and accounting for about 90% of foreign exchange earnings. Many would concur that the overall performance of Ethiopia's economy for the foreseeable future to a great extent depends on the developments in this sector. The lack of sustained economic growth and emergent food crises in the country now and in the past are the results of weak transformation of the agricultural sector. These conditions are buttressed by high population growth, environmental degradation, and poor market and institutional arrangements.

Ethiopian agriculture is largely small-scale, subsistence-oriented, and crucially dependent on rainfall. The highlands of Ethiopia, which house most of the country's agricultural potential, suffer from massive land degradation due to soil erosion caused by heavy runoff and deforestation, and the low productivity of peasant agriculture Grepperud (1996). The increasing loss of soil and other natural resources has resulted in steady declines in land and labour productivity (FAO, 1986; Hurni, 1993; Shiferaw and Holden, 1999).

Dependence on rainfed agriculture coupled with the erratic nature of rainfall is one of the main causes of widespread food insecurity in the country. Droughts occur every 3-5 years in northern Ethiopia and every 8-10 years for the whole country, with severe consequences for food production (Haile, 1988). With the lack of well-functioning social networks to provide safeguards at the local, regional or national levels, it is prohibitively difficult to survive even a single year of failed harvest. Hence a sustainable increase in food production to achieve self-sufficiency depends, at least in part, on how Ethiopia addresses its dependence on rainfall. To this effect, the construction of dams and development of irrigation schemes will provide many poor Ethiopian farmers with greater food security, an improved diet and increased income. Accordingly, in the Tigray region of northern Ethiopia, an extensive community-led microdam-based irrigation scheme was in progress, managed by the Tigray Sustainable Agricultural and Environmental Rehabilitation Commission (SAERT 1994; WIC 2002). To date about 60 have been constructed ranging in size from 50 000 to 4000 000 m^3 (unpublished data), and most are situated near human settlements (Fig 1). Regular monitoring and critical analyses under various agro-ecological zones of the ecological impact of these dams is imperative and worthwhile for timely intervention and sustainable use of them. Apparently, irrigation adds salts to soil. Soil salinization in its early stages of development reduces soil productivity, but in advanced stages kills all vegetation and consequently transforms fertile and productive land to barren land, leading to loss of habitat and reduction of biodiversity. Moreover, salinization can damage the economy of salt affected countries. In Ethiopia, the Amibara Melka Sedi area, which covers about 14 200 ha of net irrigable land in the Awash River Basin, encounters problems of salinization and rising watertables to varying degrees. The estimated cost of the development program to introduce subsurface drainage and thereby reduce salinity and rising watertable hazards is about US$ 52.2 million (Office of the National Committee for Central Planning, 1988). The social cost of salinization is not easy to quantify. Salinisation causes occupational and geographic shifting of the farm population and reduction in aggregate national income and expenditure. These events have social and economic repercussions on the country as a whole. The impacts are most apparent in rural hamlets and small towns because the opportunities for adjustment of the local economic base are more limited (Peck *et al*., 1983). Hence, this paper is motivated to provide information on salinity and arsenic risk in the environs of nine selected dams in the Mekelle plateau.

a) b)

Figure. 1. a) A community dam constructed in one of the study areas b) white salt patches at the outlet of irrigated fields in Adigudom

2. Materials and Methods

2.1 The study area

The Mekele Plateau is the eastern-central portion of the northern uplands of Ethiopia, which is known as the Tigrean Plateau. At its centre is the city of Mekelle, the capital of the northern Ethiopian region of Tigray. The Mekelle Plateau is an upland plateau with elevations ranging between 2000 and 2800 m.a.s.l. The terrain is composed of an undulating and rolling plateau, steeply dissected hills and pediments, and flood plains. The drainage pattern is characterized by the scarcity of deeply incised river valleys. The underlying geology is dominated by Jurassic Agula shale and Hintalo limestone and Mekelle dolerite sills in the Agula shale. The Plateau lies in the semi-arid zone with an average annual rainfall of 550 mm Agriculture in the plateau is based on ox-plough cultivation of predominantly cereal crops. This technology has prevailed without modification for thousands of years, harvesting the same land over and over again. The level of subsistence, except for periods of good rains, has declined radically during the past decades, with almost everything produced being consumed at the farm household level. The cropping pattern is dominated by barley, wheat and teff (*Eragrotis teff*). Drought is a recurrent factor in the farming system and responses to it include a shift to low-yielding drought resistant varieties of traditional crops.

Recently, in this particular area, nine microdams were constructed to mitigate drought and develop small scale irrigation viz., *Mai Gassa dam*; *Adi Kefaniz dam*; *Feliglig dam*; *Duranbesa dam*; *Girat Shito dam*; *Mai Haidi dam*; *Gereb segen*; *Gum Selassa* and *Mai Delle* dams were selected for water quality studies whereas three dams namely, *Gumselasa*; *Kelamino* and *Qorer* dams were randomly selected to assess the distribution of arsenic. The dams and their location characteristics are illustrated in Fig 2.

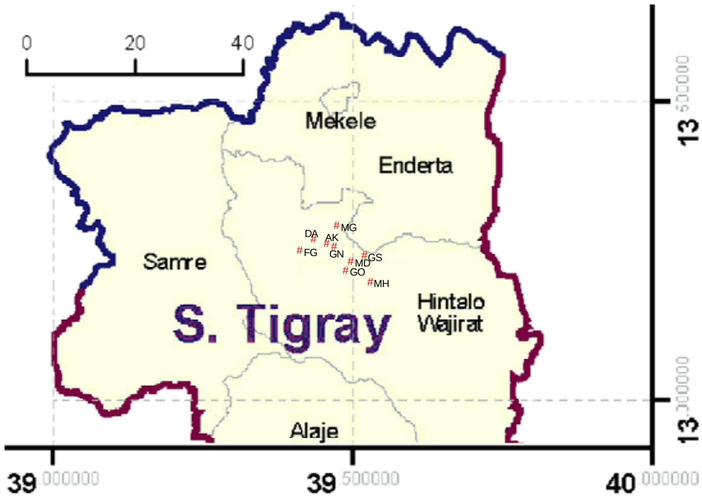

Figure. 2. Dams and their location in Mekelle Plateau where DA (Dur ambesa), MG (Mai Gasa), AK (*Adi Kefaniz*), FG (*Feliglig*), GN (*Gereb segen*), GS (*Gum Selassa*), MD (*Mai Delle*), GO (*Girat Shito*) and MH (*Mai Haidi*)

2.2 Methods

Nine profile pits were opened in the representative sites where the current irrigation practices are carried out (Fig 1). All the nine pits were morphologically described and twenty seven soil samples were collected for Lab analysis. Furthermore, nine water samples were collected from these dams. Both the water and soil samples were sent to the Analytical Services Laboratory of the International Livestock Research Institute (ILRI-Ethiopia) for examining the exchangeable Na, Mg and Ca. Bicarbonate, carbonate, sulphate and chloride were analyzed in the Soils Research Laboratory of Mekelle University. Finally, from a randomly selected three dams environs another twenty seven surface soil samples were collected to analyse the arsenic concentration. The soil samples were sent to the Ezana Commercial Mining Laboratory, Mekelle for arsenic determination using atomic absorption spectrophotometer (AAS). The electrical conductivity (EC) ($mScm^{-1}$) of the soils was determined using the equation: EC= (∑ cations, cmol kg^{-1} soils)/10 (U.S. Salinity Laboratory Staff 1954) and the sodium adsorption ratio (SAR) was calculated from the equation (Singer and Munns, 1987).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} \quad \text{[Eq.1]}$$

And the exchangeable sodium percentage of the soil (ESP) was calculated considering the percentage of exchangeable sodium ions to the total exchangeable cations of all types in the soil sample (Donahue *et al.*, 1983). Water quality in the dams was rated according to [Eq.2] as described in (LLoyd, *et al.*, 1964). All waters that would cause equilibrium exchangeable sodium percentages of 15 or greater were assumed to be unsatisfactory for general use. Descriptive statistics was used to analyse the data.

$$\left(Na * 100\right) / \left(Ca + Mg + Na\right) \quad \text{[Eq.2]}$$

3. Results and Discussion

3.1 Water resource salinization

The quality of irrigation waters depends principally up on the total amount of salt present and the proportion of sodium to other cations (Wilcox, 1958). The most satisfactory method for rating the salt content of irrigation waters involves measuring electrical conductivity. Hence, the EC of the water resource in the nine dams were varying from 230 in *Adigudom dam* to 350 µS cm^{-1} in *May Gasa dam* (Table 1). All the EC values are rated as moderate salinity hazard. All waters in these dams contain salts, which the TDS varied as little as 147 µg ml^{-1} in *Adigudom dam* to 236.8 µg ml^{-1} in *Gerebsegen dam*. Based on the ratio of soluble sodium percentage to salt concentrations, water resources from dams *May Gasa*, *Dur Anbesa*, *Gerebsegen*, *Girashito* and *Gum Selasa* were found unsatisfactory for general use as their values were greater than 15. The worst of all were waters from *May Gasa* and *Gum Selasa* dams since the values were 34.6 and 30%, respectively.

Table 1. Water resource salinization in the nine micro dams of Mekelle Plateau

Micro Dams	Na	K	Ca	Mg	EC	TDS	
	mmol$_c$l^{-1}				µScm^{-1}	Mg L^{-1}	$(Na*100)/(Ca+Mg+Na)$
May Gassa	1.22	0.02	1.65	0.66	355	227.2	34.6
Adi Karafiz	0.21	0.02	1.5	0.6	233	149.1	9.1
Filiglig	0.22	0.02	1.45	0.56	225	144.0	9.9
Dur Anbesa	0.36	0.02	1.44	0.53	235	150.4	15.4
Gerebsegen	0.71	0.04	2.35	0.59	369	236.2	19.4
Girashito	0.71	0.02	2.04	0.72	349	223.4	20.5
Mai Haidi	0.24	0.09	1.87	0.47	267	170.9	9.3
Gum Selasa	0.69	0.02	1.17	0.44	232	148.5	30.1
Maidelle	0.57	0.02	1.81	0.59	299	191.4	19.2
Mean±SD	0.55±0.33	0.03±0.02	1.69±0.36	0.57±0.08	284±59.3	182.3±38	18.6±9.05
Median	0.57	0.02	1.65	0.59	267	170.9	19.2
Min	0.21	0.02	1.17	0.44	225	144	9.1
Max	1.22	0.09	2.35	0.72	369	236.2	34.6

3.2 Soil resource salinization

A high salt level interferes with the germination of new seeds. Salinity acts like drought on plants, preventing roots from performing their osmotic activity where water and nutrients move from an area of low concentration into an area of high concentration. The actual damage done by salt to plants or soils depends on the concentration in the soil solution rather than on the quality in irrigation water (LLoyd, *et al.*, 1964). Thus, use of same water source might lead to a severe salt problem in one soil where drainage is restricted and great concentration of salts occurs. As is shown in Table 2, 59 % of the investigated soils were found saline as they have the EC (dSm^{-1}) greater 2 and SAR and ESP values less than 13 and 15, respectively. Apparently, this range will impair the growth of sensitive crops. The highest EC (3.54 dSm^{-1}) was found in the Calcisols of Girat Shito at the depth of 100-150 cm and the lowest EC was 1.22 dSm^{-1} at the depth of 100-150 cm in the Luvisols of Mai Haidi. The highest surface soil EC found on the Vertisols of May Gassa, which was 2.56 dSm^{-1} followed by the Vertisols of Gerebsegen that was 2.52 dSm^{-1}. Concurrently, the sodium hazard is dangerously emerging in the Vertisols of Girat Shito where the highest ESP (12.28%) was observed at the upper horizon followed by Vertisols in May Gassa, which was ranged from 9.64 in the surface to 10.35% at the depth of 100 cm. Detrimental effects of high exchangeable sodium on plant growth occur because of poor soil physical condition. Some plants, however, begin to show some injury at levels as low as 5 percent exchangeable sodium. This level of sodium apparently has started to cause soil structural disturbance (**Lamond, R.E. and David A. W., 1992**). Notably, the anions are equally important in affecting the growth potential of the plants. As is shown in Table 3, though all the anions are in safe range the anionic composition of the soils of the study areas are in the order of importance $HCO_3^-+CO_3^{2-}>SO_4^{2-}>Cl^-$.

Table 2. Cationic composition, salinity and sodicity parameters of the soils of the study areas

Soil Depth cm	Na^{+} Cmolc kg^{-1}	Ca^{2+}	Mg^{2+}	SAR	ESP %	EC dS m^{-1}
Vertisols, May Gassa						
0-50	2.47	21.04	2.11	0.73	9.64	2.56
50-100	2.64	19.88	2.84	0.78	10.41	2.54
100-150	2.58	19.04	3.32	0.77	10.35	2.49
Calcisols, Adi Karafiz						
0-50	0.83	13.25	1.94	0.30	5.18	1.60
50-100	1.22	15.81	3.41	0.39	5.97	2.04
100-150	1.48	14.40	3.52	0.49	7.63	1.94
Calcisols, Filiglig						
0-50	0.72	14.68	1.69	0.25	4.21	1.71
50-100	0.65	14.31	1.74	0.23	3.89	1.67
100-150	0.61	13.36	1.72	0.22	3.89	1.57
Vertisols, Dur Anbesa						
0-50	0.65	22.02	1.55	0.19	2.68	2.42
50-100	0.99	22.08	1.69	0.29	4.00	2.48
100-150	1.28	21.95	1.85	0.37	5.11	2.51
Vertisols, Gerebsegen						
0-50	0.83	21.45	2.93	0.24	3.29	2.52
50-100	1.63	19.78	3.23	0.48	6.62	2.46
100-150	2.5	24.55	4.10	0.66	8.03	3.11
Calcisols, Girat Shito						
0-50	2.7	16.14	3.15	0.87	12.28	2.20
50-100	2.85	26.98	5.29	0.71	8.12	3.51
100-150	2.78	27.79	4.87	0.69	7.85	3.54
Luvisols, Mai Haidi						
0-50	0.32	12.18	0.37	0.13	2.49	1.29
50-100	0.31	12.20	0.62	0.12	2.36	1.31
100-150	0.38	11.30	0.57	0.16	3.10	1.22
Vertisols, Gum Selasa						
0-50	0.9	20.10	1.90	0.27	3.93	2.29
50-100	0.88	20.71	1.91	0.26	3.75	2.35
100-150	1.12	19.50	2.02	0.34	4.95	2.26
Cambisols, Maidelle						
0-50	0.41	14.66	2.50	0.14	2.33	1.76
50-100	0.35	13.66	2.78	0.12	2.09	1.68
100-150	0.25	12.67	2.67	0.09	1.60	1.56
Mean±SD	1.27±0.90	17.98±4.68	2.45±1.19	0.38±0.24	5.39±2.94	2.17±0.61
Min	0.25	11.3	0.37	0.09	1.6	1.22
Max	2.85	27.7	5.29	0.87	12.28	3.54

Table 3. Anionic composition of the soils of Mekelle Plateau

Soil Depth cm	SO_4^{2-} $mmol_cl^{-1}$	$CO_3^{2-} + HC0_3^{-1}$ $mmol_cl^{-1}$	Cl^{-1} $mmol_cl^{-1}$
	Vertisols, May Gassa		
0-50	0.026	0.100	0.035
50-100	0.026	0.201	0.018
100-150	0.070	0.202	0.013
	Calcisols, Adi Karafiz		
0-50	0.052	0.304	0.014
50-100	0.052	0.201	0.005
100-150	0.035	0.203	0.004
	Calcisols, Filiglig		
0-50	0.044	0.104	0.007
50-100	0.070	0.300	0.007
100-150	0.070	0.200	0.005
	Vertisols, Dur Anbesa		
0-50	0.009	0.201	0.006
50-100	0.009	0.106	0.009
100-150	0.026	0.202	0.010
	Vertisols, Gerebsegen		
0-50	0.035	0.401	0.007
50-100	0.009	0.203	0.007
100-150	0.009	0.104	0.025
	Calcisols, Girat Shito		
0-50	0.020	0.103	0.027
50-100	0.020	0.005	0.027
100-150	0.016	0.004	0.021
	Luvisols, Mai Haidi		
0-50	0.004	0.105	0.006
50-100	0.004	0.202	0.006
100-150	0.005	0.105	0.007
	Vertisols, Gum Selasa		
0-50	0.017	0.105	0.008
50-100	0.026	0.105	0.006
100-150	0.009	0.204	0.007
Mean±SD	0.028±0.021	0.165±0.09	0.012±0.009
Min	0.004	0.004	0.004
Max	0.07	0.401	0.035

3.3 Arsenic threat

Arsenic is a semi metallic element and present in small amounts in soils and in plants and animal tissues. It occurs naturally in most soils in amounts between 1 and 70 ppm. The water soluble content is not related to the total, and may be very low in soils with high total amounts (Bear, F.E, 1964). Arsenic concentrations up to 20 ppm are quite common in soil, and up 40 ppm may be considered within the normal range (Frederic, et al., 2004). As is illustrated in Fig 3, the arsenic concentrations in soils of the Korer, Gum Selasa and Kelamino irrigated varied from 260-440, 260-300 and 260-460 ppm, respectively. In all cases arsenic is in a range serious threat as phytotoxicity in the irrigated fields of the study area.

4. Conclusions

This study revealed that in soils of the irrigated fields of the nine dams in Mekelle Plateau, Ethiopia, salinity and arsenic are building up gradually. Seemingly, increasing salinity and arsenic deposit in the soils with this trend and pace will cause phytotoxicity and eventually will impair the growth of plants. The principal quality of saline soils injurious to plants is the high osmotic pressure of the soil solution, which reduces the availability of water. Presumably, reclamation of the areas should begin now considering range of options starting from leaching to crop selection. Crop selection can be a good management tool for these soils. Where satisfactory drainage can be economically established, leaching readily removes salt. More studies are needed to better understand the processes leading to the accumulation of arsenic in the irrigated fields of Tigray. This is important because Phytotoxicity due to As is another major concern, which requires special and more expensive remedial measures.

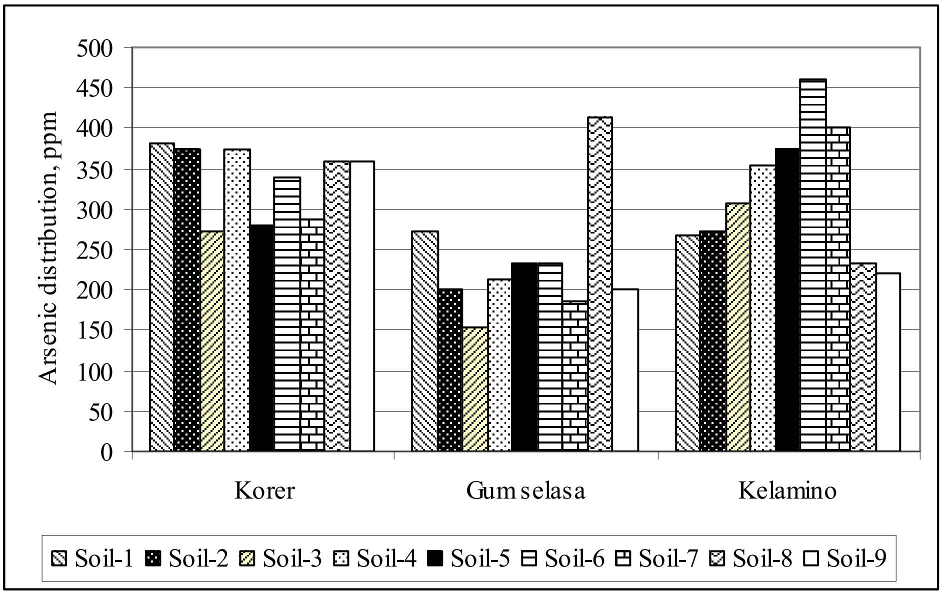

Figure. 3. Arsenic concentrations in the soils of the irrigated fields of Korer, Gum Selasa and Kelamino dams

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