Secondary Salinisation in the irrigated fields of Mekelle Plateau of the northern Highlands of Ethiopia

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1. Abstract
Due to its semi arid climate, the Tigray Plateau suffers from considerable problems due to 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. However, the impact of these dams on the environment has not been researched well. Thus, the purpose of this study was to evaluate the impact of nine dams on the environment owing to soil salinisation 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. 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.

2. Introduction
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). 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 1a). 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 (Fig. 1b). 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 water table 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 risk in the environs of nine selected dams in the Mekelle plateau.

3. Methods

The study area

The Mekele Plateau is the eastern-central portion of the northern uplands of Ethiopia, which is known as the Tigrean Plateau. The Mekele 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 Mekele dolerite sills in the Agula shale. The Plateau lies in the semi-arid zone with an average annual rainfall of 550 mm. 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 and soil salinity studies.

Soil and water sampling and analyses

Nine profile pits were opened in the representative sites where the current irrigation practices are carried out. 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-Addis Abeba, Ethiopia) for examining the exchangeable Na, Mg and Ca. Bicarbonate and carbonate were analyzed in the Soils Research Laboratory of Mekelle University. Besides, the electrical conductivity (EC) ($mScm^{-1}$) of the soils was determined using the equation: EC= ($\sum$ 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).

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

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.

$$\text{Water sodicity (WS)} = (Na * 100) / (Ca + Mg + Na) \qquad \text{[Eq.2]}$$

4. Results

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 (LLoyd, *et al*., 1964). 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.

Soil resource salinization

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 are 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, and David, 1992). Notably, the anions are equally important in affecting the growth potential of plants. As is shown in Table 2, the soil alkalinity ranges from 1.6 in May Gassa to 5.4 meq/100 g soils in Adi Karafiz. All the sampled soils were classified as hazardous in terms of residual sodium carbonate (RSC) values.

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

Micro Dams	Na	K	Ca	Mg	EC	TDS	
	mmolcl^{-1}				µScm^{-1}	Mg L^{-1}	WS
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	0.55	0.03	1.69	0.57	284	182.3	18.6
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

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

Soil Depth, cm	Na^{+}	Ca^{2+}	Mg^{2+}	SAR	ESP %	EC dS m^{-1}	CO_3^{2-} + $HC0_3^{-1}$ Meq/100g soils
Vertisols, May Gassa							
0-50	2.47	21.04	2.11	0.73	9.64	2.56	1.6
50-100	2.64	19.88	2.84	0.78	10.41	2.54	3.2
100-150	2.58	19.04	3.32	0.77	10.35	2.49	2.6
Calcisols, Adi Karafiz							
0-50	0.83	13.25	1.94	0.3	5.18	1.6	5.4
50-100	1.22	15.81	3.41	0.39	5.97	2.04	2.6
100-150	1.48	14.4	3.52	0.49	7.63	1.94	3.8
Calcisols, Filiglig							
0-50	0.72	14.68	1.69	0.25	4.21	1.71	3.4
50-100	0.65	14.31	1.74	0.23	3.89	1.67	3
100-150	0.61	13.36	1.72	0.22	3.89	1.57	2
Vertisols, Dur Anbesa							
0-50	0.65	22.02	1.55	0.19	2.68	2.42	2.6
50-100	0.99	22.08	1.69	0.29	4	2.48	4.7
100-150	1.28	21.95	1.85	0.37	5.11	2.51	3.2
Vertisols, Gerebsegen							
0-50	0.83	21.45	2.93	0.24	3.29	2.52	4.6
50-100	1.63	19.78	3.23	0.48	6.62	2.46	3.8
100-150	2.5	24.55	4.1	0.66	8.03	3.11	3.4
Calcisols, Girat Shito							
0-50	2.7	16.14	3.15	0.87	12.28	2.2	2.8
50-100	2.85	26.98	5.29	0.71	8.12	3.51	3
100-150	2.78	27.79	4.87	0.69	7.85	3.54	2.4
Luvisols, Mai Haidi							
0-50	0.32	12.18	0.37	0.13	2.49	1.29	4
50-100	0.31	12.2	0.62	0.12	2.36	1.31	3
100-150	0.38	11.3	0.57	0.16	3.1	1.22	4
Vertisols, Gum Selasa							
0-50	0.9	20.1	1.9	0.27	3.93	2.29	4
50-100	0.88	20.71	1.91	0.26	3.75	2.35	4
100-150	1.12	19.5	2.02	0.34	4.95	2.26	4
Cambisols, Maidelle							
0-50	0.41	14.66	2.5	0.14	2.33	1.76	2.8
50-100	0.35	13.66	2.78	0.12	2.09	1.68	3.4
100-150	0.25	12.67	2.67	0.09	1.6	1.56	3.8

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

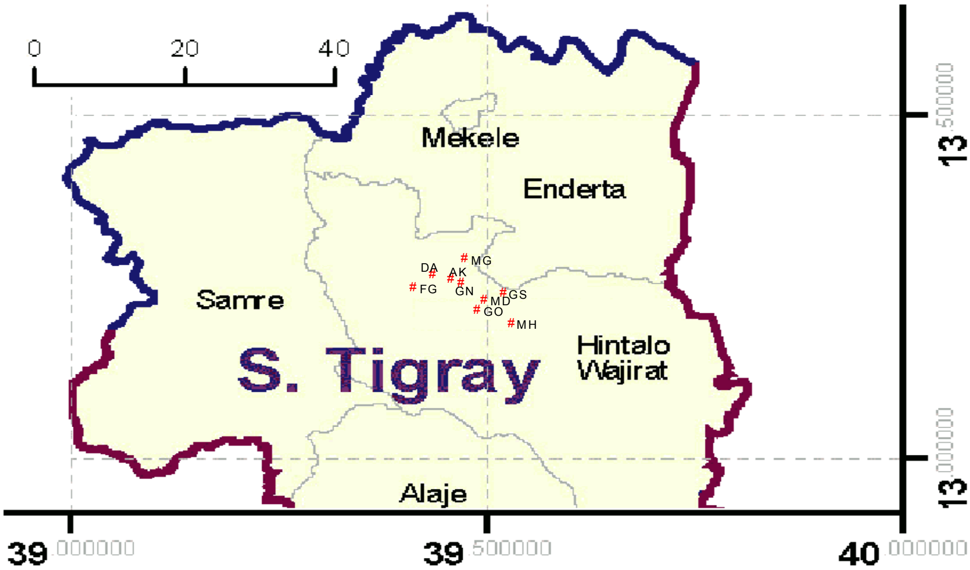

Figure 2 Dams and their location in Mekelle Plateau where DA (Dur ambesa), MG (Mai Gasa), AK (*Adi Kefaniz*), FG (*Feliglig*), GN (*Gereb segen*), GS (*Gum Selassa*), MD (*Mai Delle*), GO (*Girat Shito*) and MH (*Mai Haidi*)

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