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CONCENTRATIONS OF TRACE ELEMENTS IN WATERS, SOILS, AND PLANTS OF THE OLKARIA GEOTHERMAL FIELD, KENYA.

Gelas Simiyu and Mwakio Tole
Moi University, School of Environmental Studies
P. O. Box 3900 Eldoret, KENYA

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ABSTRACT

Concentrations of lead, zinc, copper, cadmium, and boron have been measured in geothermal waters from wells and cooling tower discharges, as well as in soils and plants that are in contact with geothermal waters of the Olkaria field. Element concentrations were also determined in naturally discharging hot springs at Hell's Gate. Results show no differences between metal concentrations in natural discharges, compared to drilled geothermal fluids. Soils in contact with geothermal fluids concentrate elements by factors of between 13 and 6000 in comparison to the metal concentrations in the overlying water column. The concentration factors between soils and water increase in the order B<Cd<Pb<Cu<Zn. Plants in contact with geothermal waters also have high metal concentrations, comparable to the levels in the soils. Green algae show a very high capacity to concentrate metals in geothermal waters, and may be good indicators of trace metal pollution in geothermal areas.

Waste geothermal waters should therefore be reinjected, rather than being disposed of on surface ponds and lagoons, to ameliorate the problem of metal enrichment in soils and their uptake by plants and animals.

1. INTRODUCTION

The Olkaria geothermal power station is located 36 km south west of Naivasha town in Kenya (figure 1). It currently generates 45 MW of electricity, and there are plans to increase the total power production to 109 MWe. The Olkaria field is a two-phase system, so that water, separated from steam has to be disposed of, in addition to disposal of the cooled waste steam after generation of electricity. Currently, wastewater is sent to conditioning ponds before it is reinjected. Plants growing in and around the conditioning ponds are fed on by cattle and wild animals from the Hell's Gate National Park, which encloses the geothermal field. Flower farms are also found within 1 – 2 km of the steam wells, and concerns have been raised about the impact of geothermal operations on soil and atmospheric pollution, in relation to the health of humans, animals and plants in the area.

Previous studies have measured concentrations of selected elements in waters and steam from the Olkaria geothermal system (Virkir/Mertz McLellan, 1977; Tole, 1990; Sinclair Knight and Partners, 1994; Simiyu, 1995; Tole, 1996; Tole, 1997), but no study has measured the trace element concentrations in the soils and plants that come into contact with the geothermal waters

This study was conducted to measure the concentrations of heavy metals in the wastewater, and to determine the potential of the metals to get into the food chain, through their concentration in soils and plants. Concentrations of metals in fluids from the geothermal power station were also compared to the concentrations in hot springs at Hell's Gate, and to those of Lake Naivasha.

2. FIELD AND LABORATORY METHODS

Samples of geothermal well waters, soils, plants, hot spring waters, and lake Naivasha water were collected at selected sites around the Olkaria geothermal power station in the period September 1993 to February 1994

Water samples were collected in triplicate, in prewashed 500 ml polyethylene bottles. One of the samples was used for pH and boron determination. Trial runs had shown that the concentrations of other elements were below the detection limits of the Atomic Absorption Spectrophotometer available. The other two samples in each case were therefore preconcentrated by evaporation, to achieve a concentration factor of 10 before analysis by AAS. During preconcentration, pH was maintained in the range 9 – 10 in order to minimise silica deposition (by addition of a pellet of NaOH). Subsequently, the pH was lowered to 1.5 – 2 in order to preserve the metals of interest, the concentrations of which were measured using a Perkin Elmer (Model 306) Atomic Absorption Spectrophotometer at the Government Chemist Laboratories, Nairobi. Analyses were conducted in duplicate, and generally agreed to within 10% of the measured value.

Sediment samples were collected in triplicate in polythene bags. They were dried in the sun for 96 hours. One of the samples was then used to determine the soil pH. The other two samples were sprayed with 0.1 m NaOH, and oven dried to constant weight (usually 48 hours at 95°C). The samples were disaggregated and sieved through a plastic sieve (approximately 80 mesh). 2 grams of the –80 mesh fraction was reacted with 20 ml of aqua regia to extract the metals. The filtered extract was analysed for trace metals as for the water samples.

Plant samples (leaves) were collected and washed with deionised water and sprayed with 0.1 m NaOH. They were then dried in the oven at 95°C for 48 hours. Elements were extracted by digestion in aqua regia, and analysed as for the water samples.

Blanks were made using 500 ml of deionised water, to which a pellet of NaOH was added, followed by evaporation to 50 ml over a water bath at 90°C. On cooling, 2 ml of conc. nitric acid was added to bring the pH to 1.5 – 2, just as in the water samples.

3. RESULTS

3.1 Waters

The mean concentrations of lead, zinc, copper, cadmium, and boron in waters in the Olkaria area are presented in **Table** 1. Geothermal well waters had 0.032 – 0.070 ppm Pb; 0.013 – 0.017 ppm Zn; 0.007 – 0.019 ppm Cu; 0.004 – 0.009 ppm Cd; and 2.95 – 9.43 ppm B; while spent steam from the cooling towers had 0.004 ppm Pb; 0.29 ppm Zn; 0.018 ppm Cu; 0.002 ppm Cd; and 2.34 ppm B. Natural hot springs in the Olkaria area had 0.016 – 0.037 ppm Pb; 0.030 – 0.450 ppm Zn; 0.005 – 0.008 ppm Cu; 0.002 – 0.004 ppm Cd; and 3.45 – 6.42 ppm B; while Lake Naivasha water had 0.015 ppm Pb; 0.016 ppm Zn; 0.004 ppm Cu; 0.002 ppm Cd; and 0.07 ppm B.

These results indicate that (i) generally, geothermal waters have higher concentrations of Pb, Cu, Cd, and B than cold Lake Naivasha water. The Zn levels are comparable. (ii) Drilled geothermal well waters do not show higher metal concentrations than natural hotspring waters. (iii) Condensed waste steam contains higher concentrations of Zn than most of the natural geothermal waters. Other metals consistently occur at lower concentrations in condensed waste steam than in geothermal waters. (iv) The pH of steam condensate is highly acidic. (v) Concentrations of metals increase down flow from the waste steam discharge point.

3.2 Soils

Concentrations of metals in soils from the Olkaria area are presented in **Table** 2. Soils in direct contact with geothermal well waters had 9.4 – 28.0 ppm Pb; 66.8 – 104.3 ppm Zn; 2.8 – 6.4 ppm Cu; 0.7 – 1.2 ppm Cd; and 18.1 – 80 ppm B. Soils in contact with spent steam discharge had 12.9 ppm Pb; 66.5 ppm Zn; 6.2 ppm Cu; 0.5 ppm Cd; and 55.7 ppm B. Sediments in contact with Lake Naivasha waters had 8.9 ppm Pb; 53.1 ppm Zn; 1.8 ppm Cu; 0.5 ppm Cd; and 77.2 ppm B.

These results show that (i) soils in contact with geothermal waters have higher concentrations of trace elements measured than those in contact with Lake Naivasha, except for B, which is quite high in Lake Naivasha sediments, despite its relatively low concentrations in the Lake water. (ii) Soils in contact with spent steam effluent show an increase in metal concentrations away from the steam discharge point.

3.3 Plants

Concentrations of trace elements in some plants in contact with waters in the Olkaria area are given in **Table** 3.

Pennisetum clandestinum shows higher concentrations of Pb, Zn, Cu, Cd, and B when growing in geothermal waters than when growing in Lake Naivasha waters. *Typha latifolia* similarly shows higher concentrations for Pb, Zn, and Cu when it grows in geothermal waters than in Lake Naivasha waters, although there is no difference for Cd, and in the case of B, the plants in Lake Naivasha have higher concentrations than those growing in geothermal waste waters. *Cyperus papyrus* shows similar trends to *Typha latifolia.* Green algae have 15 – 80 ppm Pb; 141 – 149 ppm Zn; 36 – 52 ppm Cu; 0.8 – 1.0 ppm Cd; and 68 – 73 ppm B. Except for Cd and B, green algae had higher concentrations of metals than other plants sampled in the same environment.

These results show that (i) plants take up more trace metals from soils and waters in contact with geothermal waters than with those of Lake Naivasha water. (ii) There appears to be a non geothermal source of boron in Lake Naivasha sediments, which, although not reflected in the Lake water, is in the sediments, and is taken up by plants.

4. DISCUSSION

4.1 Enrichment of elements between Waters, Soils and Plants.

Comparison of the trace element concentrations given in **Tables** 1 and 2 show that soils in contact with well waters showed an increase in Pb concentration from values of 0.032 – 0.07 ppm in water, to 9.4 – 28 ppm in soils, an increase by a factor of between 294 and 667. Zinc is similarly enriched in sediments, relative to the overlying water column by factors of between 4880 and 6516; copper by factors between of 400 and 711; cadmium by factors of between 100 and 180; and boron by factors of between 1.9 and 17. Soils in contact with waste geothermal steam discharge showed concentration factors of 440 to 3230 for lead; 229 to 7633 for zinc; 164 to 2875 for copper; 131 to 375 for cadmium; and 6 to 39 for boron. In Lake

Naivasha, the enrichment factors between waters and sediments are 593 for lead, 3321 for zinc, 455 for copper, 230 for cadmium, and 1103 for boron.

In the case of geothermal well waters, the enrichment factors between soils and waters increase in the order B<Cd<Pb<Cu<Zn. For steam waste waters, the enrichment factors increase in the order B<Cd<Cu<Pb<Zn, so that the positions of lead and zinc are interchanged in steam discharges in comparison to well waters. For Lake Naivasha waters, the enrichment factors increase in the order Cd<Cu<Pb<B<Zn. In all cases, zinc shows the highest enrichment between soils and the overlying waters. The factors controlling the enrichment processes are beyond the scope of this study, but they are likely to include temperature, pH, solubility of the most stable mineral phases, salinity of the fluids, competing adsorption reactions for metals on soil mineral surfaces, soil mineral composition, and the surface areas of the mineral grains. Apart from a distinct pH effect in the waste steam discharges, these factors were not evaluated in this work.

Comparisons between Table 2 and Table 3 shows no enrichment of elements in plants relative to the soils, except for green algae, which show enrichment factors of 0.89 to 3.8 for lead; 1.3 to 1.9 for zinc; 7.5 to 9.6 for copper; 1.1 to 1.3 for cadmium; and 0.88 to 0.98 for boron. The uptake of copper and lead by green algae showed a strong positive correlation with pH ($R = 0.964$ for Cu; $R = 0.864$ for Pb). No similar correlation was exhibited by Zn, Cd, or B.

4.2 Pollution from geothermal waters

Geothermal waters have metal concentrations that are above those in natural cold waters of Lake Naivasha, and should therefore be isolated from contact with plants and animals. Soils that come into contact with geothermal waters become highly enriched in trace metals, and should not be used for watering plants or livestock. There is need to do follow up studies to find out whether metals are continuing to increase in soils and plants, or whether the soils have reached the saturation point with respect to trace metal concentrations. Waste steam discharges show high concentrations of zinc, probably from the machinery and piping that the steam comes into contact with (since metals are generally not expected to be preferentially partitioned into the steam phase compared to the water phase). Other metal concentrations are consistently lower in the waste steam than in the well waters.

The highly acidic pH of the steam condensate also means that this effluent should not be discharged directly into any natural surface waters.

Calculation of the amounts of metals discharged from the operation of the 45 MWe power station at Olkaria indicate that, annually, there are 23 kg of Pb; 1311 kg of Zn; 87 kg of Cu; 15 kg of Cd; 14650 kg of B; 5001 kg of Hg; and 13103 kg of As. The hazards posed therefore arise both from the gross amounts released, particularly in the case of boron, mercury and arsenic, and also from the cumulative effect of accumulating metals in soils that are in contact with geothermal fluids. In the arid Olkaria area, where there is little rain to disperse the metals into surface and groundwaters, there is danger of accumulation of metals in the immediate vicinity of the power station. Reinjection, and possible recovery of economic minerals appear to be favoured at Olkaria. Although reinjection is now being practiced at Olkaria, there is a reconditioning pond into which waste steam is sent to reduce the high silica, so as not to block the reinjection wells. It is important that the reconditioning ponds be isolated from animals that may come to drink. Animals should not feed on plants that grow around the ponds.

5. CONCLUSIONS

This study has shown that concentrations of Pb, Cu, Cd, and B are higher at the Olkaria geothermal power station than in Lake Naivasha waters. Natural hot springs in the area contain as much of these metals as the drilled geothermal waters. Waste steam is highly acidic, and contains high amounts of zinc, probably from the piping and turbines. Soils in contact with geothermal waters and waste steam waters concentrate the elements by several orders of magnitude. Plant that grow in contact with waste waters and waste steam similarly show elevated amounts of trace metals when compared to those growing in contact with Lake Naivasha water. There is need to dispose of these fluids judiciously. Conditioning ponds should be completely isolated from plants and animals.

Lake Naivasha sediments have anomalously high concentrations of boron, the source of which requires further investigation.

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Table 1. Concentrations of metals in waters from the Olkaria area.

Well Waters

Locality	pH	Pb ppm	Zn ppm	Cu ppm	Cd ppm	B ppm	As ppm	Hg ppm
OW 4	9.48	0.032	0.016	0.007	0.008	4.3	3.47	1.11
OW 6	9.36	0.032	0.016	0.010	0.005	4.2	3.10	0.33
OW 10	8.60	0.033	0.017	0.007	0.005	6.2	5.31	0.94
OW 13	9.69	0.054	0.013	0.007	0.007	5.4	5.10	1.04
OW 15	8.93	0.070	0.013	0.010	0.008	7.0	0.55	3.70
OW 16	9.57	0.037	0.015	0.007	0.008	9.4	4.19	0.52
OW 20	8.79	0.042	0.016	0.009	0.009	8.3	N.D	N.D
OW 22	9.55	0.039	0.016	0.019	0.004	3.0	5.11	5.41

Waste Steam

P I	3.09	0.004	0.290	0.018	0.002	2.3	2.94	1.12
P IIA	2.99	0.006	0.114	0.012	0.002	2	5.51	5.52
P IIB	9.17	0.033	0.018	0.008	0.007	7.5	N.D.	N.D.
P III	4.17	0.023	0.018	0.016	0.004	6.2	3.76	6.38
P IV	7.07	0.048	0.210	0.042	0.003	7.4	0.00	6.51

Natural Hot Springs

HGS 1	8.44	0.037	0.180	0.007	0.003	3.5	0.15	1.59
HGS 4	8.62	0.032	0.120	0.006	0.002	4.0	1.45	0.73
HGS 5	8.05	0.032	0.030	0.005	0.004	4.6	0.13	4.11
HGS 7B	8.40	0.028	0.160	0.005	0.004	5.8	1.29	4.11
HGS 10	8.81	0.016	0.450	0.008	0.004	6.4	2.94	1.12

Lake Naivasha

Control	7.87	0.015	0.016	0.004	0.002	0.007	0.00	0.20

Table 2. Concentrations of elements in Sediments of the Olkaria area.

Sediments in contact with well waters

Locality	pH	Pb ppm	Zn ppm	Cu ppm	Cd ppm	B ppm	As ppm	Hg ppm
OW 4	9.61	9.4	97.0	3.8	1.2	72.5	0.91	2.60
OW 10	8.80	12.9	84.3	4.5	0.9	36.7	1.02	2.66
OW 13	10.32	12.4	66.8	2.8	0.7	38.3	1.14	2.52
OW 16	10.01	18.2	73.2	2.8	1.1	18.1	0.59	1.68
OW 20	8.90	28.0	104.3	6.4	1.2	80.0	1.09	2.05

Sediments in contact with waste steam waters

P I	3.97	12.9	66.5	6.2	0.5	55.7	0.81	2.40	
P IIA	3.30	17.8	68.4	16.3	0.8	76.7	N.D.	N.D	
P IIB	9.31	23.9	137.4	23.0	0.9	45.0	1.20	1.99	
P III	4.30	17.0	73.1	3.8	0.6	76.7	0.90	2.04	
P IV	7.28	21.1	112.7	6.9	0.8	75.0	1.18	2.33	

Sediments in contact with Lake Naivasha waters

Control	6.88	8.9	53.1	1.8	0.5	77.2	0.02	2.33

Table 3. Concentrations of elements in plants in the Olkaria area.

Pennisetum clandestinum

Locality	pH	Pb ppm	Zn ppm	Cu ppm	Cd ppm	B ppm	As ppm	Hg ppm
OW 4	9.61	7.2	60.1	6.3	0.9	81.7	0.37	2.04
OW 10	8.80	5.8	63.1	4.3	0.8	84.0	N.D.	N.D.
OW 16	10.01	5.0	69.9	3.8	0.8	70.0	N.D.	N.D.
P I	3.97	6.0	68.0	6.1	0.7	67.5	0.19	1.39
P IIA	3.30	5.9	72.9	6.5	0.7	68.3	N.D.	N.D.
P IIB	9.31	4.6	39.5	2.7	0.6	64.2	N.D.	N.D.
Control	6.88	3.0	26.3	3.8	0.6	64.3	0.13	0.34

Chloris gayana

OW 13	10.32	6.2	71.1	4.7	0.9	42.5	0.65	0.72
OW 16	10.01	6.3	51.6	3.8	0.8	68.0	N.D.	N.D.
OW 20	8.90	6.2	39.7	5.5	0.8	51.4	N.D.	N.D.

Typha latifolia

P I	3.97	10.3	50.2	11.5	0.7	65.0	N.D.	N.D.
P IIB	9.31	7.3	35.3	9.3	0.6	70.3	N.D.	N.D.
P III	4.3	6.7	51.0	5.9	0.6	79.0	N.D.	N.D.
P IV	7.28	2.9	28.8	9.2	0.6	50.8	N.D.	N.D.
Control	6.88		23.8	2.7	0.6	87.2	N.D.	N.D.

Schoenoplexus confusus

P IIA	3.30	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	1.10
P IIB	9.31	5.7	42.0	3.2	0.8	64.2	N.D.	N.D.
P IV	7.28	3.1	29.5	3.1	0.6	109.2	N.D.	N.D.
Control	6.88	N.D.	N.D.	N.D.	N.D.	N.D.	0.04	0.34

Cyperus papyrus

P IIA	3.30	6.3	55.4	17.8	0.6	78.3	N.D.	N.D.
P III	4.30	5.6	57.0	18.0	0.5	74.6	N.D.	N.D.
Control	6.88	2.6	23.8	6.5	0.4	83.2	N.D.	N.D.

Green algae

P III	4.17	15.1	141.4	36.0	0.8	67.5	N.D.	N.D.
P IV	7.07	20.3	149.1	51.9	0.9	73.3	0.59	0.93

Table 4. Pollution loads at the 45MWe Olkaria geothermal power station

(i) in Waste water

Component	Concentration in mg/l	Total output in tonnes/annum
SiO2	589	430
B	5.6	4.3
Na	691	490
K	97.6	70
Ca	0.9	0.6
Mg	1.0	0.2
Li	1.0	0.8

CO2	44	32
SO4	72	52
H2S	2	1.4
Cl	826	602
F	71	52
NH3	0.7	0.5
Fe	4.8	3.5
Mn	1.6	1.2
As	0.004	0.003
Br	2.5	1.8
I	0.05	0.04
P	0.1	0.07
Hg	0.0014	0.001
Pb	0.004	0.003
Cd	0.007	0.005
Cu	0.010	0.007
Zn	0.015	0.011
TDS	2418	1760

(ii) in waste steam

Constituent	Concentration in wt %	Annual output in tonnes/annum
CO2	0.49	21850
H2S	0.02	890
H2	0.001	45
CH4	0.0009	40
N2	0.0003	13
NH3	0.0003	13
Pb	0.0000004	0.02
Zn	0.000029	1.3
Cu	0.0000018	0.08
Cd	0.0000002	0.01
B	0.00023	10.3
As	0.000294	13.1
Hg	0.000112	5.0

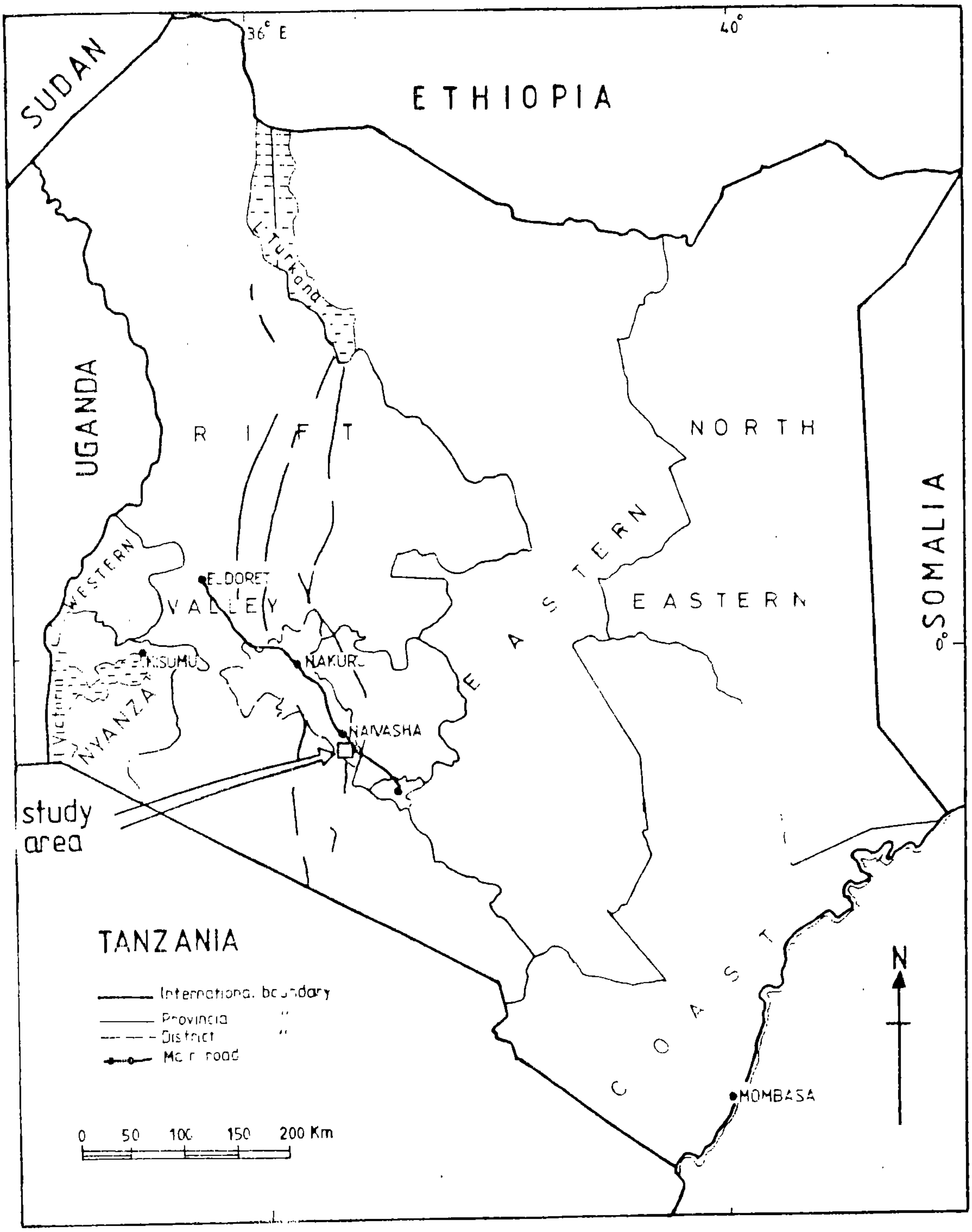

Fig 1 STUDY AREA