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INVESTIGATIONS ON SOIL AND WATER QUALITY AS AFFECTED BY IRRIGATION IN TURKANA DISTRICT, KENYA

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ABSTRACT

Irrigation technology can ensure food security in arid and semi-arid regions. However, its adoption requires efficient systems that ensure sustainable agricultural production. The aim of this study was to investigate soil and water quality as affected by irrigation in the Turkwel Scheme of the semi-arid Turkana District of Kenya. Soil samples were collected spatially and with depth from intensively, moderately and non-irrigated fields and analysed for physical and chemical properties. Irrigation and ground waters were also collected and analysed for quality determination. Phreatic water levels of shallow wells were determined through inspection pits and open shallow wells dug in the scheme. Results of non-irrigated fields indicated a non-saline soil surface with EC_e of 1.31 ds/m, which turned saline at depth of 0.20 m with EC_e of 5.57 ds/m, indicating salt deposits at this depth. Periodically irrigated fields were strongly saline on the soil surface with EC_e of 8.86 ds/m, but decreased to non-saline level of 3.41 ds/m at 0.40 m. However, intensively irrigated fields had low salinity with depth due to frequent leaching of salts. Irrigation and groundwater were of acceptable quality with EC_w of 0.13 and 0.33 ds/m, while sodicity hazard was low at SAR of 1.50 and 3.89, respectively. Water table depth had risen from about 1.80 m to 0.70 m from the soil surface between 1982 and 2006, respectively. Soil salinisation in non-irrigated and periodically irrigated fields was therefore attributed to direct phreatic evapotranspiration. Leaching of salts from the root zone, lowering the water table through drainage, and shortening the long fallow period through agronomic practices such as growing drought-resistant vegetable crops can mitigate this land degradation. These would improve food security and living standards of farmers in the scheme.

Key words: Irrigation, soil salinisation, water quality, food security, sustainability

1.0 INTRODUCTION

Intensification of land and water use is crucial for the purpose of increasing and stabilizing agricultural production for an expanding population. These needs are most acute in the arid and semi-arid regions where water requirements are greatest while the supplies by rainfall are least. In the dry lands of sub-Saharan Africa, water deficit is the most important environmental factor limiting yields in agriculture. In arid regions, irrigation is designed to permit farming and to offset drought in semi-arid or semi-humid regions. In Kenya, 83% of its land area of 5,826,460 ha is arid and semi-arid, receiving rainfall of less than 700 mm per year. This rainfall is erratic and poorly distributed, which cannot reliably support rain-fed agriculture. Agriculture in Kenya contributes to 55% of Gross Domestic Product (GDP), provides 80% of employment, accounts for 60% of export and generates about 45% of Government revenue (Blank *et al,* 2002). A high population lives in rural areas, but with dwindling land holdings in high to medium potential areas, opening of new lands for agriculture in arid and semi-arid areas has been intensified through use of irrigation technology.

However, land degradation is occurring very rapidly in these unstable environments and many countries may not achieve sustainable agricultural development unless policies and approaches change. Soil salinization has been identified as a major process of land degradation that has been the greatest cause of decreasing productivity in many irrigation projects, particularly in the Arid and Semi-Arid lands (ASALs) (FAO, 2000). The spread of salinity affects not only older irrigation schemes, but also more recently developed areas. In Kenya, salt affected soils in Taveta area had been caused by hydrological disturbances where soils not initially saline, with deep water tables, became saline and/or sodic under irrigation due to change in land use (Sijali, et. al, 2003). Over-irrigation, excess water seepage from canals during irrigation periods and lack of sub-surface drains in Taveta irrigation schemes led to accelerated waterlogging problems and a rapid rise of the groundwater table. Effects of salinity are manifested in loss of stand, reduced rates of plant growth, reduced yields, and in severe cases, total crop failure (Rhodes and Loveday, 1990).

The main objective of this study was therefore to investigate soil and water quality as affected by irrigation in the Turkwel Scheme of the semi-arid Turkana District of Kenya. The specific objectives were to investigate nature and distribution of salt-affected soils, possible causes of salinization and to develop mitigation measures for sustainable production in the scheme.

1.1 Study Area

Turkana District occupies the arid North-Western part of Kenya (shaded part in Figure 1). It covers an area of about 77,000 km^2, which includes Lake Turkana that forms the eastern boundary. It is bordered by Ethiopia to the North-East, by Sudan to the North and Uganda to the West. It has a population of 476,062 persons (GoK, 1999). It has three agro-ecological zones, very arid (zone VI), arid (zone V) and semi-arid (zone IV).

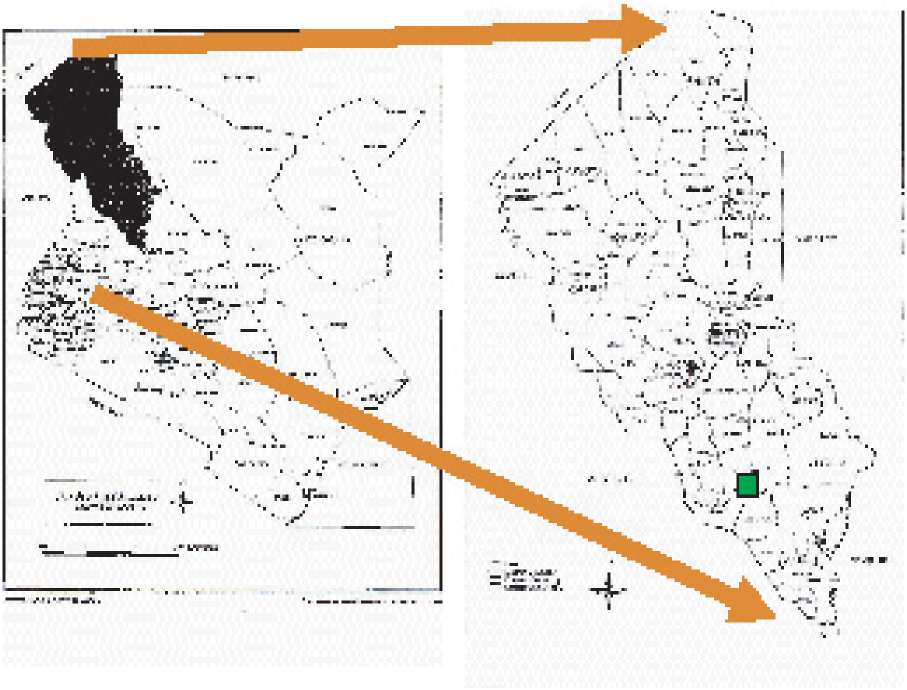

Figure 1: Location of Turkwel Irrigation Scheme in Turkana District, Kenya

The district consists of a vast low-lying plain, from which protrude isolated mountains and ranges of hills. It lies within an altitude of 400 to 900 m above sea level. Temperatures are high and fairly uniform throughout the year, with an average temperature of 30°C at Lodwar, the main town of Turkana District. Maximum and minimum temperatures are 38°C and 22.4°C, respectively. Amount of rainfall received is an average of 500 mm at Lokichoggio in the north and decreases gradually towards the central to 200 mm per annum at Lodwar. This low rainfall is erratic, unreliable and poorly distributed. Its high intensity storms produce considerable run-off in the absence of adequate tree or bush cover.

Major occupation of people in the area is pure pastoralism, covering about 64%. This is prevalent in the northern part of the district where rainfall is slightly higher to sustain pastures. Agro-pastoralism occupies about 16% and is prevalent in the south, along Turkwel and Kerio rivers, which are the main river systems in the district. Migration of people from the north and central towards the southern region was witnessed in mid -1960's. This was because of frequent and severe droughts that resulted to death livestock and subsequent famine. Shifting cultivation along the rivers was no longer possible due to increased population caused by this migration of people. This resulted in establishment of smallholder irrigation schemes along the rivers, such as Turkwel and Katilu irrigation schemes (GoK, 2005a).

The Turkwel irrigation scheme is the oldest scheme in Turkana District. It was established in 1966 by the Government of Kenya, in conjunction with FAO, on an 18-hectare (ha) land. The aim was to support 175 households to grow food as a measure to control famine in this drought-ravaged area. Crops introduced during scheme initiation were sorghum, maize, green grams, cowpeas, a variety of vegetables and fruit crops such as mangoes, citrus, bananas and dates. However, in 2003 irrigated area was expanded to 40 ha, targeting 250 households on food security (GoK, 2005b). This expansion was made possible due to formation of the Turkwel dam, which stabilised flow rate of Turkwel River throughout the year.

Sombroek, *et al.* (1980) describes Turkwel soils as brown, friable, moderately sodic sandy clay loam; with thick topsoil of loamy sand. The soils are classified as sandy loams to loamy sands, and are of high to medium texture (Kenya Soil Survey, 1987). The average slope in the scheme is about 1%, with land mainly sloping towards the Turkwel River. The main canal supplying irrigation water from the river into the scheme is about 2 km long. Field water application is by basin irrigation, where each farmer is allocated 10 basins of 10 m by 10 m. Surface drainage is composed of shallow channels running parallel to irrigation canals.

Although quantifiable data does not exist, reports from the community indicated that decline in yields and crop diversity has occurred with time since initiation of the scheme. They suspected decline was due to salt accumulation in the soils, which has led to abandonment of part of the scheme. Salinity signs in the scheme included white crystals and brownish greasy patches on the land surface, physiological wilting of crops and scorched lower leaves of some crops. Russell (1980) indicates that land affected by sodicity is usually black in colour, because the sodium carbonate present deflocculates the soi. However, such a colour was not observed in these fields. Continuous germination and growth of plants was observed during the three-months' fallow period, which may indicate a raised water table.

2.0 MATERIALS AND METHODS

Environmental degradation of the Turkwel Irrigation Scheme was studied through investigating possible sources of salts in the fields. These included immediate sources such as parent material, irrigation water and shallow groundwater.

2.1 Determination of Soil Properties of Turkwel Scheme

2.1.1 Soil Sampling

Disturbed soil samples were randomly collected from twenty four (24) sites uniformly distributed within 18 ha of the scheme. Sampling depth was 0.10-0.15 m depth to exclude partially and non-decomposed organic matter for determination of chemical properties. Soil samples were similarly collected from sixteen (16) sites covering 12 ha of non-irrigated areas neighbouring the scheme. Samples from the respective land uses were then mixed thoroughly to obtain representative samples that were packed in envelopes and taken to the laboratory for chemical analysis of major salts in the scheme.

Disturbed and undisturbed soil samples were also collected in three replicates from intensively, periodically and non-irrigated fields at depths of 0, 0.20, 0.40 and 0.60 m from the surface. This was done from close fields in a block for determination of physical and chemical properties of the soils. A soil auger was used to obtain disturbed soil samples from each depth, while a core sampler was used for undisturbed soil samples for respective depths. The core sampler was hammered gently into the soil to the required depth, the sample was then trimmed flash to the end of the cylinder using a sharp knife, covered using lids and packed in core rings. The samples were then taken to the laboratory for physical and chemical analyses using standard methods (FAO, 1980; Black *et al.*, 1983).

The experimental design used was the randomised complete block design (Rao, 1973; Steel and Torrie, 1980; Stern *et al.,* 2004). This required experimental fields to be grouped into blocks of farms so as to minimise existing variability within a block and to maximize variability between the blocks.

2.1.2 Laboratory Analyses

The analysis was done to determine physical and chemical properties of the soil. Soil texture was determined by the pipette method while average particle density was determined by the specific gravity method where a pycnometer was used. Bulk density was determined by dividing the weight of each undisturbed core sample after drying to a constant weight in an oven at 105 °C, with volume of the respective core ring.

Major ions that contribute to salt-affected soils are Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-}, HCO_3^- and CO_3. Saline soils are classified mainly on the basis of their soluble salt concentrations, while classification of alkali (sodic) soils is based on exchangeable sodium content. Since these two classifications are soil moisture dependent, they were determined in the laboratory from the saturation extracts of disturbed soil samples obtained from irrigated and non-irrigated fields. A soil sample was brought to saturation by stirring in diluted water until the soil glistened and flowed slightly without free water standing on the surface; the extract was then obtained by suction from this soil paste. The cations and anions concentrations were then determined through standard methods, where concentrations of Ca^{2+} and Mg^{2+} were assessed by versenate titration, Na^+ by flame photometer, Cl^- by Mohr's titration, SO_4^{2-} by gravimetric titration, HCO_3^- and CO_3^- by potentiometric titration (FAO, 1980). Sodium adsorption ratio (SAR) of the soils was computed from equation 1, i.e;

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad \text{..(1)}$$

where soluble sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) are ion concentrations in me/l.

Exchangeable sodium was then assessed through an empirical relationship between the SAR and the exchangeable sodium percentage (ESP) given by equation 2, i.e.,

$$ESP = 100\,(-\,0.0126 + 0.01475\ SAR)$$

$$\underline{1 + (-\,0.0126 + 0.01475\ \mathrm{SAR})}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Different crops respond in different ways to given soluble salt concentrations, which can be quantified in terms of the electrical conductivity value of a soil. Soluble salt concentrations were assessed by measuring electrical conductivity of the saturation extract (ECe) of the soil samples using a pH-EC-TDS meter.

2.2 Determination of Irrigation and Groundwater Quality

Irrigation water was obtained from the main irrigation canal as it entered the scheme. Three replicate samples were collected daily at an interval of 3 hours for 3 days. Waters collected each day were thoroughly mixed to get a representative sample. Groundwater was also collected from ten (10) shallow wells in the scheme at the same time intervals and similar representative water samples were obtained. The irrigation and groundwater samples were then packed in glass bottles and labelled for chemical analysis. Since excessive levels of exchangeable sodium can adversely affect soil physio-chemical properties, SAR and ESP of the two water sources were computed from equations 1 and 2 so as to assess their sodium hazard.

2.3 Determination of Phreatic Water Level

Ground water levels in the scheme were monitored by measuring fluctuations of water table depth during the three months' fallow period. A trench and an inspection pit were excavated in November 2005 for this purpose. Depths at which the groundwater started to ooze out of them were then monitored.

Fluctuations of the watertable were also monitored in seven (7) open shallow wells on a 4.8 ha horticultural block that was intensively irrigated. Their depths were measured for three months between November 2005 and February 2006, which coincided with end and beginning of the irrigation season. Information about the original depths and year that the wells were sunk was obtained from community members that participated in the activity.

3.0 RESULTS AND DISCUSSION

3.1 Soil Properties of Turkwel Irrigation Scheme

3.1.1 Nature and Distribution of Salt-affected Soils in the Scheme

Results of soil chemical analysis are presented in Figure 2. Ca^{2+} concentration was very high in non-irrigated fields compared to that of irrigated fields, with values of 200.0 and 12.0 me/l, respectively. In non-irrigated fields, Na^{+} concentration was higher compared to irrigated fields, with values of 76.0 and 2.7 me/l, respectively. Other than Mg^{2+}, other ions such as Cl^{-}, SO_4^{2-}, and HCO_3^{-} had higher concentrations in non-irrigated fields compared to irrigated fields. The results hence indicated presence of soluble salts in the scheme.

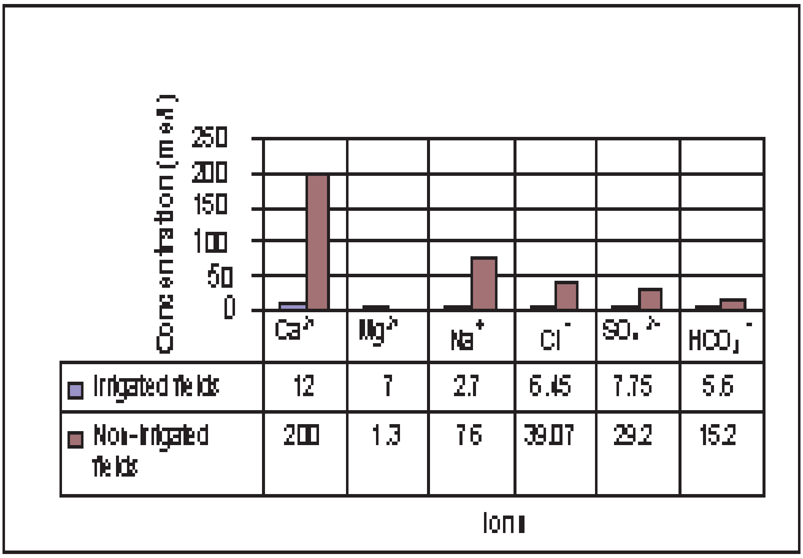

Figure 2: Major salts in soils of Turkwel Irrigation Scheme

Results of SAR, ESP and EC_e for sampling depth of 0.10-0.15 m are presented in Table 1. The SAR and ESP for non-irrigated fields were 7.58 and 9.02, while those for irrigated fields were 0.88 and 0.03, respectively. EC_e and ESP of non-irrigated fields were 6.4 and 9.02 ds/m, respectively, at a depth of 0.10-0.15 m.

Table 1: SAR, ESP and EC_e of soils at Turkwel scheme

Land use	*SAR*	*ESP*	*EC_e (ds/m)*
Irrigated fields	0.88	0.03	0.42
Non-irrigated fields	7.58	9.02	6.40

EC_e of irrigated fields was 0.42 ds/m, indicating non-saline, non-sodic soils for irrigated fields. However, non-irrigated fields indicated a moderately saline, non-sodic soil since EC_e was greater than 4 ds/m and ESP was less than the limit of 15. Once ESP exceeds 15, the structure of many soils deteriorates rapidly (Withers and Vipond, 1983).

Low ESP value was attributed to the high calcium and low bicarbonates concentrations in the Turkwel scheme soils. When calcium replaces sodium in the exchange complex, sodium salts crystallise and precipitate, reducing calcium and sodium concentration in the exchange complex of irrigated soils, which helps to preserve the soil structure (Russell, 1980). Under normal conditions, magnesium will not replace calcium to any extent. However, in presence of bicarbonates, calcium tends and precipitate as normal carbonates ($CaCO_3$). The corresponding magnesium salt, being more soluble, has low tendency to precipitate, and therefore it enters into the exchange complex, thereby replacing calcium. This explains the higher magnesium concentrations in irrigated fields compared to those in non-irrigated fields, i.e., 7.0 and 1.3 me/l, respectively. The end result of this reaction is that, as calcium is precipitated, it is lost from the solution and therefore, it increases the relative proportion of sodium in solution. This could have caused an increase in sodium hazard. However, the high concentrations of calcium in Turkwel soils, coupled with low bicarbonate concentrations, controlled the rise. Concentrations of calcium and bicarbonates in non-irrigated fields were 200 and 15.2 me/l, respectively, which reduced to 12 and 5.6 me/l in irrigated fields. Since bicarbonate concentrations were low, the HCO_3^- reacted with only a small proportion of calcium to form calcium carbonate. Therefore, proportion of sodium emanating from the reaction was neutralised by a large proportion of calcium that still remained in the exchange complex and therefore sodic soils were not formed.

In the ASALs, salts accumulate *in situ* due to low amount of rainfall experienced. The high evaporation and transpiration rates characteristic of arid climates also tend to decrease the limited amount of water available for leaching and transporting salts. This results in development of salinity or alkalinity in the soils, a process referred to as *primary salinization*. Salt presence in some parts of the scheme was obvious due to visual presence of salt crystals on soil surfaces and dump oily patches. Other indicators were physiological wilting and variability in growth of crops and scorched leaves of tomato crops due to excessive salt concentrations.

3.1.2 Salt Concentration with Land Use and Soil Depth

The results of EC_e changes with depth are presented in Figure 3 for soil profiles in non-irrigated, periodically and intensively irrigated fields. These indicated that salt concentration and distribution pattern changed with depth down the soil profile, depending on land use, indicated as irrigation practice**.**

Results indicated that EC_e of non-irrigated fields was 1.31 ds/m on the soil surface, indicating non-salinity at the soil surface. However, the soil became moderately saline with EC_e increasing to a maximum of 5.57 ds/m at a depth of 0.20 m. The salt concentration then decreased with depth to 1.85 ds/m at a depth of 0.60 m, indicating a non-saline level. This salt distribution pattern was attributed to high temperatures in the ASAL region, whereby the unsaturated zone within the soil profile can be divided into two portions (Jury *et al*., 1991). At the lower portion, water occurs in liquid phase, while the upper portion has water in vapour phase. As water from the deeper profile evaporates to vapour state, it deposits salts at the region of evaporation, which was highest at about 0.20 m depth. Therefore, for Turkwel scheme soils, the evaporation zone was in the upper 0.20 m depth. This explains why no salty patches appeared on the soil surface of non-irrigated fields. These fields supported shallow-rooted pastures for livestock without salt deposition on the soil surface. Indigenous vegetations are drought tolerant as most of them have the ability to extend roots deep to extract ground water.

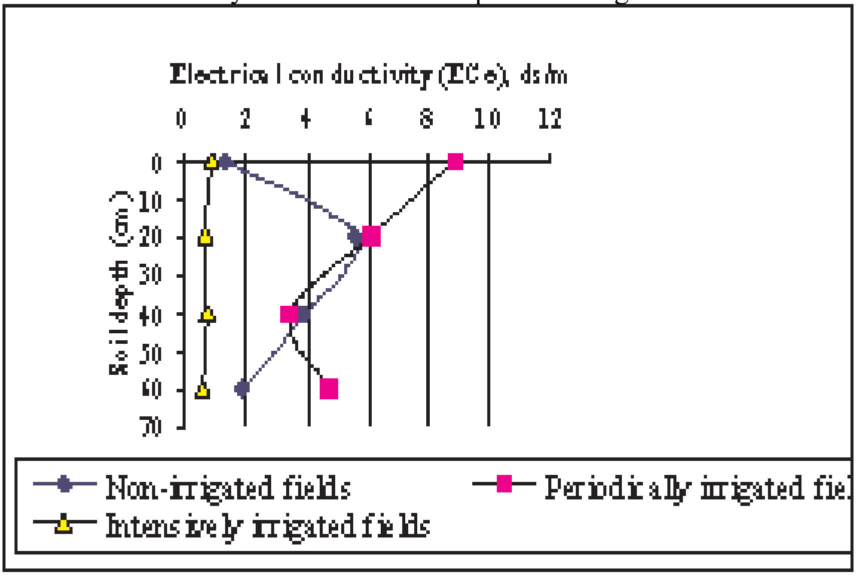

Figure 3: Concentration of salts with depth and land use

Periodically irrigated fields had an EC_e of 8.86 ds/m on the soil surface, indicating a strongly saline soil. Salinity decreased to a moderate level with EC_e of 6.08 ds/m at 0.20 m depth and to a non-saline level with EC_e of 3.41 ds/m at depth of 0.40 m. It then increased to a moderate level of 4.66 ds/m at a depth of 0.60 m. This salt concentration and distribution pattern was attributed to salt translocation from the deeper soil horizon.

On these fields, crusts on the soil surface were frequently broken during cultivation. This resulted in rise of salts from a shallow groundwater table, through the soil profile and onto the soil surface. Salts were then deposited on the surface as water evaporated into the atmosphere, hence indicating a high EC_e value in the top 0.20 m soil layer. High EC_e at 0.60 m was due to presence of a large quantity of salty groundwater at this depth, as it is a capillary fringe zone, since water table depth was at about 0.70 m.

The lowest EC_e was that of intensively irrigated fields, which had a value of 0.88 ds/m at the soil surface. The EC_e reduced gradually with depth to 0.57 ds/m at 0.60 m. This low salt concentration and low variation with depth indicated that salts in these fields were leached uniformly throughout the soil profile by frequent irrigations that applied water in excess of crop requirement. This ensured an environment that sustained vegetable production in the scheme during most months of the year.

Table 2 presents variation of mean ECe of three replicates with soil depth for the three land uses of non-irrigated, periodically and intensively irrigated fields. The means were compared by the Duncan's multiple range test (DMRT) statistical method at each soil depth and also with each land use.

Table 2: Mean ECe with soil depth at various land uses in the scheme

Soil depth (cm)	*Non-irrigated*	*Periodically irrigated*	*Intensively irrigated*
0	1.31**	8.86**	0.88**
20	5.57**	6.08**	0.68**
40	3.86**	3.41**	0.76**
60	1.85**	4.66**	0.57**

Means within rows (land use at a given soil depth) and also within columns (land use with soil depth) were all significantly different at **P< 0.01 level. This implied that salt concentration was affected by irrigation practice, and it also varied significantly with soil depth.

3.1.3 Bulk Density Variation with Depth and Land Use

Soil textural analysis from 40 soil samples of Turkwel irrigation scheme indicated texture with about 64.5% sand, 23% silt and 12.5% clay, indicating sandy loam soils using the USDA classification system. Figure 4 presents variation of bulk density with depth for undisturbed samples obtained from soil profiles dug in non-irrigated, periodically and intensively irrigated fields.

Bulk density was highest on the surface of non-irrigated fields, at a value of 1.46 g/cm^3 that is typical for sandy loam soils, which are between 1.4 to 1.6 g/cm^3 (FAO, 1986). Higher value on the surface was caused by surface compaction due to livestock grazing on undisturbed cohesive soils that were not under cultivation. Periodically and intensively irrigated fields had bulk density values of 1.27 and 1.16 g/cm^3, respectively, on surface soils. This was attributed to continuous disturbance and mixing of soils during cultivation.

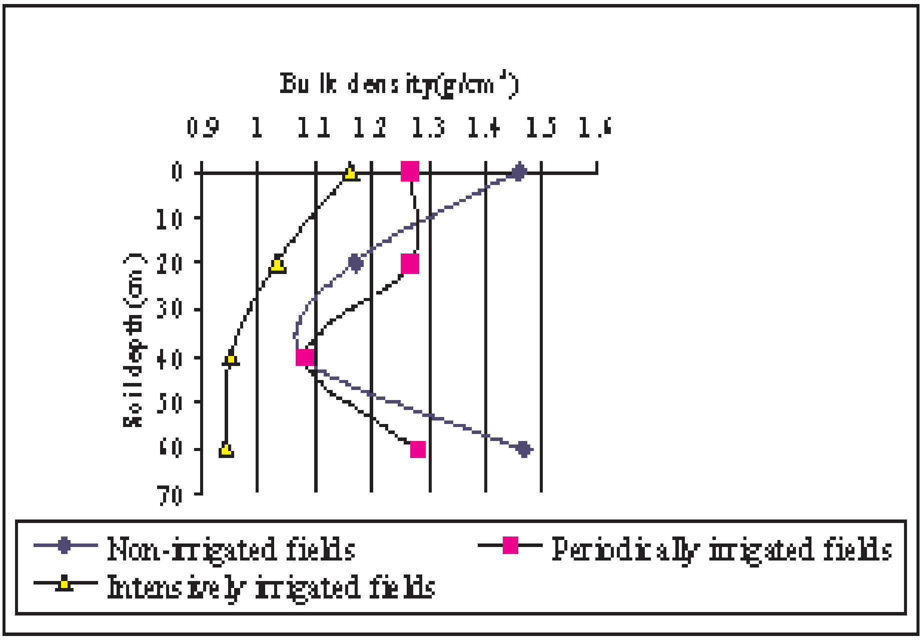

Figure 4: Bulk density of the soil with depth at various land uses

Bulk density of non-irrigated fields decreased with depth up to about 1.08 g/cm^3 at 0.40 m, after which it increased again to 1.47 g/cm^3 at 0.60 m. This higher value at 0.60 m depth may have been due to compaction of soil due to higher moisture content down the soil profile. Periodically irrigated fields had a fairly uniform bulk density of 1.27 g/cm^3 with depth, which again decreased to about 1.08 g/cm^3 at 0.40 m, indicating a soft zone at this depth. However, bulk density for intensively irrigated fields was the least and it decreased gently and uniformly with depth to about 0.94 g/cm^3 at 0.60 m. This was attributed to increased use of farmyard manure for vegetable production in these fields. Livestock were also denied access to the fields, and most crop by-products were incorporated back into the soil. These resulted in build up of organic matter in the soil, thereby affecting bulk density in these fields.

Table 3 presents variation of mean bulk density of three replicates with soil depth for the three land uses of non-irrigated, periodically and intensively irrigated fields. The means were then compared by the Duncan's multiple range test statistical method at each soil depth and also with each land use.

Table 3: Mean bulk density with soil depth at various land uses in the scheme

Soil depth (cm) *Intensively* *irrigated*	*Non-irrigated*	*Periodically*	*irrigated*
0	1.46a	1.27b	1.17c
20 b 7 1.05c	1.127a .	1	
40	1.08a	1.08a	0.95c
60	1.47a	1.28b	0.95c

Means followed by a common letter were not significantly different, even at the P<0.05 level. Means within rows (land use at a given soil depth) were all significantly different at P< 0.01 level, implying that bulk density was affected by irrigation practice in the scheme, especially in the upper 0.20 m soil depth. However, at 0.40 m depth, bulk density in intensively irrigated fields was significantly different from both non-irrigated and periodically irrigated fields. Within columns (land use with soil depth), non-irrigated and intensively irrigated fields both indicated non-significance of bulk density with depth, while periodically irrigated fields indicated significant difference at 0.40 m depth.

3.2 Irrigation and Ground Water Quality at Turkwel Scheme

All waters, whether derived from springs, streams or pumped from wells, contains appreciable quantities of soluble salts, which concentrate in the root zone (Russell, 1980). After irrigation, water enters the soil to become soil water. Its composition can change in response to factors such as precipitation of salts, organic matter decomposition and evapotranspiration. However, effects of salt precipitation are generally insignificant for most waters, where EC_w is less than 1.0 ds/m (Rhoades and Loveday, 1990).

Results of chemical analysis of both irrigation and ground waters are presented in Figure 3 and computed SAR, ESP and EC_w presented in Table 4. Salt concentration of the waters indicated EC_w values of 0.16 and 0.33 ds/m for irrigation and ground water, respectively. Concentration of Na^+ in ground water was high, about 5.50 me/l. This contributed to high SAR and ESP in ground water, i.e., 3.89 and 4.29, compared to surface water with 1.50 and 0.95, respectively. Ca^{2+} concentration in both irrigation

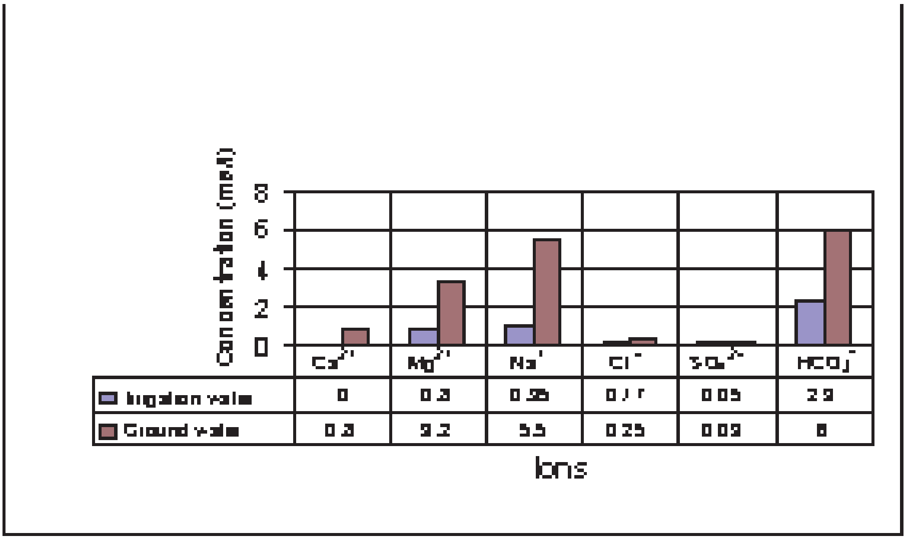

Figure 3: Salts concentration in water of Turkwel Irrigation Scheme

Table 4: SAR, ESP and EC_w of waters at Turkwel Scheme

Sample	*SAR*	*ESP*	*EC_w (ds/m)*
Irrigation water	1.50	0.95	0.16
Ground water	3.89	4.29	0.33

United States Salinity Laboratory classifies irrigation waters into various classes based

on salt concentration (Table 5), and water suitability for irrigation with respect to salinity hazard. Most irrigation waters are found in the range of 0.15 to 1.50 ds/m, although values as high as 8.00 ds/m have been used on light textured soils having deep water table without significant harm on soil and plants. Based on salinity hazard classification of Table 5, salt concentration of waters of Turkwel scheme was classified as very low and low for irrigation and groundwater, respectively. Waters of low salinity can be used for irrigating most crops on most soils.

Table 5: Salinity hazards of irrigation water

EC_w of Irrigation Water, ds/m	*Salinity Class*	*Saliniy Hazard*
0.10 – 0.25	C_1	Very low salinity
0.25 – 0.75	C_2 Low	
0.75 – 2.25	C_3	Medium
2.25 – 5.00	C_4	High
> 5.00	C_5	Very high salinity

(Hagan *et. al,* 1987; Chhabra, 1996)

However, after a period of time, these low salt levels progressively increase in the root zone, unless they are removed through leaching and drainage. Salt build-up in the soil profile gives rise to saline soils, in the process referred to as secondary salinization (Withers and Vipond, 1983). As the salinity level increases, the water becomes less suitable for salt-sensitive crops and for use on soils of low permeability. High salinity water can only be used for salt-tolerant crops with good management on well-drained permeable soils.

There is tendency of irrigation water to generate excessive levels of exchangeable sodium, which adversely affect soil physical-chemical properties. On the basis of SAR, irrigation water has been divided into four categories based on sodicity hazard (Table 6). With regard to sodicity hazard, both irrigation and ground waters of the Turkwel scheme were classified as low, with SAR values of 1.50 and 3.89, respectively.

Table 6: Sodicity hazard of irrigation water

SAR of Irrigation Water	*Sodicity Class*	*Sodicity Hazard*
< 10	S_1	Low
10 - 18	S_2	Medium
18 - 26	S_3	High
> 26	S_4	Very high

(Hagan *et. al*, 1987)

However, FAO guidelines on evaluation of quality of irrigation water are based on long term dominating influence of the water's quality (Table 7). This is on the soil-plant-water relationships that affect crop production and management.

Table 7: Guidelines for evaluating irrigation water quality (FAO, 1986)

Type of problem		*Units*	*Water quality guidelines*		
			No Problem	Increasing problem	Severe problem
Salinity (affects crop water availability), EC_w		ds/m	< 0.7	0.7 – 3.0	> 0.3
Permeability (affects infiltration rate into soil), EC_w		ds/m	> 0.5	0.5 – 0.2	< 0.2
Specific ion toxicity (affects sensitive crops) -Surface irrigation	Na	SAR	3 meq/l	33 – 9 < 3	>9 >3
-Sprinkler irrigation	Cl	meq/l	<4	4 – 10	> 10
		meq/l	<3	>3	
	B	mg/l	< 0.7	0.7 – 2.0	> 2.0
Miscellaneous effects (affects susceptible crops)	N	mg/l	< 5	5 – 30	> 30
	HCO (sprinklers)	meq/l	< 1.5	1.5 – 8.5	> 8.5
	pH	Normal range 6.5 – 8.4			

Note: Nitrogen in the form of NO_3- N or NH_4- N

The quality of Turkwel River waters was within the acceptable standards since it had an EC_w of 0.16 ds/m, which was much less than the maximum allowable value of 0.70 ds/m. The irrigation water had no problems in terms of salinity, if it was properly managed. The water was also free of toxicity problems of sodium and chloride, since SAR and chloride concentrations were 1.50 and 0.17 me/l, which were lower than the maximum allowed values of 3.00 and 4.00 me/l, respectively. Similarly, groundwater, with proper management, had no problem pertaining to salinity, since it had an EC_w value of 0.33 ds/m, which was less than the maximum allowed value of 0.70 ds/m. It had a chloride concentration of 0.25 me/l, therefore posing no problem of chloride toxicity that can be manifested at concentrations higher than 4.00 me/l. However, it may cause increasing problems of sodium toxicity when used by crops through sub-surface flow, since it had an SAR of 3.89, which was higher than maximum allowed value of 3.00.

3.3 Phreatic Water Table Depth

A trench and an inspection pit dug in November 2005 revealed that the water table was at a depth of 0.70 m at end of the irrigation period. However, after a period of three months, the water table had dropped to 0.80 m, i.e., in February

2006, which was also observed in shallow wells used for irrigation in the scheme. Table 8 presents water table fluctuation of shallow wells since they were sunken. Information from the community revealed that shallow wells were sunk in 1982. They stopped deepening a well once water filled two culverts, which is equivalent to 1.80 m.

Results show that the depth of shallow wells differed, ranging from 3.30 m to 4.30 m. A change in watertable depth was noticed, whereby phreatic water levels rose with different values in each well. It has been rising with time since initiation of the scheme; the rise was between 0.70 and 1.70 m in the wells. Between November 2005 and February 2006, the watertable level in the scheme was between 0.70 and 0.80 m from the soil surface.

Table 8: Water table depths of shallow wells in the scheme

Well No.	*Phreatic water level (m) (m)*		*Rise in water table*	*Rise in water table (m)*
	1982	**2006**		
1	1.70	0.76	0.94	3.50
2	1.50	0.80	0.70	3.30
3	1.60	0.80	0.80	3.40
4	2.50	0.80	1.70	4.30
5	1.90	0.80	0.90	3.70
6	2.20	0.80	1.40	4.00
7	1.70	0.80	0.90	3.50

Raised water table was hence evident from inspection pits and shallow wells within the scheme. Raised water tables, especially in ASAL regions, have been identified as the major cause of soil salinisation, especially when it was above the critical water table level. Raised groundwater tables contribute to salt accumulation on the soil surface through the capillarity process. The soil depth of 60 cm, which indicated a high bulk density of 1.47 g/cm^3 for non-irrigated fields, was hence within the capillary fringe.

Raised water table also maintained growth of grasses and other weeds during fallow periods. These provided an opportunity for livestock to feed on crop by-products and weeds. However, this vegetation reduced occurrence of rapid evaporation from the soil surface, thereby causing poor development of a "self mulching" soil layer that usually stops capillarity action. When reduced evaporation is maintained throughout the fallow period, it ends up increasing deposition of salts on the soil surface. Shallow water tables, especially in ASAL regions, can hence be a major cause of soil salinisation.

Raised watertable could further be caused by seepage through canals that supply water from Turkwel River to farms in the scheme. As seepage water flows through the soil, it absorbs salts in the soil and the increased salt concentration in water causes salinisation to soils in the fields. Salinisation can hence be related to low irrigation efficiency and lack of proper drainage measures. Over-irrigation without adequate drainage can cause rise in groundwater table, which results in soil salinisation from direct phreatic evapotranspiration.

3.4 Soil and Water Management Options to Minimise Salinisation in the Scheme

Salts added through irrigation waters need to be removed from the root zone at regular intervals for sustainable crop production. Various salinity mitigation measures that can be adopted in the scheme are the following:

3.4.1 Maintaining Low Water Table Depth

The main cause of salinity in the scheme was a high water table. This was due to inefficient irrigation, high seepage from the main canal and shallow drains that were not effective. This water table can be lowered below the present 0.70 m through installation of deep ditches that allow surface and sub-surface drainage. Since quality of groundwater was fair, and quality of the river water was good, groundwater from the shallow wells can also be pumped and re-used for irrigation, thereby increasing available water. This will lower the watertable and also increase the area that can be cultivated.

Agro-forestry can also be incorporated within the scheme in order to pump out water naturally at a lower cost through the evapotranspiration process. Adir *et al*., (1997) established that incorporating trees such as *sesbania sesban* intercropped with *kallar* grass lowered soil EC_e greatly in an irrigation scheme in Pakistan. They attributed this to extensive and deeper root system of *Sesbania sesban* and dense fibrous root system of *kallar* grass, which provided channels for percolating water to leach away soluble salts.

3.4.2 Leaching out Salts

This involves passage of sufficient water through the root zone over and above crop water requirements in order to leach salts out of the root zone. Usually, water used is that of a lower salinity level than the soil solution. The leached salts can then be evacuated from the root zone by the drainage system.

3.4.3 Improving Soil Structure through Application of Manure

Use of manure during planting of crops improves soil structure by agglomerating soil particles, thereby increasing soil porosity. High porosity improves soil permeability, which leads to improved soil drainage. Rate of capillary rise is inversely proportional to soil pore size and void ratio. Therefore, increased organic matter results in reduced rate of capillary rise and hence reduced salinisation. Organic matter also increases carbon dioxide evolution in the soil, which stimulates the solution of calcium in calcareous alkaline soils. This neutralises free sodium by replacing it in the exchange complex,

thereby preventing formation of sodic soils.

3.4.4 Shortening Fallow Periods

Long fallow periods were found to contribute to soil salinisation through increased salt concentration on soil surface. Soil surface of periodically irrigated fields were saline, while intensively irrigated fields were not saline. Periodically irrigated fields were under crops for only two seasons in a year, i.e., about 7-8 months, while intensively irrigated fields had crops throughout the year. Planting a cover crop during off-season periods can be investigated so as to control salinity by providing a vegetative cover on the land surface. This may involve crops such as green grams, cowpeas, and a variety of vegetables. However, their selection needs to be based on tolerance to drought and salinity, since no irrigation is undertaken during this period.

4.0 SUMMARY AND CONCLUSIONS

This study was carried out to investigate soil and water quality as affected by irrigation in Turkwel scheme of Turkana district. Non-irrigated fields supported shallow rooted pastures for livestock since the soil surface was non-saline with an EC_e of 1.31 ds/m. However, salt concentration was highest at about 0.20 m depth, EC_e being 5.57 ds/m, indicating salt deposits at this region of evaporation. Salinity then decreased to a non-saline level indicated by EC_e of 1.85 ds/m at 0.60 m depth.

Intensively irrigated fields had low salinity that sustained vegetable production in the scheme. The soil surface had an EC_e of 0.88 ds/m that gradually decreased to 0.57 ds/m at 0.60 m due to leaching of salts by frequent irrigations. However, periodically irrigated fields indicated a soil surface that was strongly saline at EC_e of 8.86 ds/m; this decreased to moderate salinity of 6.08 ds/m at 0.20 m depth and to 3.41 ds/m at 0.40 m. This was due to salt translocation from the shallow groundwater table that was between 0.70 and 0.80 m from the soil surface. Ground water table was about 1.70 m in 1982 when shallow wells were sunk in 1982 during scheme expansion. Over-irrigation and canal seepage without adequate drainage caused groundwater to rise over time, thereby resulting in soil salinisation from direct phreatic evapotranspiration.

Quality of irrigation water was good, with salinity levels classified as very low at an EC_w of 0.13 ds/m, while that from groundwater was low at 0.33 ds/m. Waters of low salinity can be used for irrigating most crops on most soils. Sodicity hazard of the irrigation and ground waters were both classified as low, with SAR of 1.50 and 3.89, respectively.

Salinity management in the scheme requires efficient irrigation practices that leach salts from the root zone, and a drainage system that removes the salty waters away from the roots, thereby ensuring sustainable agricultural production. Ground water was of acceptable quality, hence it could be pumped from the shallow wells to lower the water table; it can also be re-used to increase irrigation water available for increased crop production. The long fallow period also needs to be reduced through agronomic measures such as growing drought-resistant cover crops like green grams and cowpeas during this period. Agro-forestry trees can also be used to lower the watertable at lower cost through the evapotranspiration process, thereby minimising salt build-up in the scheme

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