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Salinization pattern and its spatial distribution in the irrigated agriculture of Northern Ethiopia: An integrated approach of quantitative and spatial analysis

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ABSTRACT

Salinity adversely affects the environment, agro-ecosystems and agricultural productivity of arid and semi-arid regions worldwide. This salinization occurs due to natural, human or both actions on the dynamic earth system. This study was conducted to quantify the magnitude and map the spatial distributions of salinity of the irrigated agriculture in northern Ethiopia. A total of 717 soil and 13 water samples from nine irrigation schemes were used for analysis. The soil samples were collected on a grid basis from 0 to 15 cm and 15–30 cm soil depths in the plant's root zone whilst surface water samples were collected from the irrigation water source, middle and lower cross-sections of the irrigation schemes. These soil and water samples were analyzed quantitatively for 14 salinity parameters and results compared with worldwide standard values. In addition, the spatial analysis was made for three basic salinity parameters of hydrogen ion concentrations (pH), Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR). Even if, there are non-significant variations between soil depths and among the irrigation cross-sections, a salinity is observed at 33% of the schemes. Higher pH average values are spatially concentrated downstream whilst SAR and EC showed inconsistent variations among irrigation schemes. The quantitative and spatial salinity analysis revealed that Gum Selassa, Gereb Kunchi and Tegahne irrigation schemes have potential salinity levels. As a result, salinity management strategies and community-based salinity management approaches that involve farmers' participation is vital to create a sense of ownership. Irrigation users and decision makers should consider possible measures of minimizing salinity build-up thereby increasing agricultural productivity in a sustainable way.

1. Introduction

Soil salinity started to affect humanity since centuries (Shahid, 2013). This soil salinization is caused due to natural or anthropogenic actions on the earth system. Today, nearly 20% of the world irrigated agriculture is threatened by salinization (Li et al., 2014; Adejumobi et al., 2016). This is even worse in arid and semi-arid regions in which 30% of the irrigated agriculture is saline (Li et al., 2014). This is due to the limited rainfall amount (< 400 mm) and high evapotranspiration conditions (Huang et al., 2010). Beyond its inherited salinity nature of the arid and semi-arid regions, 41% of the land surface is irrigated with saline water (UNDP, 1997). As a result, the sustainability of land and water resources for agricultural use remains questionable.

Salinization adversely affects the environment, agro-ecosystems, agricultural productivity and sustainability (Shahid, 2013). This is caused due to the complex degradation dynamics of the soil and water resources which has a direct impact on food security of livelihoods that further hinders societal biophysical and socio-economic base. Use of poor quality water, coupled with the intensive use of soils for irrigation, results in the development of salinity affected irrigated agriculture (Crescimanno et al., 2007). When soils under irrigation are converted to salt-affected soils, salinity contaminated irrigation agriculture persists (Im-Erb and Sukchan, 2007). Salt-affected soils vary due to physical and chemical characteristics of the soil, depth of water table, leaching capacity, crop cultivation system and salt distribution pattern (Qureshi and Akhtar, 2007). This occurs due to the natural phenomena (salt deposition from the underlying parent material) or human actions (poor drainage facility, poor quality irrigation water use or over-irrigation)

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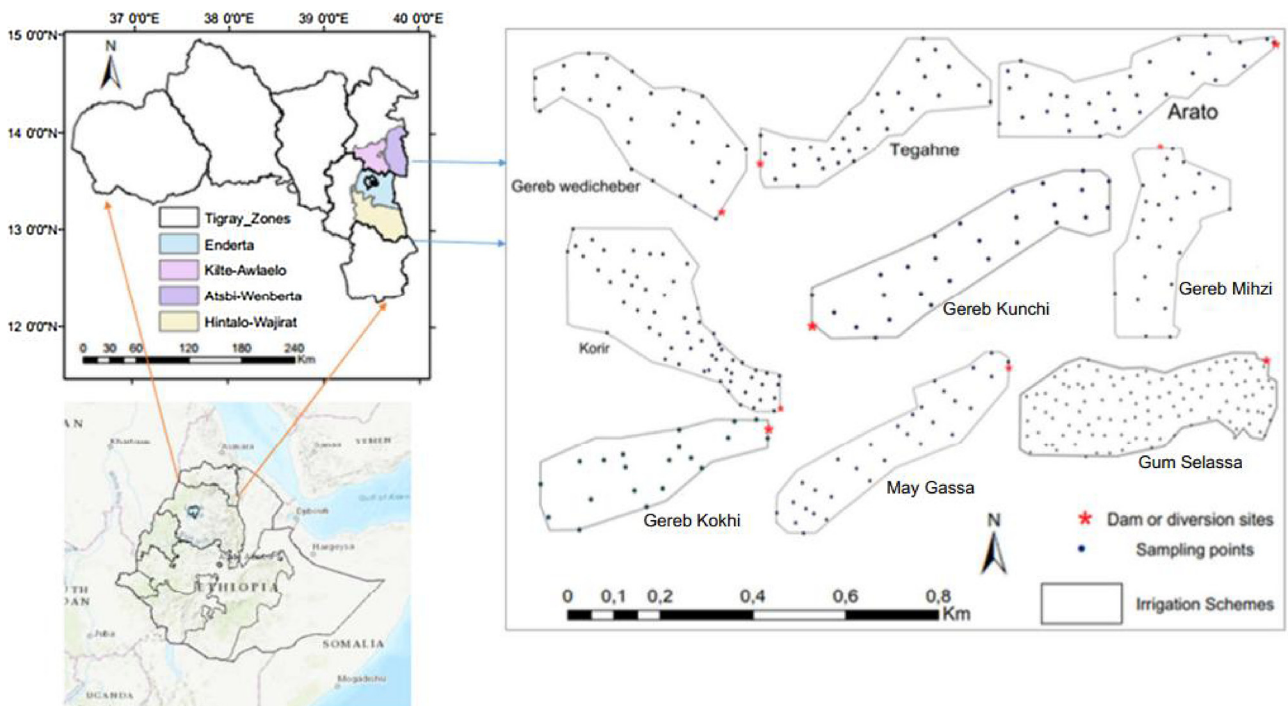

Fig. 1. Location map of the irrigation schemes, sampling points and dam / diversion sites.

(Thomas and Morini, 2005). Furthermore, salt-affected soils result from chemical, physical and biological interactions of the soil and water resources (Kidane et al., 2006). The severity of salinity hazard or salinization is associated with low agricultural productivity, on-site land degradation and is mainly an environmental problem that eventually leads to desertification (Im-Erb and Sukchan, 2007). In agriculture where human being depends on, salinity effect manifests in loss of crop stand, reduced plant growth, reduced yields, and may cause crop failure by preventing water extraction from the soil due to reduced osmotic potential (Ayers and Westcot, 1985; Dierickx, 2009).

The Tigray region in northern Ethiopia is known for its semi-arid environment, vulnerable to soil salinity as a result of the recent intensifications of irrigated agriculture. The regional government has been expanded irrigated agriculture for the sustenance of its smallholder farmers in the last twenty years (Alemayehu et al., 2009). As a result, the regional irrigated land has increased from 15,000 ha before 2004 to more than 243,000 ha in 2015 (BoARD, 2015). Furthermore, the government has an ambitious plan to irrigate 50% of the total 1.5 million hectares of available arable land in the next 10–15 years period (Gebresilassie, 2014; GTP, 2011). To achieve these goals, earthen dams and diversions have been constructed continually in the last two decades as a means of harvesting surface water for small and medium scale irrigation developments. However, despite the satisfactory achievements of the intensification of irrigated agriculture, the attention given to field level agricultural water management was non-sufficient. In addition, due to lack of knowledge and awareness of improved irrigated land and water management strategies, farmers are using traditional irrigation water application systems. Consequently, irrigation application efficiency remains below 40% in the region (Mintesinot et al., 2004; Hagos et al., 2016; Kifle and Gebretsadikan, 2016). This poor on-farm irrigation water management practice has led to waterlogging, poor water distribution and salinity development of the irrigated agricultural lands (Kidane et al., 2006). As a result, salinity eventually developed in the irrigated agricultural lands of the region, especially in the past decades. The yield and quality of the cultivated crops were hindered and consequently, farmers were forced to change their cropping strategy by introducing mitigation measures (Mintesinot et al., 2004; Hagos et al., 2016; Kifle et al., 2017; Yohannes et al., 2017; Gebremeskel et al., 2017). As a result, farmers have changed crop cultivation strategy from the cereal-based cultivation to salinity tolerant commercial crops. Even if a detailed study is hardly found, that could clearly indicate the status and salinity development over time. Farmers, extension experts and research institutions were trying to put some mitigation measures by introducing salinity tolerant improved crops such as potato, onion and some drainage facilities through leaching. Although such mitigation measures were undertaken in the irrigated agricultural areas, a considerable irrigated land of the irrigation schemes is converting into unproductive areas as a result of the on-site salinity buildups (Kebede, 2009). This indicates adequate field-level agricultural land and water management techniques were lacking in the irrigated farmlands (Kifle and Gebretsadikan, 2016; Kifle et al., 2017; Yohannes et al., 2017; Tsegay et al., 2015; Kifle et al., 2008).

Despite the existence of some local studies on salinity developments in the semi-arid region (e.g., Yazew, 2005; Bekele et al., 2012; Kebede, 2009; Gebremeskel et al., 2017), a comprehensive study to identify the main salinity sources, quantifying the magnitude and mapping its spatial distributions is lacking. Identifying the main driving forces of salinity (from the soil itself or the water applied) that forms a soluble salt accumulation in the soils of irrigated agriculture is essential in understanding and taking management measures for future agricultural productivity. Moreover, soil depth based salinity status determination at which most crops grow is vital. This is helpful to identify whether salts are going down the soil depths or emerging due to capillary rise from the groundwater tables near the surface. Therefore, this study was aimed at understanding the salinity status by quantifying the magnitude, mapping its spatial distributions in selected irrigation schemes. This study is essential to deliver and put ways forward recommendations for decision makers and irrigation users to improve the agricultural productivity in a sustainable way and minimize the salinity build-up in the soil depths of the region and other areas with similar socio-economic and agro-ecological conditions.