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Table of Content

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Full Length Research Paper

Application of a decision support tool for municipal solid waste open dumps remediation in Cape Verde

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Open dumps are places where solid waste is disposed directly on the ground, without any environmental assessment, resulting in environmental, societal and economic damages. In Cape Verde, most of the municipalities dispose their solid waste on open dumps. Cape Verde's new policies on solid waste management determined the closure and the remediation of all the dumps around the country. In this context, this research diagnosed the conditions of tree dumps in Santiago Island and one dump in Fogo Island, in order to rank them for remediation priorities. Also, remediation scenarios and actions for each of the dumps were proposed, using Decision Support Tools (DST). Data were collected by visiting the dumps and applying field questionnaires. The results demonstrated a similarity between Santiago's open dumps (Santa Cruz, Santa Catarina and Praia Municipal Dumps), having a "Medium" impact level. São Felipe Municipal Dump located in Fogo Island has the highest impact level and it is the priority for remediation actions. The decision support tool usage proved to be an important instrument to aid decision making for managing areas contaminated by Municipal Solid Waste (MSW) in Cape Verde.

Key words: Open dumps, diagnosis, remediation scenarios.

INTRODUCTION

Municipal Solid Waste (MSW) management is a basic human right. However, the public and political profile of MSW management are lower than other basic services, resulting in several consequences for society and the economy (UNEP, 2015). The storage, collection, transportation, treatment and final disposal of MSW are reported as the major problem in urban centers (Okot-Okumu, 2011; Mgimba and Sanga, 2016). A rapid population growth and urbanization in developing countries have been increased the waste generation (Kurian et al., 2005). Waste management practices in most African countries are characterized by the indiscriminate dumping of refuse in water bodies and on isolated sites, which further exacerbates the low sanitation level in most African countries (Bello et al., 2016). These management practices and poor technology

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applied in the final disposal of MSW are some of the reasons for the existence of open dumps (Hoornweg and Bhada-Tata, 2012). Open dumps are places where the waste is disposed directly on the ground without environmental controls. A typical open dumpsite consists of wastes from many sources, wastes types and compositions. In most cases, the waste deposited is not covered or compacted and it remains susceptible to open burning (Mavropoulos et al., 2016). According to “Waste Atlas: The world’s 50 biggest dumpsites” 2014 report, most of the biggest dumps are located in African countries, Latin America, the Caribbean, and North Asia, where more than two-thirds of the world's population lives (Mavropoulos et al., 2014).

Open dumps can cause serious impacts to the air, soil, surface water and groundwater, as well as social and economic impacts (Danthurebandara et al., 2012). Open dumps' environmental impacts are related to solid waste decay leaching and rainwater percolation. The leaching may contain biological and chemical pollutants that originated from the MSW, becoming a potential surface and groundwater contaminants (Moravia, 2010; Castilhos Junior et al., 2003). Air pollution is resulted from the indiscriminate burning of solid waste or from the anaerobic degradation of the organic fraction of MSW, which produces gases as methane (50- 75% of the composition in volume) and carbon dioxide (25- 50% of the composition in volume) (Ezyske and Deng, 2012; FNR, 2010). The methane is lighter than air and it is flammable. Thus, it is important to implement instruments to control the migration of the gases produced on dumpsites, especially where there are constructions near them, as the gases could be accumulated and may cause explosions (Gill et al., 1999). Another environmental impact caused by open dumps is related to soil pollution by different metals. The metals can be transferred to plants by different means (Voutsa et al., 1996). Contaminants can be found in dumps in different manners, depending on their characteristics. Despite that, contaminants almost always end up accumulated on the soil or carried to water bodies.

Open dumps cause social impacts as they become attractive to a low-income population seeking work alternatives by collecting recyclable materials. This activity put people in contact with all types of waste, also, they become susceptible to accidents. The activity hurts human dignity and configures as a public health problem, therefore, attention has been done to these problem resulting from the inhalation of particulate matter emitted at these sites (Castilhos Junior. et al., 2013; Ramos, 2016; Coelho and Sales, 2017; Peter et al., 2018). Thus, waste pickers formalization is necessary in order to improve the efficiency of the services and to comply with safety and health regulations (Okot-okumu, 2012). Beyond the social aspects, open dumps cause devaluation, degradation and unavailability of land in its surroundings because of vectors of disease, smell, smoke, noise and threats to water supply, impacting the local economy (Danthurebandara et al., 2012).

Open dumps can be considered as contaminated and degraded areas caused by improper wastes disposal. According to CETESB (2001), the area is considered contaminated when elements or substances of environmental interest are above the pre-established limits representing a risk to human health and so, immediate action is needed in order to minimize the exposure routes, as well as the restriction of local uses. So, to manage these contaminated areas, two basic principles are necessary. The first one is the identification of the contaminated area aiming to define the region of interest, identification of potentially contaminated areas; preliminary assessment and; confirmatory investigation. The second one is the recovery process of the contaminated area that whose main objective is the adoption of corrective measures in these areas in order to recover them for a use compatible with the established goals to be achieved after the intervention (CETESB, 2001).

Theoretically, the best way to recover the open dumps could be the complete removal of the deposited waste, sending them to sanitary landfills and recovering the area of an open dump with natural soil of the region. However, the cost would be high, thus making the process unfeasible (Monteiro et al., 2001). Therefore, according to (Coelho and Sales, 2017), some simple and economical actions can be done to minimize the problem of open dumps like: terminate its operation, requalifying and reducing the negative environmental impacts suffered by the area and giving them another purpose; transform the open dump into a controlled/sanitary landfill which promote the gradual recovery of the degraded area while maintaining its operation. This second option can be a long-term goal while physical and financial means still limited. If there are a number of dumps that need to be rehabilitated and only limited resources are available, a higher priority may be assigned to dumpsites with high health risk, maximum environmental impacts and public concerns and minimum rehabilitation costs (Joseph et al., 2010).

For effective planning and development of strategies for sustainable management of MSW, information about the quantity and categories of MSW is of great importance (Mgimba and Sanga, 2016). In Africa, the accelerated urban growth since the 1960s has put pressure on land resources within the cities surrounding areas, as well as, the ever-increasing population density has led to MSW generation increment (Fenta, 2017). In sub-Saharan Africa, MSW generation reaches 62 million tons per year. The per capita MSW generation in 2012 around sub-Saharan Africa was from 0.09 to 3.0 kg/cap/day (kilogram per capita day), its average was 0.65 kg/cap/day and it was projected to reach 0.85 kg/cap/day by 2025. These increasements are affected by economic development, industrialization, society's habits, place and climate. In this region, oceanic islands have the highest per capita MSW generation probably because of tourism and more complete accounting of all MSW generated (Hoornweg and Bgada-Tata, 2012). In Cape Verde, an archipelago located in the west and sub-Saharan Africa, the MSW per capita generation was 0.5 kg/cap/day in 2012 and it is estimated an increase to 0.7 kg/cap/day in 2025 (Hoornweg and Bgada-Tata, 2012). With approximately 500 mil inhabitants, the population growth is expected to be around 1.2% per year by 2030, which will increase the MSW generation (INE, 2017).

In Cape Verde, the gravimetric composition of MSW indicates that the waste with the highest percentage by weight is soil (18.6%) followed by biodegradable waste (17.4%), glass (13.2%) and paper/cardboard (10 %), corresponding to more than 59% of the total waste share (Cabo Verde, 2016). According to data from the National Statistics Institute (INE), in Cape Verde, about 77.3% of the population is covered by collection services of waste either by door-to-door or by the garbage truck and approximately 22.6% of the population dispose their waste improperly in the environment. The destination of most of the collected waste is the grounding on dumpsites (INE, 2017). There are 17 dumps, 1 controlled landfill managed by the Municipal Sanitation Divisions, serving the country's 22 municipalities. Additionally, there are 152 identified uncontrolled disposal sites (Cabo Verde, 2016). Since 2015, the Santiago island, which is the most populous island in Cape Verde, has an Intermunicipal Sanitary Landfill managed by a public-private company, for the disposal of MSW from all its municipalities. With that infrastructure, the municipalities will no longer send its MSW to the three main dumps of the island (Praia, Santa Cruz and Santa Catarina dumps), thus enabling the closure of the dumps activities and their proper recovery.

On the other hand, Fogo Island does not have any sanitary landfill. Thus, the major fraction of MSW is sent to São Felipe dump, one of the biggest dumps of Fogo Island. Cape Verde has passed thorough changes in its waste sector. In 2016 it was approved the National Strategic Plan for Waste Prevention and Management (PENGeR) which is the main guiding document for environmental and solid waste management in the country. One of PENGeR's objectives is to improve MSW management by ensuring the closure of 100% of the uncontrolled dumps by 2020, and the closure of 100% of the municipal dumps by 2030. Also, the PENGeR has strategies to ensure that all refuse is landfilled (Cabo Verde, 2016).

To achieve these goals, the first task is to decide if the site should be closed, remediated or rehabilitated. To achieve that, the environmental risks posed by the site must be assessed. These may involve technical investigations and environmental impact assessments which include consultation with the interested and affected parties (Kurian et al., 2005; Joseph et al., 2010). So, decision making and integration of knowledge from many disciplines are required for managing contaminated areas like open dumps (Bardos et al, 2001). The Decision Support Tools (DST) is an instrument that can assist that, as it is a scientific method of computerized systems for decision making (Adamoski, 2010). It can come in the form of a guide or software. The guide is provided by regulators to achieve standardization and replicable approaches to reaching a decision and the software is produced to assist in decision making through intensive computational analysis processes. The major advantages of using a computerized DST is that it provides transparency of the decision process and permits the effects of uncertainty on the decision to be quantitatively addressed (Sullivan, 2002). In general, these DST are based on multicriteria analyses that use a set of techniques whose purpose is to order or hierarchize the various options that are sometimes conflicting, helping in decision making (Dodgson et al., 2009). As examples of DST, Kurian et al. (2005) proposed the Integrated Risk Based Approach (IRBA) that provides higher priority to dumpsites with high health risk, maximum environmental impacts, minimum rehabilitation costs and sensitive public concerns. Most recent, Gomes (2019) created a DST name Relix to help developing countries in the diagnose and remediation process of their dumpsites, especially Brazil. Therefore, the aim of this research was to identify and diagnose four Cape Verde open dumps as well as to propose remediation scenarios and actions, in order to rank them by their impact level, through a DST, and help managers in the decision making.

MATERIALS AND METHODS

To achieve the goal of this research, field research was carried out to collect the necessary data for the diagnosis of Cape Verde open dumps. The Figure 1 shows the general scheme of the methodology adopted in this research. Below is the description of study area, the description of DST adopted and the procedure to collected date in the field and analyze it.

Study area

In order to estimate the environmental impacts of open dumps as well as to set priorities for their closure and remediation process, three dumps on Santiago Island (Figure 2.) and one on Fogo Island (Figure) were chosen in line with the National Water and Sanitation Agency (ANAS). Thus, the dumps that raise the most concerns in the country were analyzed.

DST chosen

The DST chosen in this research was developed in the Research Laboratory of Solid Waste (LARESO) from the Federal University of Santa Catarina, Brazil. Its purpose is to assist the decision makers in the diagnosis and the remediation of dumps. The tool is named ReLix, and it is free and can be downloaded at the LARESO repository. Its choice was due to the fact that ReLix allows the diagnosis of MSW dumps by applying a field questionnaire and its subsequent analysis in the software. The software generates the most appropriate scenarios and remediation techniques for each

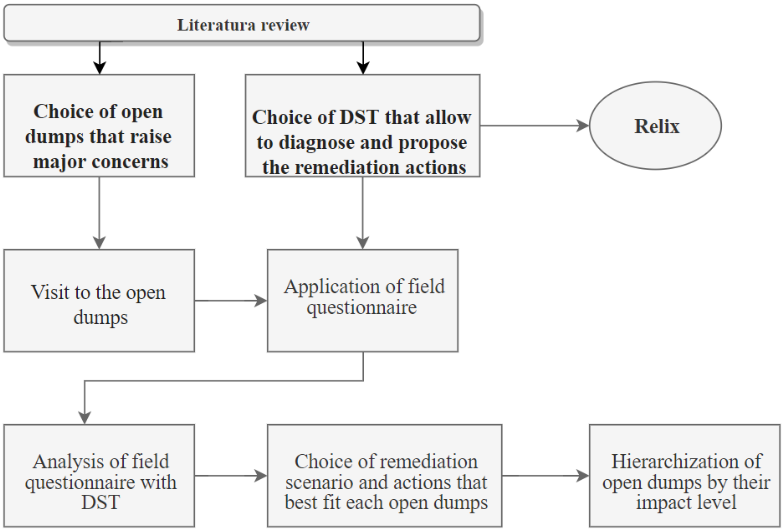

Figure 1. General scheme of the methodology.

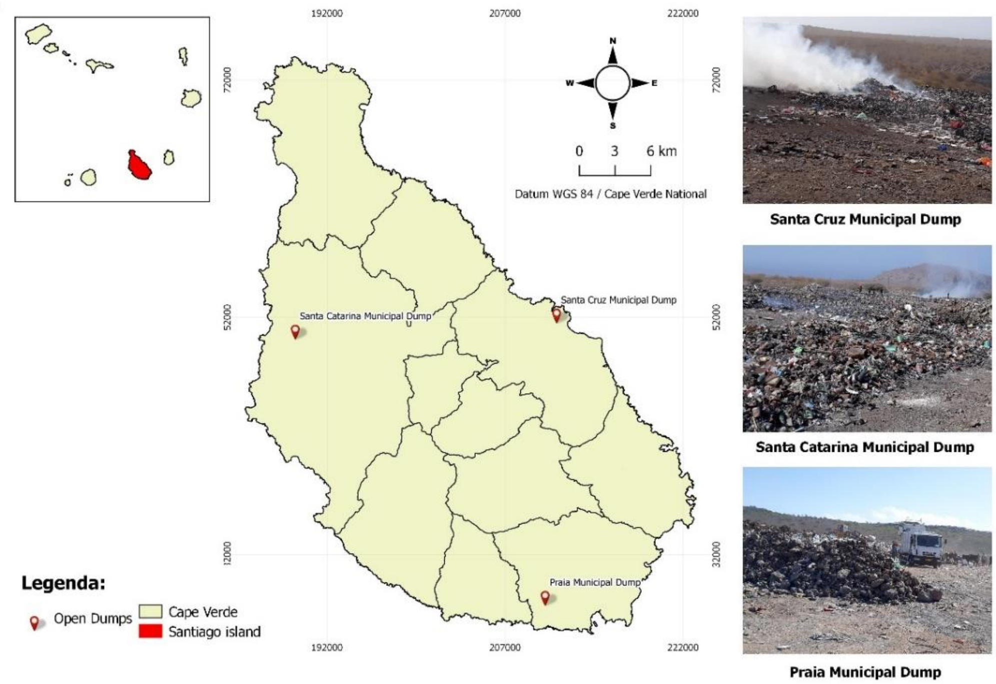

Figure 2. Map of Santiago Island and illustration of dumps situations.

diagnosed dump. The field questionnaire is divided in two parts. In the first part, the area is categorized into one of four possible situations, according to Figure 4.. In the second part, there are sixty-two questions divided into six categories: 1) Characterization of the open dump; 2) Soil and groundwater; 3) Surface water; 4) Social environment; 5) Natural environment and landscapes; 6) Atmospheric (Gomes, 2019).

Beyond the points for each localization situation and for each question of the field questionnaire, the scoring system of the software takes into consideration the qualitative assessment to consider legal aspects and relevant characteristics of the area of the open dump. Altogether there are 3 recovery scenarios, 16 recovery techniques and 34 criteria for choosing the techniques. The tree remediation scenarios possible are: 1) confinement of the waste, 2) conversion to a sanitary landfill and 3) removal of the waste. The remediation techniques for these scenarios generally include cover techniques, direct removal or mining techniques, heat treatment, sanitary landfill installation, area control, groundwater control, collection, treatment of leachate and treatment of gases (Gomes, 2019).

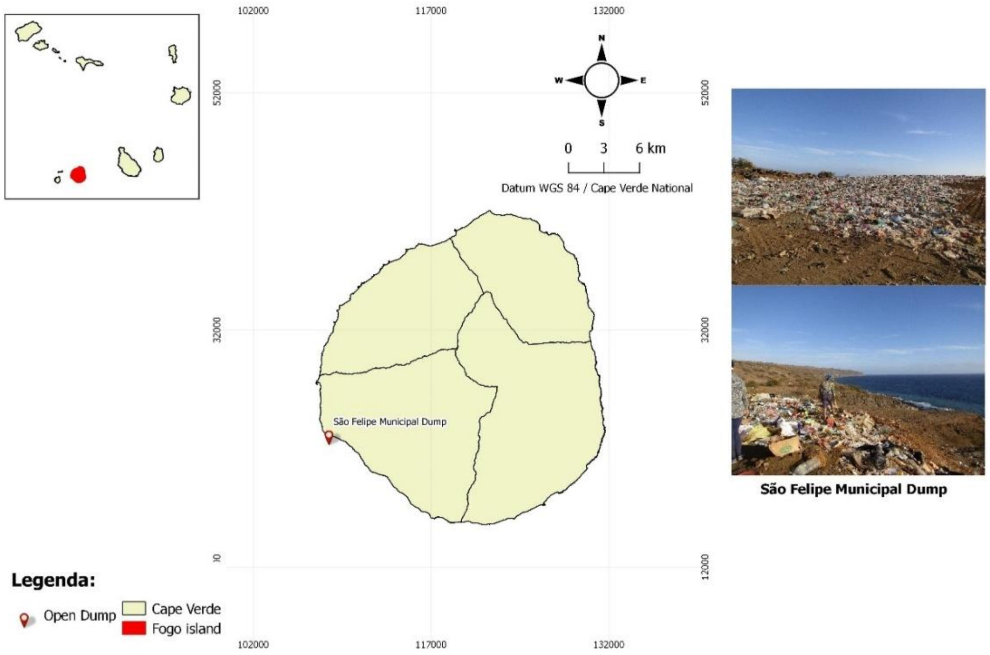

Figure 3. Map of Fogo Island and illustration of dump situation.

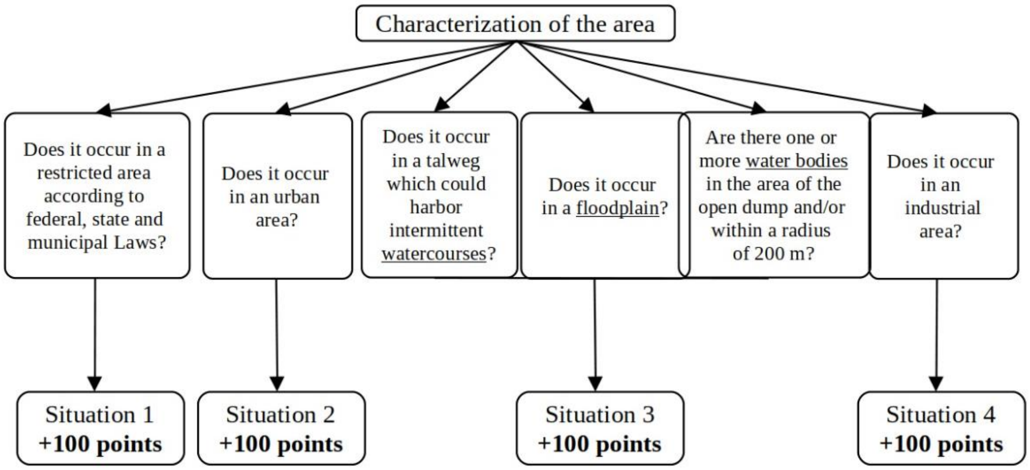

Figure 4. Possible situations of occurrence for an open dump.

The established impact levels by the DST can be seen in Table 1, as well as their scoring ranges. Besides the definition of impact level for the dumps, the Relix also allows to rank the remediation techniques and scenarios by score, which the highest is the most applicable. The score for a remediation technique is obtained according to the number of selection criteria selected in the time of completion of the field questionnaire. It varies from 0 to 5, where 0 indicates that none of these criteria was chosen. Similarly, the remediation scenario score is extracted from the number of selected techniques. After that, the DST awards 6 extra points based on qualitative criteria that consider the legal restriction on the use of the dumpsite, the possibility of the area being used as a landfill for a period exceeding 15 years and the time of operation of open dump (Gomes, 2019).

Visit to open dumps and application of field questionnaire

The visits to the dumps were in January and February 2018, where the field questionnaire was applied. The field questionnaire that comes with DST-Relix was completed by the authors according to visual observation of the open dumps and with the collaboration of the technical manager for the waste sector of each municipality that accompanied the visits. Information that could not be obtained only by the visits to the dumps, was obtained either from these technical managers. After collect the information about each open dump,

Table 1. Impact level established by the DST- ReLix.

Impact level	Score interval	Score range
Reduced	≥ 125 ≤ 160	35
Low	≥161 ≤ 266	105
Medium	≥267 ≤ 479	212
High	≥480 ≤ 832	352

Source: Gomes (2019).

Table 2. Scenario of Remediation and actions proposed for Cape Verde's diagnosed dumps.

Dump	Score /Impact level	Remediation scenario	Remediation actions
São Felipe MD	709/High	Removal of waste	Direct removal of waste to a sanitary landfill Control of the area Passive gas ventilation Groundwater control with extraction wells and subsurface drains with degradable suspension walls or treatment walls
Santa Cruz MD	394/Medium	Confinement of waste	Control of the area Passive gas ventilation Groundwater control with extraction wells and subsurface drains with degradable suspension walls or treatment walls Improvement of existing coverage
Praia MD	379/Medium	Confinement of waste	Control of the area Passive gas ventilation Groundwater control with extraction wells and subsurface drains with degradable suspension walls or treatment walls Improvement of existing coverage
Santa Catarina MD	279/Medium	Removal of waste	Direct removal of waste to a sanitary landfill Control of the area Passive gas ventilation Groundwater control with extraction wells and subsurface drains with degradable suspension walls or treatment walls

Source: Authors.

they were analysed in the DST- Relix and then, the scenarios and remediation actions were proposed, ranked by scores, as mentioned before.

RESULTS

Dumps diagnoses

The diagnoses of dumps with de DST established the impact level of the dumps and proposed remediation sceneries. Table 2 shows the results which allow hierarchizing the dumps by its impact level and assessing the priorities for the remediations actions. The São Felipe Municipal Dump had the highest impact level which means that it is the major priority for the closure process and remediation actions. Its highest score is related to the identification of the four possible situations prosed by DST showed in Figure 4. (Situation 1, 2, 3 and 4). The categories that most contribute to this result are "Characterization of the open dump" (81 scores), "Soil and Groundwater" (65.5 scores) and "Social Environment" (60 scores) (Figure 5).

The Santa Cruz Municipal Dump is in an urban area (Situation 2). It had the major scores on Santiago Island, and it is the major priority for remediation actions on this island. The categories that most contribute to its medium level impact are "Characterization of the open dump"

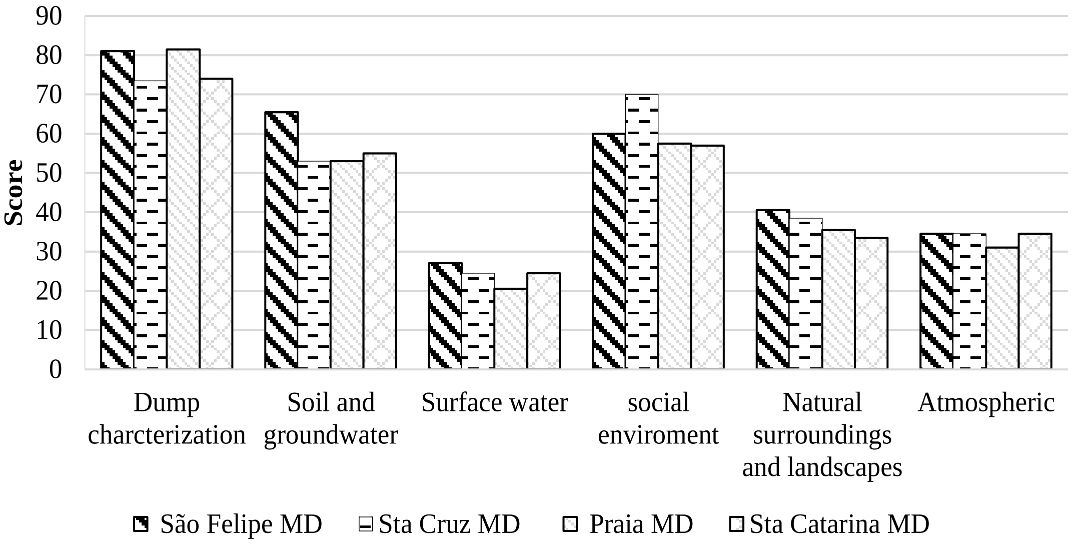

Figure 5. Open dump score by category obtained from DST- Relix.

(81.5 scores), "Social Environment" (57.5 scores) and "Soil and Groundwater" (53 scores) (Figure 5). Lastly, Santa Catarina Municipal Dump has the lowest impact level scores. None of the four possible situations proposed by DST was identified. The three main categories influenced in its medium impact level are "Characterization of the open dump" (74 scores), "Social Environment" (57 scores) and "Soil and Groundwater" (55 scores) (Figure 5).

The same DST was applied in six open dumps in Brazil by Gomes (2019). Five of them had medium impact with scores varying from 320 to 476 and only one had a high impact level with score 538. As obtain in this research, all the open dumps with medium impact had at most two situations identified. Those had high impact level had more than two situations identified. So, the number of situations identified on the field is important to the final score of the dump and its impact level.

Scenario and remediation techniques

All diagnosed open dumps demonstrated the need for remediation. For the São Felipe and Santa Catarina Municipal Dumps, the scenario proposed was "Removal of waste" which will be sent to sanitary landfills as proposed by Monteiro et al. (2001) as an ideal solution. The São Felipe dumps area is inappropriate to implement a landfill for over 15 years and it is located in a place with environmental restriction (near the sea). As recommended by FEAM (2010), to convert open dumps to sanitary landfills, the dimensions and characteristics of the terrain must allow its use for an additional period of 15 years which is not answered by these dumps. As the Fogo island does not have a sanitary landfill yet, it is necessary to implement it in order to receive the wastes from municipalities and after, a fraction of resulting material from open dumps remediation. On another hand, the Santa Catarina Dump does not have any environmental restriction but it does not meet the normative criteria for operating as a landfill for more than 15 years. As the Santa Catarina Dump has been operated for less than 30 years, there may still be a significant gas generation and waste leaching from the site (FNR, 2010; Williams, 2005; MMA, 2019), therefore, the removal of waste is the best option. In this case, the waste should be sent to the Intermunicipal Sanitary Landfill of Santiago island.

For Santa Cruz and Praia Municipal Dumps, the scenario proposed was "Confinement of waste" because both are in places with environmental restriction, they do not meet the normative criteria for operation as a landfill for more than 15 years and its operation exceed 30 years which means that the generation of gas and waste leaching is relatively low. The scenario proposed for these open dumps implicated in the conformation of the final surface of the embankment slopes, as recommended by Alberte et al. (2005), and the maximum isolation of the waste pile.

As showed in Table 2, for each dump it was proposed the remediation actions that best fit the area. The "Control of the area" was suggested for all the diagnosed dumps because it was found in all of them concerns about erosion process. This action is also necessary to avoid the irregular use and occupation of the dump's areas as there were pickers in all the diagnosed dumps. Therefore, it is necessary not only avoiding access to these areas but also to create mechanisms to insert these people in the waste formal market and give them more safety and protection at work as proposed by Okot-Okumu (2011). To reduce the risks of explosion due to gas accumulation in the waste pile, it was proposed the “Passive gas ventilation”. This choice is mainly due to the fact that quantities of gas emissions are low, so passive gas ventilation can be used to vent the gases into the atmosphere avoiding their accumulation. Besides the low emissions of gases, fire and explosion episodes have been reported in some of the dumps, that may have been caused by biogas accumulation or indiscriminate burning of waste in these dumps.

The other remediation action suggested for all the diagnosed dumps was the “Groundwater control with extraction wells and subsurface drains with degradable suspension walls or treatment walls”. This remediation action is used for groundwater contamination by waste leaching. Studies have shown that near the open dumps, the groundwater quality is worse (Ujile et al., 2012; Usman et al., 2017). Besides that, groundwater monitoring is necessary at all dumps containing a significant amount of wastes (Joseph et al., 2010). So, there is a need to monitor the groundwater quality and safeguard this import resource from Cape Verde.

“Improvement of existing coverage” was one of the suggested remediation actions for Santa Cruz and Praia Municipal Dumps because the country is located in arid climate regions with low rainfall, where waste is partially settled and where construction waste is deposited. The final soil cover (or cap) is applied to a completed disposal facility to act as a barrier in order to reduce de infiltration of water into disposal area, reduce gas migration, prevent burrowing animals from damaging the cover, prevent the emergence of insects/rodents from the compacted refuse, minimize the escape of odors and support vegetation (Joseph et al., 2010). For São Felipe and Santa Catarina Municipal Dumps this technology was not recommended because the proposed scenario was the removal of waste from the area and its transfer to a sanitary landfill. All the scenarios and remediation actions proposed aims to contain or mitigate the contamination in the site, promoting the improvement for future usage of the area.

The diagnose of the open dumps from Cape Verde with Relix was coherent with the diagnose expected by specialists as well as obtained by Gomes (2019) when applied the same DST in the diagnose of six open dumps in Brazil. The DST gave rapid information about the environmental conditions of the open dumps, helping in the decision making about the priorities in the closure and remediation processes. This work has shown that one of the major challenges in many African countries, such as Cape Verde, is the creation of technical means and infrastructure that can support MSW management. As shown by Ventura et al. (2013), improvements in the management of the MSW are necessary for Cape Verde´s municipalities. Thus, it is recommended the implementation of better waste disposal technologies such as sanitary landfills and encourages initiatives to reduce the amount of waste that is sent to final disposal sites. It is also important to avoid sending the organic fraction of the waste to sanitary landfill but to value them through composting or anaerobic digestion. To achieve that, a selective collection should be implemented concurrently with a strong environmental education that encourages waste segregation at the sources and encourages reduction, reuse and recycling of the waste.

Due to the lack of legislation in Cape Verde about contaminated areas as well as the standard procedures for the rehabilitation and recovering of the open dumps, it was used Brazilian’s standards, once the DST used came from that country. So, the legal and regulatory framework that guides the waste sector in Cape Verde should be improved to better manage the MSW in both public and private spheres. The establishment of mechanisms that can assess the quality of the services provided is also necessary, highlighting the need for continuous improvement the environmental conditions.

Conclusion

The ReLix proved to be an important DST, allowing the public manager to diagnose the dumps as well as to choose the priorities for the closure process of the dumps aiming for their subsequent recovery and adjustments. The speed and ease with which results are obtained are two of the major advantages of its usage for managing MSW contaminated areas. The higher score of São Felipe Municipal Dump shows that it is the priority for remediation processes.

As well as presented in this research, other dumps of Cape Verde can be diagnosed with this DST and give an important knowledge of impact level and remediation technologies that can be applied for their remediation process. In order to improve the diagnose, it is necessary more precise information about soil and groundwater contamination, damage to the population residing in the dump and/or surroundings, the health conditions of the population residing in the dump and/or surroundings, damages to animals, recent explosions occurrences and the possibility of gas accumulation and migration. In addition to the need for the aforementioned data, it is important to obtain information about: the amount of MSW arriving the dumps; soil drilling and groundwater analysis and determination of the piezometric level below the waste; tests for the determination of soil permeability; and estimation of leachate and biogas produced. This diagnosis only takes into consideration the environmental and social aspects of open dumps. So, we encourage the evaluation of the economic aspects of all the scenarios and remediation actions proposed in order to make the best decision for each open dump.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Impacts of climate change on sorghum production in North Eastern Ethiopia

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Climate change/variability is a global concern that is seriously affecting developing and least developed countries which rain-fed based agriculture is predominantly the basis for their livelihood and socio-economic system. Adverse impacts of climate change and variability, in most developing and least developed countries like Ethiopia, is growing in time and exert pressure on agricultural systems which changes the balance among the key determinants of crop growth and yield. As a result, the demand for investigating and understanding the expected negative impacts of climate change and variability on food production is increasing. Accordingly, this study tried to investigate impacts of climate change on sorghum production using projected future climate scenarios data. Climate change scenario data for 20 global climate models were downscaled from the fifth assessment report on coupled model inter-comparison project of intergovernmental panel on climate change. CERES-Sorghum model was calibrated and validated using soil, weather and crop management data conducted at Kobo agricultural experiment site. The result revealed that yield variation was observed across locations, climate models and time periods considered. Despite uncertainties, maximum yield reduction in sorghum is projected by the end of the 21st century when maximum insolation has reached 8.5 W/m^2. In general, the result indicated that, sorghum production in north eastern Ethiopia is expected to be affected negatively in the future. Therefore, this finding would give a preliminary information for policy and decision making process to enhance climate change adaptation.

Key words: Climate change, impact assessment, crop, models, climate, sorghum.

INTRODUCTION

Climate change/variability is a global concern that is seriously affecting developing and least developed countries which rain-fed based agriculture is predominantly the basis for their livelihood and socio-economic system (Hellmuth et al., 2007; Kotir, 2011; FAO, 2015; Zacharias et al., 2015). The adverse impacts of climate change and variability, in most developing and least developed countries like Ethiopia, is growing in time and exert pressure on agricultural systems which changes the balance among the key determinants of crop

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growth and yield (Aggarwal, 2009). Agriculture, in Ethiopia, is largely susceptible for climate variability and extremes, due to its high dependency nature of rainfed based system (Deressa, 2007; NMA, 2007; MoA, 2011). Climate change induced variations contribute to frequent drought, flooding and rising mean temperatures which seriously affect agricultural production over large areas of Ethiopia (Aragie, 2013).

Agriculture is the back bone of the entire economy of Ethiopia which currently contributes about 42% to the GDP, employs more than 85% of the total population, and contributes around 90% of the national export (NMA, 2007; Irish AID, 2018). Evidences show that whatever is happening in agriculture sector, the country's economy would be profoundly affected (Gebrehiwot and Veen, 2013; World Bank, 2016, 2019). Rainfall and temperature are the most important climatic factors that tend to affect production potential of the agricultural sector (Irish AID, 2018). The changing rainfall pattern in combination with the warming trends could make rain-fed agriculture more risky and aggravate food insecurity in Ethiopia. According to FAO (2010) report, production performance of agriculture in Ethiopia is highly linked with the rainfall performance of the cropping season in which wet season is associated with higher production and vice versa. The report by Aragie (2013) also indicated that uneven and erratic rainfall during the last four decades makes a clear divergence of Ethiopian economy from the rest of the world.

The results from most climate models also indicate projected high inter-annual rainfall variability in combination with warming will lead to recurrent droughts in Ethiopia, which negatively impacts crop production and alleviates the food security challenges (NMA, 2007; WFP, 2014; World Bank, 2016). Furthermore, heavy rains and floods are projected to increase, which causes production loss and nurturing stress.

In Ethiopia, most of the risk and impact assessments studies are more generalized and region wide rather than location specific and descriptive even if sensitivity is varied across sectors, geographic locations, time, socio-economic and environmental considerations (NMA, 2007). As a result, the information generated are uncertain to design appropriate adaptation strategies that reduce the adverse impacts of climate variability and extremes. In addition, limited capacity, to carry out analysis for advocacy and enhanced understanding of risks and impacts, is another constraint for climate change adaptation (NMA, 2007; Irish AID, 2018).

The northern parts of Ethiopia is highly characterized by low, erratic, uneven rainfall distribution and recurrent droughts. This region is seriously affected by adverse impacts of climate variability and extreme events which any variation in rainfall during the cropping season causes production loses (NMA, 2007; MoA, 2011; Irish AID, 2018). The well recognized recurrent droughts occurring in the region poses a serious threat to agricultural production and livelihood of the communities and aggravating the ongoing food shortage (FAO, 2010, 2015; Irish AID, 2018).

Nowadays, the demand of identifying production risks and designing appropriate contingency plan for possible adverse impacts of climate change and variability is increasing. This is to understand and identify cropping patterns (crops or varieties suitable for a given production environment) and management practices for optimum utilization of resources that enhance climate change adaptation (FAO, 2010). New thinking and advanced approaches are needed to precise agriculture decision that minimize production risks under a given environment and season.

The process of adaptation emphasizes understanding of the production environment, learning about risks, evaluating response options, creating the conditions that enable adaptation, mobilizing resources, implementing adaptations and revising choices with new learning (NMA, 2007; FAO, 2015). Since recent tools and scientific approaches have been used to predict and precise farming practices which are good risk management approach that reduced climate uncertainties. Process based cropping system models are a set of tools that have been used widely to answer complex questions related to crop production, economics and environmental impacts (Hoogenboom, 2000; Hoogenboom et al., 1992; Jones et al., 2003, 2010). Crop growth models integrate soils, weather, management, genetics, and pest effects in daily pattern that simulates growth, development and yields (Jones et al., 2003, 2010a and b; Hoogenboom et al., 2012). Among several crop growth models, the most widely used is a decision support system for agrotechnology transfer (DSSAT), which is designed to stimulate growth, development, and yield of a crop growing on a uniform area of land, as well as change in soil water, carbon, and nitrogen interactions that takes place over time (Hoogenboom, 2000; Jones et al., 2003; Hoogenboom et al., 2010).

Herewith, 20-global climate model outputs, from intergovernmental panel on climate change fifth assessment report of IPCC-AR5 and decision support system for agro-technology transfer (DSSATv4.6) were used. The objective of this study is to evaluate the response of selected sorghum varieties for future climate in north eastern region of Ethiopia.

Ethiopia is a center of origin and diversity for sorghum (*Sorghum bicolor* (L) Moench). The country contributed considerably a number of genetic resources for the global germplasm collections and genes. The crop is primarily grown as a food crop used for preparation different food types mainly leavened bread (locally known as *Injera*) and locally prepared alcoholic beverages (e.g. *tala* and *areke*) (EIAR, 2020).

Sorghum stands third in area coverage next to *tef* and maize and fourth in total production next to maize, teff and wheat (ATA, 2015; CSA, 2018). It covers around

16.79% of the total area allocated to grains and 16.89% of cereal production (CSA, 2018; EIAR, 2020). Sorghum is the major crop grown in dry lowland environment which accounts for more than 60% of the cultivated land. Productivity of sorghum is constrained by a number of biotic and abiotic factors which drought is the most abiotic factor in dry lowland region (ATA, 2015; EIAR, 2020).

MATERIALS AND METHODS

Description of study sites

The study was undertaken in north eastern parts of Ethiopia, one of the major sorghum production belts of the country. Two production districts, Sirinka and Kobo, were considered to undertake this study. Sirinka is situated in between 11°41' and 11°49' N latitude; and 39°07' and 39°42'E longitude with an elevation range of 1749 to 2033 m.a.s.l. Whereas Kobo is found in between 12°09' and 12°15' N latitude and 39.38° and 39.63°E longitude; which has an elevation of around 1468 m.a.s.l (Figure 1).

Climate of the study areas

Kobo has a semi-arid climate characteristic, which the mean annual temperature ranges from 18 to 27°C and a mean annual rainfall of 410 to 820 mm. Whereas, Sirinka has a tropical climate type in which mean annual rainfall ranges from 680 to 1200 mm. Regarding rainfall distribution, Kobo and Sirinka experience a bimodal rainfall pattern with little or unreliable rain from mid-February to end of April (locally known as *belg*) and more reliable and peak rain from June to September (locally known as *kiremt*) which more than 50% of the annual total rain recorded. In both districts, the mean monthly maximum temperature was recorded in June, first month of the main growing season; known as *Kiremt* (*JJAS*). June is the warmer month that a maximum day/night temperature reach its peak value in both locations. Figure 2 shows mean monthly rainfall and temperature distribution at Kobo and Sirinka districts.

Farming system

Crop dominating mixed (crop-livestock) subsistence farming system is practiced under the region (FAO, 2010; Assefa et al., 2016). Rain-fed based small scale farming system, employed under traditional farming technology, is a source of livelihood for the majority of the population. Low potential and high risks are major characteristic of the production system in the region (World Bank, 2004; Assefa et al., 2016,). Teff and sorghum are dominant crops grown in well-known region of sorghum diversity in Ethiopia (Assefa et al., 2016). Sorghum is an important food crop next to teff in the dryland region, including Kobo and Sirinka, for human diet and feed for animals (Assefa et al., 2016).

Data collection

Crop and management data

Commonly grown sorghum cultivars (*Teshale* and *Melkam*) were used as testing cultivars to evaluate production performances in the future under the changing climate. *Melkam* and *Teshale* are categorized under early and medium maturing groups, respectively. Growth, development and grain yield data for model calibration and validation were obtained from sorghum and millet improvement research program of Melkassa Agricultural Research Center (MARC). Teshale and Melkam sorghum varieties were released in 2002 and 2009 for moisture stress (dry lowland) areas.

Climate data

Long-term observed daily rainfall, maximum and minimum temperature data for Sirinka and Kobo districts were obtained from Ethiopian Institutes of Agricultural Research and National Meteorology Agency of Ethiopia. Historical climate data from 1985 to 2014 were used as a baseline data to generate future climate scenario and to simulate historical yield for comparison analysis. Solar radiation, one of the important data to run the cropping system model were estimated from latitude and temperature data using WeatherMan (Bristow and Campbell, 1984; Hoogenboom et al., 2010) software package embedded in DSSAT-CSM.

Future climate scenario data

The concept of Representative Concentration Pathways (RCP's), the recent approach on emission of greenhouse gasses and pollutants, were used to develop future climate scenario data for the study sites. Representative Concentration Pathway's (RCP's) are time and space dependent trajectories of greenhouse gas concentrations and pollutants resulting from human activities, including change in land use and industrialization (IPCC, 2014). Agricultural Model Inter-comparison and Improvement Project (AgMIP) climate scenario generation tool was used to downscale future climate scenario data for 20 global climate models (20-GCM's) for two RCP's (RCP4.5 and RCP8.5) and two time periods; 2050s (2040-2069) and 2080s (2070-2099) using delta method downscaling approach. The global climate models (GCM's) used for this study are displayed in Table 1 below. The projected future scenario data were applied to evaluate the future production performances of the two sorghum cultivars using DSSAT cropping system under the medium (4.5 W/m^2) and maximum (8.5 W/m^2) irradiance energy striking the earth.

Soil data

Soil physical properties like texture and chemical properties like pH, cation exchange capacity (CEC), organic carbon (OC), and total N were determined for the experiment site using Melkassa Agriculture Research Center soil laboratory. In addition, important soil properties such as bulk density, drained upper limit (DUL), drained lower limit (DLL), saturation (SAT), root growth factor (RGF) and saturated hydraulic conductivity (SKS) were estimated from soil texture using SBUILD software package embedded under Decision Support System for Agro-technology Transfer (DSSAT4.6). Soil physical and chemical properties for Kobo and Sirinka districts are presented in Tables 2 and 3 respectively.

DSSAT crop model

Decision Support System for Agro-Technology Transfer (DSSAT) is a generic cropping system model developed to simulate crop growth, development and yield of several crops grown under uniform area of land and a set of management conditions. It have been used for more than 25 years by researchers, educators, consultants, extension agents, growers, policy and decision makers over more than 100 countries worldwide (Jones et al., 2003).

Crop Environment Resource Synthesis (CERES) of sorghum model, which is embedded within DSSAT version 4.6 was used to simulate growth, development and yield as a function of the soil-

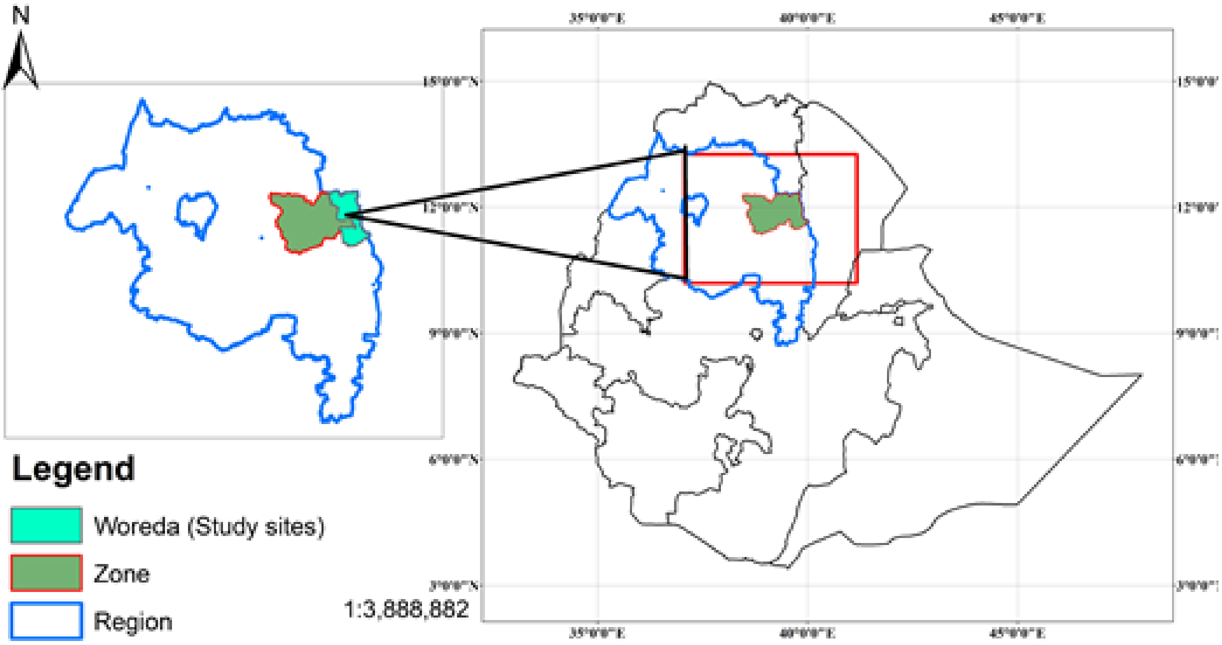

Figure 1. Map of study sites (Kobo and Sirinka).

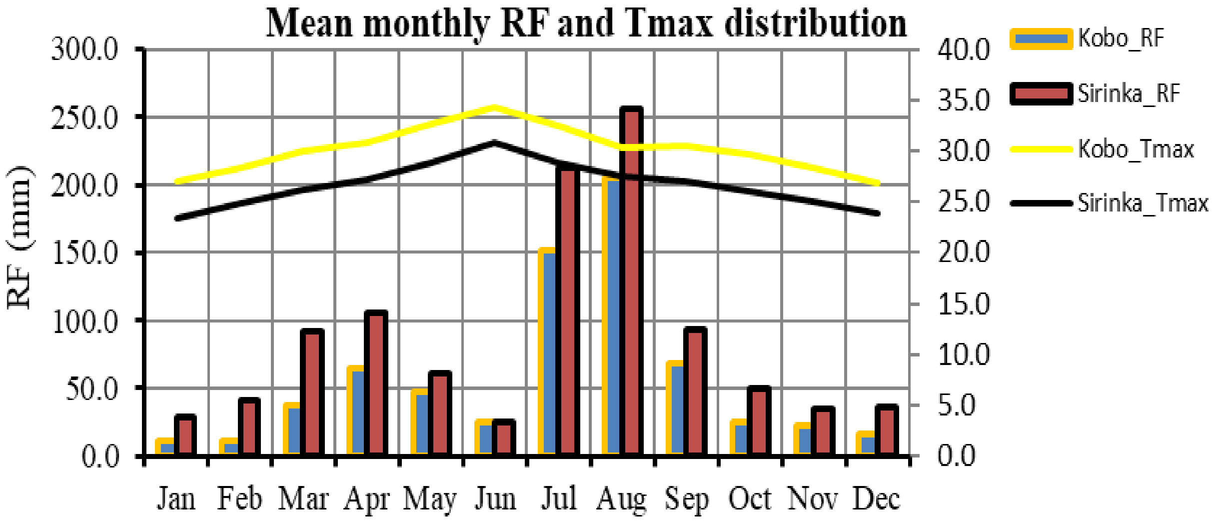

Figure 2. Mean monthly rainfall and temperature distribution at Sirinka and Kobo station (1985-2014).

plant-atmosphere dynamics, and it has been used for many applications ranging from on-farm and precision management to regional assessment of the impacts of climate variability and climate change (Hoogenboom et al., 2010; Jones et al., 2003). CERES-Sorghum model employs soil, crop management and daily meteorological data as input to simulate daily leaf area index (LAI) and vegetation status parameters, biomass production and final yield. The model calculates phasic and morphological development of crops using temperature, day length and genetic characteristics (Ritchie, 2016). The water and nitrogen balance sub models, on the other hand, provide feedback that influences developmental and growth processes (Ritchie, 2016).

Model calibration and evaluation

Decision Support System for Agro-technology Transfer (DSSAT) cropping system models need genetic coefficients to simulate growth, development and yield of specific genotypes, taking into account weather, soil water and nitrogen dynamics in soil and crop in mechanistic manner (Hunt et al., 1993; Choudhury et al., 2018). Genotype coefficient may be determined in controlled environments or under field conditions (Hunt et al., 1993), Under this study, cultivar specific genetic coefficients for two sorghum cultivars, *Teshale* and *Melkam*, were estimated using GENCAL software packages embedded in DSSAT cropping system model. In

Table 1. Coupled Model Inter-comparison Project phase 5 (CMIP5) general circulation models (GCM's) used for this study.

No.	Modelling center	Country	Model	Lat.	Lon.	Res.
1	Commonwealth Scientific and Industrial Research Organization/Bureau of Meteorology (CSIRO-BOM)	Australia	ACCESS1.0	1.87	1.25	MR
2	Beijing Climate Centre, China Meteorological Administration	China	BCC-SM1.1	2.81	2.79	LR
3	College of Global Change and Earth System Science, Beijing Normal University	China	BNU-ESM	2.81	2.79	LR
4	Community Climate System Model, Climate and Global Dynamics Division/ National Centre for Atmospheric Research	USA	CCSM4	-	-	-
5	Community Earth System Model, Climate and Global Dynamics Division/ National Centre for Atmospheric Research	USA	CESM1-BGC	-	-	-
6	Commonwealth Scientific and Industrial Research organization/Queensland Climate Change Centre of Excellence (QCCCE)	Australia	CSIRO-Mk3.6	1.87	1.87	MR
	Canadian Centre for Climate Modelling and Analysis	Canada	CanESM2	2.81	2.79	LR
7	Geophysical Fluid Dynamics Laboratory	US-NJ	GFDL-SM2G 2	2.5	2.0	LR
		US-NJ	GFDL-ESM2M	2.5	2.0	LR
8	Met Office Hadley Centre	UK-Exeter	HadGEM2-CC	1.87	1.25	MR
		UK-Exeter	HadGEM2-ES	1.75	1.25	MR
9	Institute Pierre-Simon Laplace	France	IPSL-CM5A-LR	3.75	1.89	LR
			IPSL-CM5A-MR	2.50	1.26	LR
10	Atmosphere and Ocean Research Institute (University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology	Japan	MIROC-ESM	2.81	2.79	LR
		Japan	MIROC5	1.40	1.40	HR
11	Max Planck Institute for Meteorology (MPI-M)	Germany	MPI-ESM-	1.87	1.87	LR
		Germany	MPI-ESM-MR	1.87	1.87	MR
12	Meteorological Research Institute	Japan	MRI-GCM3-	1.12	1.12	HR
13	Norwegian Climate Centre	Norway	Nor-ESM1-M	2.50	1.89	LR
14	Institute for Numerical Mathematics	Russia	INM-CM4	2.0	1.5	MR

GENCALC, coefficients for genotypes are estimated iteratively by comparing the predicted model outputs (days to anthesis, days to maturity and grain yield) to the actual observed data and altering the coefficients until the predicted and observed values approximately matched (Hunt et al., 1993). The coefficients related to phonological aspects such as flowering and maturity date were determined first and then growth related to such yield related aspect was determined (Jones et al., 2003; Hunt et al., 1993). The soil, weather and crop management data obtained during 2007 and 2008 growing season were used to adjust model parameters for Melkam; and data obtained during 2005, 2007 and 2008 cropping season for Teshale undertaken at Kobo agricultural research site were used to adjust the required model parameters.

Once the model is well adjusted, the performance is evaluated using independent data sets which was not used during model calibration process (Jones et al., 2003; Hunt et al., 1993; Romero et al., 2012). The field experiment data for model evaluation were also undertaken from the same field during 2010, 2011 and 2013 main growing season. Indicator statistics like coefficient of determination (R^2), root mean square error (RMSE), normalized root mean square error (RMSEn) and index of agreement were used to evaluate the performance or to quantify the errors of the adjusted model. The Root Mean Square Error (RMSE) which measures the agreement between

Table 2. Soil physical and chemical properties of Kobo experimental site.

Depth	Particle size analysis (%)				PH	EC	Total N	OC	CEC
cm	% Sand	% Silt	% Clay	Class	1:2.5H$_2$O	ds/m	%	%	meq/100 g soil
0-15	21	49	30	Clay loam	7.6	2.04	0.07	0.90	51.31
15-30	31	59	10	Silt loam	7.76	0.38	0.09	1.03	53.45
30-45	33	59	8	Silt loam	7.56	0.69	0.07	1.23	56.92
45-60	27	65	8	Silt loam	7.61	1.21	0.09	1.10	50.08
60-75	25	65	10	Silt loam	7.69	0.16	0.07	1.15	53.35
75-90	23	57	20	Silt loam	7.8	0.10	0.12	1.65	56.00
90-105	21	59	20	Silt loam	7.98	0.87	0.15	1.22	57.43

Source: Melkassa Agricultural Research Center (2012).

Table 3. Soil physical and chemical properties at Sirinka.

Layer (cm)	SA (%)	CL (%)	SI (%)	p^H in H$_2$O	LL cm^3/cm	DUL c^3/cm^3	OC (%)	N (%)	SAT cm^3/cm^3	RGF (0-1)	SKS Cm/h	BDM (g/cm^3)
30	12.5	55.0	32.5	5.9	0.335	0.494	1.23	0.16	0.540	1.0	0.06	1.24
60	15.0	52.5	32.5	6.3	0.308	0.454	0.72	0.18	0.498	0.407	0.06	1.29
105	27.5	37.5	35.0	*6.4*	0.225	0.359	0.42	0.13	0.459	0.192	0.23	1.36
175	22.5	35.0	42.5	6.4	0.209	0.354	0.30	0.08	0.478	0.061	0.23	1.31
200	25.0	32.0	43.0	6.5	0.194	0.337	0.28	0.08	0.471	0.024	0.23	1.33

OC- Percentage organic carbon, CL- percentage clay, SI- percentage silt, N-percentage total nitrogen, SA- percentage sand, DUL- drained upper limit, LL- lower limit, SAT- saturation, RGF- root growth factor, SKS- saturated hydraulic conduction, BDM- bulk density.
Source: Melkassa Agricultural Research Center (2012).

measured and simulated mean for days to flowering, days to maturity and grain yield (kg/ha) is computed using the following formula. The value of RMSE approaching to zero indicates the goodness of fit between the simulated and observed values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$$

where n= number of observations, P$_i$= predicted value for the ith measurement and O$_i$= observed value for the ith measurement.

The normalized root mean square error (RMSEn) is also used to evaluate the performance of the model and computed as follows:

$$RMSEn = \frac{RMSE \times 100}{\overline{O}}$$

where RMSE= root mean square error and $\overline{O}$ = overall mean of observed values.

RMSEn (%) gives a measure of the relative difference of simulated versus observed data. The simulation is considered excellent if the RMSEn is less than 10%, good if it is greater than 10% and less than 20%, fair if RMSEn is greater than 20% and less than 30%, and poor if the RMSEn is greater than 30% (Aronica et al., 2002).

In addition, d-statistic was also employed. It has been reported that this index provides better model performance indications that encompasses bias and variability than R^2 (Willmott et al., 1982). The closer the index value is to unity, the better the agreement between the two variables that are being compared and vice versa (Willmott et al., 1982). The d-statistic was computed as:

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(|P'_i| + |O'_i|\right)^2}\right], \ 0<d<1$$

where n: number of observations, P$_i$= predicted value for the ith measurement, O$_i$= observed value for the ith measurement, $\overline{O}$ = the overall mean of observed values, P'$_i$ = P$_i$- $\overline{O}$; O'$_i$ = O$_i$- $\overline{O}$.

Moreover, linear regression was applied between simulations and observations to evaluate model performance and correlation coefficient (R^2) for each simulation (Loague and Green, 1991).

Impact assessment

Finally, to quantify the impacts of projected future climate on sorghum production in parts of the great rift valley of Ethiopia, historical yield was simulated using the calibrated genetic coefficients under the historical climate (1985-2014) data. The following equation was used to estimate the yield difference in percent in between simulated and historical yield.

$$\Delta yield = \frac{Y_{predicted} - Y_{base}}{Y_{base}} x100$$

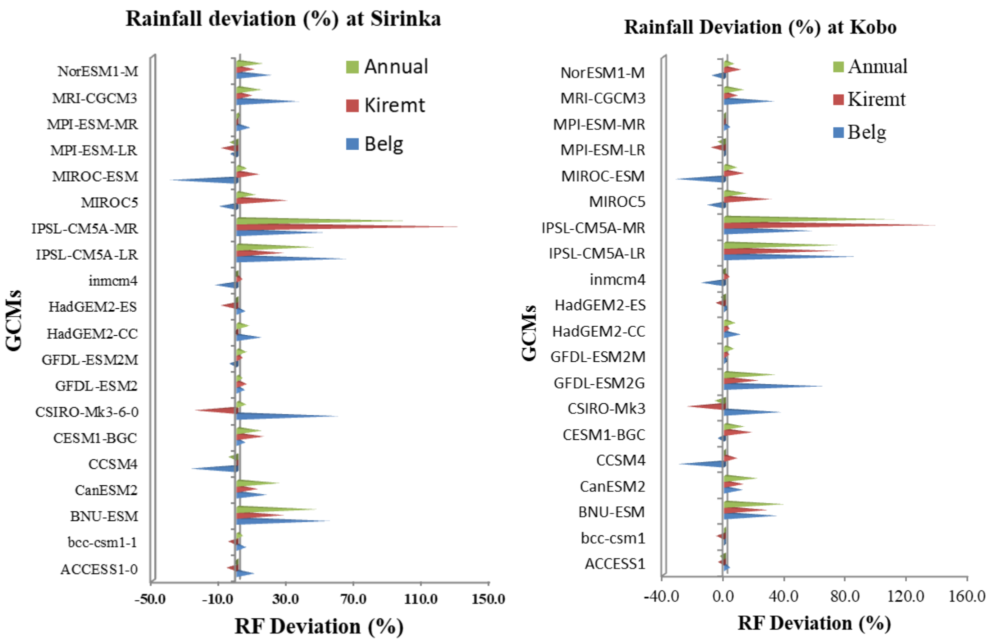

Figure 3. Projected changes in rainfall (percent deviation from historic rainfall) in mid-century (2040-2069) for Sirinka and Kobo stations.

where $Y_{predicted}$ is predicted yield (kg ha^{-1}), Y_{base} is yield of the base period (kg ha^{-1}) and Δ_{yield} is the yield difference (%).

RESULTS AND DISCUSSION

Future climate of the study districts

According to the downscaled Atmosphere Ocean General Circulation Models (AOGCMs), the overall mean model projected climate change scenarios showed a general increase in temperature and precipitation over the two selected stations in mid and end-century. Nonetheless, the projected change in seasonal and annual rainfall varied across GCMs, RCPs and time periods considered. The projected change in rainfall is highly uncertain that models are inconsistence in rainfall projections. Given that, the BNU-ESM, CanESM2, CESM1-BGC, CSIRO-Mk3-6-0, GFDL-ESM2, GFDL-ESM2M, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5, MIROC-ESM, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M climate models showed a positive deviation in JJAS (Kiremt) rainfall, whereas the JJAS rainfall under ACCESS1-0, CSIRO-Mk3-6-0, HadGEM2-ES and MPI-ESM-LR is projected to be declined at Sirinka and Kobo by mid (2040-2069) and the end (2070-2099) of the 21st century. Two climate models IPSL-CM5A-LR and IPSL-CM5A-MR projected a maximum increase in annual rainfall from 68.7 to 137.4 mm by the end of the century. On the other hand, the seasonal rainfall amount during Belg is projected to be declined from 30 to 40% under MIROC-ESM model in both stations by 2050 and 2080s. Figure 3 shows a projected seasonal and annual rainfall deviation from 2040 to 2069 under 20-GCMs at Sirinka and Kobo districts.

In general, the mean model ensemble results showed that a general increase in seasonal and annual rainfall amount in Sirinka and Kobo districts relative to the 1985-2014 mean observed climate. The projected rainfall varied across emission scenarios, time periods and locations considered. Mean model projected seasonal and annual rainfall amount is shown in Figure 4. The result also revealed that, the deviation of annual and seasonal rainfall amount would be higher by 2080s. During the major growing season (June to September), amount of rainfall is expected to be increased by 18.1% (kobo) and 25.5% (Sirinka) by 2080s under RCP8.5.

The downscaled climate change scenarios concluded a consistent increase in projected maximum and minimum temperature in the study districts. The model based projected climate change scenarios showed a consistent warming trend during the short (MAM) and the main (JJAS) growing season. The day/night warming trend is projected to be higher during the short (MAM) season relative to comparison to the main (JJAS) cropping season in both districts by mid and end of the 21st century. The scenarios from the 20-GCMs furthermore indicated that, the day/night temperature at kobo would be higher compared to its counterpart (Sirinka) under RCP4.5 and RCP8.5 scenario assumptions. Besides that, the higher increase in seasonal and annual temperature is also anticipated by most of the models considered under this study, however, variation in magnitude is well-

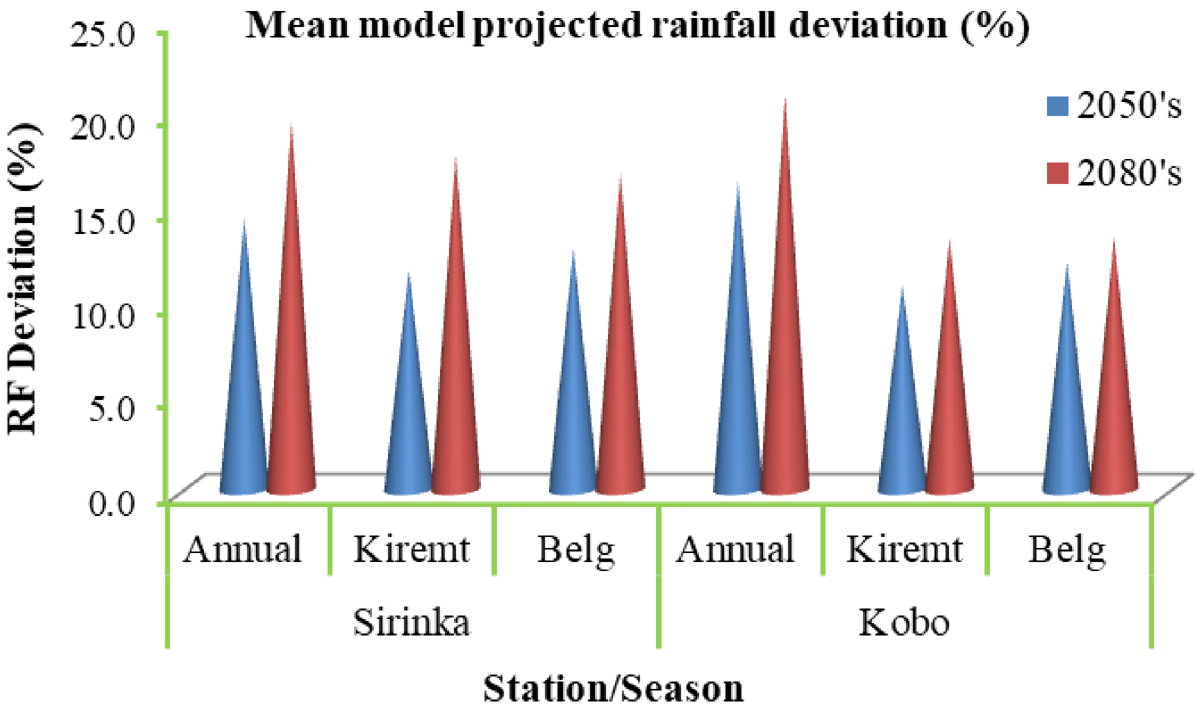

Figure 4. Mean model projected change in seasonal and annual rainfall (percent deviation from historic rainfall) amount in 2050 and 2080s at Sirinka and Kobo stations.

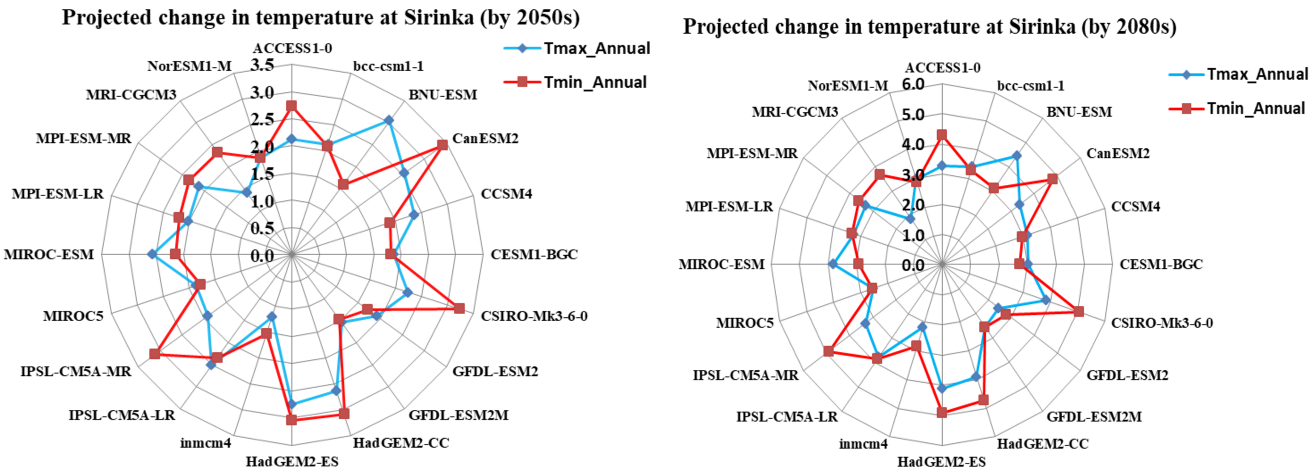

Figure 5. Projected annual maximum and minimum temperature changes of 20-AOGCMs (absolute change from observed Tmax and Tmin) in 2050 and 2080s at Sirinka.

thought-out across location and time periods. Figures 4 and 5 present the projected annual maximum and minimum temperature changes of 20-AOGCMs by 2050s under the respective stations is presented in Figure 5 and 6.

The model ensemble output of the 20-GCM's under the two RCP scenario assumption (RCP4.5 and RCP8.5) revealed a consistent day/night warming trend of the study sites, which the magnitude of change is varied depending on locations and time periods. As a result, annual day time warming is projected to be increased between 1.8 (RCP4.5) and 2.4°C (RCP8.4) by 2050s and 2.1 (RCP4.5) to 3.4°C (RCP8.5) by 2080s. Likewise, a probable increase of night time temperature from 1.8 to 2.8°C by 2050s and 2.2 to 4.8°C by 2080s is expected in the study area. Moreover, the model ensemble output

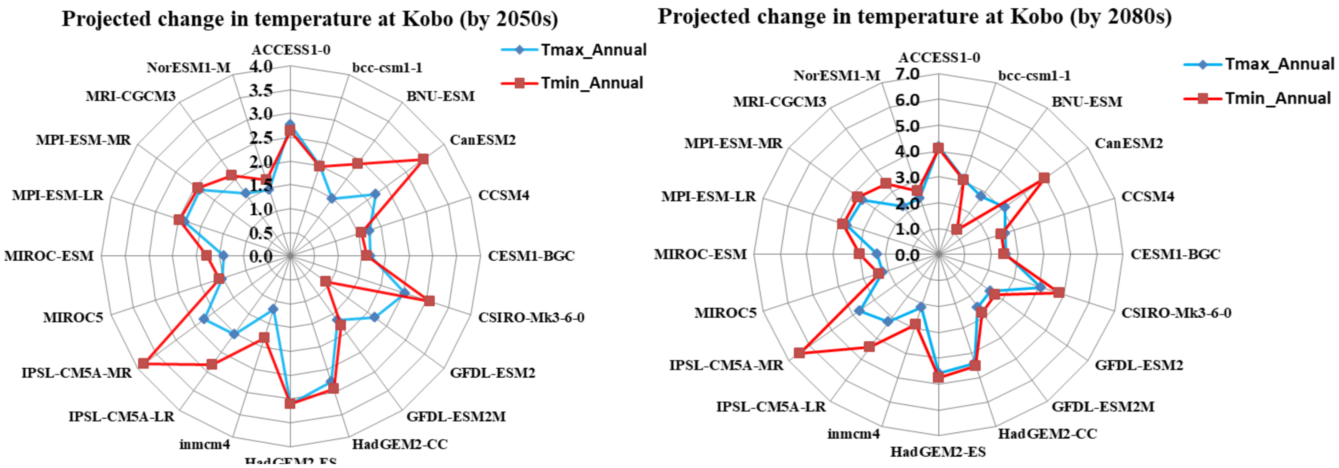

Figure 6. Projected annual maximum and minimum temperature changes of 20-AOGCMs (absolute change from observed Tmax and Tmin) in 2050 and 2080s at Kobo.

also emphasized that a higher increase in night temperature is projected by the end of 21th century. The mean observed and projected temperature changes at Kobo and Sirinka is shown in Table 5.

Model calibration

The model performance test for the estimated cultivar specific genotype coefficient is shown in Table 4. According to the root mean square error (RMSEn) statistics, CERES-sorghum is parameterized excellently for date of flowering and physiological maturity with less variation (RMSEn < 10%) expected between observed and simulated. Whereas, the model parameters for grain yield is moderately adjusted according to the RMSEn (RMSEn = 10 to 20%) statistics. The index of agreement (d-index) and coefficient of determination (R^2) statistics for model calibration indicated that parameterization done for the two sorghum cultivars is in a mode of making less uncertainty between the simulated and the observed values. Performance evaluation statistics during model parameterization is shown in Table 6.

Model validation

The model performance evaluation statistics and graphs for adjusted cultivars of the two sorghum cultivars are shown in Table 7 and Figures 7 and 8. Based on the evaluation result, the adjusted model parameters explained the observed values used for model evaluation in acceptable range for both sorghum cultivars indicated that the model is well adjusted for further application. The root mean square and the index of agreement results for both varieties showed a good fit of agreement between the observed and simulated values for grain yield, days to flowering and days to maturity days shown in Table 7. Besides this, coefficient of determination values for days to flowering and days to maturity also indicated that the model is well parameterized during calibration to simulate the observed values during validation test. In general the performance evaluation statistics indicated that the adjusted model parameters (genetic coefficients) explained well the observed values with less and tolerable differences for the two sorghum cultivars.

Hence, CERES-sorghum CSM for the two sorghum cultivars is parameterized well and showed that using the model for other application is valid.

As a result, the model is used to simulate historical yields for the two cultivars under a baseline climate (1985 to 2014) and projected climate for two time periods (2040 to 2069) and (2070 to 2099) by keeping the soil, cultivar, and management parameters constant.

Sorghum yield response for projected future climate

Future production response of the two sorghum cultivars for different GCMs at Sirinka and Kobo districts are shown in Figures 9 and 10. The result revealed that, the yield response for the two sorghum varieties is varied with the type of climate models, the time period and assumptions of scenarios considered. CanESM2, HadGEM2-ES, and IPSL-CM5A-MR climate models show a consistent decline in yield by 2050 and 2080s under the highest (RCP85) and a moderate (RCP45) emission scenario assumptions for both cultivars of sorghum. Under the highest emission scenario (RCP8.5) sorghum production is projected to decline in a range of 1 to 30% from the baseline yield. However, the projected yield, under BNU-ESM climate model, is expected to be increased from 7.6 to 18.3% at Sirinka and 1.5 to 14.3% at Kobo by 2050 and 2080s.

Table 4. Estimated Genetic Coefficients for two sorghum cultivars (*Teshale* and *Melkam*) using data obtained from Kobo agricultural research site, Northern Ethiopia.

Genetic parameter	Description	Initial coef.	Estimated coef.	
		CARGIL_1090	Teshale	Melkam
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8°C) during which the plant is not responsive to changes in photoperiod	460.0	250.1	311.7
P2O	Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P20, the rate of development is reduced	12.50	12.46	12.46
P2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P20.	90.0	101.7	154.4
P5	Thermal time (degree days above a base temperature of 8°C) from beginning of grain filling (3-4 days after flowering) to physiological maturity	600.0	492.8	480.8
G1	Scaler for relative leaf size	5.0	5.512	6.4
G2	Scaler for partitioning of assimilates to the panicle (head).	6.0	5.255	5.0

Table 5. Summary of observed and projected mean annual and seasonal (*Kiremt* and *Belg*) temperature at Kobo and Sirinka.

Station	Season	Historical observed (Mean)		Maximum temperature				Minimum temperature			
				2050s		2080s		20500's		2080s	
		TMAX	TMIN	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85
Sirinka	Annual	26.5	13.6	1.8	2.4	2.3	3.4	1.8	2.8	2.4	4.7
	Kiremt	28.5	15.6	1.8	2.3	2.2	3.4	1.8	2.7	2.3	4.6
	Belg	26.7	13.9	1.8	2.3	2.2	3.4	1.8	2.6	2.2	4.3
Kobo	Annual	30.1	14.9	1.8	2.3	2.1	4.0	1.7	2.7	2.4	4.7
	Kiremt	31.9	17.1	1.8	2.3	2.2	4.0	1.7	2.5	2.2	4.4
	Belg	30.4	15.2	1.9	2.4	2.3	4.2	1.8	2.8	2.6	4.8

Table 6. Evaluation results of CERES-sorghum for anthesis, physiological maturity and grain yield of Teshale and Melkam cultivars during model calibration under Kobo experimental site.

Crop type	Variety	Variable	Mean		R^2	RMSE	RMSEn	d-Stat.
			Observed	Simulated				
Sorghum	Teshale	Anthesis day	73	73	0.79	0.8	1.1	0.92
		Yield (kg/ha)	2809	2688	0.61	289.4	10.3	0.84
		Maturity day	111	110	0.92	1.4	1.2	0.85
	Melkam	Anthesis day	81	81	1.0	0.82	1.0	0.96
		Yield (kg/ha)	2504	2021	0.96	520.1	20.7	0.87
		Maturity day	110	109	0.97	1.3	1.2	0.92

The model result showed that the projected yield, for both cultivars of sorghum, is expected to be affected more negatively by the end of the century (2070-2099) in both locations under the medium and highest emission

Table 7. Model performance indicator statistical output for Model validation for Sorghum and wheat crop variety.

Crop type	Variety	Variable	Mean		r-Square	RMSE	d-Stat.
			Observed	Simulated			
Sorghum	Teshale	Anthesis day	73	73	0.79	0.82	0.92
		Yield (kg/ha)	2809	2688	0.62	289.4	0.85
		Maturity day	111	110	0.92	1.4	0.86
	Melkam	Anthesis day	81	81	1	0.82	0.95
		Yield (kg/ha)	2504	2021	0.96	520.1	0.87
		Maturity day	110	109	0.97	1.3	0.92

The regression line was near to the 1:1 line, indicating that the model was performed well under the test environment of calibration.

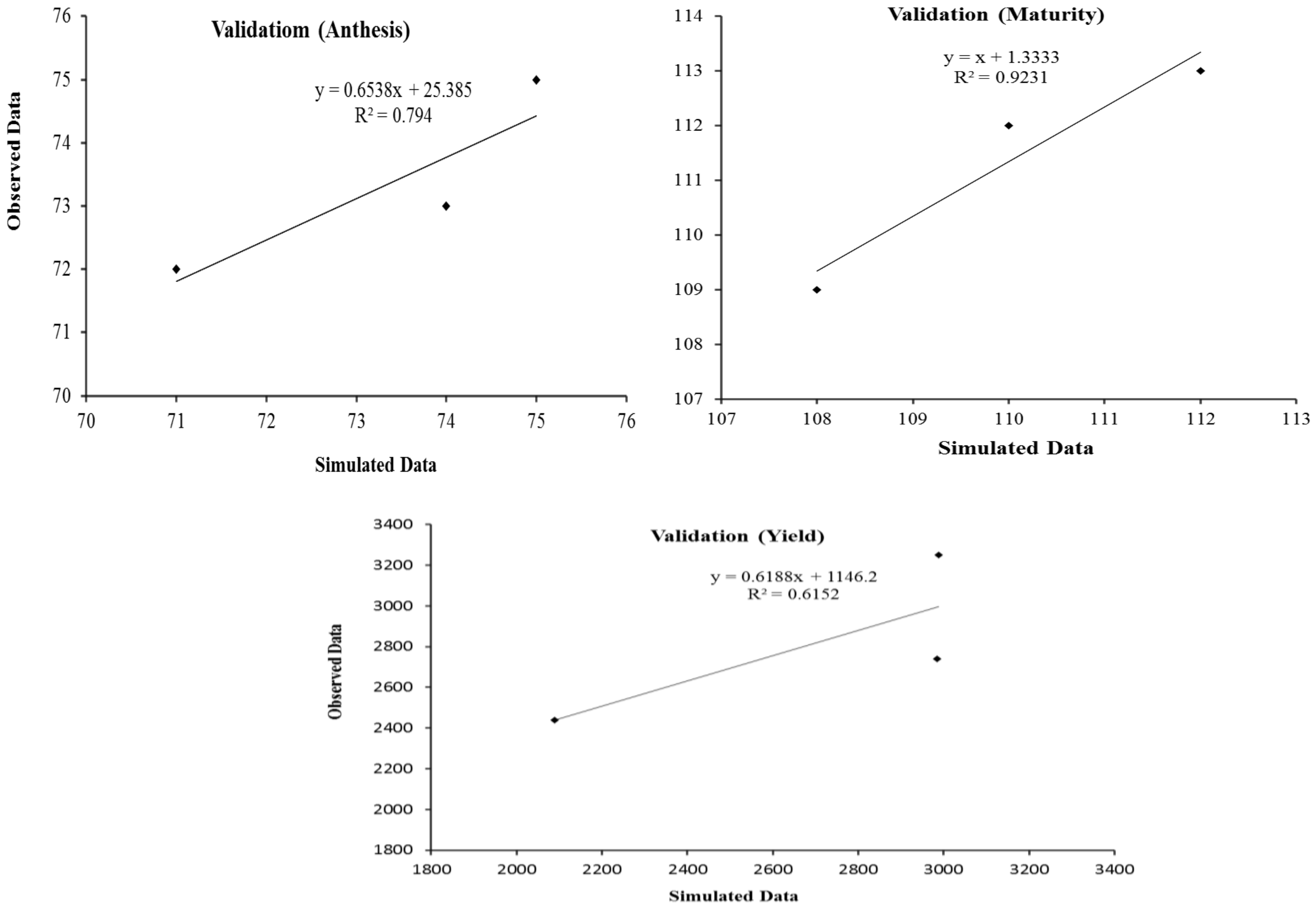

Figure 7. Relationship between simulated and observed values of anthesis, maturity and final grain yield for sorghum (Teshale) at Kobo.

scenarios than the mid-term (2040-2069) period.

Analysis result from the 20 GCMs revealed that future production of sorghum at Kobo and Sirinka is predicted to decline. Yield loss due to the projected impacts of temperature and precipitation is slightly higher for Melkam sorghum variety relative to Teshale. On average, sorghum yield is expected to decrease by 1.2 to 23% according to the assumptions of emission scenarios considered for this study by the mid and end of the 21st century under the study districts. Future production of sorghum in Kobo is more risky relative to Sirinka. In this regard, Teshale variety would be affected more due to

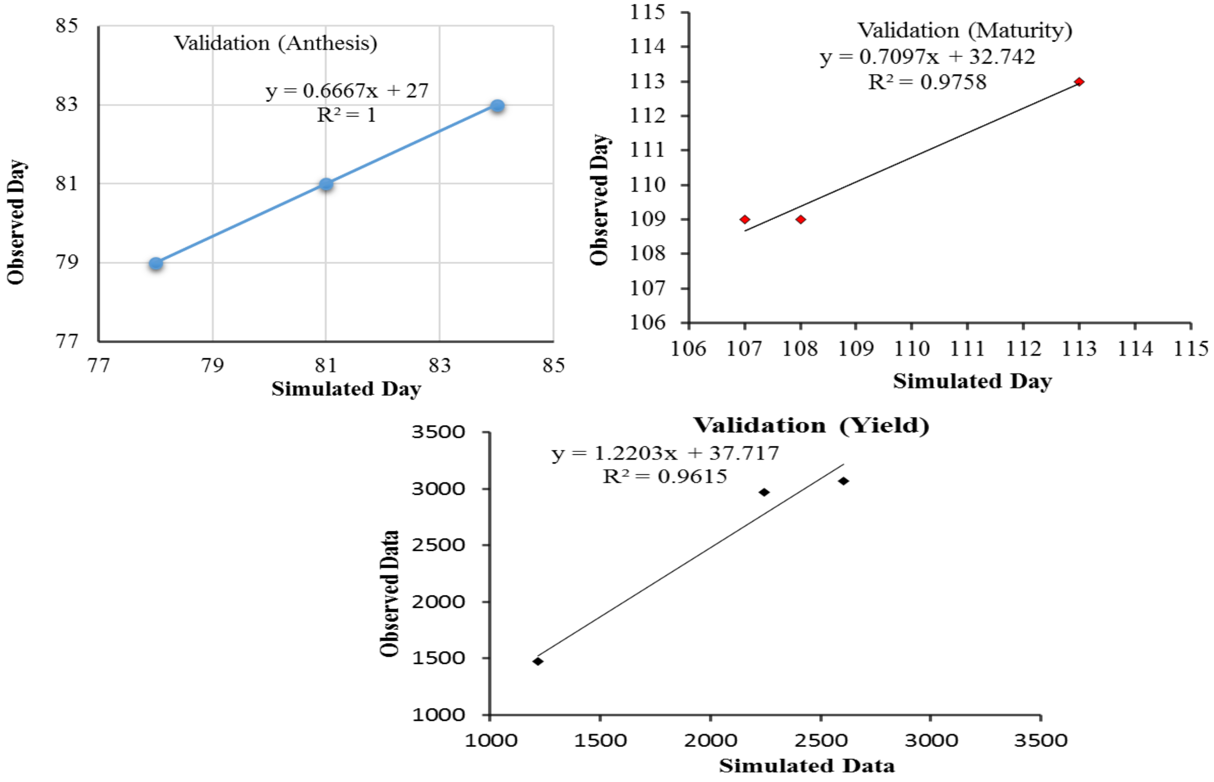

Figure 8. Relationship between simulated and observed values of anthesis, maturity and final grain yield for sorghum (Melkam) at Kobo.

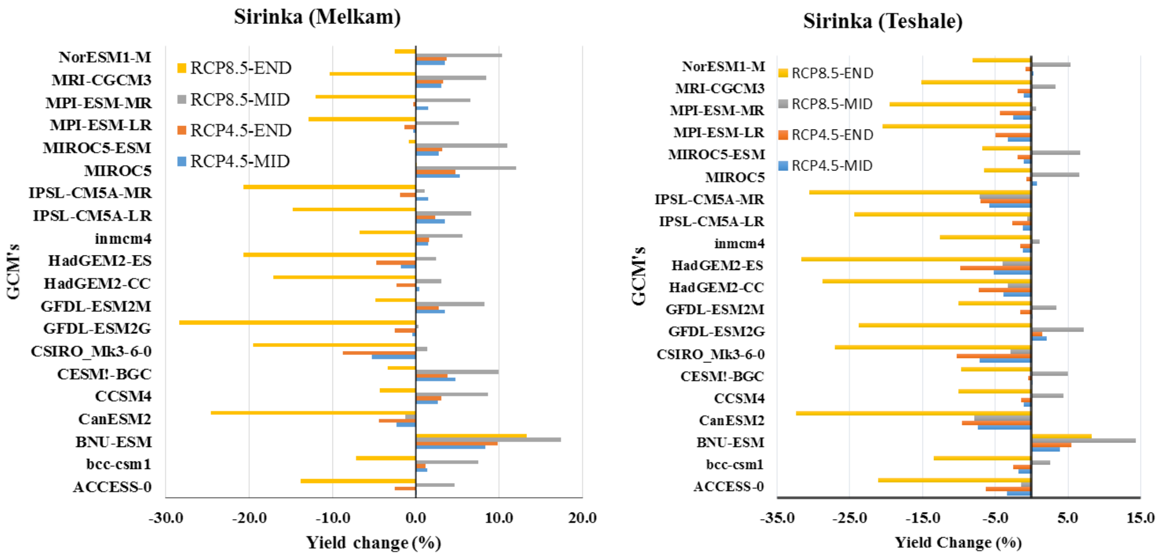

Figure 9. Yield response of two sorghum cultivars (percentage change in grain yield relative to the baseline yield) for projected future climate of 20 GCMs under RCP4.5 and RCP8.5 during mid-century (2040-2069) and end century (2070-2099) at Sirinka district.

future climate change than its counterpart (Melkam) did. Likewise, regardless of location, variety and emission scenarios, productivity of sorghum will decrease drastically towards the end of the century (2080s)

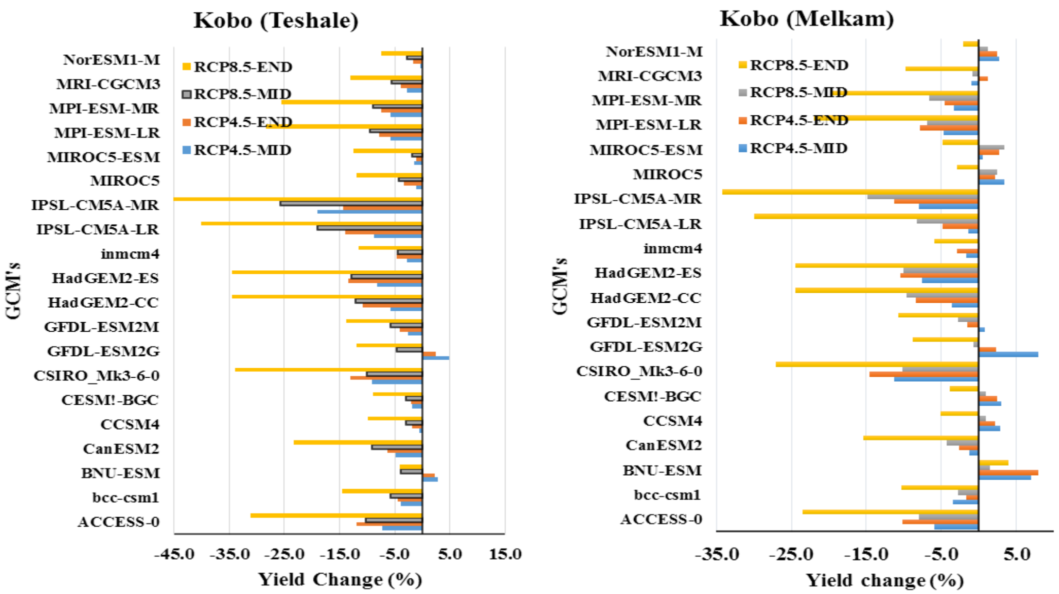

Figure 10. Yield response of two sorghum cultivars (percentage change in grain yield relative to the baseline yield) for projected future climate of 20 GCMs under RCP4.5 and RCP8.5 during mid-century (2040-2069) and end century (2070-2099) at Kobo district.

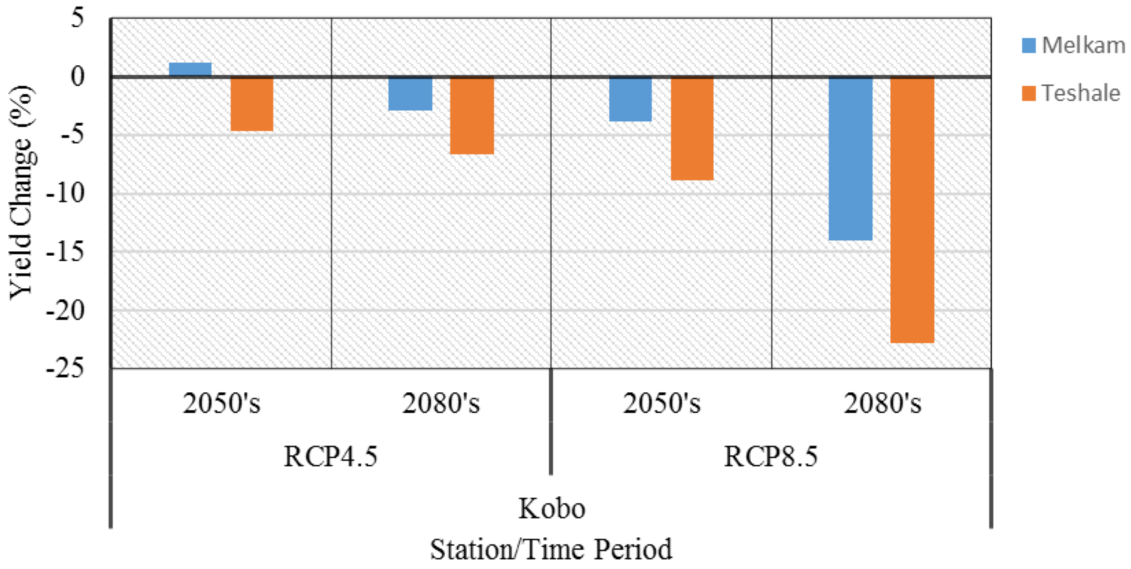

Figure 11. Yield change (%) for two sorghum varieties at Kobo by 2050s (2040-2069) and 2080’s (2070-2099) relative to the base period yield under medium and highest emission scenarios.

compared to mid-century (2050s). The simulated yield for two sorghum cultivars (Teshale and Melkam) by 2050 and 2080s averaged over 20 GCMs under two representative concentration pathways is shown in Figures 11 and 12.

According to the projected model result, the projected increase in temperature and precipitation causes according to model result, projected increase in temperature and precipitation causes a reduction in sorghum yield at Kobo and Sirinka. Moreover, the risk of future projected climate is very negatively influenced by the end of 21st century which the incoming solar radiation is reached to 8.5 W/m^2. However, the magnitude of risk varied depending on the varieties which Melkam is less risky relative to Teshale variety. The consistent increase in projected temperature and variable rainfall may

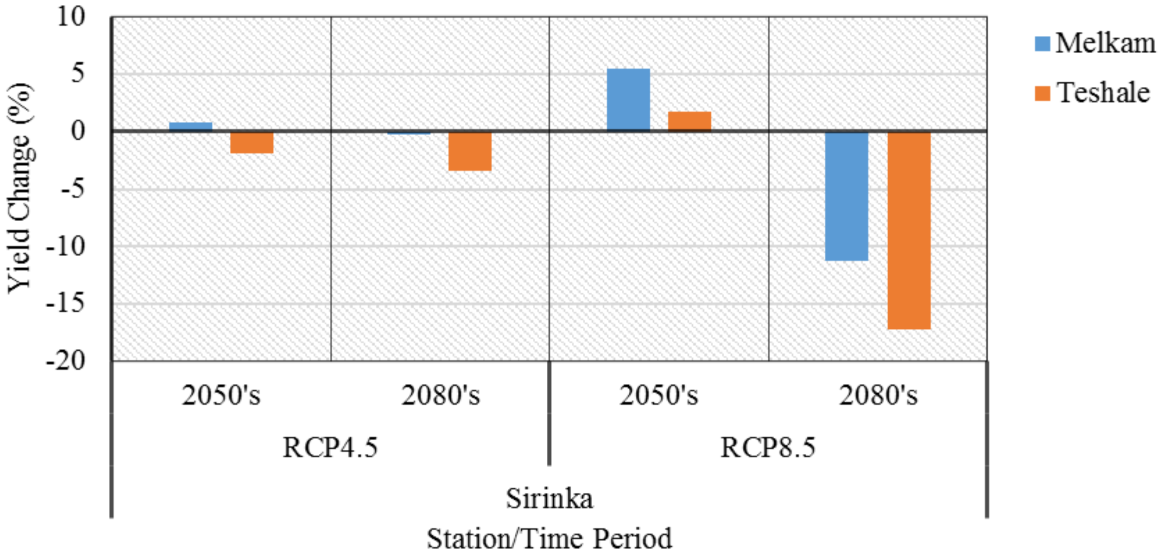

Figure 12. Yield change (%) for two sorghum varieties at Sirinka by 2050s (2040-2069) and 2080s (2070-2099) relative to the base period yield under medium and highest emission scenarios.

contributte to the predicted yield reduction through accelerating growth and development of plants which lead to less dry matter production (carbon assimilation and biomass accumulation) which highly contribute to a decline in yield (Rawson, 1992; Morison, 1996). On the other hand, the increase in temperature would increase the evapotranspiration demand of the atmosphere and hence create moisture deficit in the root zone, which in turn lead less synthesis of sugars for limited plant growth and development processes. According to Gupta (1975) high temperature is involved in a direct cause for death of plants, even adequate water is provided. Furthermore, beyond certain limit, the detrimental effects of high temperature on crop production depends on the crop, the stage of development, and the physiological processes involved in (Amon, 1975).

In general, the projected climate change in the study area will have a far-reaching effect on the livelihood of the community who is highly dependent on sorghum production for food, feed, fuel and construction materials. Therefore, it might be critical to adapt some *in situ* moisture conservation and utilization practices as well as envisaging sorghum breeding strategies that target the development of heat tolerant varieties to improve and sustain productivity of sorghum in the study area.

Conclusion

To investigate the projected impacts of climate change on future sorghum production, crop-climate simulation modeling approaches were used. For this study, Decision Support System for Agro-technology Transfer (DSSAT) were used to evaluate yield response of sorghum for the projected future climate scenarios. The crop simulation model were also calibrated and validated using soil, weather and crop management field data. To simulate future production performance of sorghum, site specific future climate scenarios were developed using delta method downscaling approach for mid and end time periods under two emission scenario assumptions (RCP4.5 and RCP8.5) for Kobo and Sirinka sites. The calibration and validation results for the two sorghum cultivars indicated that CERES-sorghum is reasonably adjusted to investigate future sorghum production in relation with projected future climate.

In general, the result revealed that future climate has a significant negative impact on sorghum yield, however, the magnitude of severity and yield variation differs depending on the type of varieties, time periods projected, emission scenarios considered and agro-ecology zone of the study area. The output from the model ensemble showed that sorghum production would be very risky by 2080 under the assumption of maximum emission of GHGs and incoming irradiance by the end of 21st century.

As a whole, unless technical and tactical measures are taken, future production of sorghum would be adversely affected by the consequences of climate change. Therefore, it is strongly recommended that more detail and further investigation should be undertaken to clearly explain and interpret the negative impacts of climate change on future food production and to explore alternative measures in order to enhance and sustain productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Comparative study of physicochemical parameters of wastewater discharged at the beaches of the Dakar Coast

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The region of Dakar is characterized by a high population density often leading to a problem of development of the sewage network not equipped with a treatment station. The ejection of these raw untreated waters on the Dakar coast continually causes pollution of bays, seawater and threatens life in the aquatic environment and human health. The objective of this study is to assess the physicochemical quality of the wastewater discharged at the beaches of Hann, Mbao and Soumbédioune by the UV-visible spectrophotometry method. The physicochemical parameters show that the temperature varies between 21.7 and 34.8°C and the pH ranged from 6.73 to 7.93. Results are European standards for the water quality. However, the conductivity ranged from 1569 to 86500 (µS/cm) and exceeds the European standard. In addition, water results obtained show that the wastewater derived from the Dakar coast is rich in nitrites (2.3 mg/L) and phosphates (65 mg/L) which clearly exceed the standards established by the legislation, WHO (2017) reference guideline. Thus, it becomes important to establish sewage treatment plants in the study areas to improve the state of the coastal environment of the Dakar coast.

Key words: Dakar Coast, wastewater, physicochemical parameters, metals.

INTRODUCTION

The coastal marine environment of Dakar suffers permanent pollution. Urban development, strong human pressure estimated at 3529300 inhabitants over an area of 547 km^2 and industrialization are the main causes of this pollution. This pollution is materialized by an ocean considered as a wastewater dump, bays receiving water from sewage disposal channels. These channels are not all connected to treatment plants (TP) (Corwin and Wagenet, 1996).

Despite urban development and industrialization, the Dakar region has only four TP (Camberéne, Niayes in Pikine, SHS of Guediawaye and Rufisque) (ONAS,

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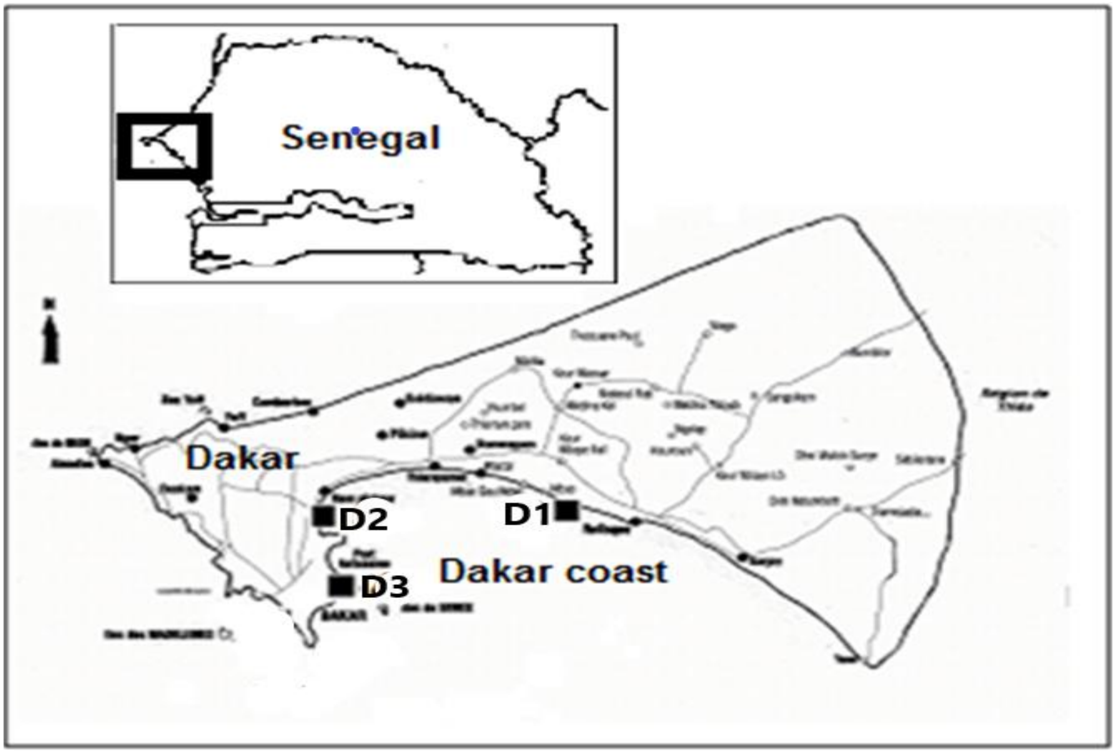

Figure 1. Location of sampling points in the Dakar coast (Senegal).

2017). These waters released into the sea are usually a mixture of pollutants harmful to the environment; aquatic organisms and human health are all threatened. In addition to the marine environment, groundwater can also be affected by sewage through percolation of effluents. These effluents can carry several pollutants (dissolved mineral salts, metals and organic matter) (IBGE, 2013). The mineral salts contained in these discharges may consist of nitrogenous elements such as nitrate ions, and phosphate **(**Germon, 2018). In addition to anthropogenic sources of nitrogen, the use of phosphorus in detergents and other chemicals increases the phosphate load in raw water. The metallurgical industry and the erosion of rocks can justify the presence of metals in these waters (Mama et al., 2011).

It is therefore important to control certain physicochemical parameters (pH, electrical conductivity (EC) and temperature) (Wali et al., 2018, 2019). The content of inorganic ions (nitrate, nitrite, phosphate) and metals in wastewater need to be regulated to prevent possible contamination. In this study, we investigated the evolution of these physicochemical parameters in wastewater from the beaches of Mbao, Hann and Soumbédioune of the Dakar coast which constitutes a significant economic region in Senegal because of its strong concentration of light and heavy industries located near the seaside. The physical and chemical characteristic of each collected wastewater sample has been identified. The test results were cross checked with WHO standards (WHO, 2017), it shows clearly there is a contamination and many samples exceed the permissible limit in the European legislation.

MATERIALS AND METHODS

Sampling points

The studied stations (Hann, Soumbédioune and Mbao) border the Atlantic Ocean (Figure 1). The Mbao Beach (D1) is home to the African Petroleum Refining Company (ASR) and a power station. Hann Bay (D2) is home to fishing activities, textile mills, fish processing plants and sewage from the eastern canal. Soumbédioune beach (D3) is a landing place for fish products and receives wastewater from the west channel (open channel IV) which passes a good part through the communes of Dakar. The Soumbédioune beach receives wastewater from the west channel (open channel IV) which crosses the most part of the Dakar's communes (Figure 1).

Sampling and preparation

The water samples were taken with 0.5 liter polyethylene bottles. These flasks were rinsed and then washed with wastewater. At each sampling, the vials are immersed in the discharge at a depth of 10 to 15 cm to prevent the ingress of air (Kelomè, 2018). Finally, the samples taken are stored in a cooler (4°C) and transported to the laboratory (Rodier et al., 2009).

Table 1. The minimum, maximum and average values of physicochemical parameters.

Parameter	Mbao		Hann		Soumbédioune	
	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD
T°	21.7-31.1	27.6 ± 4.3	25.9-31.2	29.4 ± 2.3	25.9-34.8	29.7 ± 3.6
pH	6.78-7.73	7.31 ± 0.42	6.73-7.21	6.98 ± 0.17	7.24-7.93	7.48 ± 0.27
EC	14510-86500	61902±28708.85	1715-3002	2097.2±561.65	1748-3872	2813.4±842.83
NO_2^-	0.11-2.3	1.276 ± 0.98	0.02-1.3	0.3825±0.61	0.03-0.11	0.097±0.060
NO_3^-	5-21	11.67±8.33	6-22	13 ± 6	12-24	18±8.49
Cu^{2+}	0-0.4	0.4 ±0.0	0-0.4	0.4±0.0	ND	ND
Cl_2	0.1-0.6	0.3 ± 0.24	0.7-1	0.87±0.21	0.1-1.2	0.53±0.49
Zn^{2+}	0.1-0.4	0.25± 0.13	0.1-0.5	0.275±0.17	0.1-0.3	0.2 ± 0.14
PO_4^{3-}	2.4-49	20.37± 25.06	21-63	39.8 ± 20.73	8.7-65	37.74± 25.09

Measurement of physicochemical and metallic parameters

The physical parameters (temperature, pH and conductivity) are measured in situ using a combined pH meter called HANNA instruments pH/conductivity HI. For the measurement of the pH, the apparatus was calibrated with buffer solutions pH = 7.01 then pH = 4.01. First, the pH mode is selected with the SET/HOLD button, after which the electrode is immersed in the sampled water. Finally, we wait a few seconds for the stability symbol at the top of the LCD disappears and read the pH value displayed. For the conductivity, the apparatus was calibrated by immersing the probe in the clean calibration solution HI 7031 (1413 µS/cm). EC mode is selected with the SET/HOLD button and then the same procedure as pH is used. Plastic beakers are often used to minimize electromagnetic interference. The temperature is displayed directly on the bottom left of the screen when measuring pH or conductivity. The chemical and metallic parameters were measured by UV-visible spectrophotometry using a PF-11 round-cell photometer.

Analysis of samples by photometry

The water used for the sample to be analyzed was without the standard solutions of the reagents. The sample to be analyzed was prepared by adding reagents in 5 mL of water samples taken. It was very important to respect the order and time prescribed in the analysis protocol to ensure the reaction of the reagents with the analyte.

Principle of the analysis

The device was turned on, the mode indicated (Visocolor, Visocolor Eco or nanocolor) in the protocol was chosen including the number of the filter to dose the element. The filter numbers were between 1 and 6 and each corresponds to a wavelength. The zero of the concentration was set before each determination to establish a zero reference for the measurement. To do this, the tube containing the white was placed in the measuring well and the button was presses to null zero. The photometer displayed zero and then indicates the sample was ready for analysis. The ready sample was placed in the measurement well and the M key was placed directly to obtain the concentration of the sample on the meter screen in mg/L.

RESULTS AND DISCUSSION

The temperature measured in wastewater from the Dakar coast varies between 21.7 and 34.8°C and the pH varies between 6.73 and 7.93, which is in line with European water standards (lack of local standard). However, wastewater from the Dakar Coast is highly mineralized due to its high conductivities (1569-86500 µS/cm) (Offodile, 2002). The levels of NO_3^- (0-24 mg/L), Cu^{2+} (0-0.4 mg/L), Cl^- (0-1.2 mg/L) and Zn^{2+} (0-0.5 mg / L) remain in compliance with the standards. However, the concentrations of NO_2^- (0-2.3 mg/L) and PO_4^{3-} (0-65 mg/L) phosphates exceed 0.1 mg/L (0.3 and 10 mg/L (Rocher et al., 2017).

The averages and extrema of the physicochemical parameters show that the raw water discharged at Hann and Soumbédioune have almost the same degree of contamination. The average electrical conductivity of Mbao is 20 times higher than that of Soumbédioune and 30 times higher than that of Hann. This difference may be due to the rise of waves in the channel which causes a fusion of the discharge and the seawater. Seawater has strongly influenced the conductivity, which makes the values obtained in Mbao comparable to those obtained by Diagne et al. (2017). Levels of nitrite ions are less important than concentrations of nitrate ions. The Mbao nitrite values are at least 2 times higher than those of the other sites (Table 1).

Figure 2 shows the average content of the physicochemical parameters for the three sites studied on the Dakar coast. The results obtained are particularly marked by high levels of undesirable anthropogenic elements such as nitrates (NO_3^-) and phosphates (PO_4^{3-}) which increase the electrical conductivity (Moses et al., 2017; Sureshkumar et al., 2016; Amadou et al., 2014).

However, the phosphate contents are higher than those of the nitrates in addition to that the highest value was found in the water samples coming from Soumbédioune. These high levels of phosphates can be due to domestic activities and industrial effluents very rich in phosphorus coming from the IV channel which crosses practically all the Dakar region. The use of cleansers and the phosphate's production in Senegal has consequences on the values obtained in Soumbédioune wastewater. The

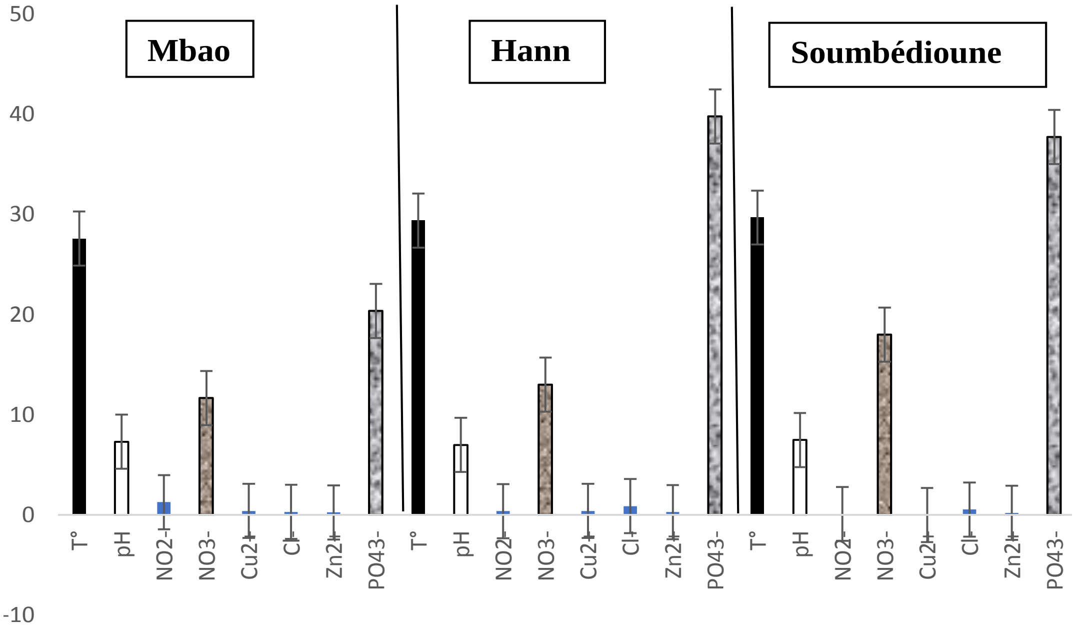

Figure 2. Average levels of physicochemical parameters for the three sites studied on the Dakar coast.

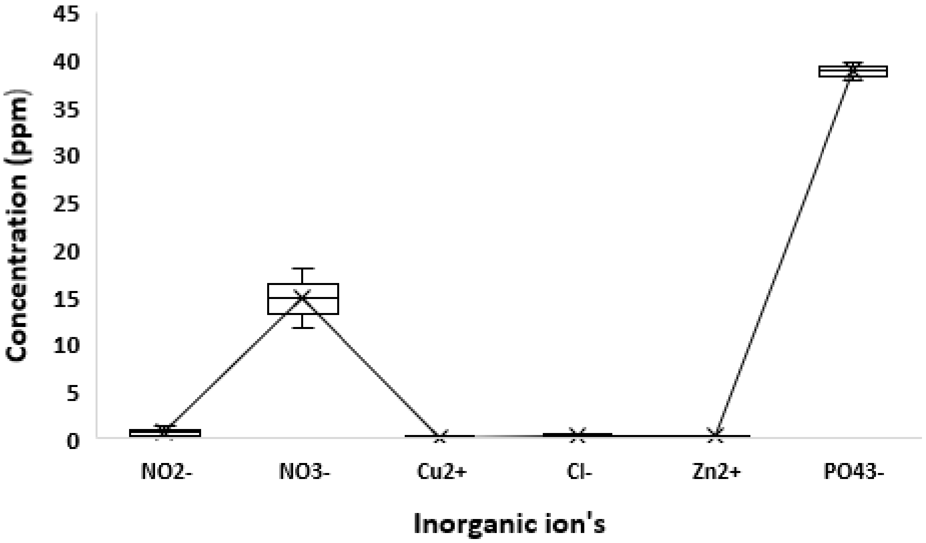

Figure 3. Average levels of inorganic ions for the six months following the three sites.

pooled average levels of the three sites show pollution dominated by inorganic ions (Figure 3). Phosphate ions are much more representative among these measured mineral salts. The contents of copper (Cu^{2+}), zinc ($Zn^{2+)}$ and total chlorine 2 are almost nil. The low metal content may be due to the condition of the channels. The latter filled with garbage and debris sees their masses of residual sludge increase and the sediments of these sludge are matrices with high metal retention capacity (Deschamps et al., 2006). So, this is a predominantly inorganic pollution that is generally non-biodegradable and possibly toxic. With phosphate, nitrate can lead to eutrophication of aquatic environments (Diallo et al., 2011; Ounoki and Achour, 2014).

A correlation analysis between temperature and pH found in all analyzed water samples from the Dakar region was established. A significant positive correlation between the two parameters was found (Figure 4). Good

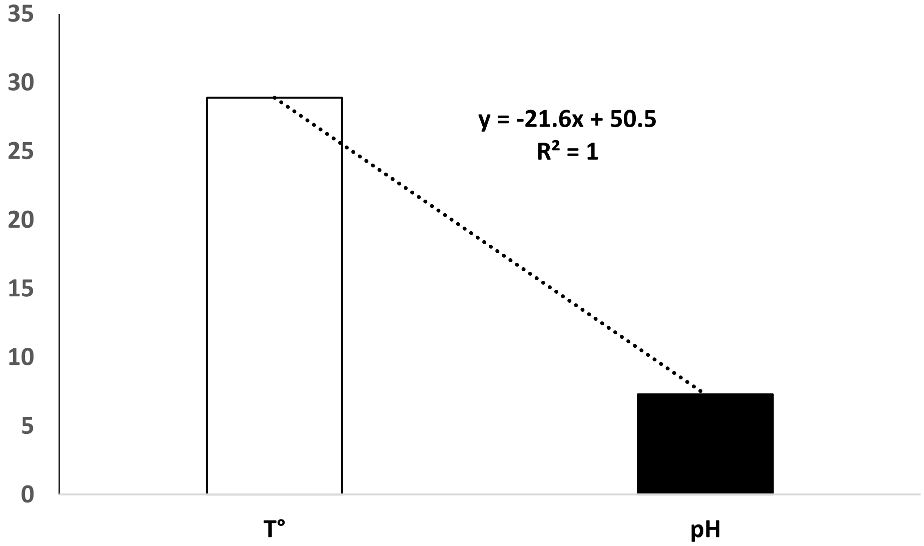

Figure 4. Correlation between temperature and pH in the different samples of water studied.

regression ($p < 0.0001$) was obtained with a satisfactory correlation coefficient ($r = 1$). The ordinate at the origin of the regression is negative (-21.6) and the slope is 50.5, which indicates that the value of the temperature measured in the wastewater is always higher than that of the pH. This shows a very great influence of the temperature on the measurement of the pH. For the measurement of pH, the temperature can intervene on the electrodes of the apparatus and on the liquid to be dosed. These two parameters are involved in the absorption and desorption at the water-sediment interface (Foli and Foli, 2012). We can see that the higher the temperature of the site, the higher its pH.

Conclusion

In this study the quality of discharged water released directly without any prior treatment at the beaches of Hann, Mbao and Soumbédioune located in the Dakar coast was examined for six months (August and December 2017). The measurement results revealed the presence of nitrate (NO_3^-), copper Cu^{2+} (0-0.4 mg/L), total chlorine ion 2 (Cl_2) and zinc (Zn^{2+}) which meet the standards of releases established by the scientific community. But nitrite ions (NO_2^-) and phosphate ions (PO_4^{3-}) exceed noticeably the standards established by legislation WHO (2017) reference guideline. Discharged waters from sites in the Dakar region have fairly high levels of nitrates and phosphates. These high levels of nutrients in the wastewater reflect the production and use of these nutrients in the Dakar region. Thus, it becomes important to establish sewage treatment plants in the study areas to improve the state of the coastal environment of the Dakar region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Spatiotemporal variation of irrigation water quality at Bochessa Watershed in Central Rift Valley of Ethiopia

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Water quality is a highly concerning issue as long as irrigation is planned to be used for crop production. Hence, groundwater at Bochessa catchment was assessed to determine the spatiotemporal variability of its quality and to evaluate its suitability for irrigation. For this study, 8 boreholes were selected and sampling was done during the dry and wet seasons between 2015 and 2017. Totally 48 water samples were collected from monitoring boreholes for laboratory analysis. Water samples were analyzed for 13 parameters including major cations and anions. The general linear model of two ways analysis of variance was used to determine the variability of parameters across the seasons and locations. The results revealed that about 46.0 and 16% of the parameters showed significant variation at $P<0.05$ across seasons and locations, respectively. This suggests temporal variation has a noticeable effect on the quality of groundwater. Almost all quality parameters showed a declining trend during the wet season. This also confirmed that how temporal variation influences groundwater quality in the area. SAR values in all locations were found within the limit and the water is suitable for irrigation. However, its values showed an increasing trend over time suggesting sodicity may challenge irrigation practices. Therefore, management practices such as; irrigation-fallowing, leaching, and choice of crops may help the farmers to maintain soil productivity.

Key words: Agriculture, groundwater, permissible limit, quality parameters, suitability.

INTRODUCTION

Food insecurity issues in developing countries including Ethiopia make irrigated agriculture an important area of interventions. FAO (2017) and CSA (2018) reports indicated that more than eight million peoples were faced with the food shortage problem annually in dry regions of Ethiopia. Major causes that attributed to this problem are climate variability and extreme weather conditions during cropping seasons (Husien et al., 2017; FAO, 2017; Hadera, 2018). For instance, 2015/2016 El Niño-induced drought caused crop failure mainly in dry parts of the country (FSIN, 2018). Continuous seasons of poor rainfall coupled with prolonged drought in such areas strained

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livelihoods, destroyed crops and pushed up food prices. Besides, more than 80 percent of populations live in rural areas where rain-fed agriculture is the dominant source of household income (Edossa et al., 2014; Abduselam, 2017; CSA, 2018). This situation makes the livelihood of the farming community extremely vulnerable to changes in weather conditions. Hence, the use of irrigated agriculture is a key factor to counter the problems created by fluctuating weather conditions.

Central Rift Valley Lakes Basin where the present study site located is well known for a shortage of rainfall but potentially suitable for irrigated agriculture (Legesse and Ayenew, 2006; Ayenew, 2007; Halcrow, 2008). Edossa et al. (2014) and Kefyalew (2016) reported that agricultural activities are considered as the main source of income for households in the area to sustain life. Despite this fact, agricultural practices are traditional and only practiced during the rainy seasons. The government and non-governmental organizations have given due attention to improving the situation by facilitating infrastructures for irrigation practices. Several authors argued that sustainable irrigated agriculture highly depends on an adequate supply of quality water (Edossa et al., 2014; Abay et al., 2016; Husien et al., 2017; Qureshi et al., 2018; Sankar et al., 2018). Ayers and Westcot (1985) suggested that early day's water quality has often been neglected because good quality water supplies have been plentiful and readily available. Pascual et al. (2014) and Mesfin (2015) reported that demand for irrigation showed an increasing trend over time. The supply of water for irrigation practices in the future requires sound planning to ensure the available quality water must be used productively.

The suitability of water for irrigation is determined by the type and total amount of salts present in the water (Bauder et al., 2011; Husien et al., 2017). The problems associated with irrigation water may vary both in kind and degree and can be modified by manipulating soil conditions, choosing proper crops and relying upon favorable climate seasons (Adamu, 2013; Mesfin, 2015; Husien et al., 2017). There is no prescribed limit on water quality; rather its suitability is determined by conditions that could affect the accumulation of water constituents. The water quality variation may arise from its sources or may develop over time through leachates from cultivated lands. Variations in irrigation water quality can also be affected by climate and surrounding land-use practices. For instance, the use of poor quality water for irrigation may aggravate salinity problems, but practicing fallowing for some time may help to reduce the severity. Thus, monitoring the quality of available water source is very important in assuring its supply for future needs.

Water quality variability occurs not only across locations but also over time. Hence, the evaluation of its quality across time and location is critical to use the available water resources in an efficient manner. Abel et al. (2011), Reddy (2013) and Islam et al. (2016) reported that the variability of water quality can pose management challenges in irrigated fields. Thus gathering reliable information on trends of water quality is essential to design appropriate farm management practices. Tessema et al. (2014), Abay et al. (2016), Islam et al. (2016), Nag and Suchetana (2016) and Husien et al. (2017) suggested that knowledge on irrigation water quality will help a lot during the development of strategies for farm management practices. Some works on irrigation water quality evaluation were done in the present study area (Mesfin, 2001; Halcrow, 2008; Pascual-Ferrer et al., 2014; Abay et al., 2016; Hadera, 2018). However, these works did not consider the spatial and temporal variability of irrigation water quality at the farm level. Therefore, the present study was undertaken with three main objectives, namely i) assessing seasonal and spatial variation of irrigation water quality; ii) determining the suitability of water quality for irrigation and iii) suggesting possible management options to the farmers.

MATERIALS AND METHODS

Description of the study area

Location

The study area is located in Adamitulu District in the South Western Shewa zone of the Oromiya Regional State of Ethiopia (Figure 1). Geographically, the area extends from 7° 50' 00'' to 7° 53' 57'' N latitude and from 38° 42' 00'' to 38° 46' 00'' E longitude. The site is located in the Central Rift Valley region about 160 km south of Addis Ababa, nearby Ziway town. The study site has an area of 1020 hectares and accommodates more than 700 households that are dependent on a mixed crop-livestock production system. The altitude of the study area ranges from 1600 - 1950 m above sea level in the tropical semi-arid zone in the middle part of the Ethiopian rift valley system. There is a small variation in the length of days in different seasons and the area is suitable for tropical crop production.

Climate and land use

Metrological data (1997 - 2017) obtained from the nearby weather station (Ziway Branch) are presented in Figure 2. The average relative humidity varied from 46.5% during the dry season to 75.5% during the wet season. The average minimum temperature were 19.2°C while the average maximum temperature was 27.5°C. A major rainfall event in the area occurs between June to September and a minor rainfall event occurs between March and May. The main rainy season contributes more than 75% of the total annual rainfall that the area received. The mean annual rainfall in the area varied from 600 to 850 mm and the rainfall pattern is erratic and unreliable. However, annual average potential evapotranspiration is approximately 1200 mm which signifies the importance of irrigation to filling the gap. The geology of the area is marked by a thick cover of volcanic and fluvial lacustrine deposits (Woldegabriel et al., 1990; Halcrow, 2008). The oldest volcanic rocks are also found in the western and eastern escarpments. Alemayehu et al. (2016) reported that the Solonchacks is the major soil type exhibited in the area and in most cases such type of soils developed from salt-rich parent materials. The property of the soil ranges from slightly alkaline to strongly alkaline in reaction and dominantly sandy loam

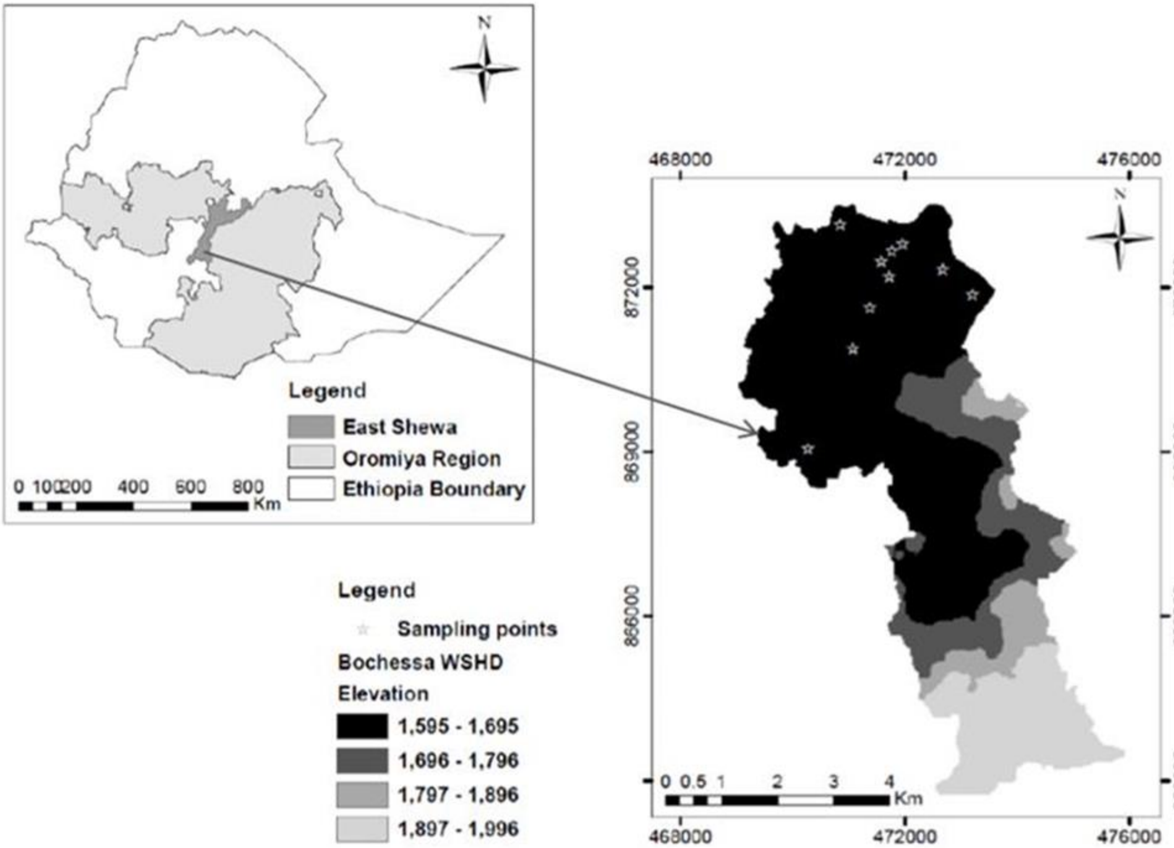

Figure 1. Location map of the study area and sampling boreholes (ArcGIS 10.3).

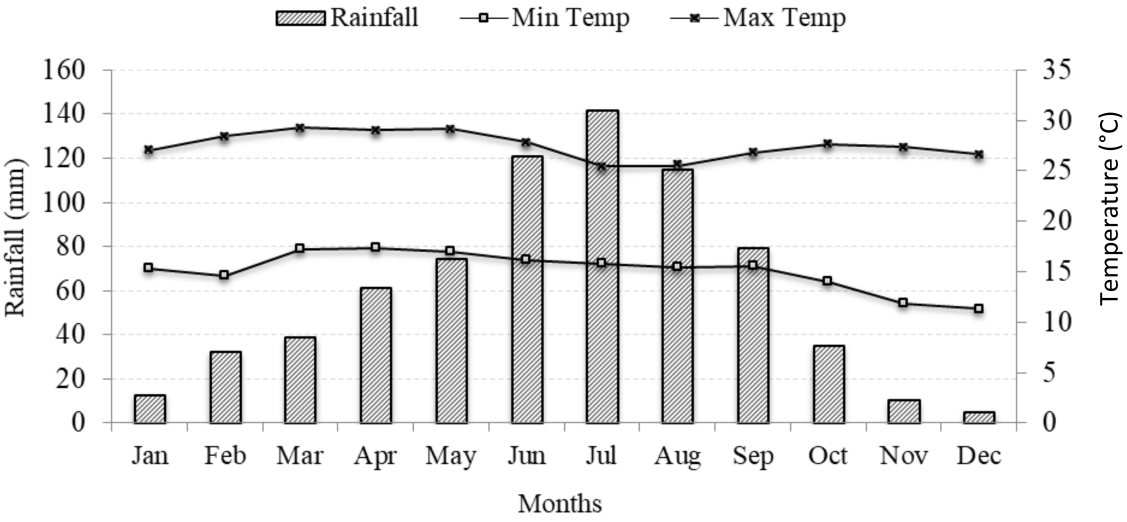

Figure 2. Mean monthly rainfall and average monthly maximum and minimum temperature of the study area (Microsoft Excel 2010).

in texture. Topographically the area is characterized by plain to undulated hills located adjacent to the escarpment of the central part of the Ethiopian mountain channels.

The major land-use types in the area are related to cultivation and grazing. The cultivable land is concentrated in the flat area while grazing land is located in the hilly area and lakeshores. The major cash crops grown in the area with help of irrigation are; tomato *(Solanum lycopersicum)*, leafy cabbage (*Brassica carinata)*, onion (*Allium cepa*) and green beans (*Phaseolus vulgaris*). The main food crops are maize (*Zea mays* L.), teff (*Eragrostis teff*) and wheat (*Triticum asteivum*). These crops are mainly cultivated during the rainy seasons. The most dominant types of livestock found in the area are cattle and goats with limited numbers per household. The natural vegetation is situated nearby the lake and river banks and is mainly composed of bushes and acacia species. In general, the economy of the study area is largely based on subsistence crops and animal production activities.

Site selection

The study area was selected based on food insecurity problems that are prevalent in the area due to unreliable climatic conditions. Moreover, the site is well-known for the shortage of rainfall but is suitable for irrigated agriculture with the help of surface or groundwater sources. Agriculture is the most dominant form of economic activity in the area which supports the livelihood of inhabitants. However, the farming system is traditional and highly dependent on rain as a source of water. Recently, governmental and non-governmental organizations have given due attention to developing small scale irrigation facilities in the area to improve the situation. Irrigation practices, in most cases, are highly linked to the availability of good quality water sources. The use of unsuitable water sources for irrigation may lead to deterioration of soil quality. Therefore, assessing the seasonal variability of irrigation water quality at the farm level is critical to provide reliable information to the users. It can help them to improve on-farm water management practices to maintain the productivity of farmlands.

Sampling techniques

The characteristic features of the boreholes were fully understood before the actual work by doing preliminary surveys in the area. The survey was conducted by using an informal discussion with extension workers and model farmers who actively engaged in irrigation practices. The discussion pays more attention to irrigation practices and trends of input utilization. The obtained information's indicated that in the dry season most farmers practiced irrigation with help of groundwater. The information's further outlined that boreholes found near to the farm fields were more utilized for irrigation purposes while near the home yards were utilized for domestic consumption. Moreover, the water level data collected before the actual work indicated that boreholes used for irrigation showed more fluctuation compared to boreholes used for house consumption. Based on these facts, the boreholes near the vegetable farms were selected for monitoring and sampling purposes. The analyzed quality parameters and sampling frequency are chosen carefully concerning preliminary survey results and the objectives of the study. This study focused only on eight monitoring boreholes, four of which were pumped by the motor pump and the remaining four, by rope and washer pumps. The depth of boreholes varied from 5 m (near the lake) to 12 m (far from the lake). The diameter for all monitoring boreholes was 1 m on an average. The water level in boreholes varied from 0.15 m in the dry season to 2 m in the rainy season.

Sample collection

The sampling activity was done twice per year (during dry and rainy seasons) for three consecutive years (2015 - 2017). This study hypothesized that seasonal and spatial variability affects irrigation water quality, which in turn could influence its suitability for irrigated agriculture. Hence, this study was carried out mainly to evaluate the extent of seasonal and spatial variation effects on the quality of irrigation water in the area. Eight samples were collected from eight different shallow wells during each sampling period. A total of 48 samples were collected during the entire investigation period for laboratory analysis by using plastic bottles. The bottles used for the sample collection were washed carefully with detergent to maintain the quality of the data for laboratory analysis. The bottles were filled to the top, sealed and labeled with a unique code number which was maintained throughout the laboratory analysis period to enhance the accuracy of results. The collected water samples were preserved in the icebox, transported and analyzed according to the standards set for irrigation water quality (Ayers and Westcot, 1985). The analysis was carried out at Arba Minch University Water Quality Laboratory Center.

Laboratory analysis

Analyses of physicochemical properties of the water samples were done using standard laboratory procedures. The electrical conductivity (EC) and pH respectively were determined using conductivity meter and pH-meter as suggested by Greenberg et al. (1992). Soluble cations such as Na^+ and K^+ were determined by flame photometer after proper calibration with combined Na-K standard solutions (RTI, 1991). Soluble Ca^{2+} and Mg^{2+} were analyzed directly by atomic absorption spectrophotometer (APHA, 1998). Chlorides (Cl^-), calcium carbonate ($CaCO_3$), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions were measured by the argentometric method by titrating against silver nitrate standard solution with potassium chromate indicator by using the procedure suggested by Greenberg et al. (1992). Similarly, phosphate (PO_4^{3-}), nitrate (NO_3^-) and boron (B) were determined by spectrophotometric methods as described by AOAC (1990) (Table 1). Sodium adsorption ratio (SAR) was estimated by using equation 1 as suggested by Richards (1954). The concentrations of all ions in this equation are expressed in milliequivalents per liter.

$$SAR = \frac{Na\ meq/l}{\sqrt{(Ca + Mg)/2}} \tag{1}$$

Residual sodium carbonate (RSC) in irrigation water and its effects on the sodium content of the soil was estimated using Equation 2 as suggested by Raghunath (1987). Concentrations of all the ions in this equation are expressed in milliequivalents per liter.

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \tag{2}$$

The magnesium adsorption ratio (MAR) represents magnesium hazard in irrigation water. The high value of MAR in irrigation water may cause calcium-induced nutritional deficiency. It was estimated using Equation 3 as described by Raghunath (1987). Ionic concentrations in Equation 3 are expressed in milliequivalents per liter.

$$MR = (Mg * 100)/(Ca + Mg) \tag{3}$$

Soluble sodium percentage (SSP) is used to evaluate how sodium ion concentration in irrigation water affects soil properties. The SSP was estimated using equation 4 as suggested by Todd (1980). The presence of a high concentration of sodium ion in irrigation water tends to be absorbed by clay particles that in turn could disperse Mg and Ca ions. This exchange process of Na ion in water for Ca and Mg ions in soil reduces the permeability and eventually results

Table 1. Analytical methods used and recommendations of water quality for agricultural uses.

Parameter	Analytical methods	Unit	Degree of restriction on use			Source
			None	Slight to moderate	Severe	
PH	pH-meter	-	<7	7 - 8.4	>8.4	Ayers and Westcot (1985)
EC	Conductivity meter	dS/m	<0.7	0.7 - 3	>3	
Na	Flame photometer	mg/L	-	0 - 920	>920	
Ca	Spectrophotometer	mg/L	-	0 - 400	>400	
CO_3	Titration method	mg/L	-	0 - 3	>3	
HCO_3	Titration method	mg/L	<92	92 - 519	>519	
K	Flame photometer	mg/L	-	0 - 2	>2	
Mg	Spectrophotometer	mg/L	-	0 - 60	>60	
Cl	Titration method	mg/L	<142	142 - 355	>355	
NO_3	Spectrophotometer	mg/L	<5	5-30	>30	
PO_4	Spectrophotometer	mg/L	-	0 - 2	>2	
B	Spectrophotometer	mg/L	<0.7	0.7 - 3	>3	
$CaCO_3$	Titration method	mg/L	<75	75 - 300	>300	Sawyer and McCarty (1967)

in soil with poor internal drainage due to its clogging effect. The concentrations of all ions in this equation are expressed in milligrams per liter.

$$SSP = \left(\frac{Na + K}{Ca + Mg + Na + K}\right)*100 \tag{4}$$

The permeability of soil can be affected by sodium, calcium, magnesium and bicarbonate contents of irrigation water. The permeability index (PI) of irrigation water was estimated by using equation 5 as suggested by Doneen (1964). The ionic concentrations in this equation are expressed in milliequivalents per liter.

$$PI = \left(\frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na}\right) \tag{5}$$

Kelly's ratio (KR) is used to determine sodium ion related problems in irrigation water. The KR was estimated using equation 6 as described by Kelly (1963). Ionic concentrations in this equation are also expressed in milliequivalents per liter.

$$KR = \frac{Na}{Ca + Mg} \tag{6}$$

Statistical analysis

Generalized linear model procedure in the statistical package for the social science (SPSS) version 16 application was used for data analysis. The general linear model of two ways analysis of variance (ANOVA) was used to determine differences among the mean of water quality parameters across seasons and locations. The mean of each parameter was compared across the seasons and sampling locations using post-hoc comparison tests. It was carried out to find the exact difference between the mean of each quality parameter across all locations and seasons. The probability level for the determination of significance was 0.05.

RESULTS AND DISCUSSION

This study was conducted to assess the seasonal and spatial variations in water quality of Bochessa catchment for stallholder irrigation. The results of laboratory analysis of different parameters were recorded and the mean values were from the analysis of variance (ANOVA) for each borehole, are given in Tables 2 and 3. Graphical illustration of the variations in the trend of water quality parameters over time and distance from the lake are shown in Figures 3 and 4. The values of SAR, RSC, SSP, PI, MAR, and KR estimated using Equations 1, 2, 3, 4, 5 and 6 are given in Table 4. The results of the correlation coefficient analysis among the parameters are also shown in Table 5.

Seasonal variability of groundwater quality

Adamu (2013) and Hadera (2018) have shown that the quality of irrigation water influences soil productivity to a greater extent. Hence, the quality of irrigation water should be considered during the planning of any irrigation project. Michael (1992) and Hillel (2000) emphasized that water quality evaluation should focus at the farm level for recommending possible management options to the users. The present evaluation was done at the farm level to suggest some possible on-farm management practices. Subsequently, farmers can use it to improve management practices in irrigated fields. It may be observed from Table 2 that about 46% of water quality parameters analyzed showed significant differences at P<0.05 at all sampling periods. Moreover, about 62% of the water quality parameters showed a decreasing trend during the wet season. This implies that seasonal variations had a noticeable impact on the quality of

Table 2. Variation of water quality parameters across the season at Bochessa catchment.

Parameter	Dry season	Wet season	Average	Sig	LOS
PH	8.29^a	8.13^a	8.21	0.27	NS
EC	2.18^a	1.94^b	2.06	0.05	*
$CaCO_3$	255.50^a	228.33^a	241.92	0.16	NS
Na^+	511.46^a	472.79^a	492.13	0.21	NS
Ca^{2+}	48.88^a	28.77^b	38.83	0.00	*
CO_3^{2-}	107.54^a	125.08^a	116.31	0.33	NS
HCO_3^-	1060.00^a	1170.20^a	1115.10	0.31	NS
K^+	461.71^a	304.59^b	383.15	0.04	*
Mg^{2+}	$46.9.00^a$	49.43^a	48.17	0.67	NS
Cl^-	137.58^a	128.46^a	133.02	0.57	NS
NO_3^-	21.34^a	31.43^b	26.39	0.02	*
PO_4^{3-}	1.06^a	0.67^b	0.87	0.02	*
B	0.43^a	1.49^b	0.96	0.01	*

Note: Same letters refers not any difference among the means of parameters across the sources (P=0.05), * Significant at ≤ 5%, NS: Non significant, LOS: Level of significant.

Table 3. Variation of water quality parameters across the location at Bochessa catchment.

Parameter	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6	BH-7	BH-8	Average	Sig.	LOS
PH	8.2^a	7.9^a	8.1^a	8.2^a	8.4^a	8.3^a	8.4^a	8.2^a	8.2	0.62	NS
EC	1.9^a	1.8^a	2.3^a	2.0^a	2.4^a	1.9^a	2.1^a	2.2^a	2.1	0.15	NS
$CaCO_3$	292.5^a	332.5^b	242.7^a	234^a	206.7^a	232.5^a	160.8^{ab}	233.7^{ab}c	241.9	0.03	*
Na^+	429.5^a	444.8^a	502.5^a	497.0^a	592.0^a	431.7^a	505.7^a	533.8^a	492.1	0.19	NS
Ca^{2+}	42.7^a	49.7^a	35.9^a	40.0^a	33.3^a	32.9^a	36.8^a	39.2^a	38.8	0.69	NS
CO_3^{2-}	126.0^a	80.7^a	125.7^a	131.3^a	131.0^a	134.3^a	124.2^a	77.3^a	116.3	0.52	NS
HCO_3^{3-}	980.0^a	1103.0^a	1246.0^a	1158.0^a	1134.0^a	1062.2^a	999.8^a	1237.5^a	1115.1	0.83	NS
K^+	347.7^a	336.5^a	403.0^a	537.3^a	339.7^a	344.3^a	338.5^a	418.2^a	383.2	0.73	NS
Mg^{2+}	60.7^a	56.8^a	52.3^a	49.2^a	42.7^a	47.8^a	33.2^a	42.3^a	48.1	0.41	NS
Cl^-	118.3^a	101.3^a	158.5^a	123.0^a	153.8^a	137^a	137.8^a	134.3^a	133.0	0.65	NS
NO_3^-	28.2^a	22.0^a	30.3^a	20.0^a	26.0^a	23.6^a	25.2^a	35.9^a	26.4	0.41	NS
PO_4^{3-}	0.9^a	0.8^a	0.4^a	0.8^a	0.5^a	0.9^a	0.9^a	1.6^a	0.9	0.06	NS
B	0.4^a	0.7^a	0.7^a	1.0^a	0.7^a	0.8^b	1.7^a	1.7^a	1.0	0.24	*

Note: * Significant at P≤ 0.05, NS: Non significant, BH: Boreholes, LOS: Level of significant, Sig: Significant.

irrigation water in the area.

The pH value during the study period ranged from 8.13 to 8.29 (Table 2). The pH was higher in the dry season as compared to the wet season. This may be attributed to the dilution effects of rainfall that was experienced in the area during the wet season. Its value during the study period remained greater than 8.00 suggesting that the water is alkaline in nature. Adamu (2013) and Reddy (2013) noted that pH is not an important criterion for irrigation, because it can be buffered by soil and most crops can tolerate a wide range of pH levels. The estimated pH values during the study period were within the permissible range. However, as the average pH value (8.21) of the water approaches the upper limit, its continuous use may have adverse effects on soil quality.

The EC values ranged from 1.94 to 2.18 dS/m (Table 2). The highest value was observed in the dry season. The EC values were within the permissible limit for agricultural purposes as compared to the standard value given in Table 1. However, the EC value was above the threshold levels for most of the vegetable crops grown in the area. Ayers and Westcot (1985) noted that different crops have different salt tolerance limits. The recommended EC threshold values for some of the sensitive vegetable crops grown in the area beans, cabbage, onion, and tomatoes vary from 0.7 to 1.7 dS/m (Ayers and Westcot, 1985). But, the level of measured salt concentration in the irrigation water was not suitable for growing these crops. The irrigation water with EC_w=1.5 dS/m is not suitable for salt-sensitive crops such as beans but may

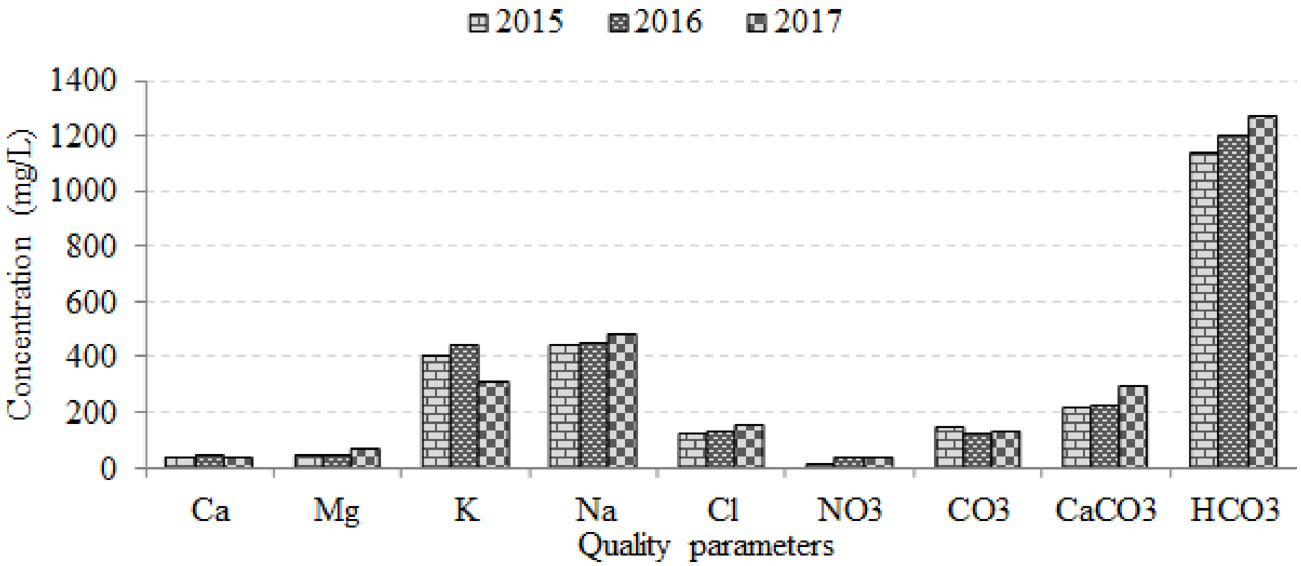

Figure 3. Graphical expression of the trend of water quality indicators across the year in the area.

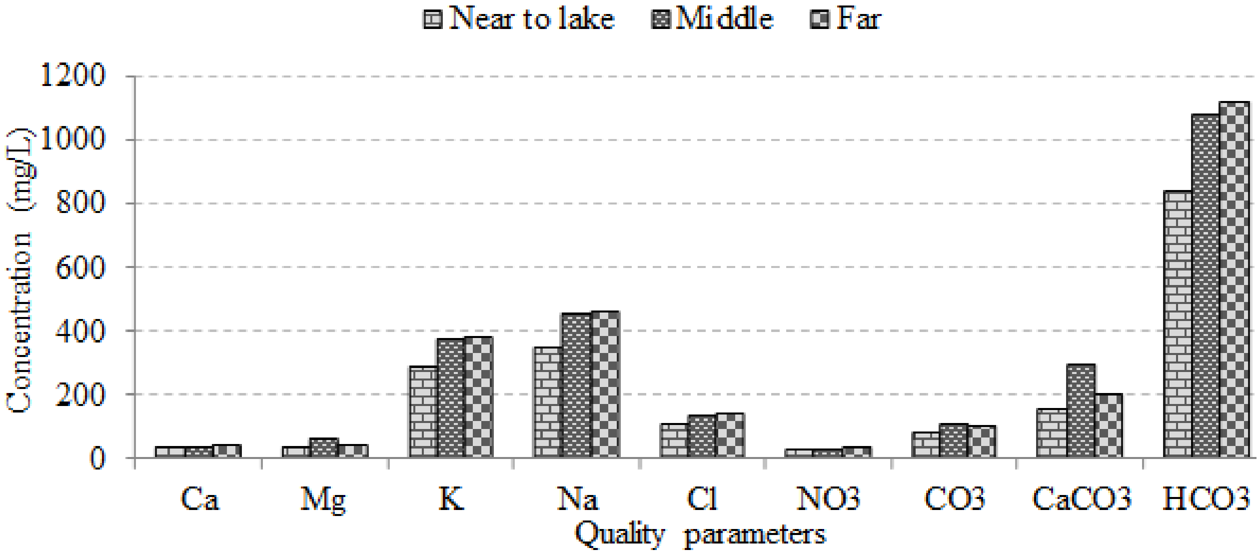

Figure 4. Graphical illustration of the trend of water quality indicators away from the lake towards west direction.

be used for tolerant crops like a tomato. Therefore, the use of groundwater in the study area may adversely influence the production of salt-sensitive crops. Still, it is possible to use the water for salt-sensitive crops with strong management practices while maintaining the soil salinity within the salt tolerance limit of the crops.

Total hardness as expressed by $CaCO_3$ ranged from 228.33 to 255.50 mg/L (Table 2). The values of $CaCO_3$ were lower during the dry season. This might be attributed to the dilution effects created by rainwater during the wet season. Concentrations in all sampling periods were more than 200.00 mg/L (Table 2). Sawyer and McCarty (1967) recommended the $CaCO_3$ value <75 mg/L as soft, 75 to 150 mg/L as moderate, 150 to 300 mg/L as hard and above 300 mg/L as very hard. The average measured value of $CaCO_3$ is equal to 242.00 mg/L confirmed that the assessed water samples across the season can be ranked as hard. The measured values of CO_3^{2-} and HCO_3^- in the water samples ranged from 107.54 to 125.08 mg/L and 1060.00 to 1170.20 mg/L, respectively (Table 2). The values were relatively high during the wet season as compared to the dry

Table 4. Some of calculated irrigation water quality parameters at Bochessa catchment.

Parameter	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6	BH-7	BH-8	Average
SAR	10.20	11.40	12.60	12.70	17.30	11.70	14.50	14.80	13.20
RSC	13.20	16.80	23.70	22.80	24.40	21.20	17.90	26.70	20.80
PI	66.30	68.10	72.10	65.60	77.90	71.10	73.50	72.10	70.80
SSP	79.30	79.50	83.90	85.20	87.20	81.50	87.00	85.90	83.70
KR	2.80	3.50	3.70	3.80	6.20	3.70	4.9.00	4.80	4.20
MAR	69.30	64.90	70.20	68.30	65.60	69.60	54.6.00	63.50	65.80

Note: BH; Borehole.

Table 5. Correlation coefficient of irrigation water quality parameters across the season.

						Dry season						
Parameter	**pH**	**EC**	**Na**	**Ca**	**CO_3**	**HCO_3**	**K**	**Mg**	**Cl**	**NO_3**	**PO_4**	**B**
pH	1.00	0.03	0.11	-0.39	-0.01	0.13	-0.15	**-0.71**[a]	-0.07	0.29	0.38	0.02
EC		1.00	**0.66**[a]	-0.35	**0.71**[a]	0.04	-0.01	0.26	**0.75**[a]	-0.22	-0.06	**0.52**[a]
Na^+			1.00	**-0.59**[a]	0.39	0.27	-0.09	-0.07	**0.74**[a]	0.19	-0.06	0.39
Ca^{2+}				1.00	-0.29	-0.06	-0.13	0.34	-0.4	-0.14	-0.11	-0.29
CO_3^{2-}					1.00	-0.17	-0.08	0.31	**0.55**[a]	**-0.44**[b]	-0.36	**0.57**[a]
HCO_3^-						1.00	0.22	-0.28	0.02	0.31	**0.43**[a]	-0.16
K^+							1.00	0.14	-0.2	0.05	-0.33	-0.22
Mg^{2+}								1.00	0.33	-0.36	**-0.61**[a]	0.16
Cl^-									1.00	0.02	-0.13	**0.64**[a]
NO_3^-										1.00	0.24	-0.11
PO_4^{3-}											1.00	-0.29
B												1.00
						Wet season						
pH	1.00	0.04	0.13	-0.29	**0.65**[a]	-0.30	-0.28	**-0.42**[b]	0.17	0.18	-0.05	**-0.42**[b]
EC		1.00	**0.47**[b]	-0.04	0.11	**0.58**[a]	0.37	-0.14	**0.70**[a]	-0.21	-0.03	0.17
Na^+			1.00	0.24	0.08	0.13	-0.18	-0.04	**0.51**[b]	**0.56**[a]	0.33	0.21
Ca^{2+}				1.00	**-0.50**[b]	0.16	-0.03	0.31	-0.21	**0.41**[b]	**0.62**[a]	**0.49**[b]
CO_3^{2-}					1.00	-0.2	-0.12	-0.28	0.29	-0.11	-0.38	**-0.53**[a]
HCO_3^-						1.00	**0.66**[a]	-0.36	0.25	**-0.51**[b]	0.12	**0.59**[a]
K^+							1.00	-0.3	-0.11	**-0.75**[a]	-0.02	**0.58**[a]
Mg^{2+}								1.00	-0.04	0.31	0.23	-0.15
Cl^-									1.00	0.06	-0.22	-0.25
NO_3^-										1.00	**0.42**[b]	-0.08
PO_4^{3-}											1.00	**0.53**[a]
B												1.00

Note: [a] Correlation is significant at $p < 0.01$; [b] Correlation is significant at $p < 0.05$.

season. The acceptable ranges for HCO_3^- and CO_3^{2-} lie between 0 to 519 mg/l and 0 to 3 mg/l, respectively (Table 1). But, the measured average values of both HCO_3^- and CO_3^{2-} were by far higher than the acceptable limits (Table 2). Therefore, the assessed water in the area could be described as being at severe risk with regards to carbonates and bicarbonates. Abay et al. (2016) also recorded high values of HCO_3^- and CO_3^{2-} in the area.

The measured values of calcium and magnesium ions varied from 28.77 to 48.88 mg/L and 46.90 to 49.43 mg/L, respectively (Table 2). The higher value for Ca^{2+} was observed in dry season while for Mg^{2+} the higher value was observed in the rainy season. The permissible range of Ca^{2+} and Mg^{2+} for irrigation lies between 0 to 400 and 0 to 60 mg/L, respectively (Table 1). Thus, the measured values of Ca^{2+} and Mg^{2+} for irrigation water during the study periods were within the safe limits. The values of Mg^{2+} remained higher than the values of Ca^{2+}. Therefore, there may be Mg^{2+} related problems as it deteriorates soil structure, particularly where the water is sodium-dominated and highly saline. The concentration of sodium ion (Na^+) varied from 472.79 to 511.46 mg/L (Table 2). The higher value of Na^+ was also observed during the dry season as compared to the wet season. The permissible limits of Na^+ for irrigation water ranged from 0 to 920 mg/l (Table 1). This suggested that the measured value of Na^+ was within the safe limit and is suitable for irrigation purposes. However, its value remained higher than 400.00 mg/l and it showed high value compared to other cations during the investigation period. Therefore, Na^+ concentration in irrigation water pays attention to maintain soil quality in the area. Abay et al. (2016) and Hadera (2018) also reported similar results earlier concerning to sodium ions.

The concentration of nitrate (NO_3^-) and phosphate (PO_4^{3-}) varied considerably. The measured values across the season ranged from 21.34 to 31.43 mg/L and 0.67 to 1.06 mg/L, respectively (Table 2). The highest value of NO_3^- was observed during the wet season while the highest value of PO_4^{3-} was found during the dry season. This might be attributed to poor farm management practices that were experienced in the area. Edossa et al. (2013) reported that farmers in the area use on average 300 kg ha^{-1} DAP and 340 kg ha^{-1} urea for irrigated vegetable crop production. This implies that fertilizers were not wisely used in the irrigated fields in the area. As shown in Table 1, the permissible range of NO_3^- and PO_4^{3-} for irrigation water varies from 0 to 30 mg/L, and 0 to 2 mg/L, respectively. Thus, the concentration of NO_3^- was beyond the critical limit during the wet season and it was within the normal range in the dry season. Therefore, the use of improved fertilizer management practices at the farm level is important to reduce the leaching of nutrients to the groundwater. There is no restriction on PO_4^{3-} level as far as water for irrigation is concerned. The concentration of potassium ion (K^+) varied from 304.59 to 461.71 mg/L (Table 2). The concentration of K^+ was very high as compared to the standard limit which is equal to 2 mg/L (Table 1). This may be attributed to the nature of the underlying rocks that are found in the area.

Other common toxic ion and elements that are found in irrigation water are chlorine (Cl^-) and born (B). Their concentration across the season varied from 128.46 to 137.58 mg/L and 0.43 to 1.49 mg/L, respectively (Table 2). The value of Cl^- did not vary substantially across the seasons, but the variation in B was remarkable. However, the concentrations of both components across the seasons were found to be within the acceptable limits for irrigation and are equal to 355 and 3 mg/l, respectively (Table 1). Therefore, using this water for irrigation may not result in toxic effects on growing crops with regards to Cl^- and B. The overall seasonal analysis of water quality in the catchment indicated that 69% of the estimated parameters were within the acceptable limits for irrigation. Thus the majority of water quality parameters were within the permissible levels and suitable for irrigation. Halcrow (2008) and Abay et al. (2016) also reported similar results from the same study area earlier.

It may be observed from Figure 3 that the majority of the parameters related to water quality increased across the year. This means that the seasonal variations had considerably influenced the quality of irrigation water. However, pH, EC and Ca^{2+} did not show remarkable change over time. The variations in CO_3^{2-} and $CaCO_3$ with time were inconsistent. The water quality parameters which increased with time could influence the poor farming practices that existing in the area. Therefore, the practice of improved irrigation management practices is of paramount importance in the area. The use of irrigation water for crop production neglecting proper management practices could negatively affect the quality of water and soil in the catchment. Thus, monitoring the quality of groundwater across the fields at some time interval is crucially important in taking timely action to alleviate the limitations.

Spatial variability of groundwater quality

It may be observed from Table 3 that the majority of water quality parameters did not vary considerably with sampling locations. About 85% of the quality parameters were more or less the same at $P<0.05$ with sampling locations. This implied that chemical compositions of earth materials were by and large similar across the fields. The spatial variability did not influence the constituents of groundwater in the area. The values of pH and EC in the area are ranged from 7.90 to 8.40 and 1.80 to 2.40 dS/m, respectively (Table 3). The pH values at some locations were approaching the upper limit suggesting that continuous irrigation may influence soil quality in the area. However, the average values of pH and EC were equal to 8.20 and 2.10 dS/m respectively which were below the recommended critical limits for irrigation (8.40 and 3.00 dS/m) (Table 1). Therefore, the use of this water for irrigation will not as such adversely affect soil quality. Abay et al. (2016) also reported more or less similar findings earlier from this area.

The measured values of different irrigation water quality parameters at different locations within the catchment are given in Table 3 and the variations are shown in Figure 4. It may be observed from Table 3 that the mean values of the quality parameters followed by the same letter in the same row were not significantly different from each other. The concentration of Ca^{2+}, Mg^{2+} and Na^+ in irrigation water at different sampling locations varied from 32.90 - 49.70 mg/L, 33.20 to 60.70 mg/L and 429.50 to 592.00 mg/L, respectively (Table 3). The concentration of Na^+ was higher than Ca^{2+} and Mg^{2+}. This may cause toxicity problems following surface irrigation. The measured value of Ca^{2+}, Mg^{2+}, and Na^+ were within the permissible ranges and the water was suitable for irrigation as confirmed by the standards given in Table 1. The concentrations of Mg^{2+} at different locations were relatively higher as compared to Ca^{2+}. Therefore, there might be Mg^{2+} related problems on soil quality as Mg^{2+} makes the soil more alkaline particularly under Na^+ dominated conditions (Adamu, 2013). These findings agreed with the previous findings reported by Hadera (2018) in same the area.

The concentration of common toxic ions such as chloride (Cl^-) and the element boron (B) varied from 101.30 to 158.50 mg/L and 0.40 to 1.70 mg/L, respectively (Table 3). They are unlike Na^+, and are essential for plant growths, but needed in small quantities only. The concentration of B varied across sampling locations while Cl^- did not show such a variation. This might be attributed to farm management practices that existing in the area. Moreover, it may be observed from Figure 4 that both of these parameters showed an increasing trend along the way from the lake to intensively cultivated vegetable fields. This could also confirm as to how farm management practices influence different water quality parameters across the fields. The continuous use of fertilizers and other chemicals in such fields could change the levels of certain parameters. Concentrations of Cl^- and B at all sampled locations were within the acceptable limits that are set for irrigation purposes (Table 1). Similarly, high values for both of the parameters in the same area were also reported earlier by Halcrow (2008) and Abay et al. (2016).

The value of $CaCO_3$, CO_3^{2-} and HCO_3^- at all sampling locations varied from 160.80 to 332.50 mg/L, 77.30 to 134.30 mg/L and 980.00 to 1246.00 mg/L, respectively (Table 3). The CO_3^{2-} and HCO_3^- did not vary across sampling locations while $CaCO_3$ varied significantly at different sampling locations. The values of all these parameters were high at all sampling locations during the investigation period. The concentrations of CO_3^{2-} and HCO_3^- in irrigation water at all locations were above the permissible limit for irrigation as given in Table 1. Thus the analyzed water samples were hard and could influence the efficiency of drippers in trickle irrigation systems due to clogging effects. Therefore, checking the function of each dripper at a certain time interval is critical in improving efficiency as long as the water is supposed to be used for irrigating farmlands. The frequent use of water for agricultural purposes could have a negative influence on soil quality suggesting the use of appropriate on-farm water management practices. Similar values were also reported by Hadera (2018) in the same area with regard to these parameters.

Concentrations of nutrient parameters such as; NO_3^-, PO_4^{3-} and K^+ at all sampling locations varied from 20.00 to 35.90 mg/L, 0.40 to 1.60 mg/L and 336.50 to 537.30 mg/L, respectively as given in Table 3. Their values did not show as such any remarkable variations across sampling locations. But, in all cases, high concentrations were observed in the area during the investigation period. This might be attributed to the dominance of vegetable production experienced in the area. Such type of farming system favors intensive use of agricultural inputs which in turn could increase the concentration of such nutrients in nearby water sources (Edossa et al. 2014). Edossa et al. (2013) reported that farmers on an average used 300 kg ha^{-1} di-ammonium phosphate (DAP) and 340 kg ha^{-1} urea in the area. This also supports the above argument that emphasizes unwise use of fertilizer in agricultural fields can increase the concentration of these nutrients in nearby water bodies. This suggested that regular monitoring of water quality in vegetable production areas is essential to provide reliable information to the farmers. The average values of NO_3^- (26.40 mg/l) and PO_4^{3-} (0.90 mg/L) were within the acceptable limit for irrigation (Table 1). But, the value of K^+ was above the acceptable limit. The K^+ exhibited a similar situation under both time and space in the area. The most likely factor that could cause a high concentration of K^+ in the area is the nature of underlying rocks. This finding agreed with some previous results reported by Halcrow (2008) and Hadera (2018).

The overall spatial analysis of irrigation water quality parameters in the catchment indicated that about 69% of the parameters were within the permissible limits for irrigation. The rest, 31% of the quality parameters were above the permissible limits recommended for irrigated agriculture. This suggests a low degree of restriction on the use of water for irrigation in the study area. However, almost all quality parameters showed higher values across sampling points during the investigation period. The concentration of all quality parameters studied showed similar trends with seasonal analysis in the catchment. Farm management practices and the nature of underlying rocks, in general, are the most likely factors that cause spatial variability of irrigation water quality in the area.

The variations in some of the constituents of groundwater with distance from the lake in the area are shown in Figure 4. It may be observed from Figure 4 that almost all the studied irrigation quality parameters increased with the distance from the lake. This could be due to farming practices that were taking place across the fields. The intensity of cultivation, of course, increased with distance from the lake towards the west direction. The intensive farming practices require more inputs (fertilizers and other chemicals) which in turn could increase the concentration level of some of the components. Sodium and potassium were the dominant cations while bicarbonate was the dominant anion found a bit far away from the lake (Figure 4). Major cations and anions showed an increasing trend of going away from the lake. This may also confirm how farm management practices would influence groundwater quality in the area. In general, farm management practice was the most likely factor that can cause spatial variability of groundwater quality in the nearby area.

Suitability of groundwater quality for irrigation

The sodium adsorption ratio (SAR) is an index that shows the potential of irrigation water in inducing sodic soil conditions. The values of SAR were estimated using Equation 1 and it ranged from 10.20 to 17.30 meq/L (Table 4). The values were higher for all the samples. This might be attributed to the high concentration of sodium as compared to calcium and magnesium ions. Ayers and Westcot (1985) suggest that water having SAR values less than 15 meq/l is considered as fair and suitable for irrigation. It may be observed from Table 4 that the estimated average value of SAR is equal to 13.20meq/l. It was less than the critical limit. Thus, this water was suitable for irrigation. However, the SAR value approached the upper limit of suggested critical value (15 meq/L) and the continuous use of this water may aggravate the sodicity problem in the area. Therefore, regular monitoring of water quality during the irrigation season is very important to maintain soil fertility. Higher SAR values were also reported by Abay et al. (2016) and Hadera (2018) in the same area.

Residual sodium carbonate (RSC) values were estimated using equation 2. The estimated values across the sampling locations are given in Table 4 and it varied from 13.20 to 26.70 meq/L. The values of RSC were higher for all the studied samples in all sampling locations. Water with a high concentration of carbonates and bicarbonates could increase sodium hazards in the area. Higher concentrations of residual carbonates favor precipitation of Ca^{2+} and Mg^{2+}. Raghunath (1987) recommended that RSC values <1.25 meq/L are considered as good, 1.25 to 2.50 meq/L are marginally suitable and above 2.50 meq/L are unsuitable for irrigation. The estimated average value of RSC in our present study was equal to 20.8 meq/L. It was higher than the recommended limit (2.50 meq/L). Therefore, the use of this water for irrigation may have a negative influence on soil quality. This also suggests that groundwater quality issues should be taken into account while planning for irrigation. Abay et al. (2016) and Hadera (2018) also reported high RSC values in the same area.

The magnesium adsorption ratio (MAR) values were estimated using Equation 3 and the values are given in Table 4. The values varied from 54.60% to 70.20% with an average of 65.80. Raghunath (1987) suggested that MAR <50% can be considered as suitable for irrigation whereas >50% are unsuitable for crop plants. The estimated MAR values in all sampling locations were higher than the limit suggested by Raghunath (1987). Regular use of this water may cause Ca^{2+} related problems for irrigated crops.

Soluble sodium percentage (SSP) and Kelly's ratio (KR) are also two widely used parameters for evaluating the suitability of water quality for irrigated agriculture. Because excess sodium ion concentration in irrigation water produces undesirable effects on soil and crops. The SSP and KR values were estimated using equations 4 and 6, respectively and are given in Table 4. The SSP and KR values varied from 79.30 to 87.20% and 2.80 to 6.20, respectively. The values of SSP below 60% (Todd, 1980; Reddy, 2013) and Kelly's ratio <1 (Kelly, 1963) are considered as good and safe for irrigation. However, the estimated values of both parameters in the study area were higher than the recommended values. This suggests that the continuous use of this water may cause sodium related problems.

The permeability index (PI) is employed to evaluate the effect of long-term use of irrigation water on soil quality. The estimated values of the PI are given in Table 4. The PI values varied from 65.60% to 77.90% in the area during the investigation period. According to Doneen (1964) water having PI values greater than 75% is considered excellent, between 25 and 75% is good and below 25% is unsuitable for irrigation. The average estimated PI value equal to 70.80% (Table 4) confirmed that the assessed water samples can be ranked as good. This suggests that irrigating the fields with the available water may not as such influence the permeability of the soil.

Correlation analysis

The Pearson's correlation coefficient was calculated to explore the degree of relationships among the quality parameters of groundwater. The greater the value of correlation coefficient is, the better and more useful the regression variables (Patil and Patil, 2011). The results showed that certain attributes of irrigation water showed significant relation with each other, whereas others did not show any significant form of relationships among themselves. As indicated in Table 5, the EC was positively correlated with most of the irrigation water quality parameters during the dry season in the area. Strong positive correlations were observed between EC and Na^+ (r = 0.66), EC and CO_3^{2-} (r = 0.71), EC and Cl^- (r = 0.75), EC and B (r = 0.52), Na^+ and Cl^- (r = 0.74), CO_3^{2-} and Cl^- (r = 0.55), CO_3^{2-} and B (r = 0.57), Cl^- and B (r = 0.64) at P<0.01 level of significant during the dry season (Table 5). Strong negative correlation coefficients were found between pH and Mg^{2+} (r = −0.71), Na^+ and Ca^{2+} (r = −0.59) and Mg^{2+} and PO_4^{3-} (r = -0.61). The result also outlined that the irrigation water quality parameters in the dry season could be correlated to a certain extent with each other.

As shown in Table 5, the EC and Ca^{2+} were positively correlated with most of the irrigation water quality parameters in the area during the wet season. High positive correlation were observed between pH and CO_3^{2-} (r = 0.65), EC and HCO_3^- (r = 0.58), EC and Cl^- (r = 0.70), Na^+ and Cl^- (r = 0.51), HCO_3^- and K^+ (r = 0.66), HCO_3^- and B (r = 0.59), K^+ and B (r = 0.58), NO_3^- and PO_4^{3-} (r =

0.42), PO_4^{3-} and B (r = 0.53) at P<0.01 level during the wet season (Table 5). The pH and NO_3^- were negatively correlated with most of the irrigation water quality parameters during the wet season in the area. The existence of strong positive correlation (r = 0.42) between NO_3^- and PO_4^{3-} in wet season might be associated with poor fertilizer management practices. Because they did not shows such strong relationship in dry season (Table 5). Strong negative correlation coefficient were found between pH and Mg^{2+} (r = −0.42), pH and B (r = −0.42), Ca^{2+} and CO_3^{2-} (r = −0.50), CO_3^{2-} and B (r = −0.53), HCO_3^- and NO_3^- (r = −0.51), and K^+ and NO_3^- (r = −0.75). Our results further illustrated that the physicochemical properties of irrigation water in the study area were independent of various quality parameters.

CONCLUSION AND RECOMMENDATIONS

Irrigation practice is a key factor to counter the problems created by a shortage of rainfall in arid and semi-arid areas of Ethiopia. Water quality evaluation, in this regard, is very important to provide reliable information to the farmers. The variability of water quality with time and space can pose management challenges in irrigated fields. Therefore, this study was carried out in the area mainly to evaluate the variability of water quality parameters across the seasons and locations and to determine its suitability for irrigation. The results revealed that the majority of the studied quality parameters did not show any significant variation at P<0.05 across various seasons and locations. However, some water quality parameters such as; EC, Ca^{2+}, K^+, NO^-, $PO4^{3-}$and B showed significant variations across the seasons while only $CaCO_3$ and B showed such variations at various sampling locations. This suggests that temporal variations are more important during the planning of irrigation water management practices in the area as compared to spatial variations. Based on the results obtained, all crops can be grown effectively with the quality of the assessed water in the area. However, management practices such as; irrigation-fallowing, leaching, use of gypsum and choice of salt tolerant crops may help to maximize the yield when crops are to be irrigated with this water.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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