Assessing heat stress vulnerability and adaptation strategies among farmers in semi-arid regions of West Africa

A case study of Senegal

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1. Introduction

Climate change has a high influence on agriculture and could lead to crop yields losses in rainfed areas in West Africa. It is considered to be the most climate-dependent sector of all human activities, which leads to high concentration of anthropogenic Green House Gases (GHG). According to the IPCC 2014 these GHG causing variations in meteorological variables such as temperature, rainfall and solar radiation that determines the resources availability and control fundamental process involved in the crop growth and development. In the developing countries these variations negatively impact crop yields and vary from one region to another with some important socio-economic consequences (Sultan et al., 2016). Sahel is a transition belt in the Africa continent that lies between the arid Sahara and the savannah. This transitional belt is highly vulnerable to climate change and the livelihoods that are mostly connected with it. The Sahel agriculture is comprised of small holder farmers that are engage in often of subsistence agriculture.

Due to the climate change the agriculture in West Africa faces the challenge of meeting the importance for food as national incomes and population increase while production becomes more uncertain. Hence the crop production models can provide helpful information on yields of various crops under a range of climate change scenarios and on the impact of adaptation strategies. According to the Akponike, 2008; Ganyo et al., 2019, the crop production is limited by factors, which includes the climate change and variability, weak soil fertility and water stress, lack of access to improved variety of seeds, inputs and markets. Therefore, in-depth studies are required for climate change scenarios to develop agronomic management strategies and resilient agriculture practices should also be formulated to improve the productivity and reduce food insecurity.

As West Africa is one of the sub-tropical regions mostly affected by the climate change and the agriculture mostly depends on rainfall which influenced by the Monsoon. The studies of Descroix et al. 2015; Panthou et al. 2012; Sagna et al. 2015; Sylla et al. 2010; Salack et al. 2016, explains that the different climatic phenomena like extreme events such as droughts and floods co-occur with disruptions in the overall rainfall regime as frequent false starts or early cessation of rainy season, an increase in the frequency of daily showers, an increase in the number of hot days and nights, and a downtrend in daily temperature variation.

Moreover, increased incidences of recurring dry years and drought events are the evidence of increasing climate change related risks in the semi-arid regions. In current scenario, farmers often experience extreme weather events which puts their food and income security at risk. The heat prone regions of the country are confined primarily to the arid, semi-arid, and sub-humid regions of African countries. Among those regions the Sahel region is one of most semiarid regions with low and erratic rainfall coupled with extreme temperatures and intense

solar radiation makes these regions the most vulnerable. In arid and semi-arid regions, like the analysis of the relationship between environmental parameters and vegetation cover is prerequisite to understand the Spatio temporal changes of agricultural activities for their planning and management in improving agricultural prospects of smallholder's farmers in the present scenario (Mahajan and Dodamani, 2016).

On this background the present study endeavours to evaluate the heat stress intensity and frequency over Senegal of West Africa. The analysis is focused on Senegal, where erratic and extremely variable rainfall is the primary constraint for productive and profitable farming. Soils in semiarid regions have frequently been degraded by historical land use, resulting in low soil organic carbon (SOC) content and poor structure. This study computes the Assessment of the impacts of heat stress areas in semi-arid regions with regional weather/climate through synergy of different observational techniques and the mitigating of the climate change to assess the risk of climate and weather on farming system through crop simulation models.

2. Study locations

Senegal is the western country in Africa. It covers an area of 201,000 square km and shares boundaries on the north with Mauritania, on the east with Mali, on the southwest with Guinea, and on the south with Guinea-Bissau. The country is essentially flat with low plains which are always less than 200meters in elevation. The climate which is primarily characterized by a short rainy season (June – September) and a long dry season is influenced by three major semi-permanent meteorological systems. The most common feature of the climate since 1960's has been the gradual decrease in both length of the rainy season and the total amount of rainfall at each latitude. These climate fluctuations have had a serious effect on the agriculture and its impact on food production (CEAS, 1979).

Selected 25 locations over the Senegal as shown in fig.1. and these locations are considered as environments which are described as water stressed environments where the performance of agriculture and allied activities is highly dependent and sensitive to the amount and distribution of rainfall during the crop season. The geographical selected locations with geographical features are shown in table.1. These locations cover a latitudinal range from 12 to 16 deg and Longitudinal range from -17 to -12 deg. Whereas the annual rainfall at these locations ranges from 300 – 1400 mm with maximum temperature varying between 25 to 37 deg and minimum temperature 20 to 24 deg. The stations such as Ziguinchor, Kolda, Kédougou, Sédhiou and Missirah receives more rainfall than those of other stations. Agriculture is very important to the economy of Senegal as most of the people grow food crops such as millet, Sorghum and Rice.

Urgent need to develop and implement solutions from research and innovation that support systems transformation in order to contribute to restore land; enhance nutrition, health and food security; improve climate resilience. The agriculture is highly vulnerable to a changing climate and the yield performance of crops under future climates (especially the

associated drought and heat) and also due to changing atmospheric GHG concentrations are speculative creating uncertainties in food securities in vulnerable countries like Senegal.

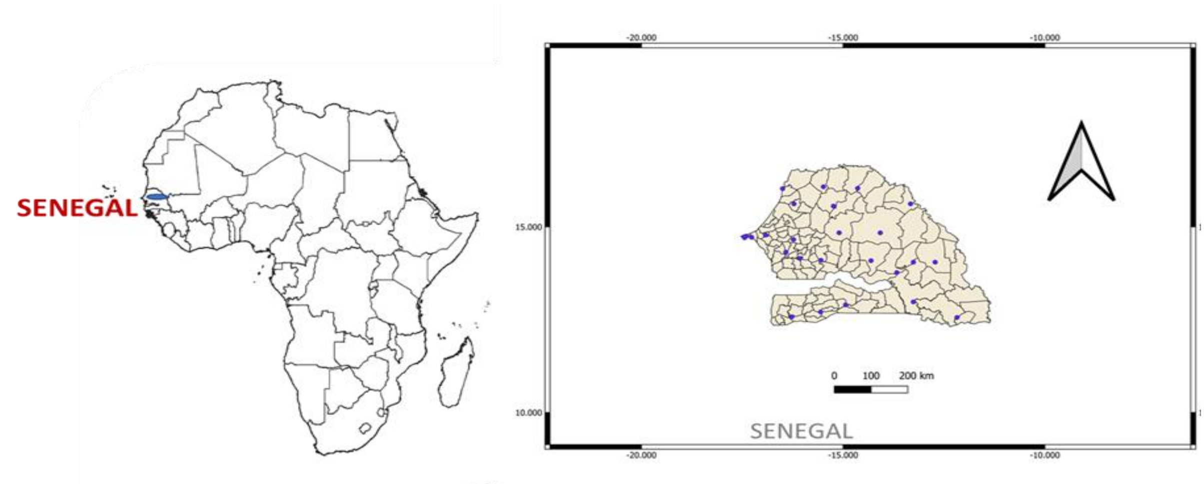


Fig.1. Study Locations over the study area

Table.1. Geographical Locations

LOCATION	LAT	LON	ELEVATION (M)	ANNUAL		
				Rainfall(mm)	Tmax	Tmin
PIKINE	14.75	-17.40	16	477	25.57	23.20
DAKAR	14.73	-17.46	29	519	25.37	23.44
THIÈS	14.78	-16.92	77	499	32.20	21.06
RUFISQUE	14.72	-17.27	10	519	25.37	23.44
ZIGUINCHOR	12.58	-16.27	9	1297	32.89	21.42
SAINT-LOUIS	16.03	-16.50	0	352	33.25	21.16
KAOLACK	14.15	-16.07	7	699	34.50	21.38
DIOURBEL	14.66	-16.23	10	616	35.56	21.12
LOUGA	15.62	-16.22	31	458	34.96	20.67
TAMBA	13.77	-13.67	30	664	36.32	22.66
KOLDA	12.90	-14.94	17	1091	34.16	21.48
FATICK	14.32	-16.42	8	616	35.56	21.12
KÉDOUGOU	12.56	-12.18	127	1269	34.48	22.00
KAFFRINE	14.10	-15.55	15	720	35.22	21.39
SÉDHIOU	12.71	-15.56	21	1335	32.87	20.93
MATAM	15.62	-13.33	27	473	36.63	22.72
MBANE	16.08	-15.49	26	379	35.85	21.21
GAMADJI SARRE	16.04	-14.64	51	359	36.73	22.05
YANG	15.56	-15.24	36	454	36.45	21.71
BARKEDJI	14.84	-15.10	52	534	36.32	21.88
VELINGARA	14.84	-14.08	55	531	36.62	22.36
KOUMPENTOUM	14.09	-14.31	48	685	36.07	22.43
BALA	14.05	-13.26	64	705	36.31	22.78
TAMBACOUNDA	14.05	-12.72	62	782	35.93	22.54

MISSIRAH	12.98	-13.26	31	1117	35.24	22.32

3. Data and Methodology

The study used NASA Power from the NASA Langley Research Centre POWER (Prediction Of Worldwide Energy Resources) Project (https://power.larc.nasa.gov/) from 1990-2021. The parameters such as maximum and minimum temperature, relative humidity and rainfall used for the present analysis. The downloaded data are at daily time step from which monthly and seasonal averages and normals were calculated for trend analysis, identifying heat stress regions using Rainfall Anomaly Indices, wet and dry days indices for the heat prone regions.

From the precipitation data, the Annual Rainfall Anomaly Index (RAI) was calculated to analyse the frequency and intensity of the dry and rainy years in the studied area. In addition, the monthly RAI was calculated for specific years of the historical series aiming to analyse the distribution of rainfall in the years of greatest anomaly. RAI, developed and firstly used by Rooy (1965) and adapted by Freitas (2005), constitutes the following equations:

RAI = $3[\frac{N-\bar{N}}{\bar{M}-\bar{N}}]$, For positive anomalies ……………………… (1)

RAI = $-3[\frac{N-\bar{N}}{\bar{X}-\bar{N}}]$, For negative anomalies ……………………… (2)

Where:

N = current monthly/yearly rainfall, in order words, of the month/year when RAI will be generated (mm)

$\bar{N}$= monthly/yearly average rainfall of the historical series (mm)

$\bar{M}$ = average of the ten highest monthly/yearly precipitations of the historical series (mm);

$\bar{X}$ = average of the ten lowest monthly/ yearly precipitations of the historical series (mm);

Thus, the positive anomalies have their values above average and negative anomalies have their values below average. As mentioned, criterion has been developed and applied to identify wet and dry spells over the study regions using the rainfall threshold derived from local evaporation climatology that is daily mean evaporation (DME) over the area of interest as mentioned by Kamalkishor RA , et al., 2015. The rainy days with less than the threshold depth of precipitation are accounted for the wet spell if they occur in an uninterrupted sequence, then the isolated sub threshold rainfall will be discarded, and considered as part of a dry spell. Then

calculated the duration, and rainfall amount of wet spells and calculated the number of wet spells per rainy season.

After finalizing the heat prone areas, the trends in the rainfall were also evaluated graphically using probability of exceedance charts. Calculated solar radiation using DSSAT model and prepared the met files for crop simulation models. Then analysed the crop yields and biomass for sorghum crop by considering different amounts of fertilizers. To evaluate the usefulness of the rainfall data in farm level decision making, the reliability assessment is focused on the decision maker's requirements which is to know whether the season is going to be AN or BN. Hence, the assessment was aimed it evaluating the forecasts' ability to indicate whether the seasons is AN or BN with respect to amount of rainfall received. For classifying the season as AN or BN we used the long term mean from the RF data as threshold value. The productivity of the crops in different seasons was evaluated to identify the minimum amount of rainfall below which the productivity of the crop was reduced significantly. The value of the seasonal climate forecast was evaluated by comparing these amounts with the 80% reliability values derived from the reliability assessment. If the crop threshold is below the 80 % reliability value, it is considered that the skill is suitable for use in farm level decision making.

4. Identifying Heat Stress Vulnerability regions in Senegal

Identifying the heat stress regions over Senegal by characterizing the nature of long-term climate change trends over study area from 1990-2021 by using the Nasa Power meteorological data as discussed in the section 3. The different parameters considered for the analysis vary in both spatial and temporal resolutions for the considerations of the vulnerable regions. Moreover, this is important to study the relationship between socio-economic heat stress regions and climate indices required to understand the Spatio temporal changes for their planning and management in improving agricultural prospects of smallholder's farmers in the present scenario.

4.1. Spatial Distribution of various Meteorological parameters

The variability in increased temperature will significantly change the interannual variability in the global carbon cycle, which is strongly in turn influenced and affects the agriculture. The high temperature and solar radiation lead to a higher evaporation from water resources, then the variability and scarcity of water resources and high temperature affect negatively the production in rainfed agriculture. The analysis of the Maximum temperature distribution during the study period, shows maximum over the entire region more than the 33ºC in all the seasons. The spatial distribution of the temperature shows very less variation, as it varies minimum 25 ºC at the Dakar and a maximum of 36.7 ºC at Matam and Gamadje Sarre (fig.2).

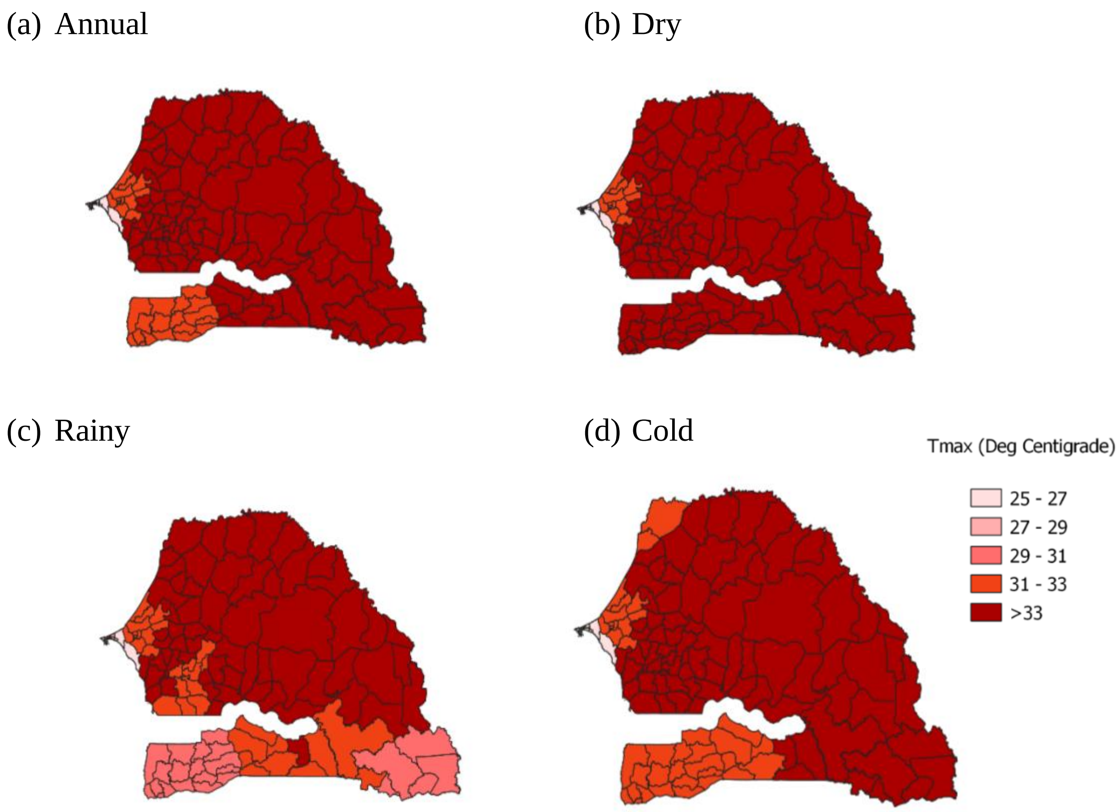


Fig.2. Spatial distribution of mean maximum temperature of all the seasons from (1990-2021) over the study area

Fig.3. shows the distribution of minimum temperature spatially over the study region. The annual mean minimum temperature ranges from 20 ºC to 23 ºC over the entire region and for the dry season it ranges from the 18 ºC - 25 ºC, whereas for the cold season the minimum temperatures ranges from 18 ºC - 23 ºC, but for the rainy season the temperatures are little high ranging from 23 ºC -26 ºC. Hence this spatial variability of maximum and minimum temperature lets the farm management difficult and would generally contribute to increased vulnerability for people in drylands, intensifying the challenges that people living in semiarid areas will face for their sustainable development.

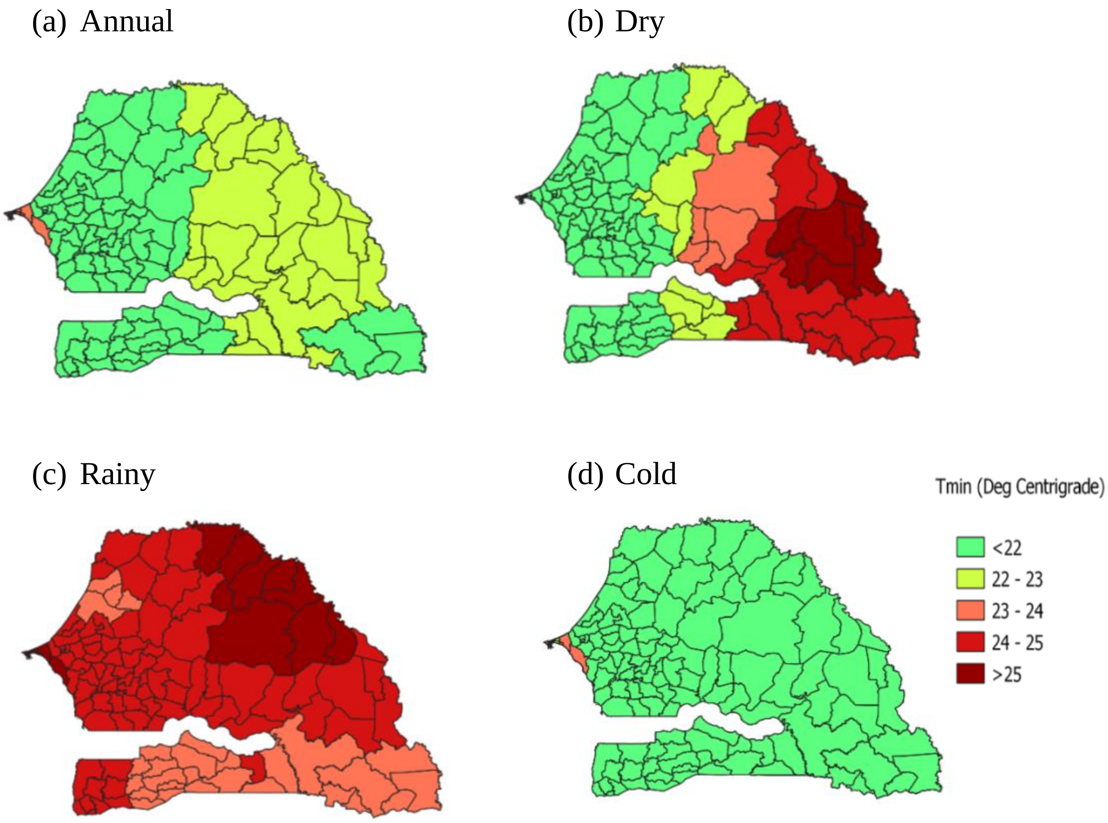


Fig.3. Spatial distribution of mean minimum temperature of all the seasons from (1990-2021) over the study area

Relative humidity (RH) is one of the climate factors that can modify final yield and quality of crops through its impact on processes with a short as well as with a long response time and it directly influences the water relations of plant and indirectly affects crops and finally economic yield. Very high or very low RH is not conducive for high grain, the increase in RH during panicle initiation to maturity increased grain yield of sorghum under low humidity conditions due to favourable influence of RH on water relations of plants and photosynthesis. With similar amount of solar radiation, crops that are grown with irrigation gives less yield compared to those grown with equal amount of 'water as rainfall. This is because the dry atmosphere, which is little affected by irrigation, independently suppresses the growth of crops. The spatial distribution of RH (fig.4.) shows very less value at the Gamadji Sarre, Matam, Mbane and Yang-Yang and whereas increased percentage of 80% at Dakar. Even in the cold and dry season the above four regions records RH in the range of 30% to 40% and in the rainy season also the RH ranges from 50 – 60% at the Gamadji Sarre, Matam, Mbane and Yang-Yang and RH recorded high at Dakar 86%. Thus, this is one of the parameters used to identify the heat stress regions over the Senegal and the further studies are interested on these four regions.

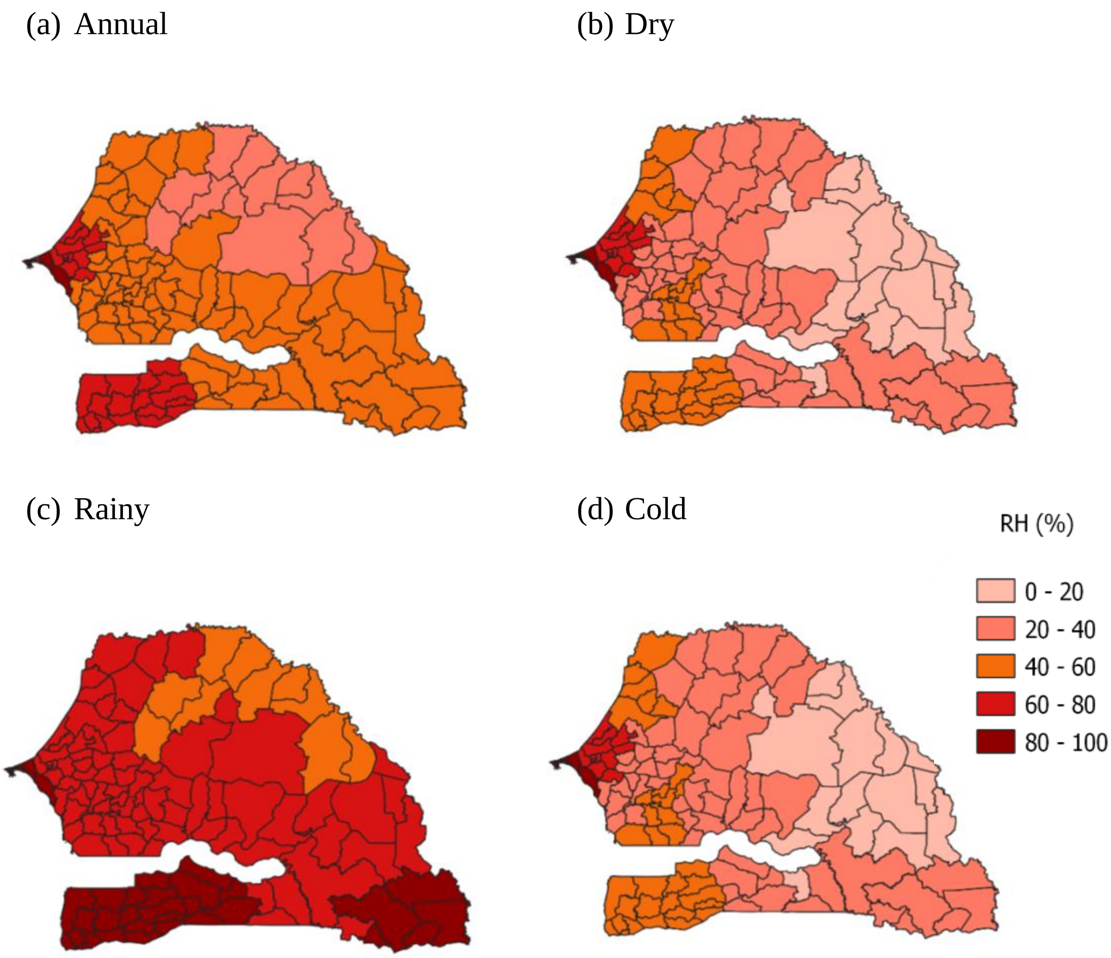


Fig.4. Spatial distribution of mean Relative Humidity (%) of all the seasons from (1990-2021) over the study area

The climatic indicators, such as temperature, humidity, and radiation were initially considered, but precipitation was chosen, as it has the highest correlation with all the factors. The analysis of the rainfall seasonal distribution during 1990-2021 period (fig.5.), shows their abundance during rainy season and their scarcity during the dry and cold season. The spatial distribution of the rainfall shows a big variation, it varies from a minimum of 330 mm at the Gamadji Sarre and a maximum of 1100 mm at the Sédhiou in the rainy season. RF is characterized by its scarcity, spatial and temporal variability with average of total annual rainfall varies from 1300 mm to 350 mm. The study focuses in Gamadji Sarre, Matam, Mbane and Yang-Yang region which has very low rainfall amount ranges from 330mm to 400mm compared to the other regions. This spatial variability lets the farm management difficult as low agriculture production, and high competition for land and water resources. Rainfall is usually torrential and are characterized by great spatial-temporal variations and inter and intra annual variations and the frequent dry years, drought persistence are more frequent in the study area.

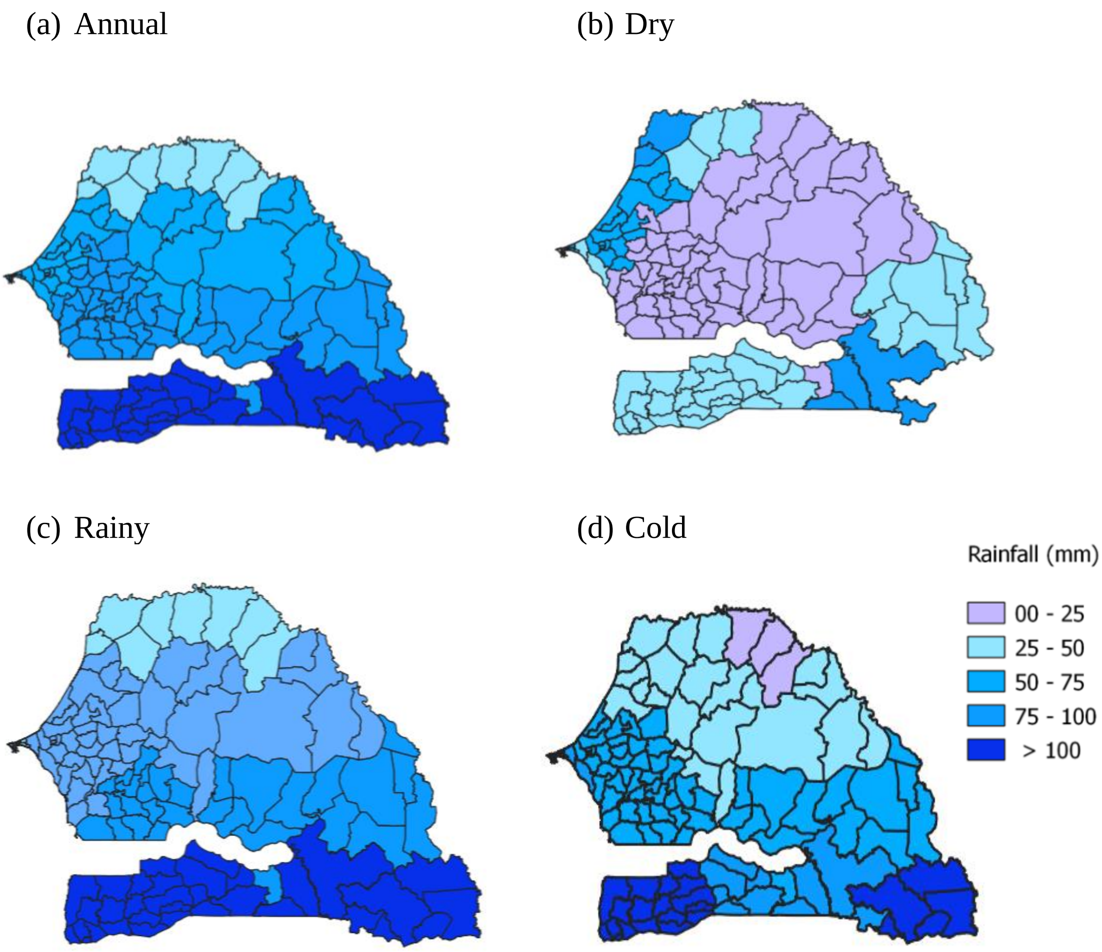


Fig.5. Spatial distribution of rainfall (mm) of all the seasons from (1990-2021) over the study area.

4.2. Analysis for selecting Heat stress regions

Assessment of heat stress regions is one of the most important aspects in agricultural planning and management. Agricultural heat prone assessment is a crucial element for planning suitable actions for improvement of conditions in heat stress situations. It demands analysis and understanding of past heat prone regions and its impact for the period of occurrences. The study also showed Spatio-temporal distribution of the maximum temperatures (fig. 6) high at some regions leads to heat prone areas and fig. shows very low humidity as marked in the figure. At additional risk of heat stress in a region characterized by another important indices such as RAI and Dry-Wet days analysis for finalizing the heat stress regions.

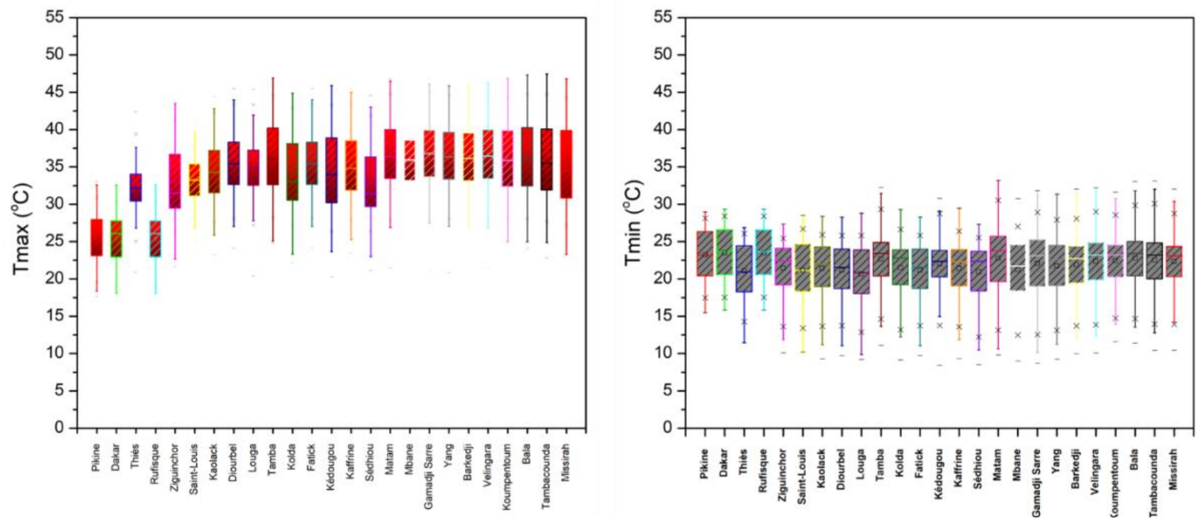


Fig.6. Maximum and Minimum Temperatures distributions over the study areas

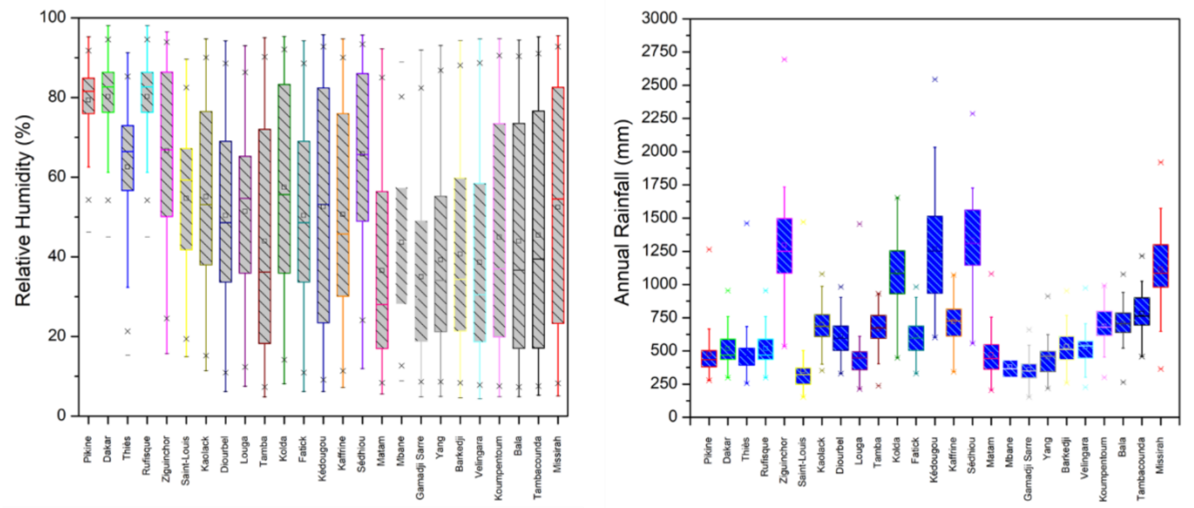


Fig.7. Distribution of Relative Humidity and Rainfall amount from 1990-2021

Fig.7. shows the distribution of the relative humidity and rainfall amount for identifying the heat stress regions, in which the relative humidity and rainfall amount are directly proportional to each other as observed the RH value shows very less range over the heat prone regions in the same way the rainfall amount also very less in those regions. But there are some more locations where the recorded rainfall amount is very less, whereas the RH records more. Fig.8. explains the dry and wet days of all regions, in which the percentage of wet days are very less over the four regions particularly Matam, Mbane, Gamadji Sarre and Yang- Yang compared to other areas. As observed in the right side plot the number of dry days and wet

days are inversely proportional, as there is an increased in the dry automatically there is a decrease in the wet days. The figure shows clearly as mentioned in the above four regions the number of dry days were increased with decreased wet days. Hence finally those four regions are confirmed as heat prone areas for further analysis.

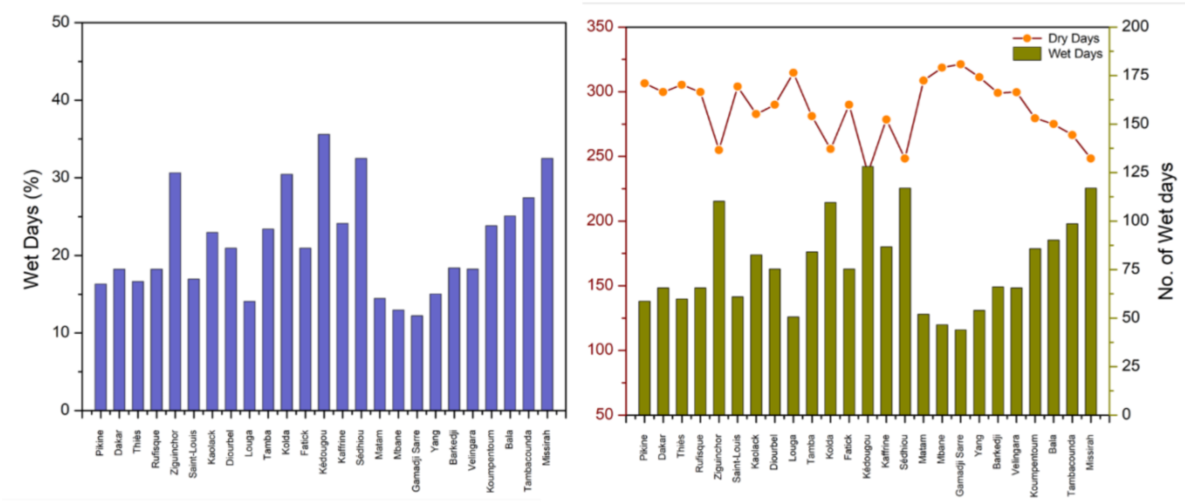


Fig.8. Dry and Wet days indices over the regions

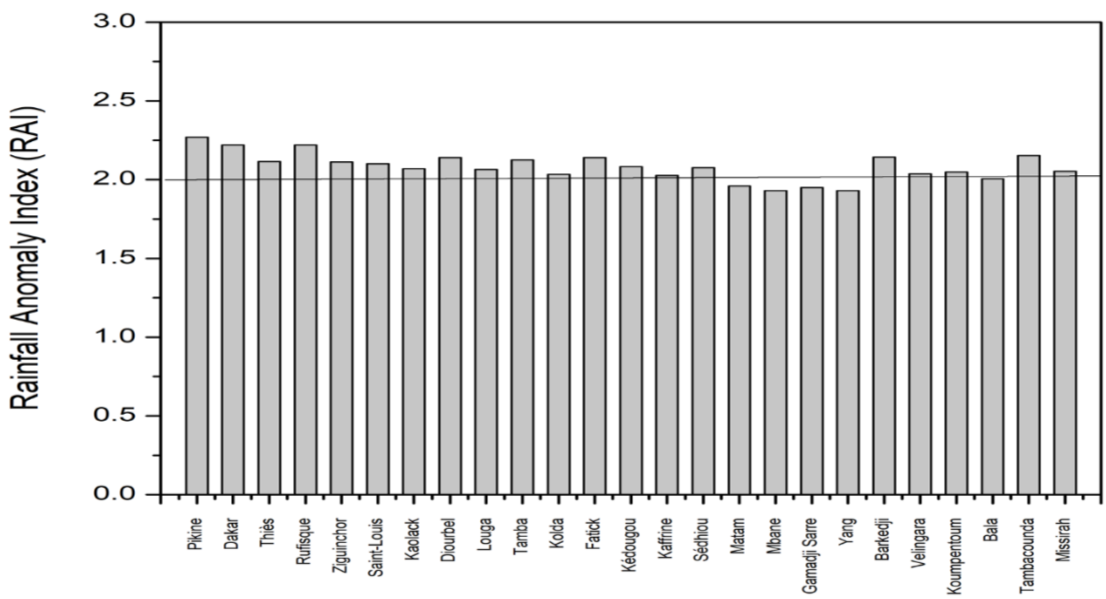
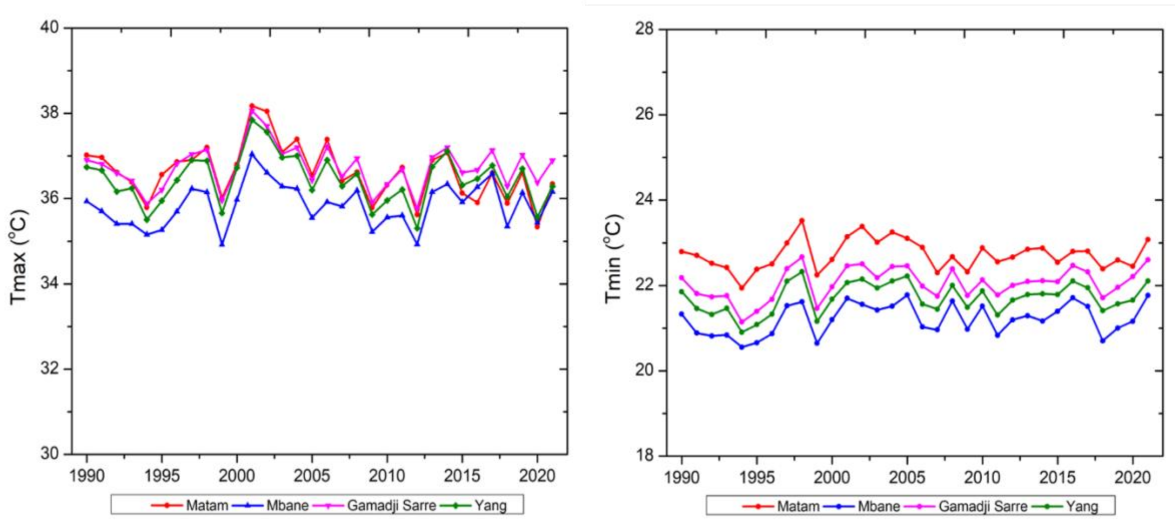


Fig.9. Rainfall Anomaly Index during the rainy season

Rainfall Anomaly index was one of the important indices for the identification of the wet, dry, humid and extreme humid conditions. Fig.9. clearly shows the four regions shows the value less than 2 that is less humid leads to record less amount of rainfall, as the other regions are more than the 2 means more humid with enough rainfall amount. Hence this is one of the important analyses for confirming the heat stress regions among the other areas.

4.3. Trend Analysis of Meteorological parameters over the heat prone areas

The nature of climate change in Matam, Mbane, Gamadji Sarre and Yang-Yang was analyzed using the long-term climate data. In the climate scenario where the climate is assumed to change in the current pattern. As many studies make clear the GHG emissions continue to rise throughout the 21st century, which is generally taken as the basis for worst-case climate change scenarios. The Fig.10. shows the nature of long-term trends in mean annual maximum and minimum temperature, RH and precipitation for the four regions. It is quite interesting to note that the mean annual temperature of four region shows very less variation as there was no statistically significant trend in the annual minimum temperature, whereas the solar radiation and rainfall are inversely proportional, as the solar radiation shows the decreasing trend leads to the increasing trend in the rainfall amount over the study period.



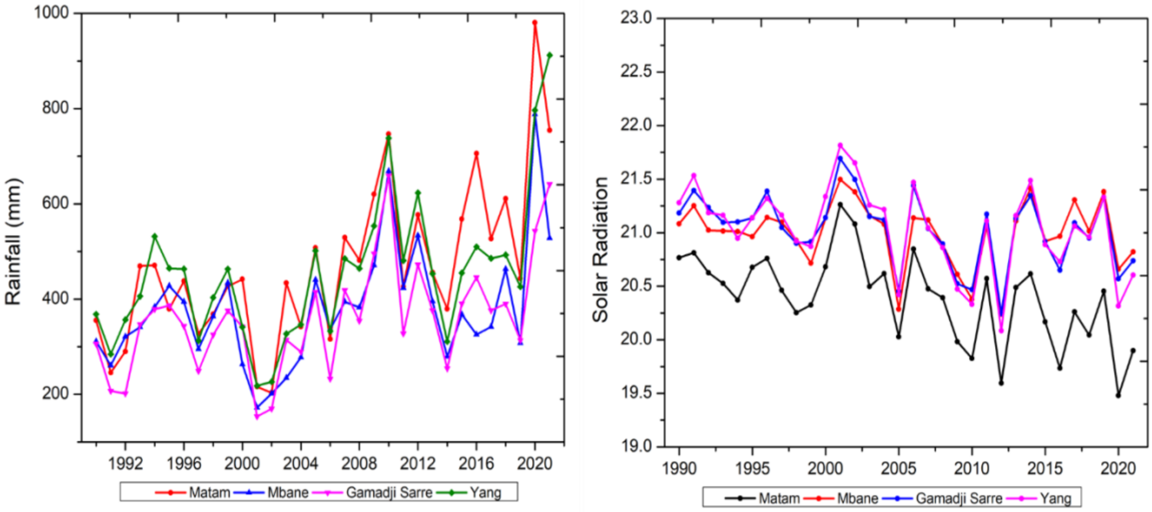
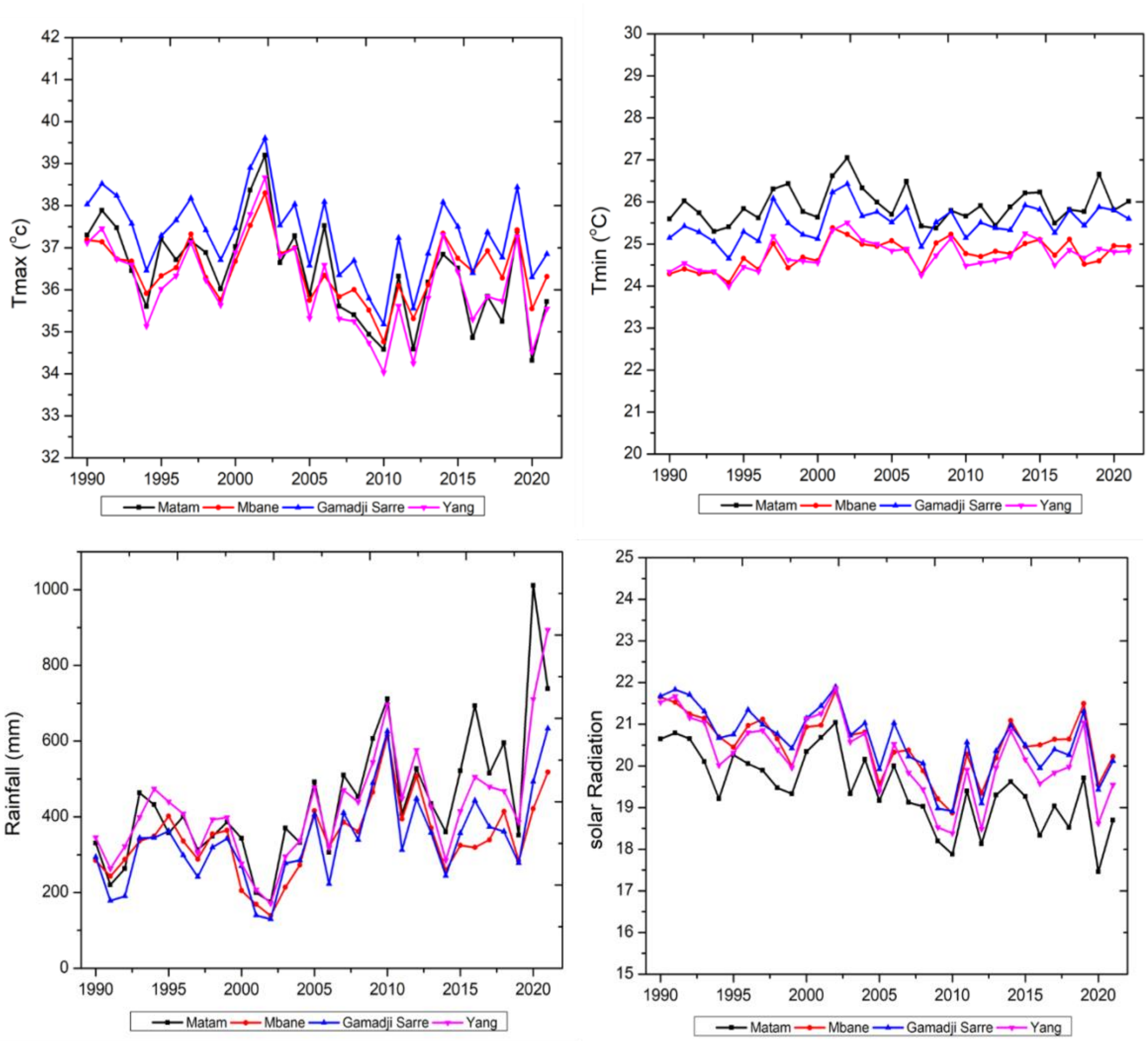


Fig.10. Annual trend analysis of meteorological parameters over the heat prone areas



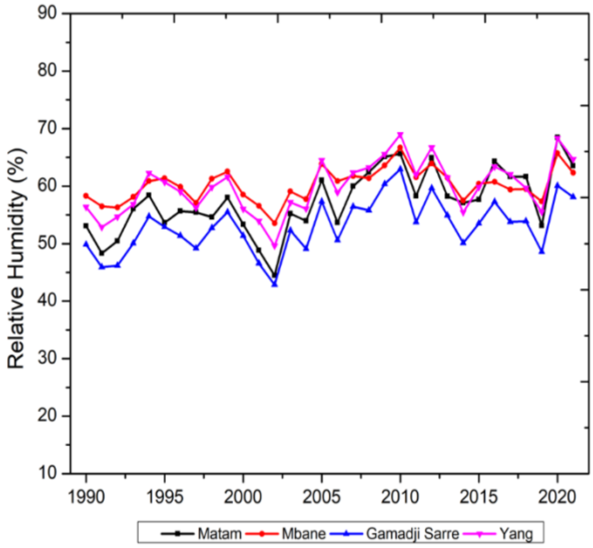


Fig.11. Seasonal trend analysis of meteorological parameters over the heat stress regions

The seasonal trend analysis of the Matam, Mbane, Gamadji Sarre and Yang-Yang as shown in the fig. 11. The nature of long-term trends in mean seasonal maximum and minimum temperature, RH, solar radiation and precipitation for the four regions. The interesting results to note that the mean seasonal temperature of four region shows very slight decreasing trend, as there was no statistically significant trend in the seasonal minimum temperature, whereas the solar radiation and rainfall are inversely proportional, as the solar radiation shows the decreasing trend leads to the increasing trend in the rainfall amount over the study period. The RH seasonal trend shows slight increasing trend over the period, which leads to increase in the amount of rainfall.

4.4. Distribution of rainfall amounts over the regions

For developing the heat stress assessment, the understanding the concept of distribution of rainfall is important. The trends in the temporal variability of the amount of rainfall for the heat prone regions were computed by constructing probability of exceedance charts (Fig.12). The temporal variability and distribution rainfall amounts for all the locations. At Matam the minimum amount of RF 200mm ranges to maximum 750mm except in the year 2020 (1000mm), at Mbane the rainfall distribution ranges from 170mm to 780mm, whereas Gamadji Sarre shows the rainfall distribution 150mm to 650mm. Yang-Yang shows the RF distribution ranges from 200mm to 900mm.

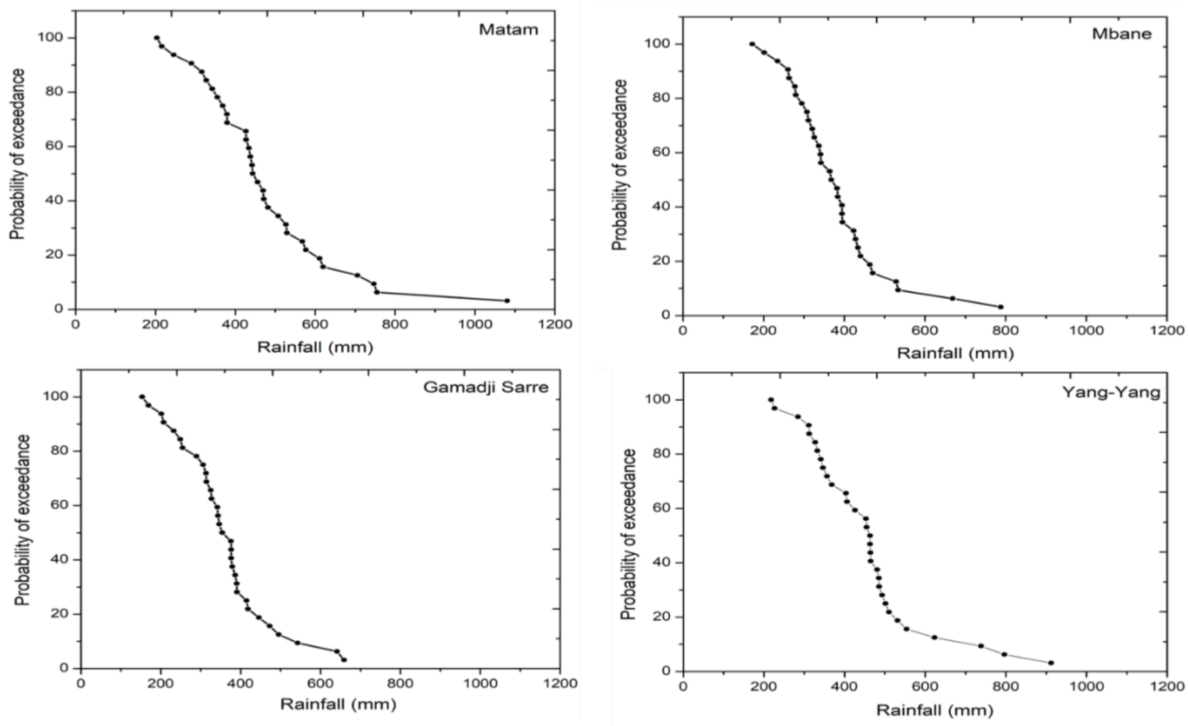


Fig.12. Distribution of rainfall amounts over heat stress regions

5. Simulation of crop growth and yields using Crop Model

This study was aimed to address the related usefulness of rainfall data sets in estimating crop growth and performance. Regions in Senegal are differently vulnerable to climate change and would have differential impacts on its agricultural systems. How crops respond to a changing climate will be driven by complex interactions between soil properties, crop type, weather, soil nutrient dynamics (esp. N and P), and agronomic practices is speculative, and the identification of context specific adaptation practice is often complex (Joseph et al., 2020). For this, conducted a scenario analysis with system simulation model APSIM using sorghum as a test crop. APSIM is a widely used farming system model that simulates crop growth and development as a function of soil, climate, and management variables (Holzworth et al. 2014). APSIM has been widely tested in Africa to simulate the performance of sorghum and other crops (Akinseye et al. 2017; Whitbread et al. 2010). In this study, APSIM (version 7.8r3867) was configured with sorghum and a standard soil profile with 91 mm PAWC, 0.52% organic carbon to 40 cm depth, and 100 cm rooting depth for all locations. The soil is a loamy sand and other parameters are set to match this texture. These include curve number to 85, U or first stage evaporation to 3.5, falling rate (Cona) or second stage evaporation to 6, diffusivity constant to 250, diffusivity slope to 22, and SWCON to 0.7. Simulations were conducted for rainy season at four locations, using a standard set of crop management practices. Sorghum sowing was triggered by a rainfall criterion which is set to 30 mm rainfall over three days

during the month in which the rainy season starts, used with a plant population of 50,000 plants/ha. Other management practices used are one tillage with the disc before the sowing window starts and application of 40 kg N as urea N at the time of planting.

5.1. Yield analysis of Sorghum crop in Senegal

The yield performance of currently believed to be robust crop systems, agronomic practices and crop varieties under extreme climatic conditions and changing atmospheric gases concentrations are speculative creating uncertainties in food securities in these vulnerable countries. Hence to explore the possible responses of a given crop under different conditions of climate and management and help us identify climate-smart adaptation practices, which in turn would help in developing new cultivars and best agronomic practices with the natural resources available. In this study, an effort has been made to understand the nature of interannual yield variability under a climate change context. Most of the people grow food crops such as millet, sorghum, rice and Groundnuts (Peanuts) are the primary cash crop for farmers. Considering the rainfall data sets in estimating the amount of rainfall and the number of rainy days, an assessment was carried out to examine the differences in crop growth and yield. For this assessment, used a soil whose plant available water content and organic matter content were set to represent the conditions that are common to the majority of the smallholder farms in these areas. The profile used in the simulations has a plant available water capacity of 90 mm to one-meter depth and organic carbon content of 0.5% in the top layer. One tillage operation was preceded the sowing operation and 40 kg N was applied at the time of sowing. Simulations were carried out to observe the biomass and crop yields assessments in all the four locations.

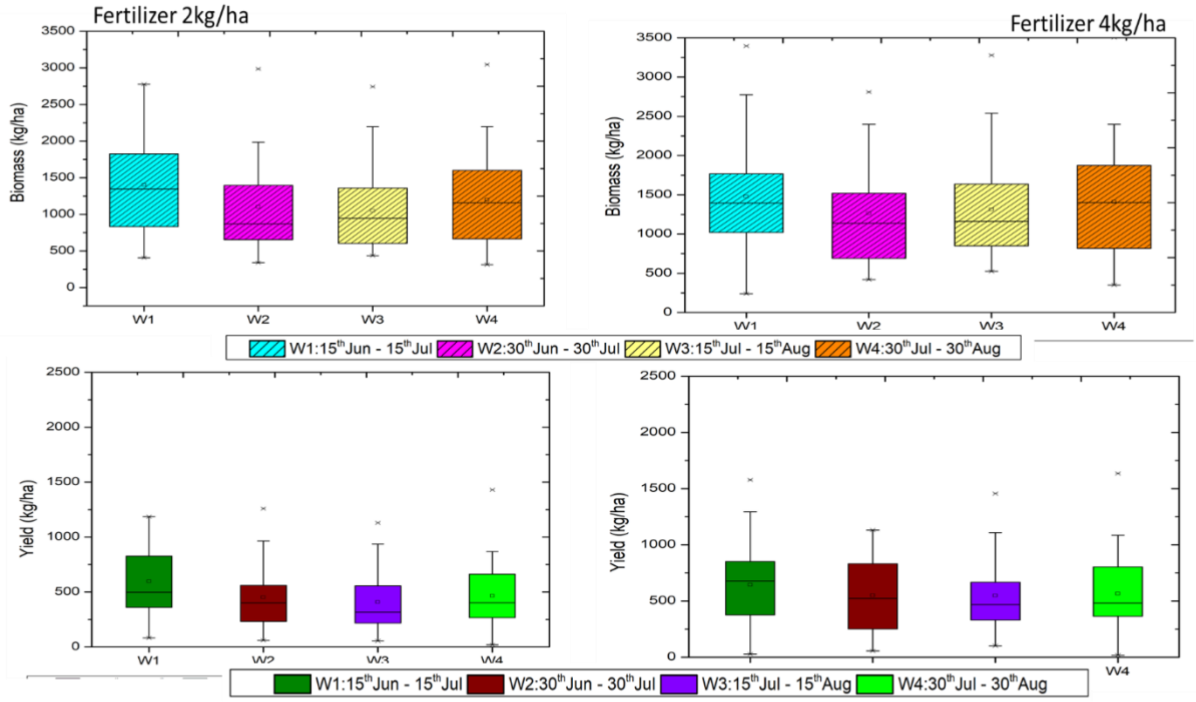


Fig.13. Biomass and Yield analysis of Sorghum crop at Matam

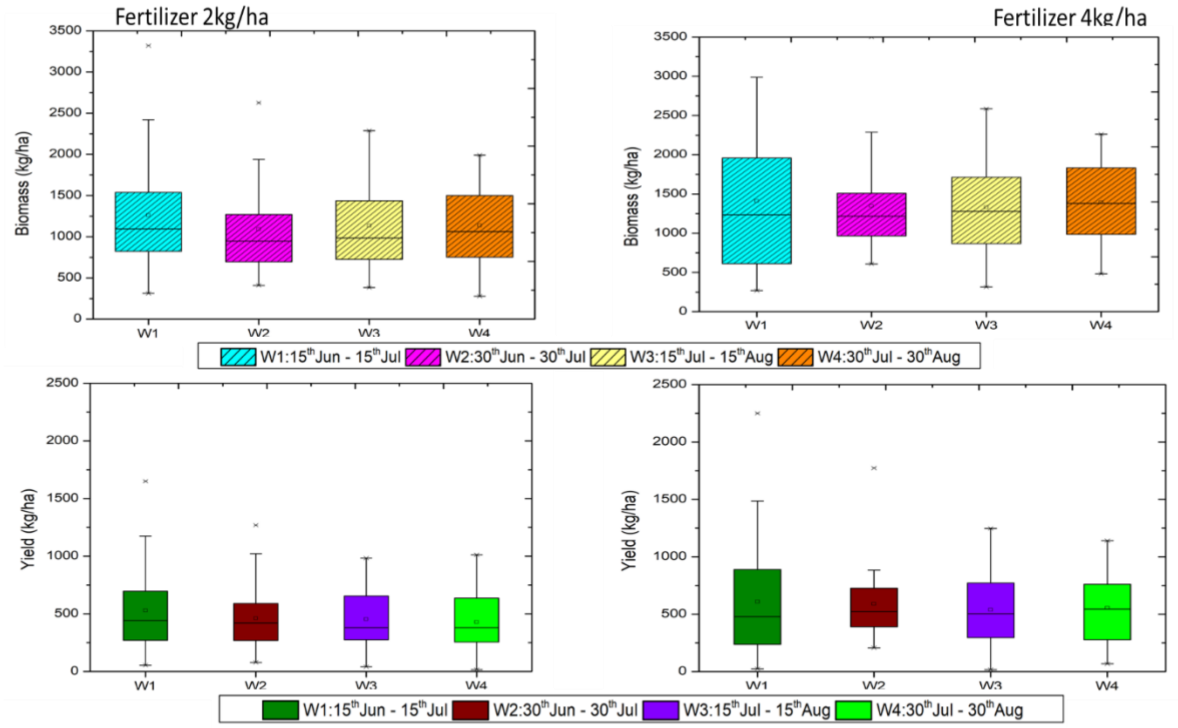


Fig. 14. Biomass and Yield analysis of Sorghum crop over Mbane

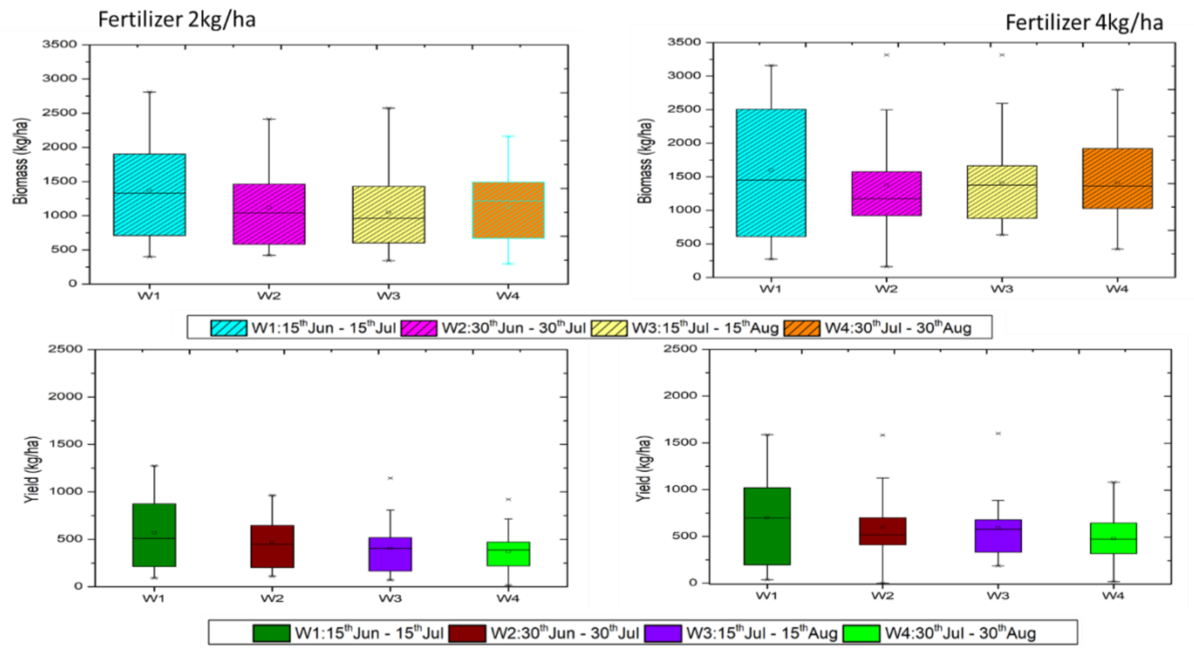


Fig. 15. Biomass and Yield analysis of Sorghum crop over Gamadji Sarre

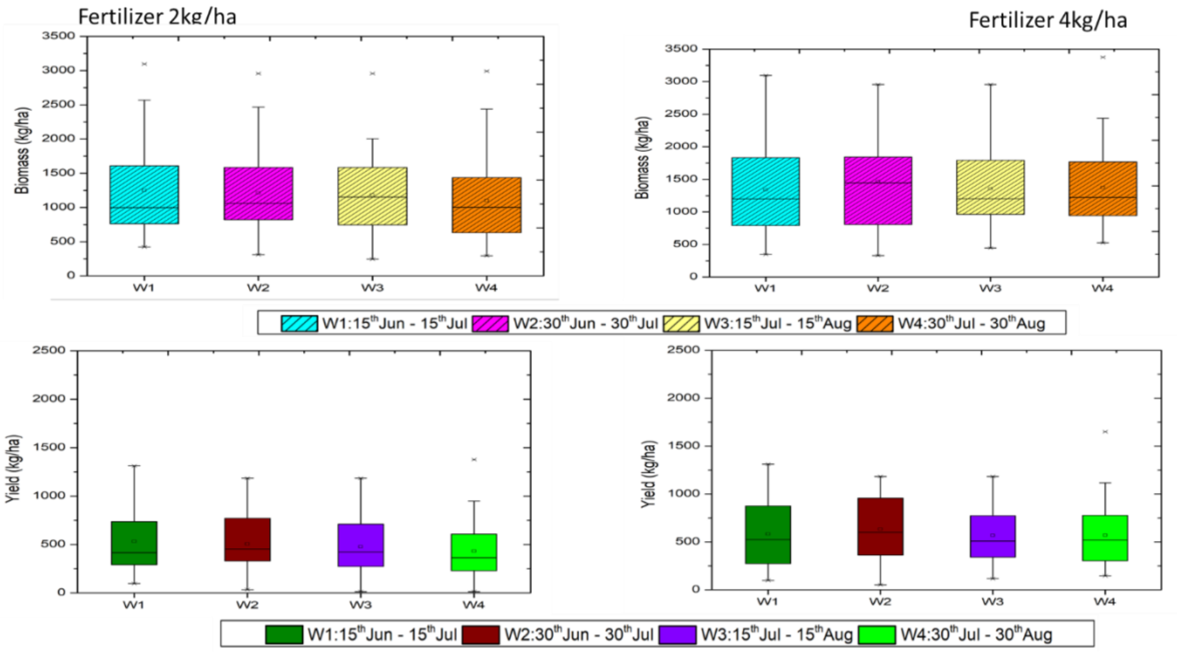


Fig. 16. Biomass and Yield analysis of Sorghum crop over Yang-Yang

The interannual sorghum yield was simulated using the APSIM model using four different sowing windows (W1:15th Jun – 15th Jul; W2: 30th Jun – 30th Jul; W3: 15th Jul – 15th Aug; W4: 30th Jul – 30th Aug) and with two fertilizers amount (F=2kg/ha and 4kg/ha) during the rainy seasons as shown in Fig. 13,14,15, &16. The sorghum yields results showed increasing yield in the W1, then W2, W3 and less yield in W4 for both the fertilizers amounts for all locations. In Matam for F=2kg/ha nearly 25% decreased in the yield for rest of the windows compared to W1 and for F=4kg/ha average 14% decreased in yield. Then an average there is an increased in the yield of 17% with more fertilizer amount. At Mbane for F=2kg/ha nearly 15% decreased in the yield for rest of the windows compared to W1 and for F=4kg/ha average 07% decreased in yield. Then an average there is an increased in the yield of 18% with more fertilizer amount at 4kg/ha. For Gamadji Sarre the fertilizer amount F=2kg/ha nearly 27% decreased in the yield for W2, W3 &W4 windows compared to W1 and for F=4kg/ha nearly 20% decreased in yield. Then an average there is an increased in the yield of 23% with more fertilizer amount. In Yang-Yang the fertilizer amount F=2kg/ha nearly 11% decreased in the yield for rest of the windows compared to W1 and for F=4kg/ha average 1% decreased in yield. Then an average there is an increased in the yield of 17% with more fertilizer amount.

5.2. Assessing the minimum amount of rainfall with 80 % or higher reliability

The reliability assessment has indicated to have the required skill for use in farm level decision making. This assessment was conducted using the long-term average rainfall as the threshold to classify whether the season is AN or BN. Then considered is to evaluate the usefulness of the forecasts by identifying the amount of rainfall that can be forecasted with the required skill which according to farmers is 80% or correct at least four out of five years. This can be done by changing the threshold used to classify a season as AN or BN. We repeated the reliability assessment using the same methodology but with different amounts of rainfall to classify the season as AN or BN until the skill scores reached 80% reliability. The amount of rainfall used in getting to this skill level is then considered as the amount of rainfall that can be expected with 80% reliability when the season was forecasted to be AN. Substantial changes in the skill scores were observed when the amount of rainfall used to define AN and BN seasons was changed. After summarising the best level of reliability that can be achieved with the better skills. The amount of rainfall that was used to achieve these skills is the amount of rainfall that can be expected 80% times when the season gets AN rainfall. In general, these amounts are lower than the long averages at all the locations. The magnitude of this difference varied from 28% at Matam, 24% at Mbane, 26% at Gamadji Sarre and 27% at Yang-Yang. The success ratio indicates the percent of years in which this amount of rainfall occurs with AN season.

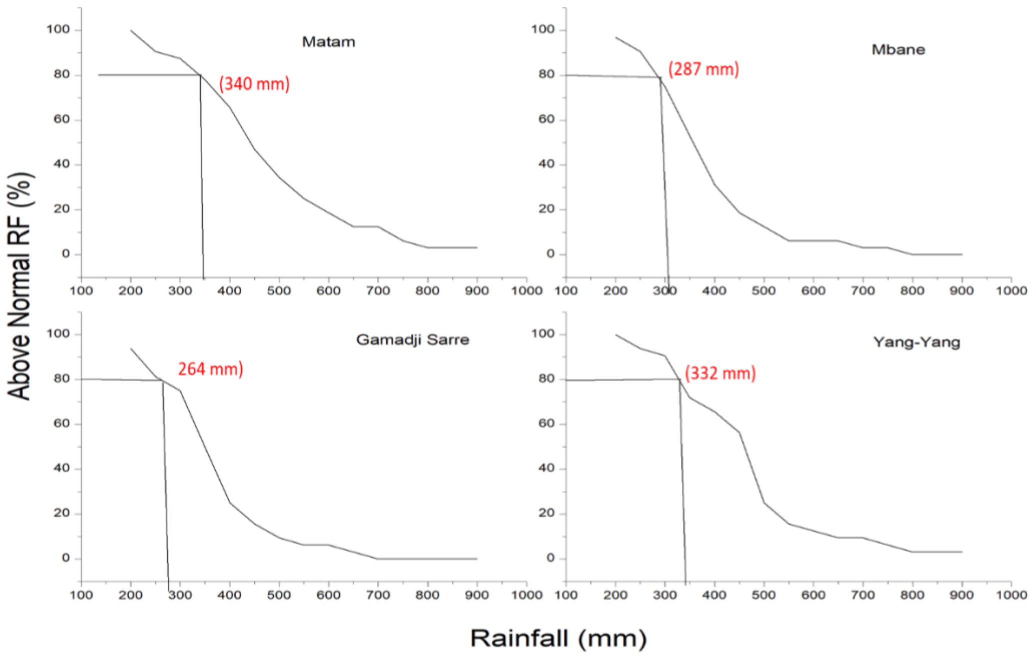
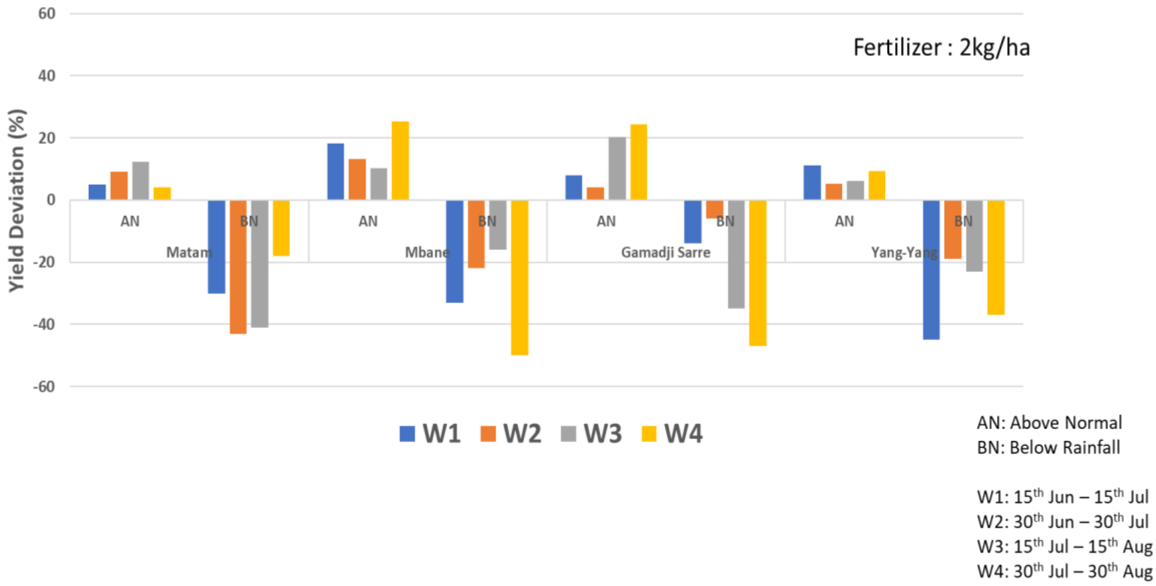


Fig.17. Assessing the minimum amount of rainfall over the heat stress regions with 80 % or higher reliability.

5.3. Potential role of reliability of rainfall amount in climate risk management

The role of these reliability in influencing farm level decision making was assessed using the simulated crop production statistics. Initially, analysed how major crops in these areas performed during the AN and BN seasons identified using the 80% reliability rainfall amounts. At four locations, a substantial reduction in the yields of all crops was observed during the BN years. For example, at Matam yields of sorghum crop, were reduced by 33% during the BN seasons and increased by nearly 8% in the AN for F=2kg/ha, but whereas for fertilizer 4kg/ha yield reduced 35% for BN increase in 9% for AN on an average of all windows. In Mbane crop yields, were reduced by 30% during the BN seasons and increased by nearly 17% in the AN for F=2kg/ha, but whereas for fertilizer 4kg/ha yield reduced 37% for BN and increase in 20% for AN. At Gamadji Sarre the crop yields, were reduced by 26% during the BN seasons and increased by nearly 12% in the AN for F=2kg/ha, but whereas for fertilizer 4kg/ha yield reduced 30% for BN and there is no increase in the yield for AN. In Yang-Yang sorghum yields, were reduced by 31% during the BN seasons and increased by nearly 8% in the AN for F=2kg/ha, but whereas for fertilizer 4kg/ha yield reduced 41% for BN and increase in 10% for AN. This partially is attributed to the amount of rainfall used to classify these seasons which is less than the long term means and hence, the BN seasons are much drier which explains the observed reduction in the yields.



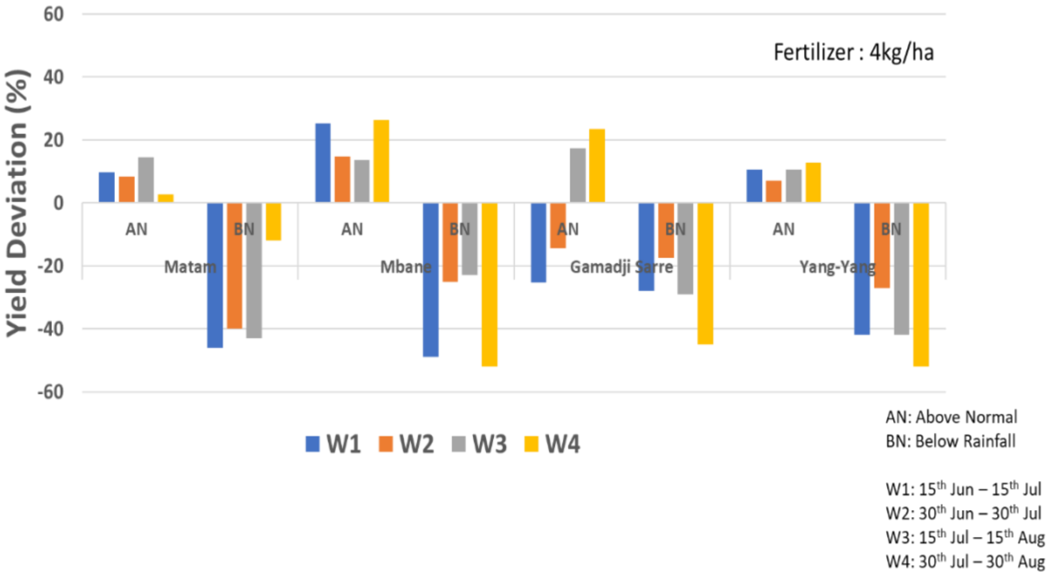


Fig. 18. Change in yields of sorghum crop grown in the selected areas during the above and below normal seasons. The above and below normal seasons were identified using 80% reliable forecast amounts

6. Summary and conclusion

The present study endeavours to evaluate the heat stress intensity and frequency over Senegal of West Africa. Present research computes the assessment of the impacts of heat stress areas in semi-arid regions with regional weather/climate through synergy of different observational techniques and the mitigating of the climate change to assess the risk of climate and weather on farming system through crop simulation models. For this analysis selected 25 locations (cover a latitudinal range from 12 to 16 deg and Longitudinal range from -17 to -12 deg) over the Senegal which are highly dependent and sensitive to the amount and distribution of rainfall during the crop season. Agriculture is very important to the economy of Senegal as most of the people grow food crops such as millet, Sorghum and Rice.

Analysis starts with the distribution of the temperatures, relative humidity and rainfall amount for identifying the heat stress regions. Form this trend analysis it observed that more temperatures at those some particular regions with less rainfall amount. RAI also computed for assessing the heat stress regions, results show mostly these four regions (Matam, Mbane, Gamadji Sarre ad Yang-Yang) lies below the value 2 leads to less humid with limited rainfall Then assessed the dry and wet days of all regions, in which the percentage of wet days are very less over the four regions particularly Matam, Mbane, Gamadji Sarre and Yang- Yang compared to other areas. As observed the number of dry days and wet days are inversely proportional, as there is an increased in the dry days automatically there is a decrease in the wet days. In the four regions the number of dry days were increased with decreased wet days with only 12-15% wet days. Hence finally those four regions are confirmed as heat prone areas for further analysis.

This study was aimed to address the usefulness of rainfall data sets in estimating crop growth and performance. Regions in Senegal are differently vulnerable to climate change and would have differential impacts on its agricultural systems. Crops respond to a changing climate will be driven by complex interactions between soil properties, crop type, weather, soil nutrient dynamics (esp. N and P), and agronomic practices is speculative, and the identification of context specific adaptation practice is often complex. For this, we conducted a scenario analysis with system simulation model APSIM using sorghum as a test crop.

The seasonal climate data for the period 1990 to 2021 were further evaluated for its reliability for the yield percentages with the help of rainfall data. The interannual sorghum yield was simulated using the APSIM model using four different sowing windows (W1:15th Jun – 15th Jul; W2: 30th Jun – 30th Jul; W3: 15th Jul – 15th Aug; W4: 30th Jul – 30th Aug) and with two fertilizers amount (F=2kg/ha and 4kg/ha) during the rainy seasons. The sorghum yields results showed increasing yield in the W1, then W2, W3 and less yield in W4 for both the fertilizers amounts for all locations. In Matam for F=2kg/ha (4kg/ha) nearly 25% (14%) decreased in the yield percentages, with an average increased in the yield of 17% with more fertilizer amount. At Mbane for F=2kg/ha (4kg/ha) nearly 15% (7%) decreased in yield and with an increased in the yield of 18% with more fertilizer amount. For Gamadji Sarre the fertilizer amount F=2kg/ha (4kg/ha) nearly 27% (20%) decreased in the yield, an average

increased in the yield of 23% with extra fertilizer amount. In Yang-Yang the fertilizer amount F=2kg/ha (4kg/ha) nearly 11% (1%) decreased in yield with increased in the yield of 17% with more fertilizer amount.

Since the aim of this assessment is to evaluate the usefulness of the forecast in farm level decision making, the reliability assessment is focused on the decision maker's requirements which is to know whether the season is AN or BN. Hence, the assessment was aimed it evaluating the amount of rainfall ability to indicate whether the seasons is AN or BN with respect to amount of rainfall received. For classifying the season as AN or BN we used the long term mean from the data as threshold value and then the mean RF amount above the threshold as AN yield and below the threshold value consider the BN yields. The reliability assessment was conducted by plotting the probability distribution graphs for AN rainfall amount from that obtaining the reliability value at 80%.

The role of these reliability in influencing farm level decision making was assessed using the simulated crop production statistics. At four locations, a substantial reduction in the yields of sorghum crop was observed during the BN years. For example, at Matam yields of sorghum crop, were reduced (increased) by 33% (8%) during the BN (AN) seasons for F=2kg/ha, but for F=4kg/ha reduced (increased) by 35% (9%) during the BN (AN). In Mbane crop yields, were reduced (increased) by 30% (17%) during the BN (AN) seasons for F=2kg/ha, but for F=4kg/ha reduced (increased) by 37% (20%) during the BN (AN). At Gamadji Sarre the crop yields reduced (increased) by 26% (12%) during the BN (AN) seasons for F=2kg/ha, but for F=4kg/ha reduced (increased) by 30% (0%) during the BN (AN).In Yang-Yang yield reduced (increased) by 31% (8%) during the BN (AN) seasons for F=2kg/ha, but for F=4kg/ha reduced (increased) by 41% (10%) during the BN (AN).

This partially attributed to the amount of rainfall used to classify these seasons which is less than the long term means and hence, the BN seasons are much drier which explains the observed reduction in the yields. Since seasonal climate data is mainly used in the selection of crops to be planted and for allocation of land to various crops, production and productivity of the major crops grown in the district was analysed as a function of amount of rainfall received during the season. For these the simulated sorghum yields are considered for the period from 1990 to 2021. The productivity of the crops in different seasons was evaluated to identify the minimum amount of rainfall below which the productivity of the crop was reduced significantly. The value of the seasonal rainfall amount was evaluated by comparing these amounts with the 80% reliability values derived from the reliability assessment. If the crop threshold is below the 80 % reliability value, it is considered that the levels of skill is suitable for use in farm level decision making.

This analysis indicates the potential role the seasonal climate forecasts plays an important role in preparing better decisions in selecting the crops, allocating land to various crops, and preparing necessary inputs. Depending on the risk-taking ability of the farmer, can plan to

diversify the farm with drought tolerant crops and short duration varieties to spread risk and reduce the area under water sensitive crops to avoid major losses during the seasons forecasted to be below normal. Farmers can also consider alternative management practices aimed at conserving soil moisture and provision of life saving irrigations where possible. Overall, the analysis has indicated that the available which has the potential to reduce the risk and improve the profitability of the agricultural systems if decision makers use this information as a basis in planning and conducting farm operations**.**

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