The influence of the subtropical high-pressure systems on rainfall and temperature distribution in Suriname and implications for rice production in the Nickerie District

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ABSTRACT

The influence of the subtropical high-pressure systems on rainfall and temperature distribution in Suriname and implications for rice production in the Nickerie District

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The objective of this research is twofold. First of all an investigation is done on the influence of the subtropical high pressure systems, the North Atlantic high and the South Atlantic high on the rainfall and temperature in Suriname. The second objective was to examine the influence of these systems on rice production in the Nickerie District. Rainfall, temperature data of Suriname and the sea level pressure data as the characteristics for the subtropical high-pressure systems from 1971-2008 were examined. Furthermore, rice production data of the Nickerie District from 1971-2008 were also investigated in relation with the temperature, rainfall and the subtropical high-pressure data. The rainfall and temperature distribution and the relation between the subtropical highs and the rainfall and temperature are determined with the regression and correlation analyses. No uniform trend is identified for the seven selected stations in Suriname but on the other hand, the temperature pattern is almost uniform and shows a seasonal cycle. Furthermore, an increase occurred of 0.01-0.05 0C/year in the temperature for the selected stations in the past 39 years, 1971-2008. The subtropical highs central pressure started to increase since 1991 and is still increasing up to the present. Simple correlation and regression analyses showed that there is a positive and negative relationship between the subtropical high-pressure systems and the rainfall and the temperature. Finally, the rice production is negatively related to the temperature and positively related to the rainfall, except in the second sowing season.

Keywords: Subtropical high-pressure system, South Atlantic high-pressure system, North Atlantic High pressure system, Rice production

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LIST OF ACRONYMS

ANLY annual

ADRON Anne van Dijk Rijst Onderzoeks centrum Nickerie

Dipl.Met Diplomet Meteoroloog

DJF December, January, February

IPCC Intergovernmental Panel on Climate Change

ITCZ Inter Tropical Convergence Zone

JJA June, July, August

MAM March, April, May

MSL Mean sea level

MSLP Mean sea level pressure

Mb Millibar

MLY Monthly

MDS Meteorologische Dienst Suriname (Meteorological Service Suriname)

NOAA National Oceanic and Atmospheric Administration

NCEP National Center for Environmental Prediction

NCAR National Center for Atmospheric Research

NSTH North Atlantic Sub Tropical High

R Correlation coefficient

RR Rainfall

SON September, October, November

SSTH South Atlantic Sub Tropical High

SSTH South Atlantic Sub Tropical High

TT Temperature

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1 INTRODUCTION

The subtropical highs are areas of relatively high surface pressure at the earth's surface and the five highs are identified as the North Atlantic high, North Pacific high, South Indian Ocean High, South Atlantic high and South Pacific high. The position of the highs varies between 40N – 40 S. Subsidence is very common in subtropical high-pressure zones, and therefore a lack of rainfall and a high evaporation causes the world's greatest dessert (Lamb, 1972).

The subtropical highs undergo variations of intensity and position in the course of the year. These highs are closest to the equator during the respective winter and during the summer are displaced pole ward. In addition to the latitude displacement, the North and South Atlantic highs are located further east in the boreal winter, and shifted further West in the boreal summer. The longitude displacements of the highs are, on the other hand not well understood. Furthermore, the vertical motion field associated with the subtropical highs and their annual changes influence the surface weather and climate (Hastenrath, 1990). This focus of the study is on the North Atlantic and the South Atlantic high. Suriname is above the equator and therefore in between of these two high-pressure systems. These systems might have some influence on the weather and climate of Suriname and thus other possible impacts on other sectors.

High-pressure systems affect temperature and rainfall pattern over some parts of the world like Asia and have caused shifts in seasonal climate. In addition, a change in climate can have both positive and negative impact on agriculture (Easterling et al., 2007). The focus of this study is on the influence of the North Atlantic high (Bermuda-Azores high) and the South Atlantic high (St.Helena high) on rainfall and temperature distribution in Suriname and the implications for rice production in the Nickerie District.

The climate of Suriname has two wet and two dry seasons and it has been observed that sometimes the start of the rainy seasons is delayed and/or it might rain considerably more in some years than others might. Furthermore, in some years the dry seasons may be warmer than normal, while in other years the dry seasons may be cooler than is typical. It is for these reasons that it was decided to examine whether the position and strength of the subtropical high-pressure systems might cause a late start to the wet season and influence rainfall and temperature patterns during the wet and dry seasons.

The rice farmers depend on the rainy season to start the sowing of rice and since water is one of the production factors for rice, it is important to know whether a change in this production factor might have an impact on the rice yield. Rice farming in Suriname is irrigated and mechanized, but some rice production is still rain-fed. The Nickerie District uses some of its water resources for irrigation purposes, but whenever there is reduced rainfall, this causes a decrease in the water levels. Moreover, other factors like salt water intrusion into the soils and aquifer could combine to have a negative impact on rice production. Since rice production contributes significantly to the country's GDP, a late start of the rainy season might cause a delay in the sowing of rice and hence a decrease in the rice yield might occur. This in turn would have an adverse effect on the country's ability to earn revenue. Rice occupies an important place in the world cereal crop. Moreover it is a staple food of million in the world and for Suriname.

In addition, there are no studies conducted yet at the local level regarding the impact of weather related events on rice production.

The principal aims of the research are: (1) To determine the extent to which the subtropical high-pressure systems influence seasonal rainfall and temperature distribution in Suriname and (2) to evaluate the impact of rainfall and temperature on rice production

These aims will be pursued by carrying out a number of tasks with the following objectives:

To investigate changes in the pattern of rainfall distribution and temperature caused by the subtropical high-pressure systems during the wet and dry seasons over the period 1971-2008.

To evaluate the extent to which changes in temperature, rainfall and other climate variables correspond to similar patterns of global and regional change, and thus may be attributable to changing atmospheric concentrations of greenhouse gas emissions.

To identify and describe the potential impacts of any detectable changes in these climate variables on the rice production in Suriname.

To develop a preliminary adaptation framework for responding to potential climate change impacts in the rice sector.

The research will seek to answer a number of issues, including the following:

- Do the position and strength of the subtropical high-pressure systems affect the seasonal rainfall and temperature pattern?
- When do the subtropical high-pressure systems exert the greatest influence on the rainfall and temperature distribution over Suriname?
- What are the observed changes in temperature and rainfall over Suriname during the period 1971-2008?
- What are the implications of these temperature and rainfall changes for the rice production in Suriname?
- Are seasonal changes in rainfall and temperature in Suriname related to global and regional greenhouse gas emissions?
- What viable adaptation policies might Suriname consider implementing in the rice sector with the given projected climate change impacts?

The findings from this research might therefore prove useful to the following groups:

- Scientists and researchers who are interested in the influence of the subtropical high pressure systems on seasonal changes of rainfall and temperature and their relationship to rice production
- Farmers who might be considering adapting their rice sowing schedule, owing to possible climate changes,
- National policy makers who design policies for agriculture projects, including rice cultivation, and
- Researchers investigating aspects of climate change, in particular temperature and rainfall changes, at the regional and local level

The remainder of this section consists of information to the background of study and provides a review of the country’s characteristics and the climatic environment.

1.1 Background to the study

The position of Suriname is at the north of the equator, on the North East coast of South America. The geographical position is between 4^0 – 6^0 North latitude and 54^0 – 58^0 West longitude. Paramaribo is the capital of the country and is at the coastal zone of Suriname.

Figure 1.1-1: Map of Suriname with the ten Districts and the selected meteorological stations Source: Meteorological Service Suriname

The borders of the country are to the north the Atlantic Ocean, French Guiana to the east, Brazil to the south and Guyana to the west. The land area of Suriname is about 164000 km2 and the country is divided into 10 administrative districts (Marowijne, Commewijne, Wanica, Paramaribo, Para, Brokopondo, Sipaliwini, Saramacca, Coronie, and Nickerie) (fig.1.1-1), with the capital Paramaribo being the major urban area.

The country's population is about 492.829 (ABS, 2007) 90% of which is living at the coast. The population density is the largest in the capital (First National Communication, 2005). Because of the agricultural history, Suriname has a diverse population representing ethnic groups from four major continents. The citizens of Suriname are descendants of African slaves and Asian indentured servants (from India, Indonesia, and China) who were brought to the colony to work as agricultural workers on the plantations. Agriculture is confined mainly to the coastal plains and the river valleys and has great potential for expansion. Rice is the chief crop while other important crops are citrus fruits and bananas. Shrimp fishing and small-scale fishing are expanding along the coastal areas (Bruijning et al., 1977).

The country's population is about 492.829 (The Northern half of the country is mainly low and flat and it is topographically divided into a flat coastal plain and low hills further inland. There is a gentle rise to 600 or 700 m along the southern border. The overall pattern of the hinterland is interrupted by the central highlands and a few locations rise to slightly over 1000m (Boedhram et al., 1988). Tafelberg is within this area, its height is 1026m, and furthermore the highest peak in Suriname is the Juliana Top, which is 1230m (Boedhoe, 2004).

1.2 Nickerie District

The study area for the rice production is the Nickerie District, the westernmost district of Suriname (fig 1.1-1). The surface area is about 5.353 square kilometres and the population in this District is about 36.639 (ABS, 2007). The main agriculture activities in the District are rice and banana farming, which make an important contribution to the country's GDP (Nationaal rijstprogramma, 2008).

Lowland rice cultivation started in the 1890s in the Nickerie District and this district is the main rice district of Suriname. The soils are very suitable for rice and large quantities of water for irrigation purposes are available (Sital, 2002). Three sources of water are allocated for irrigation of the rice polders (figure 1.2-1). The irrigation resources are the Nickerie River, the Nannie Swamp, and the Corantijn River (Nationaal Rijst programma, 2008). The rice farmers in the Nickerie District use several rice varieties and irrigation water is available for wet rice farming. Furthermore, there are two rice crops in one year.

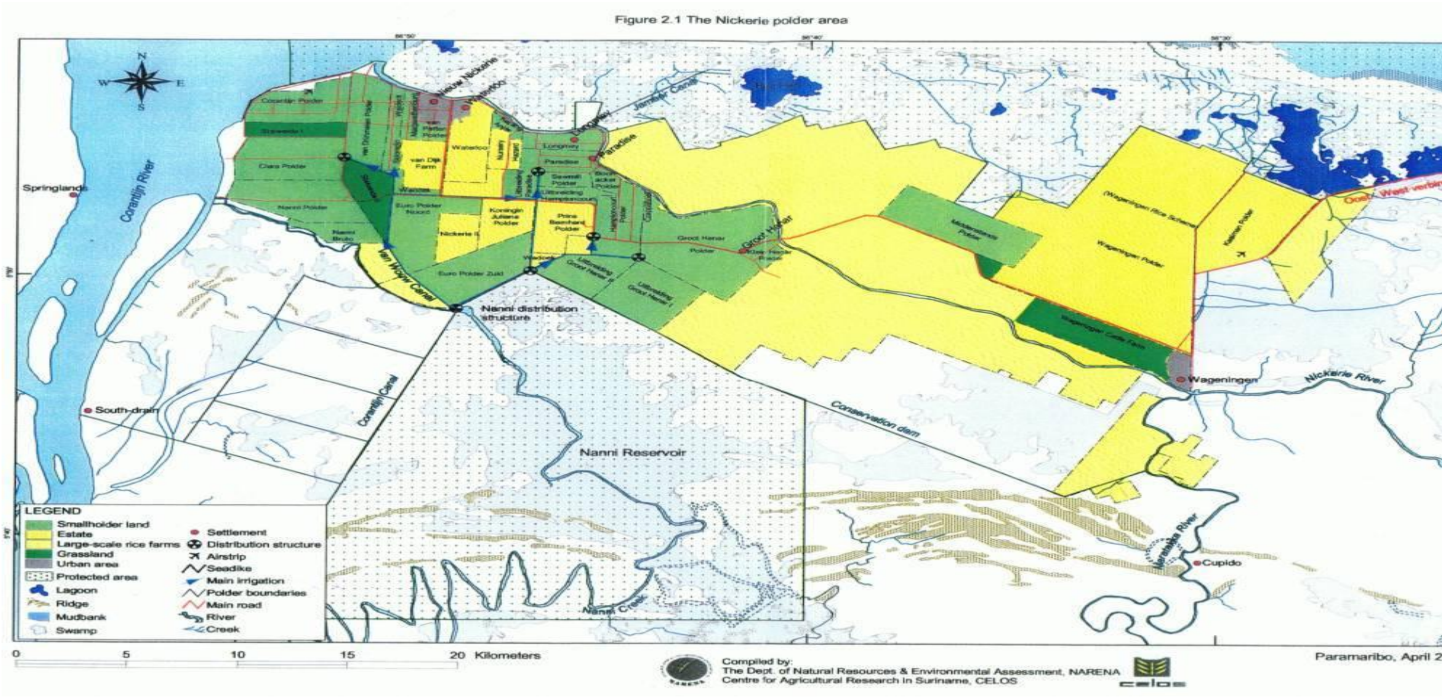
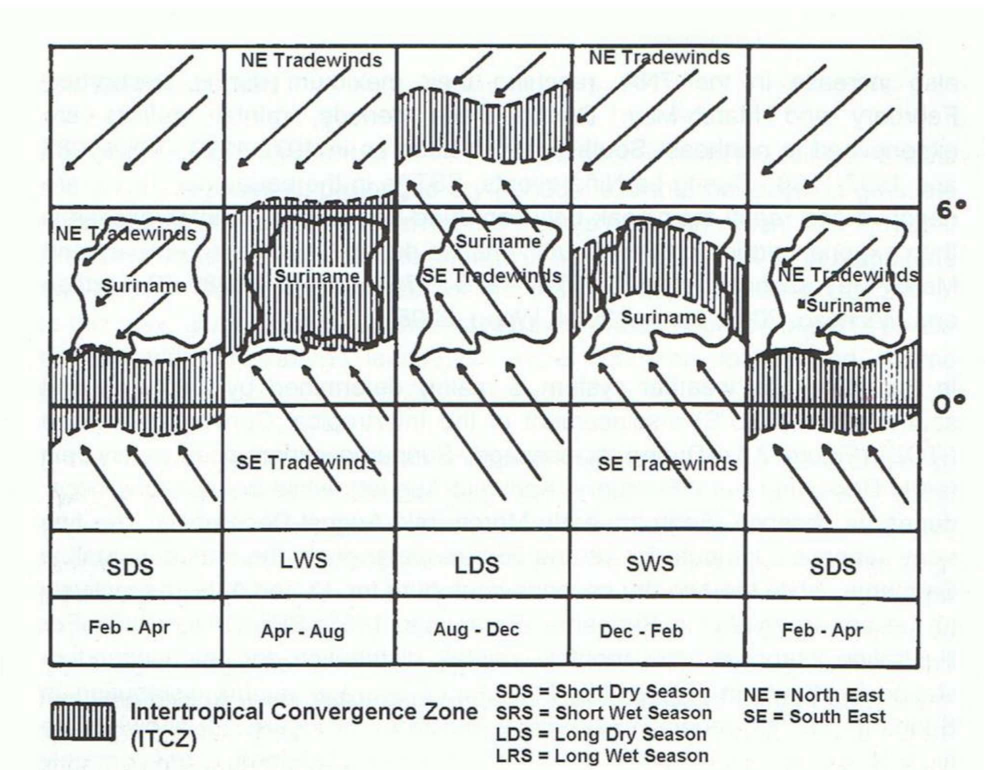


Figure 1.2-1: Map of Nickerie polder

Source: Sital, 2002

1.3 The climatic environment of Suriname



Source: Nurmohamed, 2008)

Figure 1.3-1: Movement Intertropical Convergence Zone (ITCZ)

The annual migration of the Intertropical Convergence Zone (ITCZ) from south to north and back over the equator (fig.1.3-1) influences the tropical climate in Suriname. The meridian translation of the ITCZ results in the passage of its centreline over Suriname twice annually. Most of the climatological elements manifest a strong semi-annual component of oscillation. There are two wet seasons and two dry seasons identified. Rainfall exhibits considerable variation during the year, while the temperature is relatively stable.

Four seasons are recognised based on the rainfall distribution namely:

The short wet season, starts at the beginning of December and ends at the beginning of February. The ITCZ is moving southwards over Suriname at this time of year. The prevailing winds during this season are the northeast trade winds. These trade winds imply downstream increase in speed and therefore it strengthened subsidence. Monthly rainfall amount is about 200 mm, but less than this amount may occur. The short dry season starts at the beginning of February and lasts until the end of April. The ITZC is moving further to the south during this period. The equatorial trough is its southernmost position during these months. The long wet season starts at the beginning of May and ends in the middle of August, and the ITCZ is moving toward the north over Suriname during this period. Most areas can expect a monthly rainfall total of at least 200mm and the wettest month for Suriname is May, with a monthly average value of about 325 mm. The long dry season commences at the middle of August and ends at the beginning of December. By this time, the ITCZ would have migrated over Suriname, and would be located above the Atlantic Ocean. The driest months occur during this season and normally September and October are the driest months, often with a monthly average total of less than 100 mm a month. The rainfall average over the Central highlands, the interior and some parts of the coastal area record even less than 50 mm per month. Furthermore, October is on the average drier than September.

It should be noted that annual variation could be rather great, so that for some years, the short rainy season or the short dry season may not occur, but both the long rainy and long dry seasons are always encountered (Boedhram et al., 1988). The annual average weather condition for Suriname is displayed in table 1.3-1.

Table 1.3-1 the average weather conditions for Suriname

Parameter	Average Value	Variation
Temperature	27.3 ^{0}C	17.2 ^{0} C – 35.0 ^{0}C
Wind velocity	2 m/s	
Wind Direction	North East – South East	
Rainfall	2060 mm	1900 mm – 3000 mm
Humidity	80%	
Sunshine	58 %	

The rainfall distribution is not evenly during the year and therefore the wet season records more rain than in the dry season. The average monthly total is about 260mm during the wet season and about 120 mm during the dry season. With respect to temperature, the long dry season records the highest temperatures (Meteorologische Dienst Suriname, 1968). Rainfall and water availability are important production factors in agriculture, including rice cultivation.

This paper includes in chapter two a description of previous studies done by several researchers with regard to the effect of the subtropical highs and weather related events on agriculture. Chapter 3 addresses the data and methods used in the study, the observed rainfall and temperature patterns, and the reanalysed sea level pressure data (obtained from NOAA) are examined in chapter 4 and 5. Microsoft Excel 2003 for Windows was utilized to process and analyse the data. Furthermore, chapter 6 concentrates on the influence of the Subtropical highs on the rainfall and the temperature. Furthermore, the effect of rainfall and temperature on the rice production is assessed in chapter 7. Chapter 8 addressed a preliminary adaptation framework in the rice sector and the paper ends with conclusion and recommendations in chapter 9.

2 LITERATURE REVIEW

2.1 Introduction

Mankind faces a multitude of challenges. One of those challenges is anthropogenic climate change and the uncertainties that are associated with it. According to the Intergovernmental Panel on Climate Change (IPCC), global mean temperature will increase by 1.60 C and 4.90 C above 1990 levels by 2050 and 2100, respectively (Yohe et al., 2007). Furthermore, the IPCC has projected decreased rainfall totals in some parts of the world in the future, which will pose another threat to agricultural production. Research elsewhere has shown that rice production is expected to be under great stress due to the projected temperature increase and declining rainfall totals (IRRI, 2007). This will have a negative effect on world food security.

2.2 The subtropical high pressure system and the climate

The Subtropical high-pressure belts are the zones with the highest average pressure and are near 30^0 N -30^0 S. These pressure belts lie in a transition region between the tropics and the middle latitudes. The weather in the zone of these highs is dominated by strong subsidence which results in very little cloud formation and strong sunshine. Subsidence usually occurs in subtropical high-pressure zones, and the general lack of rainfall and a high evaporation produce the world's greatest desert (Lamb, 1972).

Several persons have conducted studies on the intensity and position of the subtropical high-pressure systems and their relation to climate. Barry et al. (1976) noted that global climate is closely related to high-pressure cells. It is estimated that warming causes an annual shift in the subtropical high-pressure belt from its average position of 37^0 to 41^0 – 43^0 N (Barry et al., 1976). In addition, this annual shift would cause drought in the Mediterranean, California, Middle East, Turkestan, and the Punjab (Barry et al., 1976). Moreover, it displaces the thermal equator from 6^0 to 9^0 – 10^0 with increasing desertification in the belt 0^0 – 20^0. Drought in Southern Israel was due to the increase in area and persistence in subtropical high-pressure cells and therefore related to this mechanism. The major drought in the Sahel since 1970s has been attributed to an eastward and southward extension of the Azores high (Barry et al., 1976). The extension of the Pacific high causes a sharp decrease in rainfall from March to April (Barry et al., 1976).

Markgraf (2001) studied the seasonality of the subtropical highs and noted that the subtropical high over the South Atlantic has little seasonality in its central pressure and position between winter and summer. However, there is a seasonal cycle in the sea level pressure (SLP) with the lowest pressure occurring during December –February and the highest pressure occurring during June - August (Markgraf, 2001). Thompson (1998) examined the position and the intensity of the subtropical highs and these vary according to the results of the study. The subtropical high-pressure systems are relatively permanent (Thompson, 1998).

Mu et al. (2002) examined the changes of the subtropical high over the West Pacific in the last one hundred years. The CCM3.6 model, a GCM developed in National Centre Atmospheric Research (NCAR) was used to model and simulate the subtropical high over the West Pacific. The Intensity Index series for the Subtropical High over the Western Pacific was constructed using this model. Observed sea surface temperature from 1900-2000 was used for this construction. He concluded that there is a close relationship between the climate characteristics and the Subtropical high. The location and activity of the rain belt can be successfully forecast, if the subtropical high is properly predicted. In addition, the increasing intensity of the There is a close relation between the Subtropical high and global warming and furthermore the variation of the subtropical high intensity is directly related to sea surface temperature increase. The study reveals a high correlation between the subtropical high intensity and the global average temperature for the Northern Hemisphere and China (Mu et al., 2002). However, an intensification of the Subtropical high also facilitates the warming climate (Mu et al., 2002).

He Xue-zhao (2002) has examined inter-decadal change in the Western Pacific Subtropical High and the related climatic effects. According to his findings, this Subtropical high is a very important atmospheric circulation system and it influences the summer climate over eastern China. Furthermore, inter-decadal change was analysed and there was a significant decadal shift in about 1979/1980. The Western Pacific Subtropical high has enlarged, intensified, and shifted southwestward since 1980. The precipitation exceeded 63.9 mm above normal during the summers of 1980-1999, while during 1958-1999 it was 27.3 mm below normal. The southwestward expansion of the Western Pacific Subtropical High (WPSH) has also led to a significant warming in southern China. The summer mean temperature during 1980-1999 was $0.37\ ^{0}$ C warmer than that of the period 1958-1999. Therefore, the study reveals a temperature increase due to the expansion of the Subtropical high. Furthermore, the Subtropical High responds to sea surface temperature and these changes are mainly responsible for inter-decadal variability of the Western North Pacific Subtropical High. The mean height for the 500hPa level was examined for this study, and it was found that height changes in the selected region can account for much of the variations of the subtropical high (He Xue-Zhao., 2002).

With respect to the influence of the WPSH on the rainfall, the correlation is determined between the WPSH index and the summer rainfall of 160 stations. When the WPSH index is high, there is likely to be more rainfall in the region. With regard to the temperature, not much attention has been paid to this variable. However, during the summer months, continuously high temperature usually has negative effects on agriculture and extremely heat waves direct to severe drought. The study done by He et al (2002) with regard to the influence of the WPSH and the temperatures shows that there is a negative correlation coefficient between the two variables. It reveals that when the subtropical high is strong, the summer temperatures are low due to the increasing rainfall. The study focused on temperature data for 17 stations. On the other hand, a study for southern China shows a positive correlation between the temperature and the subtropical high. However the inter-decadal changes of temperature are noticeable, and since the 1970's air temperature has become higher and the anomalously high temperature continues to the present (He et al., 2002).

He et al. (2002) used the data set of atmosphere circulation for the period 1958-1999 from the National Centers of Environmental Prediction and National Center of Atmospheric Research (NCEP/NCAR) and the 500hpa reanalyse data in the study. With respect to rainfall and temperature, China Meteorological Administration (CMA) provided the data. These authors concluded that there are many factors influencing WPSH, and one of these is the internal dynamic processes and external forcing. However, the anomalous lower boundary conditions may be the most important one responsible for inter-decadal changes in the WPSH (He et al., 2002).

Gamble et al. (2007) conducted a study on the cause of the Caribbean mid summer drought (MDS), which lasts from July to August. The expansion and intensification of the North Atlantic High Pressure (NAHP) into the Caribbean region often causes a mid summer drought (MDS) from July to August. The expansion of this high result in stronger trade winds and cooler sea surface temperature, which leads to increased subsidence and diminished Caribbean rainfall (Gamble et al., 2007).

2.3 Rainfall and temperature in the Caribbean, Central and South America

Large inter annual variations in rainfall are associated with tropical climates and can have a strong impact on human activities. It is therefore important to forecast anomalous rainy seasons well in advance.

2.3.1 Rainfall and temperature in the Caribbean and Central America

With regard to the Caribbean, average annual temperature has increased by more than 0.5^0 C over the period 1900-1995 and the rainfall data show a decreasing trend. A case study in Cuba shows that there was a temperature increase of 0.6^0 C in the past 45 years and rainfall data show a decline approximately 200mm for the same period. Furthermore, evidence was presented to show that there is much greater seasonal, inter-annual, and decadal scale variability in the rainfall (Watson et al., 1997).

The climate of the Caribbean is marked by a dry and wet season and the rainy season shows a bimodal seasonal cycle in rainfall pattern. Furthermore, the rainy season starts in May and ends in November. Gianini et al. (1998) examined inter annual variability of the rainfall in the Caribbean and Central America. The authors found that the North Atlantic Sea level pressure (SLP) affects the Caribbean rainfall directly by changing the pattern of surface flow over the region. Moreover high sea level pressure anomalies in the region of the North Atlantic High result in stronger trade winds and on the other hand less Caribbean rainfall. They analysed monthly rainfall records from The National Oceanic and Atmospheric Administration (NOAA), National Climatological Data Center (NCDC), Global Climate Perspectives Systems (GCPS) to characterize the seasonal and inter annual variability of Caribbean rainfall. 188 stations located in Central America, the Antilles and Northern South America was selected based on geographical location and length of records. The selected stations for the study are between 58^0 N - 25.8^0 N, and 90.8^0 W - 60.8^0 W and, it have data for at least 25 years between 1900 and 1995. The correlation between the variables and the North Atlantic high index was determined with statistical analyses and the average sea level pressure (SLP) was estimated (Gianini et al, 1998).

Hastenrath (1972, 1976) has also examined the rainfall variability in the Caribbean and Central America. He showed in his study that certain factors that influence rainfall needed to be considered. These include topography, variation with altitude and differential divergence effects.

2.3.2 Rainfall and temperature in South America

The beginning of the rainy season plays a big role for the seasonal total rainfall. Brant Liebmann and Jose A. Marengo (2001) examined the inter-annual variability of seasonal rainfall in the Brazilian Amazon basin. The variation in the start and end dates of the rainy season is an important contributor to seasonal total rainfall. Sea surface temperature influences the timing of seasonal total rainfall, rather than the rate of precipitation during the rainy season. Furthermore, sea surface temperature appears to influence the subtropical highs. Hasanean (2004) conducted a study of the subtropical highs. He examined twenty years of data for the subtropical high and it seemed that the sea surface temperature influences the North and South tropical Atlantic. The inter-annual variation of the central pressure of the subtropical high is examined and it seems that the variation of the subtropical high's intensity follows a cyclic pattern. It is assumed that the centre of action of the subtropical high is characterized by non periodic behaviour (Hasanean, 2004).

A study of the rainfall variability in Suriname conducted by R.Nurmohamed, S.Naipal and C. Becker (2006) reveals that the rainfall distribution for the annual precipitation is the highest in the mountainous area and the lowest in the low-lying areas. Rainfall data from 1961-1985 were examined to determine the spatial variability. The highest rainfall at all stations occurs in May-June and the lowest rainfall in October-September. Furthermore, a decreasing trend in annual precipitation occurs in central and southwest Suriname, while a rising trend in the other areas of Suriname is observed (Nurmohamed et al., 2006).

2.4 Global climate change and agricultural production

Subsistence and commercial agriculture on Small Islands and low-lying coastal regions like Suriname are likely to be affected adversely by climate change. Due to their characteristics, these countries are prone to several threats associated with climate change including sea level rise and extreme events. Agriculture, especially coastal agriculture, will be adversely affected through sea level rise, seawater intrusion in the freshwater lens, soil salinization and a decline in water supply. Locations away from the coast also face changes extremes e.g. flooding and drought, which are likely to have negative effects on agricultural production. In addition anticipated land loss, soil salinization and low water availability will likely threaten the sustainability of agriculture and food security in these locations (Mimura et al., 2007).

Subsistence agriculture supported local food security, while cash crops e.g. sugar cane and bananas earn foreign exchange for these countries. The projected impacts of climate change include extended periods of drought, loss of soil fertility and degradation because of increased precipitation. Both drought and increased precipitation will negatively affect agriculture and food security. Therefore a climate change adaptation strategy is needed otherwise the cost due to these effect will be extremely high, as the World Bank (2000) has shown in a study of the economic and social implications of climate change and variability for selected Pacific Islands. An adaptation measures implemented in the Maldives to ensure agriculture and food security is the use of hydroponics systems as an alternate method of growing fruits, vegetables and other foods crop production (Mimura et al., 2007).

However not all effects of climate change on agriculture are expected to be negative. Increased temperature in high latitude islands is likely to make conditions more favourable for agriculture and it provides opportunities to improve resilience of local food systems. Assessment done for the small islands reveals that the impacts of climate change and non climate related forces on commercial agriculture, as well as subsistence agriculture and food security are not well addressed yet (Mimura et al., 2007). Annual precipitation in many parts of the tropics is likely to vary significantly from one year to another and this can have serious implications for agriculture (Hastenrath, 1972).

Easterling et al. (2007) suggests that moderate warming benefits crop yield in mid to high latitude regions but on the other hand an even slight warming decreases yields in seasonally dry and low latitude regions. Modelling results in the mid to high latitude regions find that low to moderate increases in temperature (1-3^0 C); together with carbon dioxide (CO2) increase and rainfall changes can have small beneficial impacts on crop yield. However, the impact on crop yield in low latitude regions is likely to be negative and further warming would have even more negative yield impacts in all regions (Easterling et al., 2007).

On the other hand, agriculture activities contribute to greenhouse gases (GHG) emissions in the atmosphere. Agriculture releases a large amount of carbon dioxide (CO2) into the atmosphere and the estimated emission of total global anthropogenic emissions of greenhouse gases (GHGs) due to agriculture activities is about 10-12 % (Smith et al., 2007). The GHGs emissions are expected to increase because of population growth and changing diets in the future. Greater demand for food is likely to cause an increase in the annual GHGs emissions in the coming decades (Smith et al., 2007).

2.4.1 Rice production and climate

The full impact of climate change on rice production is still unknown and what measures should be taken to reduce the impact. Climate change threatens to distress rice production across the world. The International Rice Research Institute (IRRI) has conducted some research on the impact of climate change on rice. The work started since 1961 and the focus has been on increased temperature and rice production. Recently, some attention has been paid to the effect of high carbon dioxide on rice production and rice crop resilience to heat stress (IRRI, 2007).

According to Easterling et al. (2007), temperature increase can have adverse impacts on the rice production. The rice production in Asia could decline by 3.8% during the current century. For India, a 2^0C increase in mean air temperature could decrease rice yield by about 0.75 tonne/ha and for China rain-fed rice yield by 5-12% (Easterling et al., 2007). Diminished rainfall results in a decrease of the seasonal total rainfall. Moreover, a change in rainfall pattern can also affect rice production. A study carried out by Doodnauth (2006) for the island of Leguan in Guyana, revealed that there is a clear relationship between variation in rainfall and rice yield. Furthermore inconsistent weather and climate has affected rice yield directly and especially during periods of extreme weather events. The relationship between rice yield and rainfall variability were determined with statistical analyses (Doodnauth, 2006).

2.4.2 Climate and rice production in Suriname

The tropical rainforest climate and bimodal rainfall pattern of Suriname offer the possibility to grow two rice crops per calendar year on the same land. However, the rice variety used for rice cultivation is not the rain fed type, but the irrigation variety is used (Witter et al., 1994). Biscay (1984) has done an assessment of on-farm practices for improved rice production in the Nickerie District. Part of the assessment was to determine the relationship between the solar radiation and grain yield. According to his findings, there is an increase in grain yield with an increase in solar radiation. However, it was pointed out that solar radiation and temperature are not the only basic factors in optimizing rice production. There are other very important factors needed like availability of water, rainfall, machinery and labour (Bishay, 1984). Unfortunately, there is no further research conducted yet about the impact of climate change on rice production in Suriname.

3 RESEARCH METHODOLOGY

Knowing and understanding the influence of the subtropical high-pressure systems on the seasonal rainfall and the temperature is needed in order to assess their effects on the society and therefore on the economy. The methodology used in this research consists of the following components: literature review; data selection and processing, selection of methods/techniques and application; data analyses, processing of results and interpretation.

3.1 Literature review

All literature was sought regarding the research topic. The libraries of the Meteorological Service Suriname, Ministry of Agriculture and Husbandry, ADEK Library, ADRON and the internet were the sources for the literature.

3.2 Data collection

The primary data collection method involved the conduct of interviews with key persons from Meteorological Services Suriname, Ministry of Agricultural and Husbandry, Rice Research Centre (ADRON), water resources agency and 30 randomly chosen farmers. The rice polders of the Nickerie District (fig.1.2-1) are huge and are divided in Noord Oost polder, Groot Henar, Corantijn Polder and Euro Polder (Sital, 2002). In order to get a good coverage of the farmer's experiences, thirty farmers were randomly chosen from these polders, taking into account that the farmers represent the farmer's population in the different polders. The farmers were randomly chosen with assistance of ADRON, since this research centre is familiar with the rice farmers. Two weeks were used for the field orientation in the Nickerie District. Given the circumstances, it was necessary to choose thirty farmers randomly for an interview and data collection in order to gather weather related information. The farmers were spread over the Nickerie District, and they vary from small-scale rice farmers to large-scale rice farmers. Some farmers were not available, since it was harvest time during the conducted interviews. Although randomly chosen, special attention has been given that the farmers represent the farmers from the different polders (fig.1.2-1). In Addition, the elders from the rice District were also visited and interviewed. Field visits to the rice fields in the district, rice processing locations and the rice mills were undertaken. Valuable observations and information were obtained from these visits.

The secondary data collection was based on a literature review, internet sources, reanalysis data, and retrieval of existing data from relevant agencies and libraries. The sea level pressure reanalysis data on the subtropical highs for the time series 1971-2008 on a monthly basis were obtained from the National Oceanic and Atmospheric Administration (NOAA). The reanalysed sea level pressure data from 1971-2008 were utilized for this study (Kalnay et al., 1996).

The Meteorological Service of Suriname provided the annual and monthly rainfall and temperature data for this study. In addition, the Ministry of Agriculture, Husbandry and Fisheries made available the rice production data for the period 1971-2008.

Seven meteorological stations (Table 3.2.1) were selected based on the following criteria:

- The selected stations represented the geographic region
- The stations have at least 10 years of data to obtain reliable statistics

Table 3.2-1: Selected meteorological stations in Suriname.

Station Name	Latitude/Longitude		Region	Years of Data
Cultuurtuin	05 57 00 N	057 02 00 W	Northern	1971-2008
Nickerie	05 50 00 N	055 10 00 W	West Northern	1971-2008
Zanderij	05 28 00 N	055 12 00 W	Northern Central	1971-2008
Stoelmans eiland	04 21 00 N	054 25 00 W	Eastern Central	1971-2005
Tafelberg	02 23 00 N	056 43 00 W	Central	1977-2008
Sipaliwini	03 47 00 N	056 09 00 W	Southern	1971-1986
Kwamalasoemoetoe	02 02 00 N	056 07 00 W	Southern	1971-2008

Source: Meteorological Services of Suriname

3.3 Data processing and analysis

The main software used for the processing and analysis of the data was Microsoft Excel. This software was utilized to create tables and graphs. Simple regression and correlation analysis were applied to determine the positive and negative trend for the temperature and the rainfall pattern for the past 37 years for the selected meteorological stations. The same was done for the rice production in the Nickerie District and for the sea level pressure data.

Correlation coefficients were determined between the Subtropical high pressure and the rainfall and temperature for the selected stations with the correlation analysis. Monthly and annual rainfall and temperature were compared with the sea level pressure data during the same period. Finally, the relationships are determined between rice production, the rainfall, and the temperature in order to investigate the implications for the rice production. The long term average annual rainfall was used as the ‘normal’ to determine a wet or dry period, while with respect for the monthly data, the long term monthly average was used as the norm.

3.4 Limitations

There is not much published literature on the research themes explored in this research. Therefore, there was limited background information and analysis available to the student. The challenge therefore was to decide on an effective methodology that would produce adequate results for interpretation. Some information was also missing from the existing data series. In such cases, linear interpolation was used to complete the time series.

4 RAINFALL PATTERN OF SURINAME 1971-2008

4.1 Introduction

The seasonal rainfall for seven stations was examined to investigate the influence of the subtropical high-pressure system, specifically whether there is a relationship between rainfall and the subtropical high system. The focus is on the North Atlantic Subtropical high-pressure system, also called the Azores High and the South Atlantic High pressure system, also known as the St.Helena High. The subtropical high-pressure systems are characterized by the sea level pressure. The association between the rainfall and the sea surface pressure has been stipulated by means of the comparison of the average of the variables. Correlation and regression analyses are applied to identify whether any statistical relationship exists between the variables.

The climate of Suriname is a tropical rainy climate and there four season in a year: two wet seasons and two dry seasons. The short wet season is from December until the beginning of February, the short dry season from the beginning of February until the end of April, the long wet season from the beginning of May until the middle of August and the long dry season lasts from the middle of August until the beginning of December. The Inter Tropical Convergence Zone (ITCZ) is a strong determining factor for rainfall in Suriname. Figure 1.3-1 shows the North-South and back movement of the Intertropical Convergence Zone (ITCZ) above Suriname. The annual average and monthly average rainfall data of seven selected meteorological stations were examined to detect any changes in the rainfall pattern over the past 37 years 1971-2008.

4.2 The Coastal Part of Suriname

The selected stations in the northern part are Nickerie, Cultuurtuin and Zanderij. To detect any changes in the rainfall, monthly and annual rainfall data of these stations were examined. Monthly and annual rainfall data for Nickerie covers the period 1971-2008 and the data is presented in Appendix A.

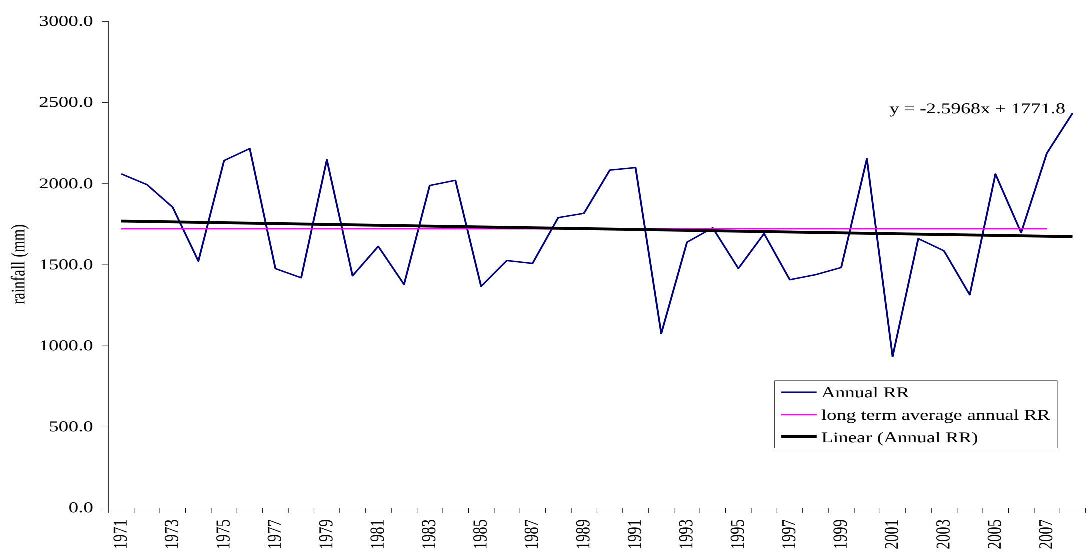


Figure 4.2-1: Nickerie annual precipitation 1971-2008

Figure 4.2-1 shows the annual precipitation 1971-2008 for Nickerie. The long period annual mean rainfall is 1721.12 mm.

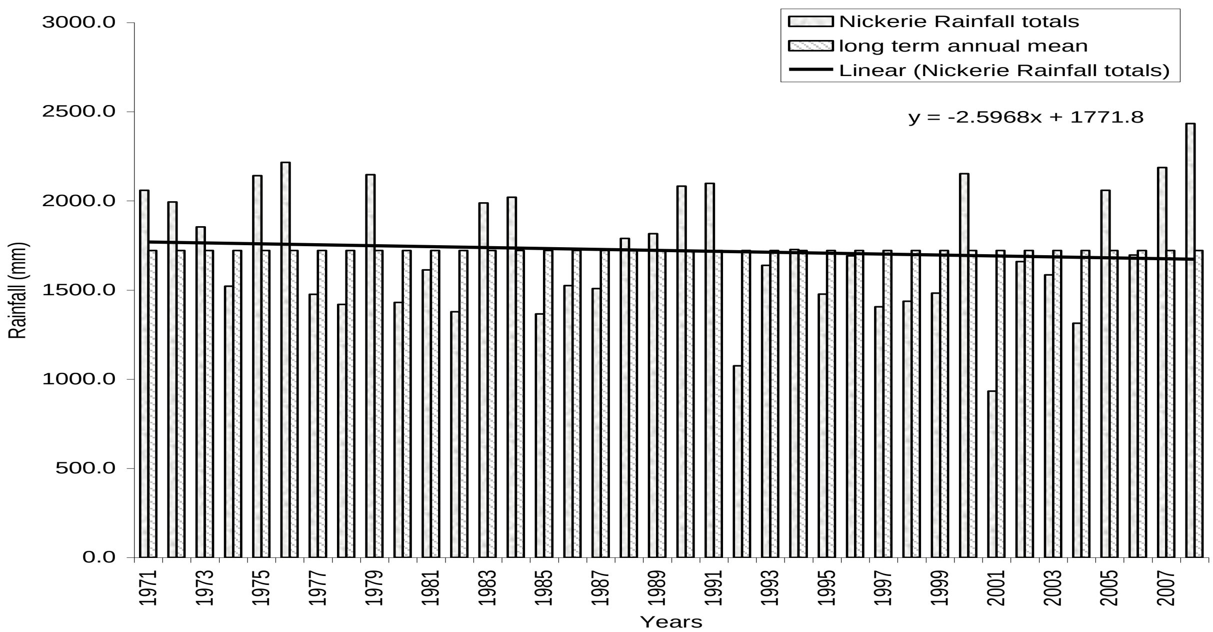


Figure 4.2-2: Nickerie annual rainfall distribution 1971-2008

The negative regression coefficient indicates a negative trend for the past 39 years; therefore, the rainfall has decreased slightly for this period (fig.4.2-1). The long-term average annual rainfall, 1721.12mm is used as the 'normal' for wet and dry years (fig 4.2-2). The monthly rainfall distribution 1971-2008 for Nickerie is illustrated in figure 4.2-3.

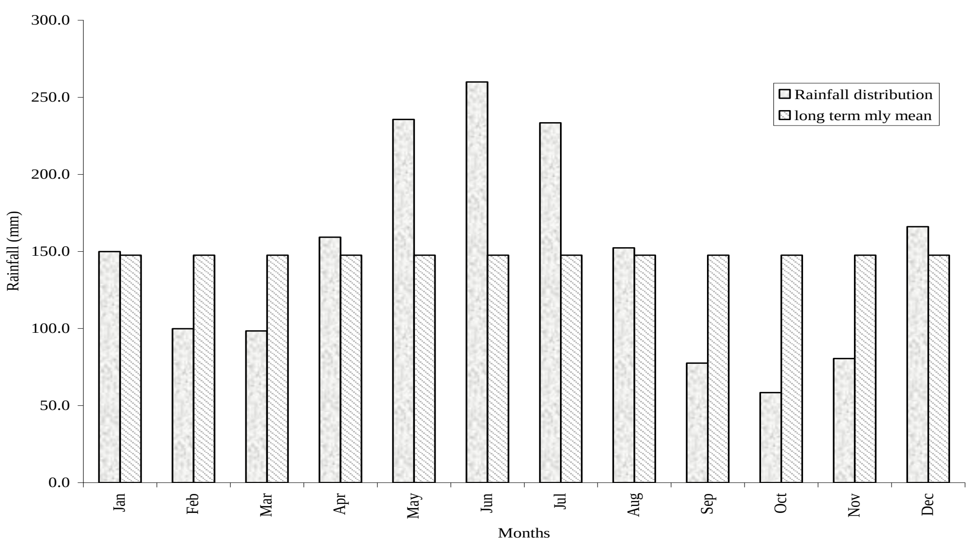


Figure 4.2-3: Nickerie monthly Rainfall distribution 1971-2008

The highest monthly average rainfall occurred in June and is equal to 259.89mm, while the lowest average rainfall, 58.41 mm, was recorded in October (fig.4.2-3). The long term monthly average is 147.56 mm, which is used as the norm. All the years with values above this norm are considered ‘wet years and those with values below this norm are considered ‘dry years’. It should be noted however that June falls within the rainy season and October falls within the dry season.

The other station in the coastal area is Cultuurtuin. Its data set covers the period 1971-2008. Appendix A presents the rainfall data for Cultuurtuin. Figure 4.2-4 illustrates the annual course of the rainfall for Cultuurtuin during 1971-2008.

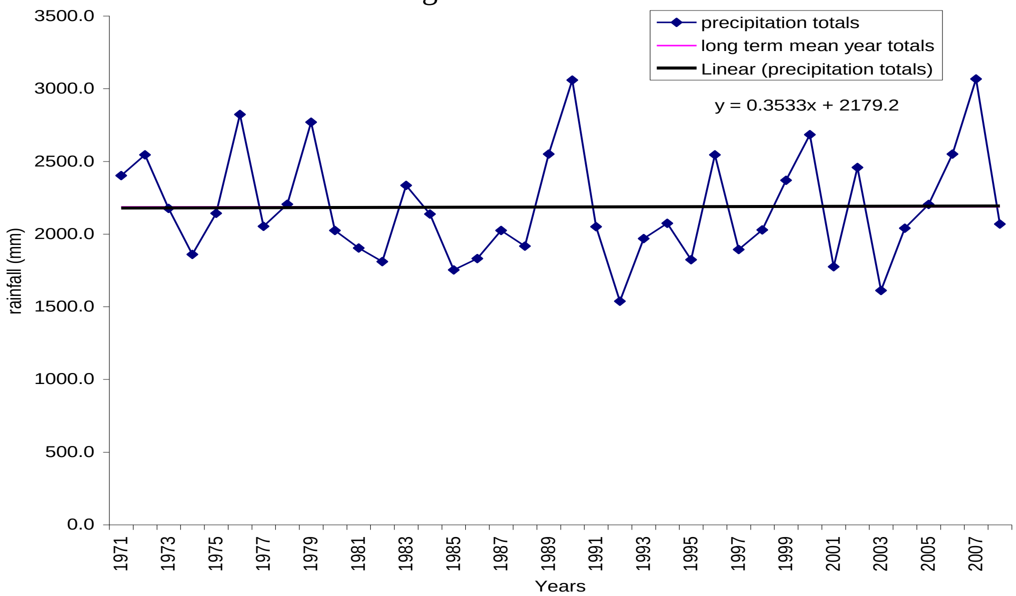


Figure 4.2-4: Cultuurtuin annual precipitation 1971-2008

The positive regression coefficient indicates that there has been a slight increase in rainfall in the past 39 years at Cultuurtuin (fig 4.2-4). The annual rainfall distribution for Cultuurtuin is illustrated in figure 4.2-5.

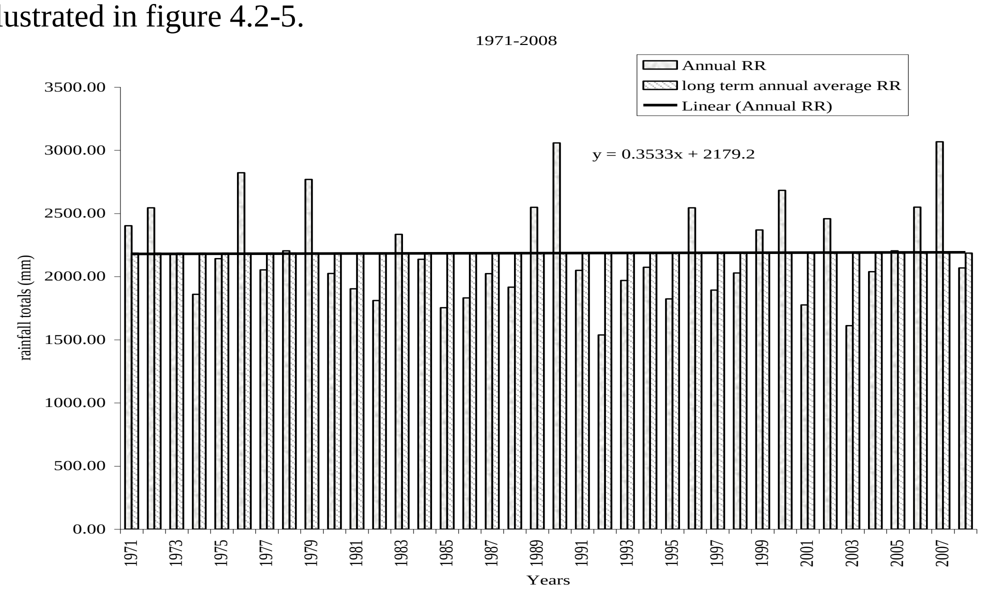


Figure 4.2-5: **Cultuurtuin annual rainfall distribution 1971-2008**

The long-term annual average of 2186.0 mm is used as the normal to determine the wet and dry years (fig.4.2-5). Cultuurtuin experiences a slight increase in rainfall during 1971-2008. The monthly rainfall distribution for Cultuurtuin is illustrated in figure 4.2-6.

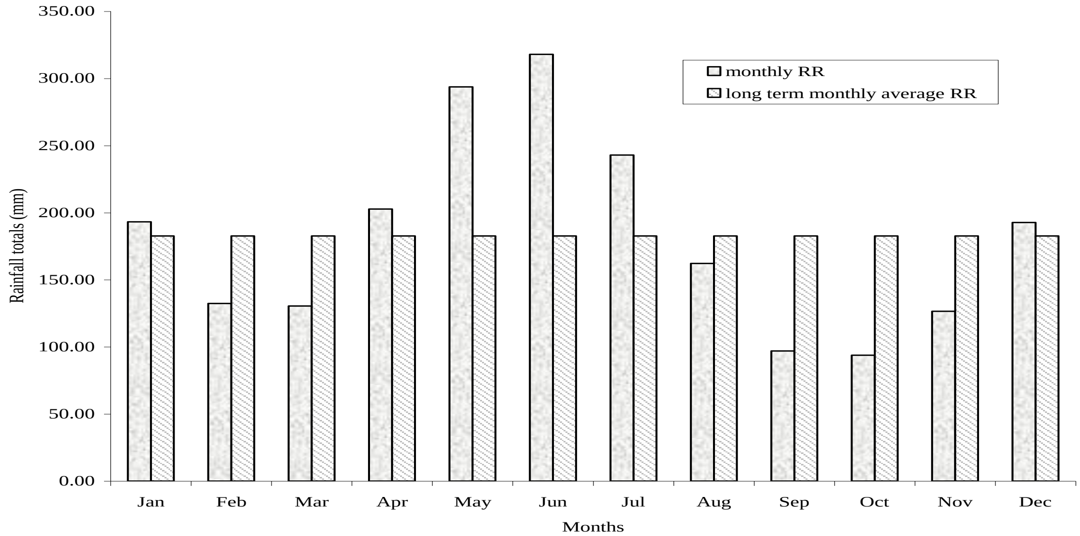


Figure 4.2-6: Cultuurtuin monthly rainfall distribution 1971-2008

The highest monthly rainfall total of 317.99 mm was recorded in June and a minimum value of 93.88mm for October (fig.4.2-6). The long term monthly average of 182.68 mm is used as the norm to make the distinction between the wet period and the dry period. June falls within the long wet season and October lies within the long dry Season (fig. 4.2-6). Finally, the third station in the Coastal area is Zanderij and the data set covers the period 1971-2008 (Appendix A). Figure 4.2-7 illustrates the annual rainfall course for Zanderij 1971-2008.

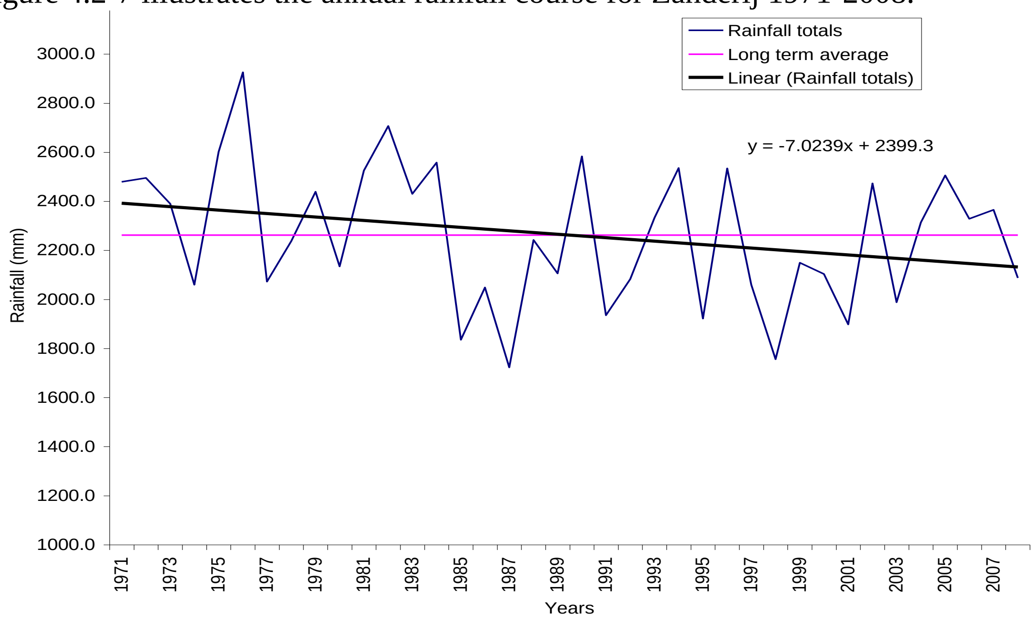


Figure 4.2-7: Zanderij Annual precipitation 1971-2008

The line graph for the annual rainfall totals for Zanderij (fig.4.2-7) shows a noticeable decrease in rainfall through the years (1971-2008). The linear regression line has an equation of y = -7.0239x +2300.3 and the regression coefficient is -7.0239. The negative regression coefficient of -7.02 indicates a rainfall decrease of 7.02mm/year for Zanderij in the past 37 years. The annual rainfall distribution 1971-2008 for Zanderij is displayed in figure 4.2-8.

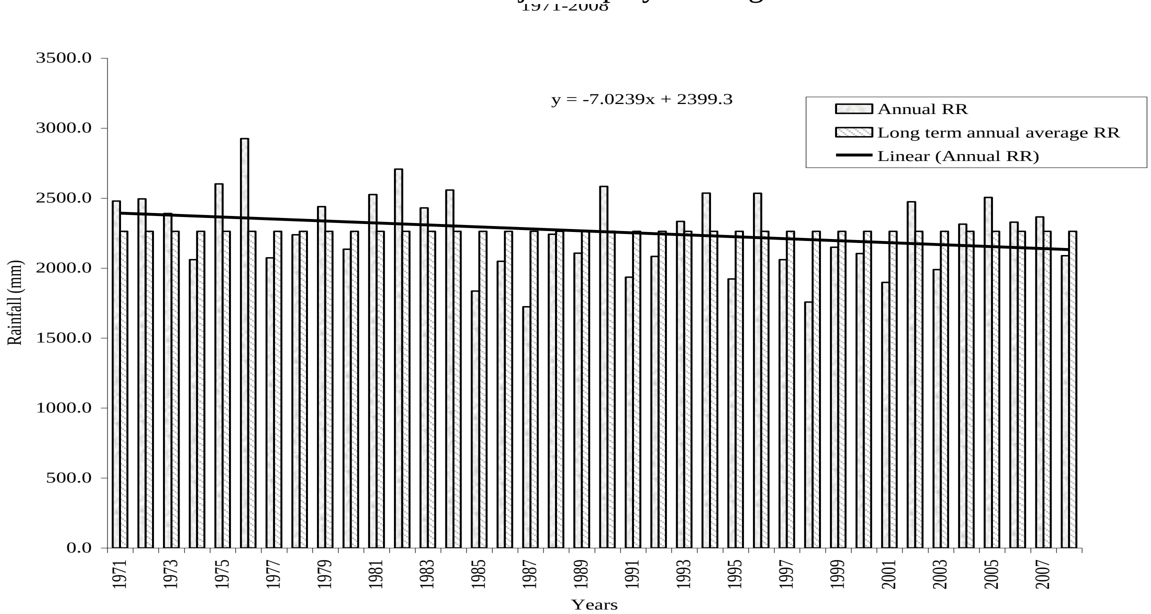


Figure 4.2-8: Zanderij Annual rainfall distribution 1971-2008

The annual precipitation totals show a negative regression (fig. 4.2-7). However, some years are considered wet, because their values exceed the long period yearly precipitation average (fig.4.2-8). The long-term precipitation average is 2262.4 mm. The years that have exceeded this amount are 1971, 1972, 1973, 1975, 1976, 1979, 1981, 1982, 1983, 1984, 1993, 1994, 1996, 2002, 2004, 2005, 2006 and 2007. The wettest year that occurred during the period 1971 – 2008 is in 1976, when the total precipitation recorded was 2925.30 mm. All the other years, which have less than the long-term average is considered, dry years. The overall trend for the station Zanderij is one of decreasing rainfall.

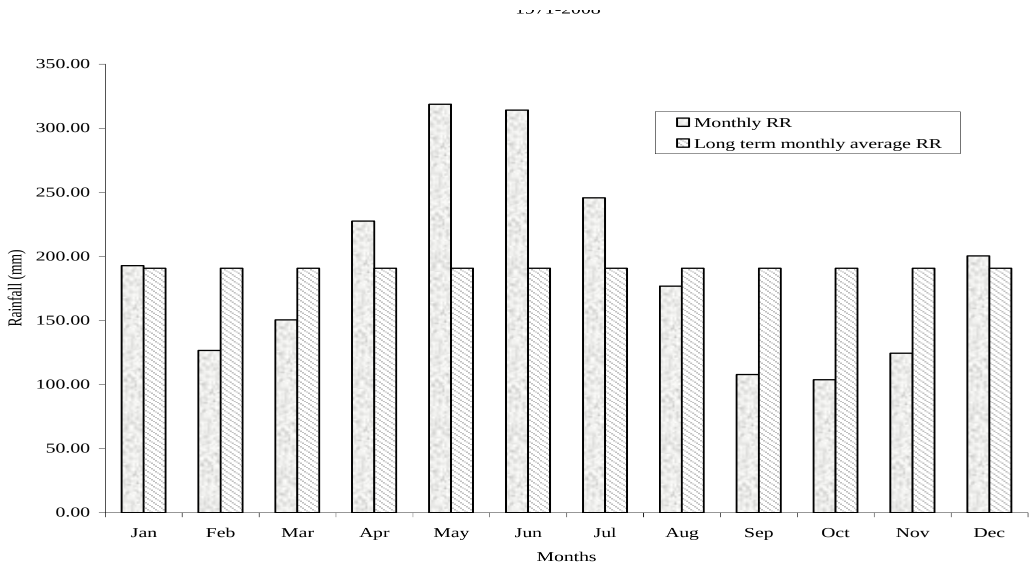


Figure 4.2-9: Zanderij Monthly rainfall distribution 1971-2008

Figure 4.2-9 illustrates the monthly rainfall distribution. In comparison with the long-term monthly mean, the data shows increased rainfall during April – July and a decrease during August and November. The long-term monthly mean is 190.7 mm and is used as a norm for determining the wet and dry months. The illustration in figure 4.2-9 shows that Zanderij has experienced only one Wet season from April to July and November has exceeded also the long term monthly mean of 190.7 mm. All the other months are below or equal to the long-term monthly average.

4.3 The Central Part of Suriname

The selected stations in the Central Part of Suriname are Stoelmans Eiland and Tafelberg. Stoelmans Eiland is an island located at the Marowijne River and Tafelberg berg (fig.1.1-1) is within a mountainous area where the Tafelberg Mountain has a peak of 1026 m (Boedhoe, 2004). The data set for Stoelmans Eiland covers the period 1971-2008 (Appendix A). The annual rainfall 1971-2008 for Stoelmans Eiland is illustrated in figure 4.3-1.

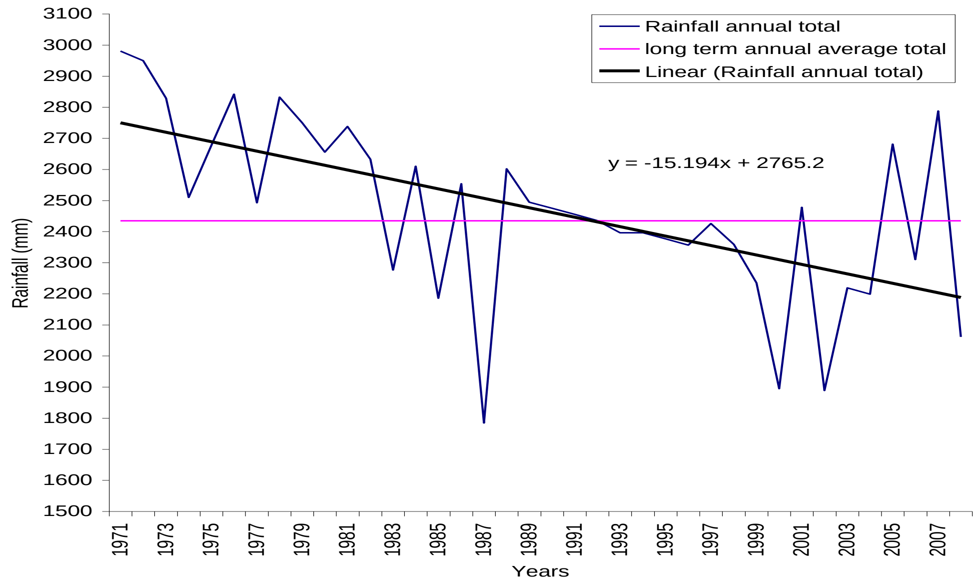


Figure 4.3-1: Stoelmans Eiland annual rainfall 1971-2008

The graph for the annual rainfall totals (Figure 4.3.1) shows a decline in the rainfall through 1971-2008. The regression equation of y=-15.194x+2765.2 has a negative coefficient of -15.194. The missing data are determined using the excel function “forecast”, which is similar to linear interpolation. The annual rainfall distribution is illustrated in figure 4.3-2 in order to get a better grasp of the wet and dry years during 1971-2008.

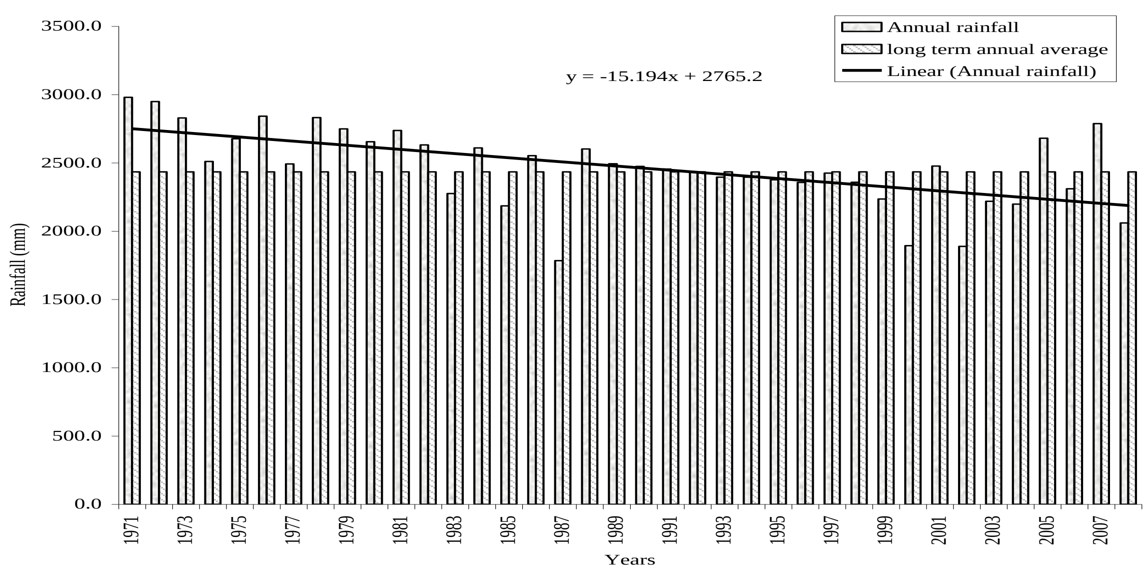


Figure 4.3-2: Stoelmans Eiland annual rainfall distribution 1971-2008

The columnar diagram (fig. 4.3-2) shows a clear decline in the rainfall during the years, which the data cover. Some years are above the long term average annual total precipitation and these are 1971, 1972, 1973, 1974, 1976, 1977, 1978, 1979, 1981, 1980, 1984, 2001, 2005, 2007. Therefore, these years are noted as wet years, since it has exceeded the long-term annual total average precipitation. The year with the highest rainfall total is 1971 and in that year an amount of 2980.40mm was measured. A minimum precipitation of 1786.4 mm was recorded in 1987 (fig.4.3-2). The illustration in figure 4.3-3 represents the monthly rainfall distribution for Stoelmans Eiland 1971-2008.

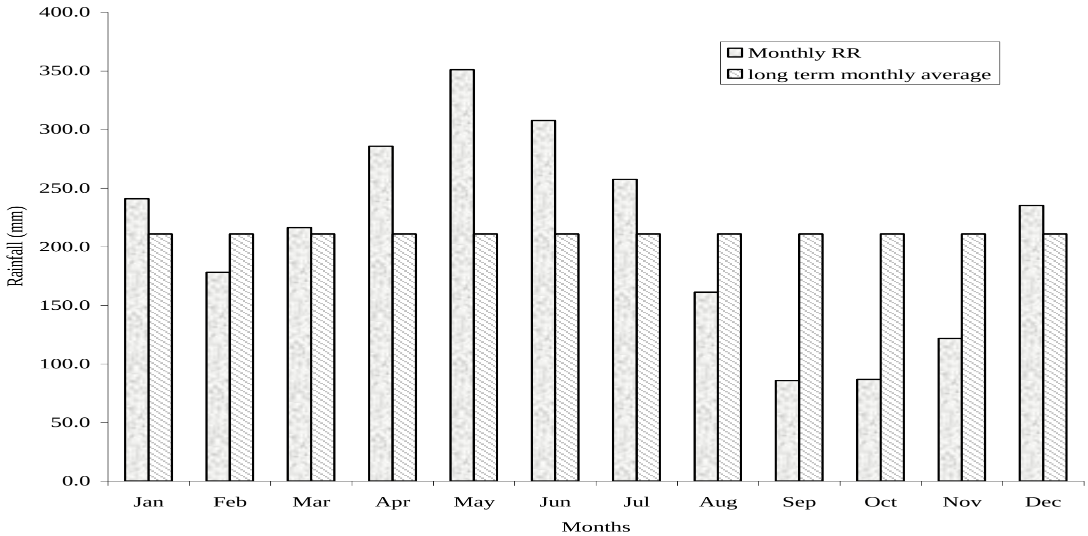


Figure 4.3-3: Stoelmans Eiland monthly rainfall distribution 1971-2008

The monthly rainfall distribution (fig.4.3-3) shows a peak during May, which is in the wet season. The long-term monthly average of 210.8 mm is used as a norm to determine the wet and dry seasons. The monthly rainfall, which is above the long-time monthly average, can be considered the amount of rainfall recorded during the two wet season, and the amount of rainfall below the long-time monthly average is the total amount of rainfall recorded during the dry season.

The second selected station for the Central Part of Suriname is Tafelberg. Tafelberg is in the central southern part of Suriname and the data series for this station only covers the years 1971-1986. The other data is missing, because the station was closed and not operational after that period. However, because of its position in the central southern part of Suriname, it is very important to examine the data for Tafelberg. The annual rainfall for Tafelberg is illustrated in figure 4.3-4 and the data set covers 1971-1986.

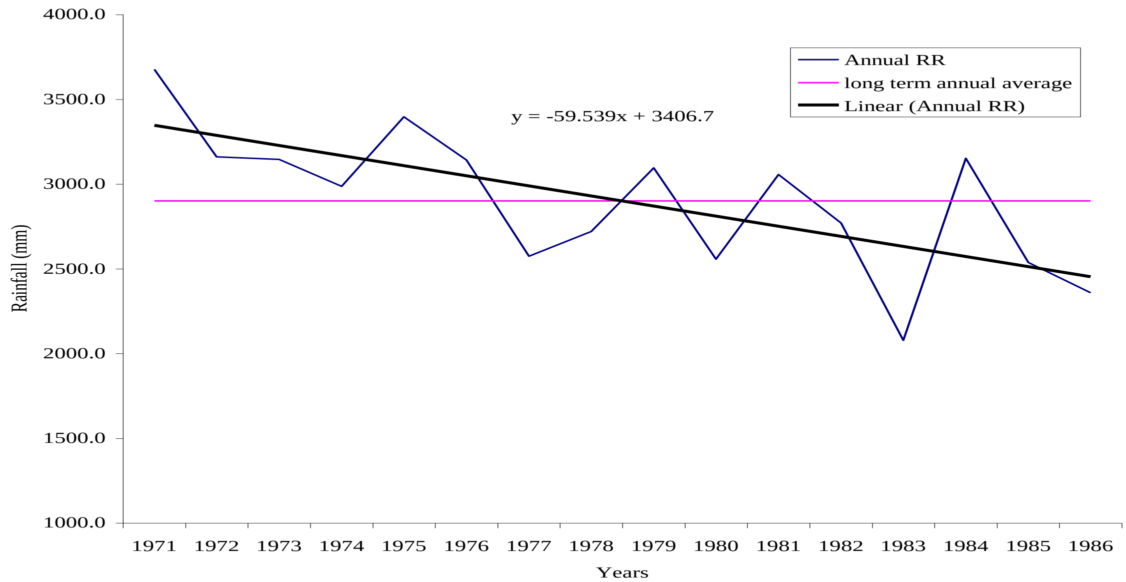


Figure 4.3-4: Tafelberg annual rainfall 1971-1986

The trend for the rainfall for Tafelberg (fig.4.3-4) shows a decline during the period 1971-1986. The regression equation is y =-59.539x+3406 and the regression coefficient is -59.539. This equation indicates that the rainfall has decreased in time for Tafelberg during the period 1971-1986. The annual rainfall distribution 1971-1986 for Tafelberg is illustrated in figure 4.3-5. The long-term annual average rainfall is used to determine the wet and dry years for this station.

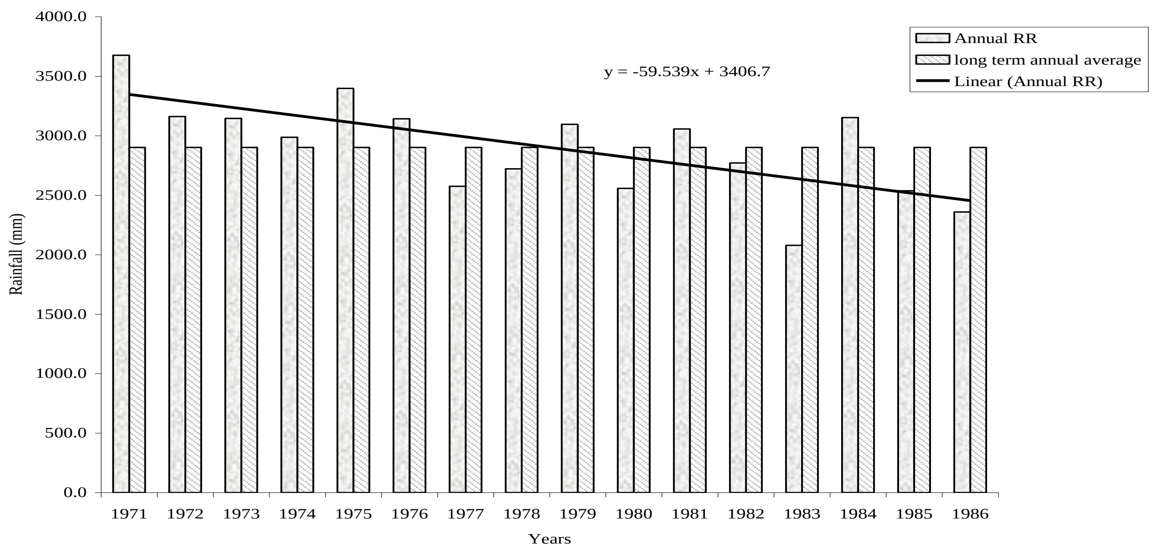


Figure 4.3-5: Tafelberg annual rainfall distribution 1971-1986

The annual rainfall distribution (fig.4.3-5) shows that in some years, values are above the long-term average and in some years, the totals are below this average. However, the rainfall pattern shows an overall decline over the period 1971-1986.

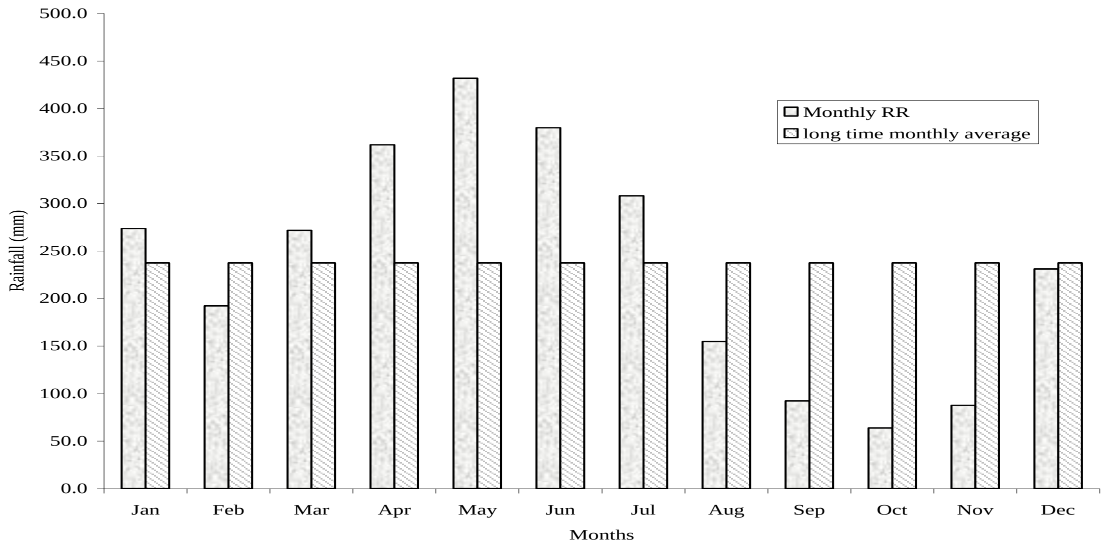


Figure 4.3-6: Tafelberg seasonal rainfall distribution 1971-1986

Figure 4.3-6 illustrates the monthly rainfall pattern for Tafelberg and the wet and dry seasons are identified in this graph. However, most of the months are still below the long-term monthly average of 237.41mm. For January, March, April, May, June and July, their monthly rainfall totals are above the long-term average. These months are considered wet, because the rainfall totals are higher than the long-term average, which is would normally be expected during the rainy season. According to the illustration in figure 4.3-6, the long rainy season lasts from first March until the end of July, and May has the highest monthly rainfall totals. For the short wet season, the January rainfall total exceeded the long-term average.

All the rainfall values displayed in figure 4.3-6, which are above the long term monthly average were recorded in the wet seasons. The long-term monthly average of 237.4 mm is used as the normal to determine the wet and dry seasons. Two wet season are identified for Tafelberberg from figure 4.3-6. The season that has rainfall totals less than the long-term monthly average is considered the dry season and the short dry season extends from Mid February until mid March. The long dry season lasts from mid August until the end of December.

4.4 The Southern Part of Suriname

The southern part of Suriname is depicted by the selected stations Kwamalasoemoetoe and Sipalwini. The rainfall pattern in the southern part of the country is investigated by examining the data for Kwamalasoemoetoe and Sipaliwini. The time series for Kwamalasoemoetoe is from 1977-2008. The data set has a lot of missing values. Figure 4.4-1 represents the annual rainfall, 1977-2008 for Kwamalasoemoetoe.

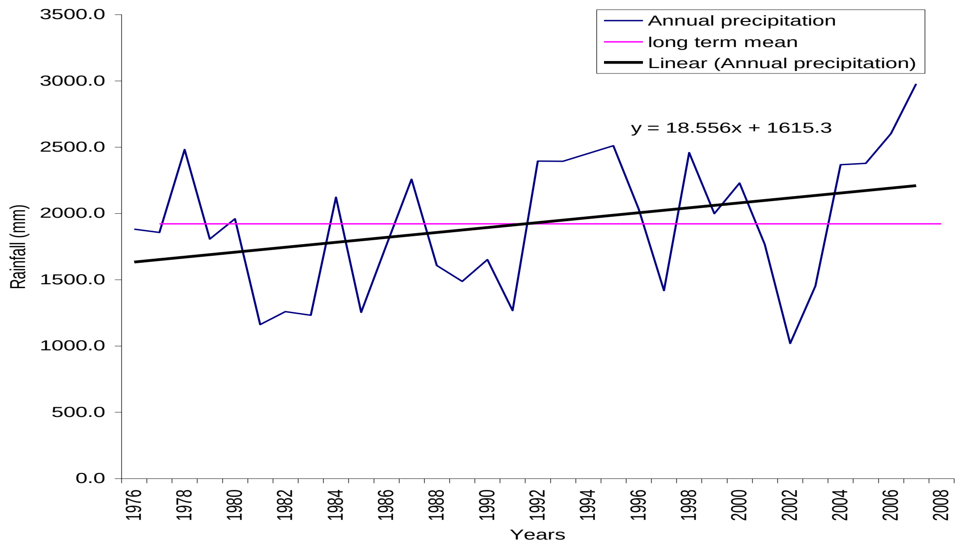


Figure 4.4-1: Kwamalasoemoetoe annual rainfall 1977-2008

The annual rainfall for Kwamalasoemoetoe (fig.4.4-1) shows an increasing trend, but there is a lot of missing data. However, the regression coefficient is positive, which indicates that the rainfall is increasing with time. The regression equation is y = 18.558x+1615.3 and the long-term annual total for the station is 1921.5mm. The annual rainfall distribution is presented in figure 4.4-2 for Kwamalasoemoetoe.

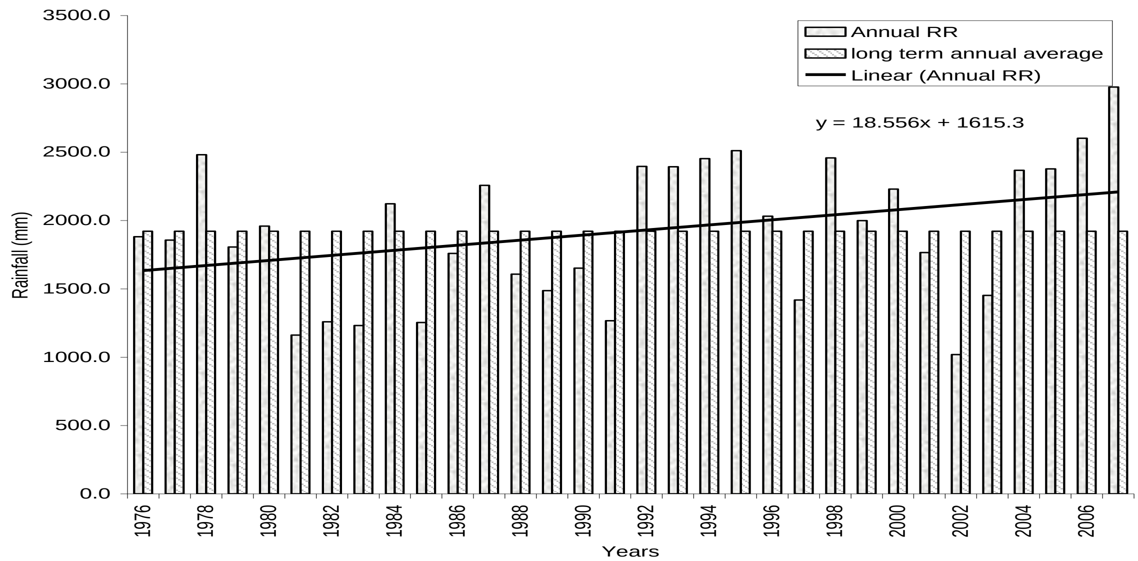


Figure 4.4-2: Kwamalasoemoetoe annual rainfall distribution 1976-2008

The annual rainfall distribution for Kwamalasamoetoe (fig. 4.4-2) shows that twelve years for Kwamalasoemoetoe are considered as wet years because the annual total precipitation has exceeded the long-term average rainfall. All the others years can be considered as dry years. The years that exceeded the long-term average are 1979, 1981, 1985, 1988, 1993, 1995, 1996, 1999, 2000, 2005, 2006, 2007, and 2008. Figure 4.4-3 depicts the monthly rainfall distribution for Kwamalasoemoetoe.

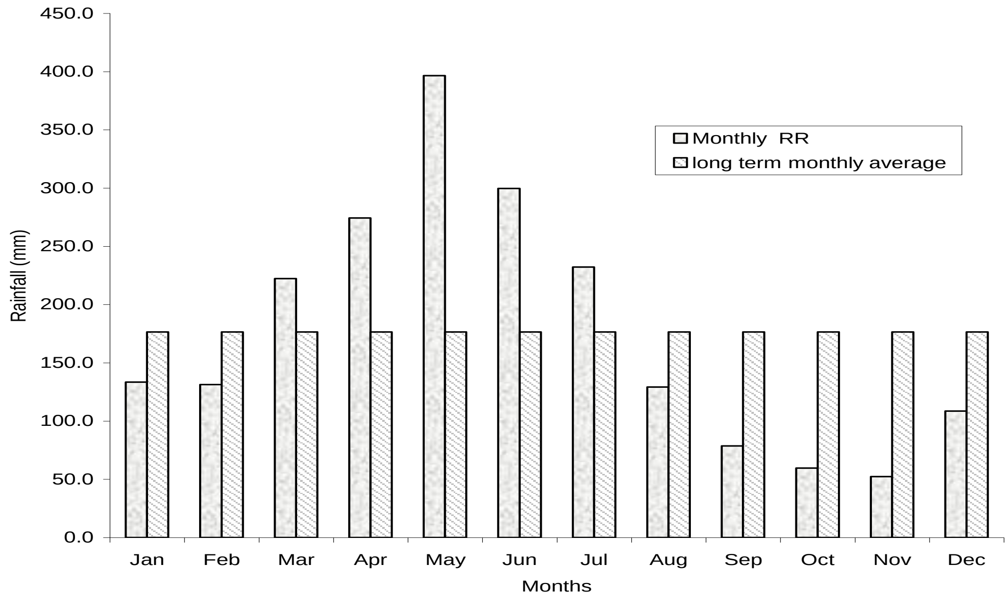


Figure 4.4-3: Kwamalasoemoetoe monthly rainfall distribution 1977-2008

The highest monthly rainfall total, 396.51mm, was recorded in May, which falls within the wet season (fig.4.4-3). The long-term monthly average rainfall is 175.57 mm. All the months that have a monthly rainfall total of less than the long term monthly average of 176.5 mm can be considered dry months. The months that have exceeded the long-term monthly average are March, April, May, June and July. These months can be considered as wet months. Kwamalasoemoetoe experienced only one wet season as illustrated in figure 4.4-3 and this starts in March and it ends at the end of July. All the other months fall within the dry season. The second stations in the southern part of Suriname are Sipaliwini and the rainfall patterns are displayed in the figures 4.4-4 until 4.4-6.

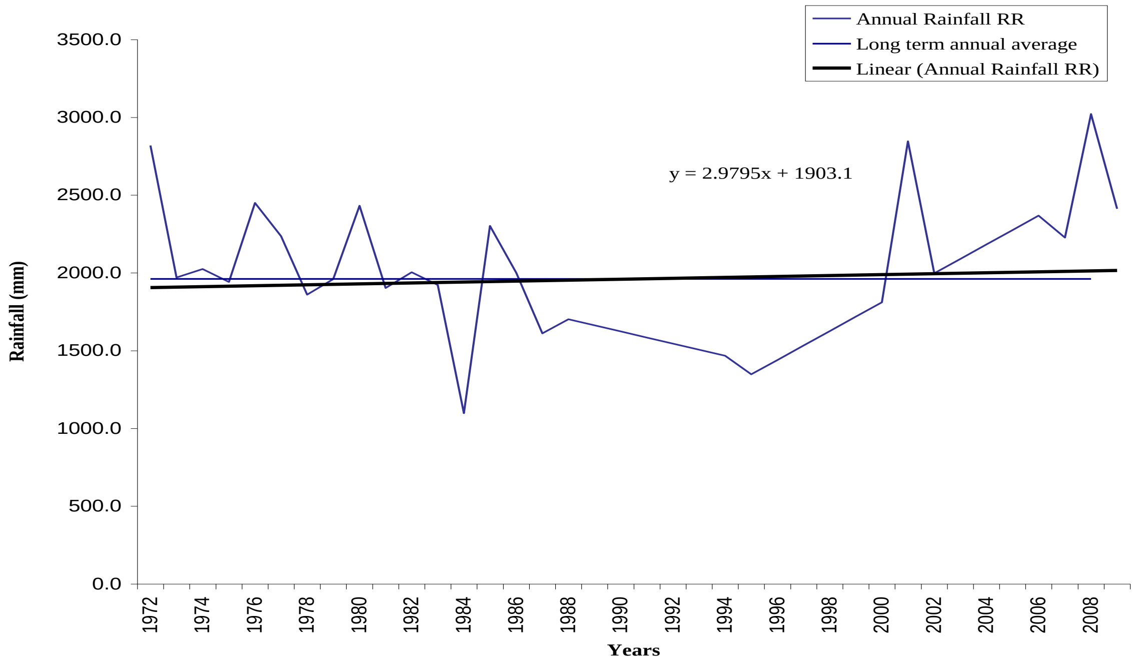


Figure 4.4-4: Sipaliwini annual rainfall 1971-2008

The annual rainfall for Sipaliwini (fig.4.4-4) shows a slight increase through the years 1971-2008. The regression line has a positive coefficient of 2.98. The annual rainfall distribution for Sipaliwini is displayed in figure 4.4-5.

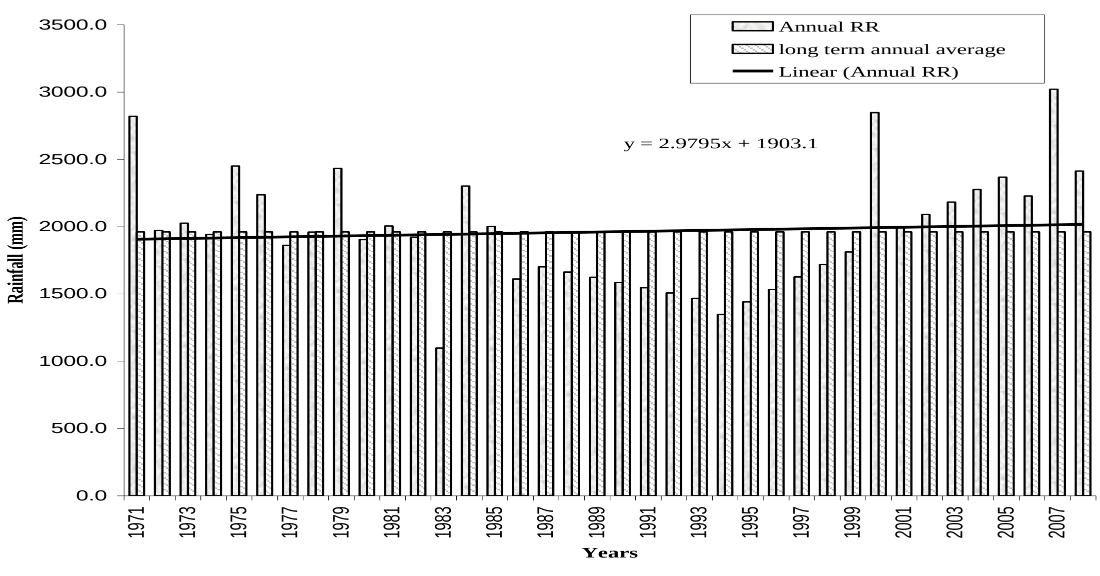


Figure 4.4-5: Sipaliwini annual rainfall distribution 1971-2008

The annual rainfall distribution for Sipaliwini (fig. 4.4-5) shows that 17 years are relatively wet years, because their monthly rainfall totals are above the long term annual totals. The years that are relatively wet years are 1971, 1973, 1975, 1976, 1979, 1981, 1984, 1985, 2000, 2002, 2003, 2004, 2005, 2006, 2007 and 2008. The wettest year was 2008, when a total of 3021.1mm of rainfall was recorded, and the driest year was 2008 with a total of 2412.4 mm.

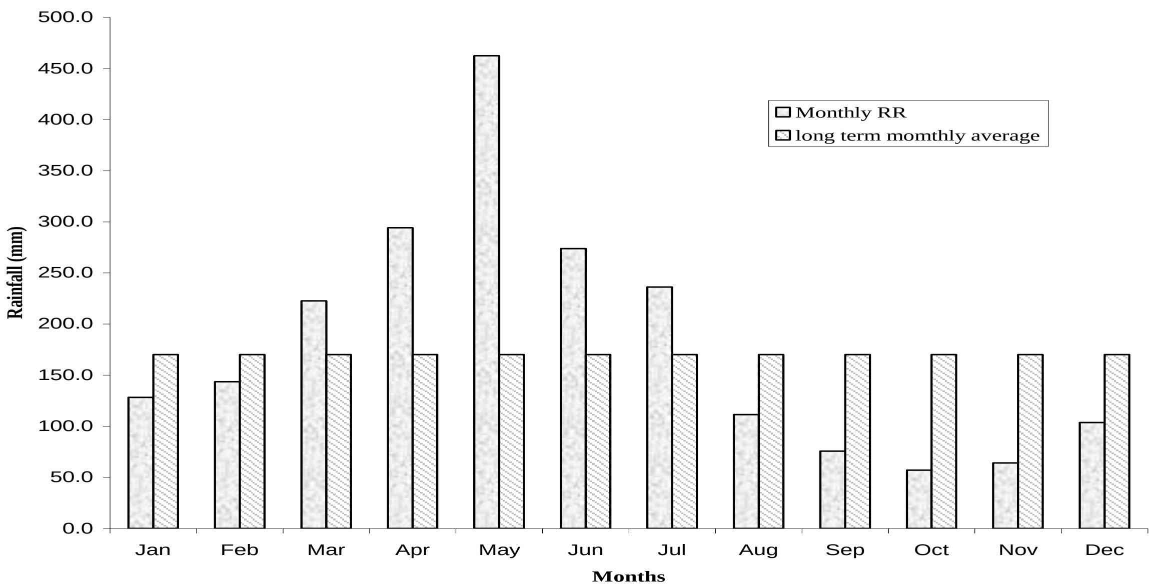


Figure 4.4-6: Sipaliwini monthly rainfall distribution 1971-2008

The monthly rainfall distribution for Sipaliwini (fig.4.4-6) shows that the long wet period lasts from March-July and thus there is only one wet season. All the other months are considered dry, because the monthly rainfall values are less than the long-term monthly average. The long-term monthly average is 181.1mm. The dry season lasts from August until February.

4.5 Results and discussion

Seven meteorological stations spread across Suriname were selected and the rainfall data for the years 1971-2008 were examined (Appendix A: table A.1). Unfortunately, some stations in the interior of Suriname have incomplete data sets. In the case of Tafelberg, this station has only sixteen year of data. The data sets for Kwamalasoemoetoe and Stoelmans Eiland also have a lot of missing values. In such cases, linear interpolation was used to insert the missing values. The average seasonal rainfall 1971-2008 for the selected meteorological stations in Suriname is presented in table 4.5-1.

Table 4.5-1 : Observed average seasonal rainfall (mm) for selected meteorological stations in Suriname

Station	period	DJF	MAM	JJA	SON
Nickerie	1971-2008	415.6	493.2	645.5	216.4
Cultuurtuin	1971-2008	521.0	631.8	718.6	320.7
Zanderij	1971-2008	519.7	696.4	736.4	335.8
Stoelmans Eiland	1971-2005	656.1	853.1	726.5	294.3
Kwamalasoemoetoe	1977-2008	373.4	893.1	661.3	190.5
Tafelberg	1971-1986	697.0	1065.5	842.7	243.6
Sipaliwini	1971-2008	375.6	979.3	621.3	196.7

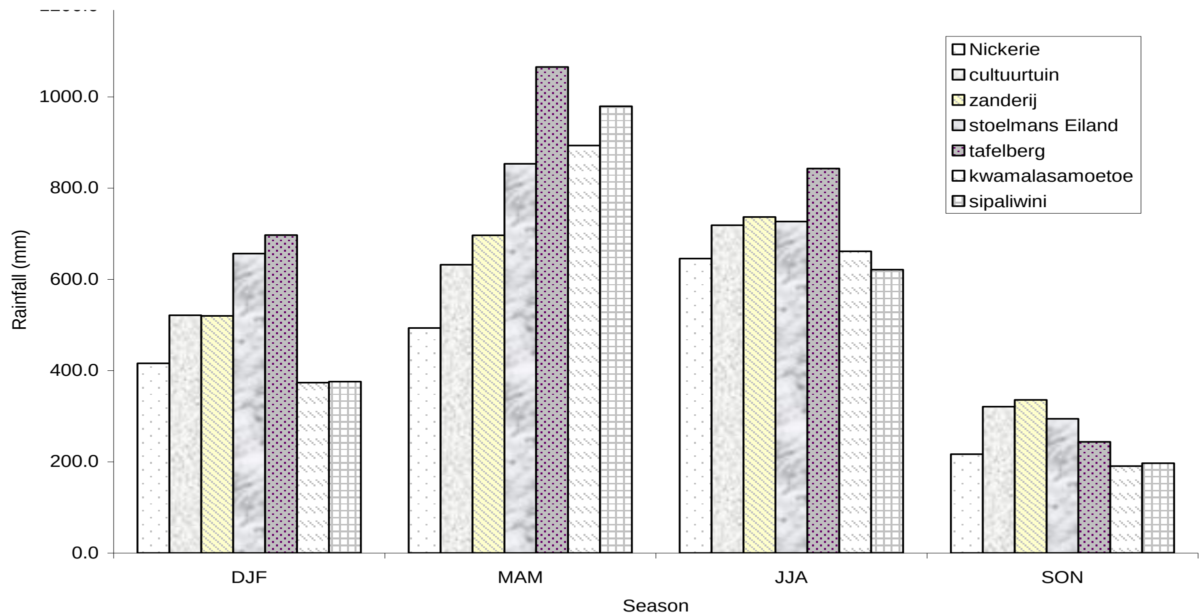


Figure 4.5-1: Seasonal rainfall distribution for selected meteorological stations in Suriname 1971-2008

The seasonal rainfall distribution illustrated in figure 4.5-1 shows that the rainfall is less in the coastal area and that the rainfall increases toward inland and thereafter it decreases to the south of the country again. Tafelberg records the highest seasonal rainfall total for DJF, MAM, JJA, and Zanderij receives the highest rainfall in SON. The observed monthly rainfall for the selected meteorological stations in Suriname is presented in table 4.5-2.

Table 4.5-2: observed average monthly rainfall (mm) for selected meteorological stations in Suriname.

Station	Position	period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nickerie	05 57 00 N 057 02 00 W	1971-2008	149.8	99.8	98.4	159.2	235.6	259.9	233.4	152.3	77.5	58.4	80.5	166.0	1721.1
Cultuurtuin	05 50 00 N 055 10 00 W	1971-2008	196.1	133.9	132.7	207.7	291.4	317.7	245.5	155.3	97.1	96.1	127.4	191.0	2186.0
Zanderij	05 28 00 N 055 12 00 W	1971-2008	192.8	126.6	150.4	227.4	318.6	314.0	245.7	176.7	107.7	103.7	124.4	200.4	2262.4
Stoelmans Eiland	04 21 00 N 054 25 00 W	1971-2005	241.0	180.0	216.2	285.8	351.0	307.7	257.5	161.2	85.8	86.7	121.7	235.1	2461.4
Kwamalasoe moetoe	02 23 00 N 056 43 00 W	1977-2008	133.5	131.3	222.4	274.3	396.5	299.7	232.3	129.3	78.6	59.6	52.3	108.6	1921.5
Tafelberg	03 47 00 N 056 09 00 W	1971-1986	273.6	192.3	271.8	361.8	431.8	379.8	308.1	154.8	92.3	63.8	87.6	231.1	2900.6
Sipaliwini	02 02 00 N 056 07 00 W	1971-2008	128.3	143.6	222.7	294.2	462.4	273.8	236.1	111.4	75.6	57.0	64.0	103.7	1961.2

Source: Meteorological Service Suriname

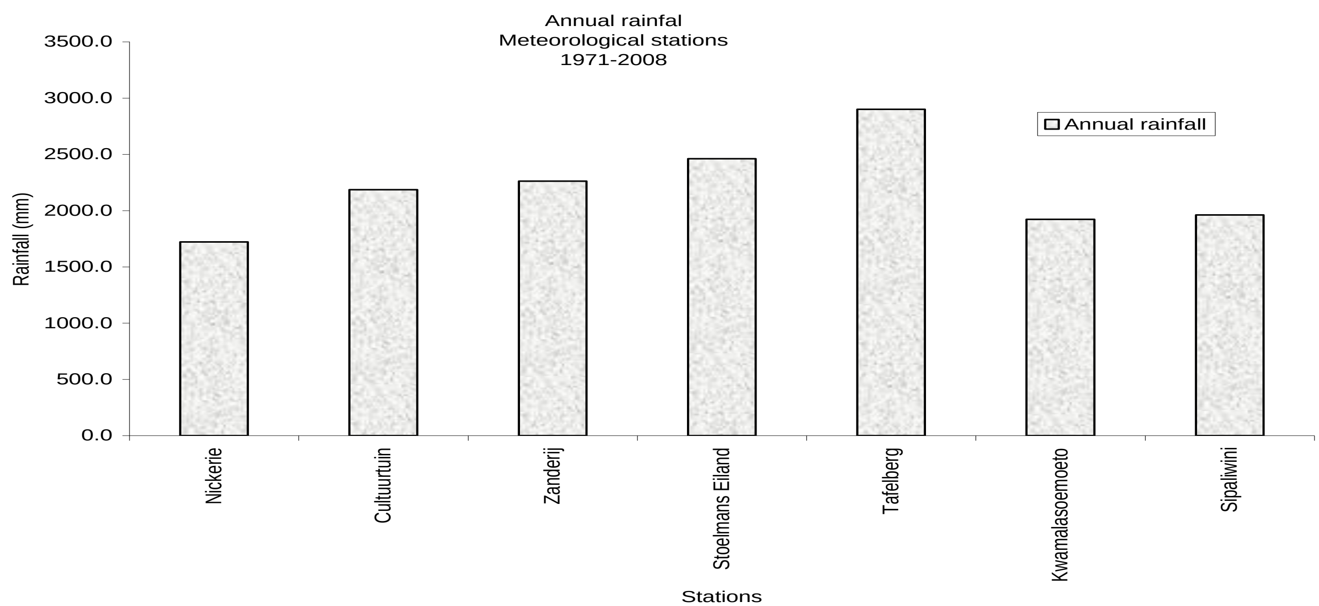


Figure 4.5-2: average annual rainfall distribution for selected meteorological stations in Suriname 1971-2008

The annual rainfall distribution as illustrated in figure 4.5-3 identifies that Tafelberg has the highest annual rainfall. The annual rainfall starts to increase in the coastal area toward the central part of the country thereafter it decreases again in Southern direction. The monthly rainfall for the selected meteorological stations in Suriname is illustrated in figure 4.5-4

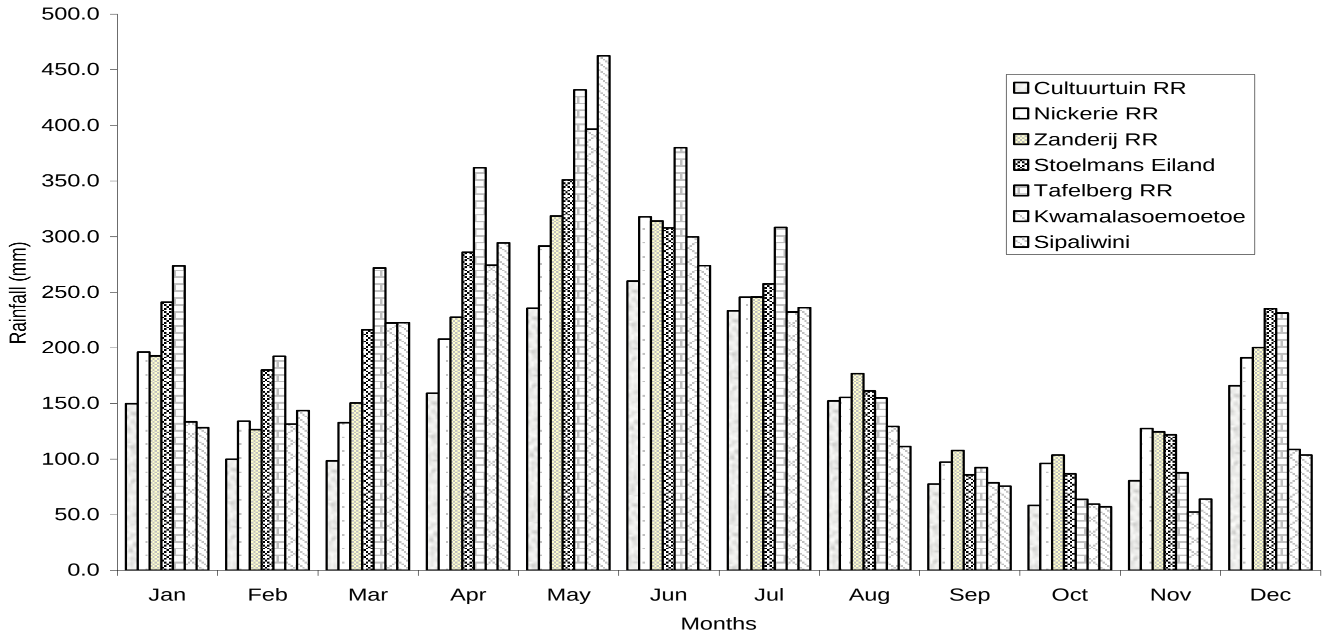


Figure 4.5-3: Monthly rainfall (mm) for selected meteorological stations in Suriname 1971-2008

The monthly rainfall totals for the selected meteorological stations in Suriname (fig.4.5-4) show that rainfall is highest during April-June and lowest in September – October. Sipaliwini has the highest monthly rainfall in May, which is in the long wet season. The monthly rainfall is similar for all stations, and shows a seasonal cycle. The seasonal cycle is related to the annual migration of the Inter tropical Convergence Zone (ITCZ) (fig.1.3-1) (Emanuels, 1968). Table 4.5-3 presents the rainfall statistics for the seven selected meteorological stations in Suriname with the data coverage 1971-2008.

Table 4.5-3: Rainfall statistics 1971-2008 for selected meteorological stations in Suriname

No	Station	Long term annual mean (mm)	Long term monthly mean (mm)	Maximum (mm)	Minimum (mm)
1	Nickerie	1721.1	147.6	2434.0	933.3
2	Cultuurtuin	2186.0	182.7	3067.0	1538.2
3	Zanderij	2262.4	190.7	2925.3	1723.4
4	Kwamalasoemoetoe	1921.5	176.5	2976.9	1019.5
5	Stoelmans Eiland	2461.4	210.8	2980.0	1784.6
6	Tafelberg	2900.6	237.4	3676.7	2078.1
7	Sipaliwini	1961.2	181.1	3021.0	2412.4

The rainfall statistics displayed in table 4.5-2 show that the maximum rainfalls vary between 2434 – 3676.7 mm and the minimum rainfalls vary between 933.3 – 2412.4 mm. Tafelberg have recorded the highest rainfall values and Nickerie has recorded the lowest rainfall value.

Table 4.5-4 presents the positive and negative trend of the rainfall 1971-2008 for the selected meteorological station.

Table 4.5-4: Rainfall linear trend (mm/year) in average annual rainfall for selected meteorological stations in Suriname

no	Station	Position	Regression Coefficient (R)	Rainfall data time range	Trend	Result
1	Nickerie	05 57 00 N 057 02 00 W	-2.596	1971-2008	Negative(-)	drier
2	Cultuurtuin	05 50 00 N 055 10 00 W	0.35	1971-2008	Positive(+)	wetter
3	Zanderij	05 28 00 N 055 12 00 W	-7.02	1971-2008	Negative (-)	drier
4	Stoelmans Eiland	04 21 00 N 054 25 00 W	-15.19	1971-2008	Negative (-)	drier
5	Tafelberg	03 47 00 N 056 09 00 W	-59.54	1971-1986	Negative (-)	drier
6	Kwamalasoemoetoe	02 23 00 N 056 43 00 W	18.56	1977-2008	Positive (+)	wetter
7	Sipaliwini	02 02 00 N 056 07 00 W	2.98	1971-2008	Positive (+)	wetter

Four stations out of the seven selected meteorological stations in Suriname show a drier rainfall pattern (table 4.5-2).

Figure 4.5-5 illustrates the rainfall linear trend for the seven selected meteorological stations in Suriname for the period 1971-2008.

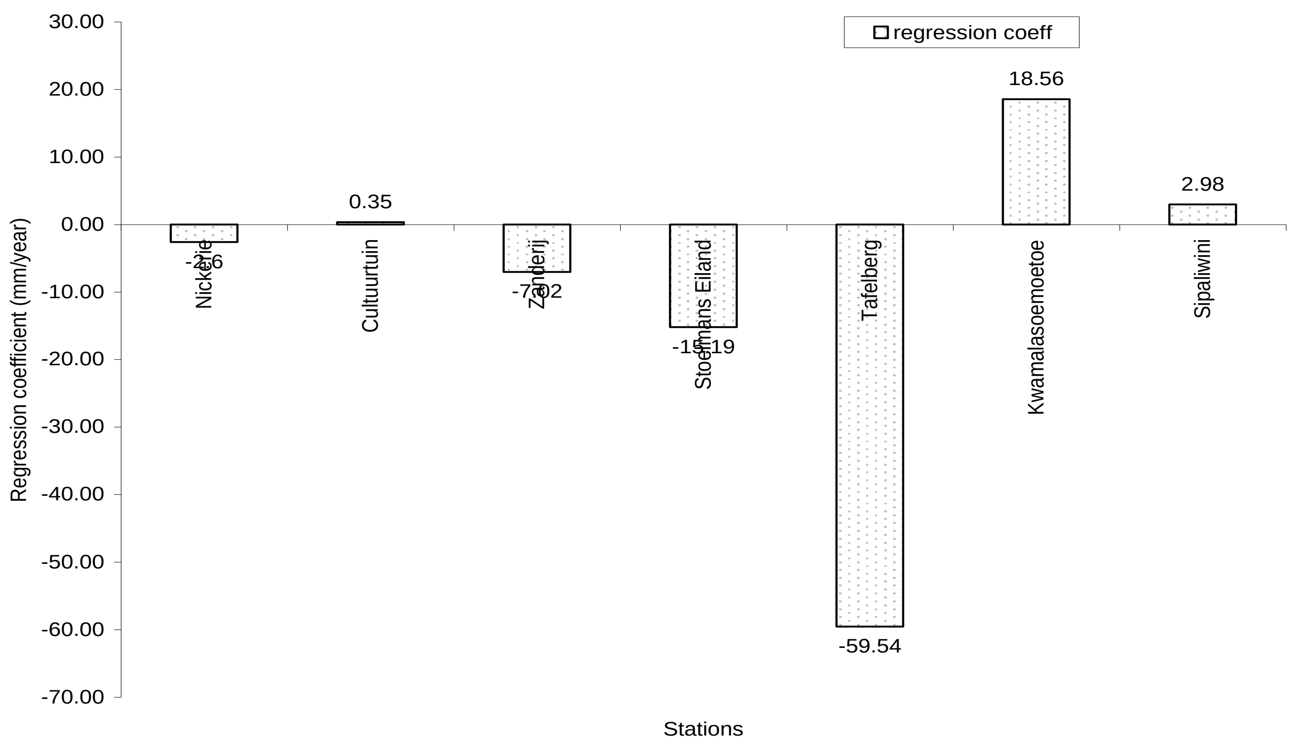


Figure 4.5-4: Rainfall linear trend for selected meteorological stations in Suriname 1971-2008

Rainfall at Cultuurtuin, Kwamalasoemoetoe and Sipaliwini, three out of the seven stations(fig.4.5-5) showed an upward trend during the period 1971-2008, which means that the stations have become wetter over the past years. One of these stations, Cultuurtuin is located at the North of Suriname and the two other stations, Kwamalasoemoetoe and Sipaliwini are in the southern part of the country. However, the west coastal station, Nickerie, has experienced a decrease in rainfall for these years 1971-2008 as well Zanderij and Stoelmans Eiland.

5 TEMPERATURE PATTERN OF SURINAME 1971-2008

With regard to the temperature pattern for Suriname data from the same seven selected meteorological stations were examined. The analyses of the temperature are divided for three parts of the country, the coastal, central and southern part. The length of the data series varies from 16 year to 37 years, spread over the period 1971-2008. As with the rainfall data, linear interpolation was used where there were missing values in the data sets.

5.1 The Coastal Part of Suriname

The coastal part of the country is represented by the stations Nickerie, Cultuurtuin and Zanderij. The time series, monthly and annual average temperatures for the years 1971-2008 were examined for these stations. The course of the annual average temperature 1971-2008 for Nickerie is illustrated in figure 5.1-1.

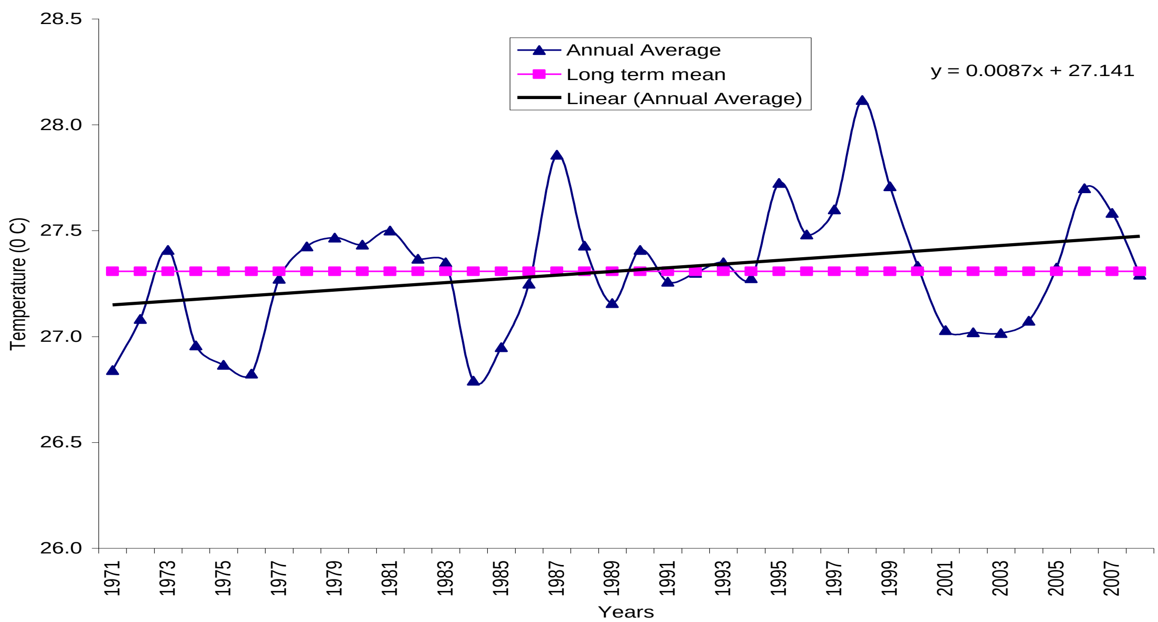


Figure 5.1-1: Nickerie annual average temperature 1971-2008

The long-term average temperature for Nickerie is 27.3^0 C. The graph in figure 5.1-1 shows an increase in the annual temperature at Nickerie over the period 1971-2008. The norm for the temperature is the long term mean of 27.3^0C. This upward trend started about 1990-1991 and the regression equation is y =0.0087x + 27.141.

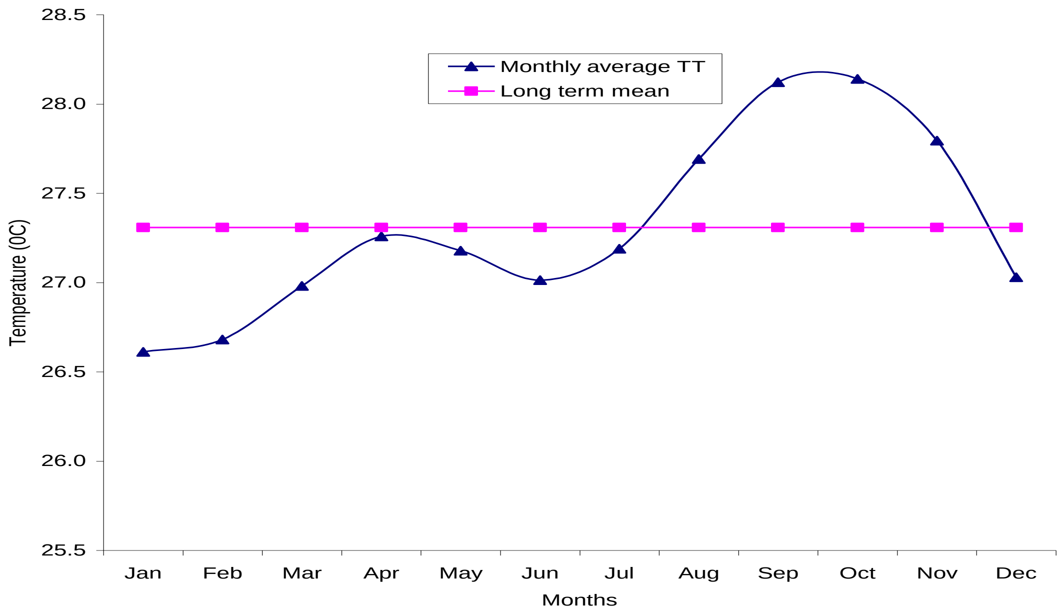


Figure 5.1-2: Nickerie monthly average temperature 1971-2008

The monthly temperature graph shows that higher temperatures were recorded during August to December (fig.5.1-2), which is not surprising, as this coincides with the dry season (which lasts from mid August until the beginning of December). Lower temperatures were recorded during December to August. The norm for the temperature is the long-term average of 27.3 ^{0} C.

The second station in the coastal part of Suriname is Cultuurtuin and the long-term average temperature for Cultuurtuin, 27.3 ^{0} C is used as the normal. The illustration in figure 5.1-3 represents the annual temperature for Cultuurtuin 1971-2008.

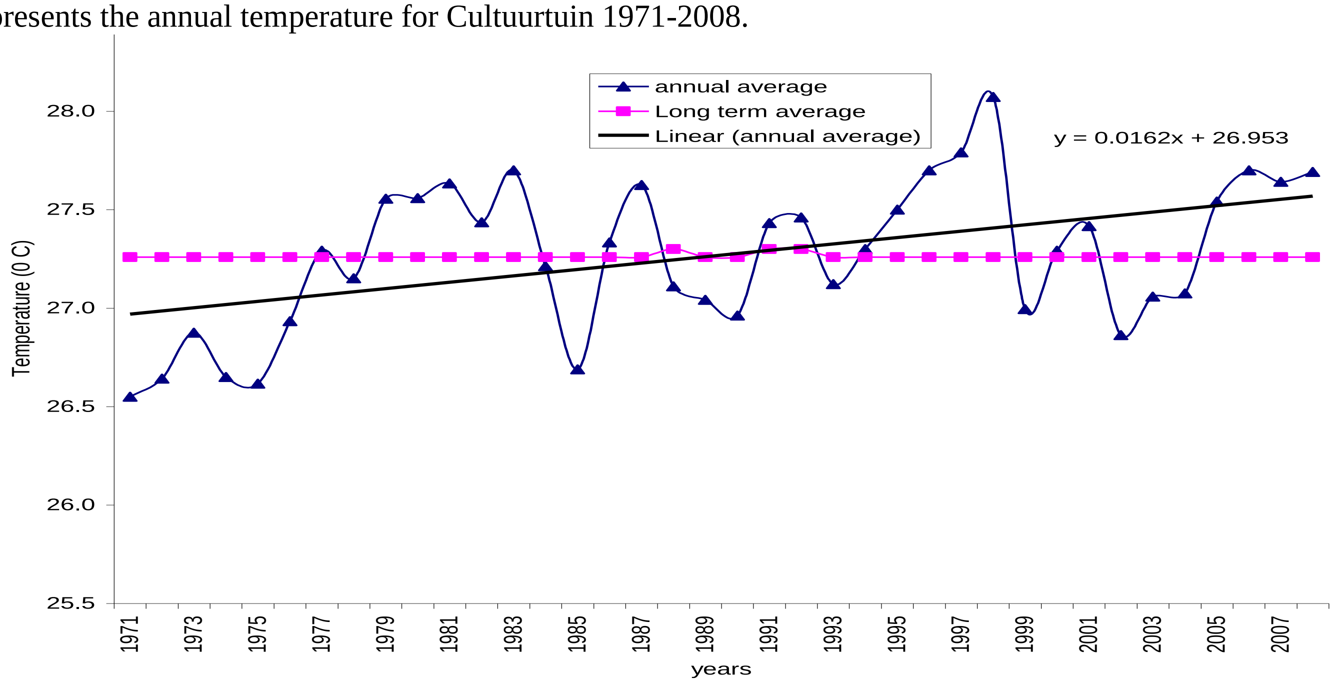


Figure 5.1-3: Cultuurtuin annual average temperature 1971-2008

The annual average temperature graph (fig.5.1-4) shows an upward trend. A positive regression coefficient is an indicator that the temperature is increasing through time. The upward trend began around 1990-1991. The monthly average temperature for Cultuurtuin 1971-2008 is represented in figure 5.1-4.

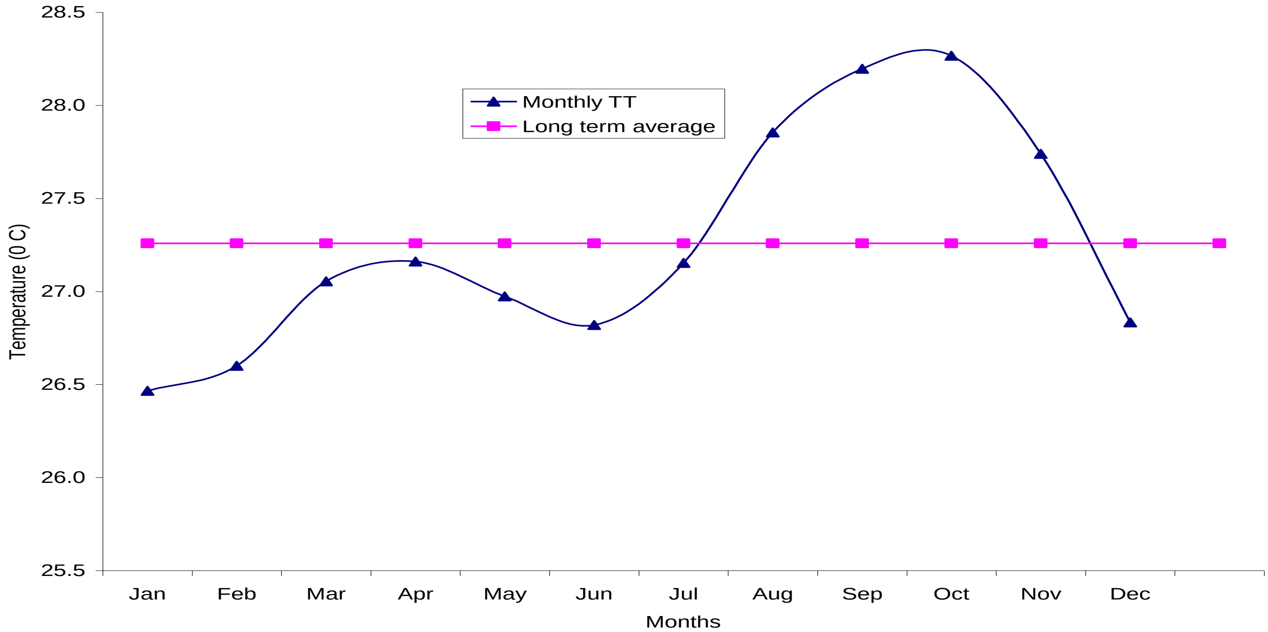


Figure 5.1-4: Cultuurtuin average monthly temperature 1971-2008

The maximum temperature for Cultuurtuin was recorded in October, during the dry season (fig.6.1-4). The third station in the Coastal area is Zanderij and the annual average temperature (1971-2008) is illustrated in figure 5.1-5.

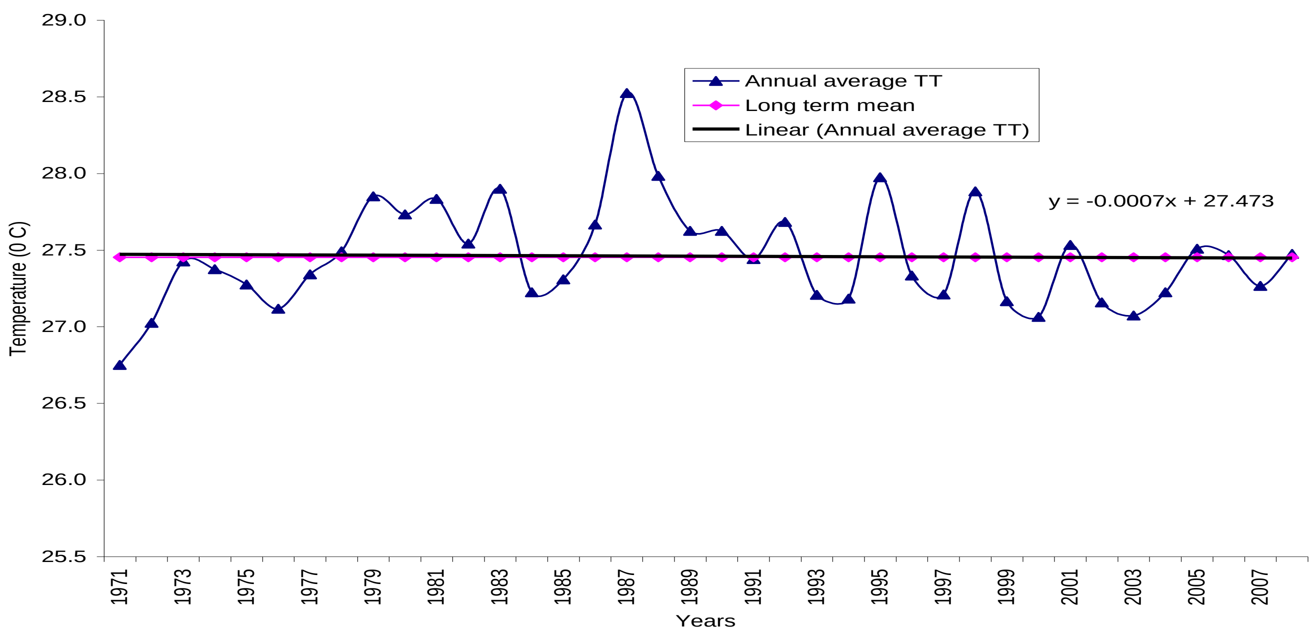


Figure 5.1-5: Zanderij average annual temperature 1971-2008

The annual temperature (fig.5.1-5) shows a downward trend, with a regression coefficient of -0.0007. This suggests that the temperature showed a slightly decrease over the period. The regression equation is y=-0.0007X + 27.473. Figure 5.1-6 shows the average monthly temperature for Zanderij 1971-2008.

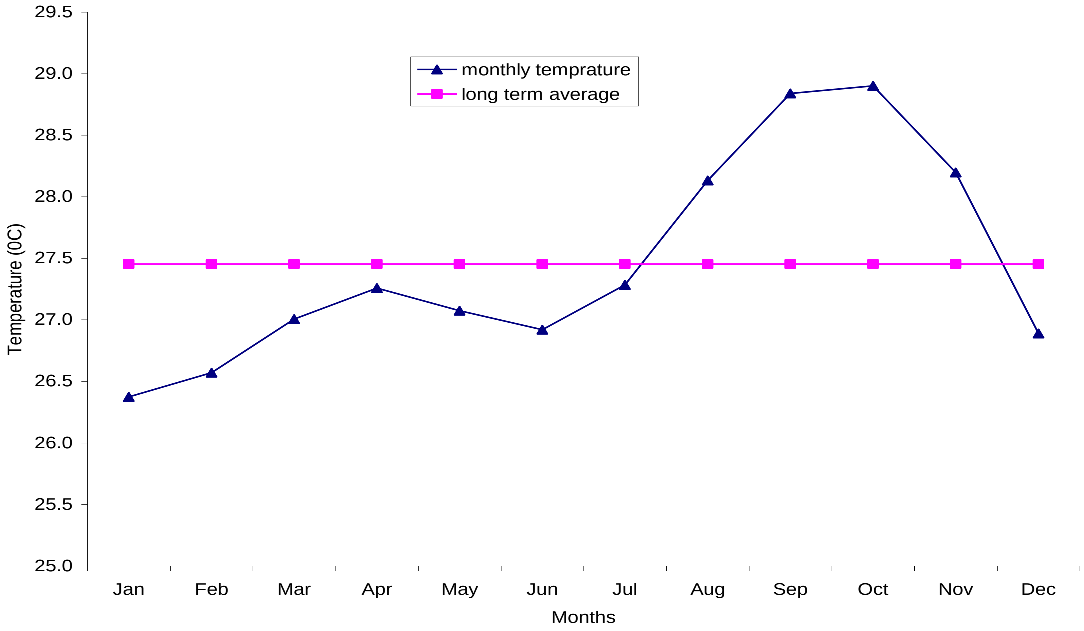


Figure 5.1-6: Zanderij average monthly temperature 1971-2008

The seasonal temperature pattern (fig.5.1-6) shows that high temperatures are observed during the dry season. The long-term average temperature of 27.4 ^{0}C is used as a norm to determine the high and low temperatures. Low temperatures are observed during the short and long wet seasons and in the short dry season.

5.2 The Central Part of Suriname

The central part of Suriname is represented by the stations Stoelmans Eiland and Tafelberg. The annual and monthly average temperatures for Stoelmans Eiland, 1971-2005 are illustrated in the figures 5.2-1 and 5.2-2.

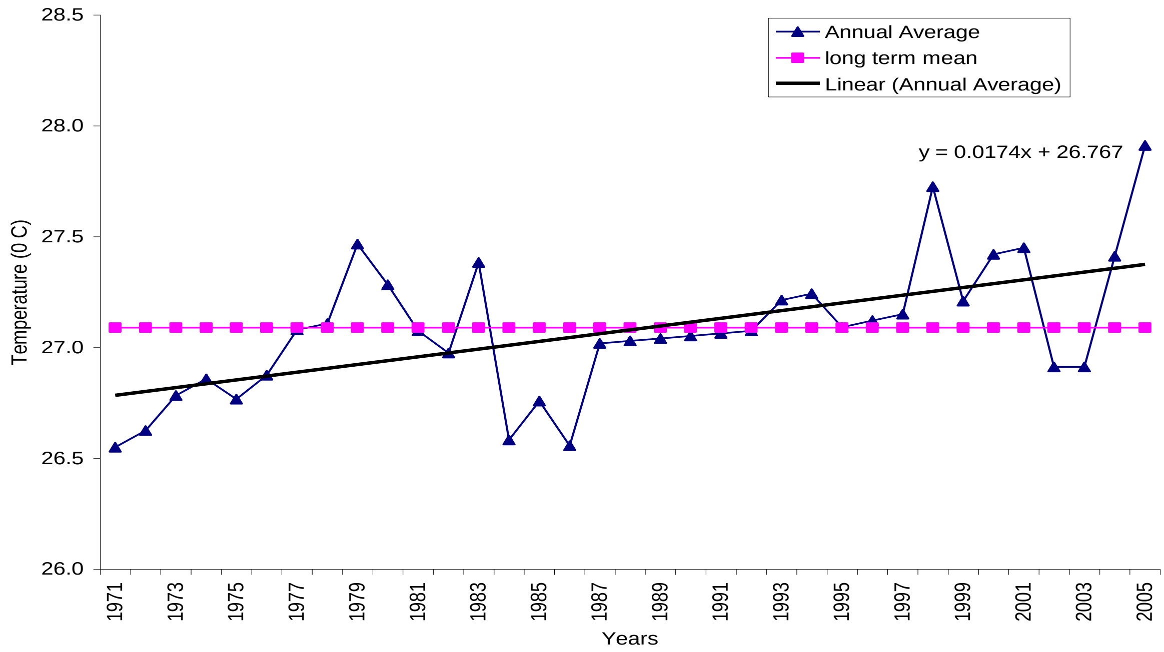


Figure 5.2-1: Stoelmans Eiland average annual temperature 1971-2005

The temperature has increased for Stoelmans Eiland in the years for 1971-2005 as illustrated in figure 5.2-1. The next figure 5.2-2 illustrates the monthly average temperature for Stoelmans Eiland 1971-2005.

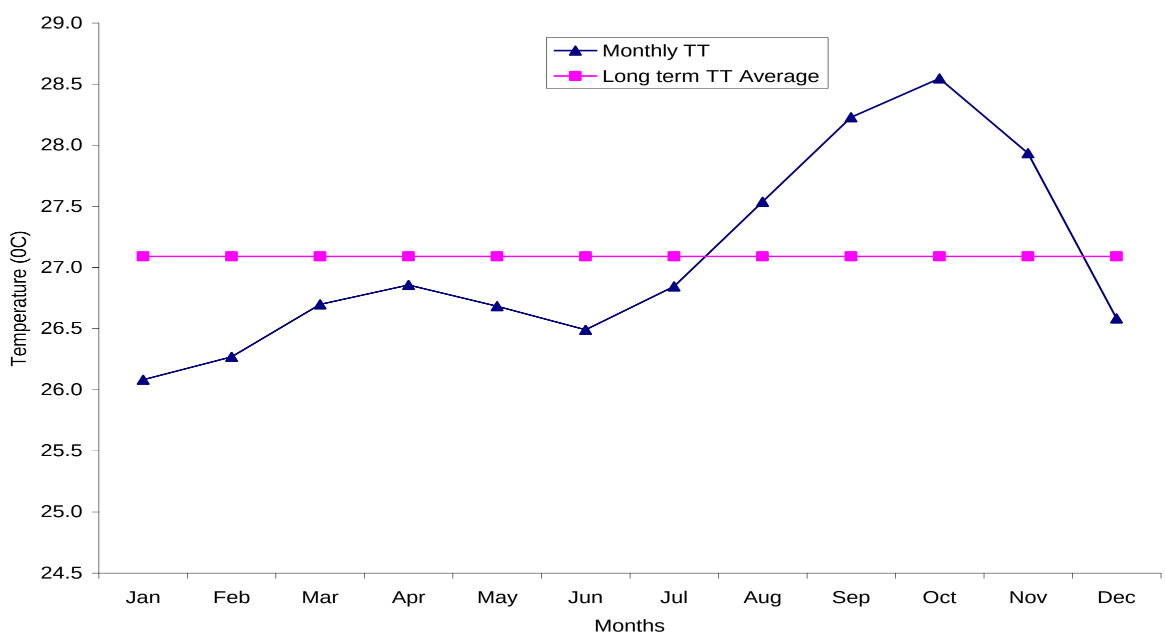


Figure 5.2-2 Stoelmans Eiland average monthly temperature 1971-2005

High temperatures are recorded from August to December and maximum temperature is observed in October. October is within the long dry season. The second station in the Central part of Suriname is Tafelberg. This station is almost at the central of the country (fig.1.1-1) and the data set covers 16 years of data, 1971-1986. Figure 5.2-3 illustrates the annual average temperature for Tafelberg (1971-1986).

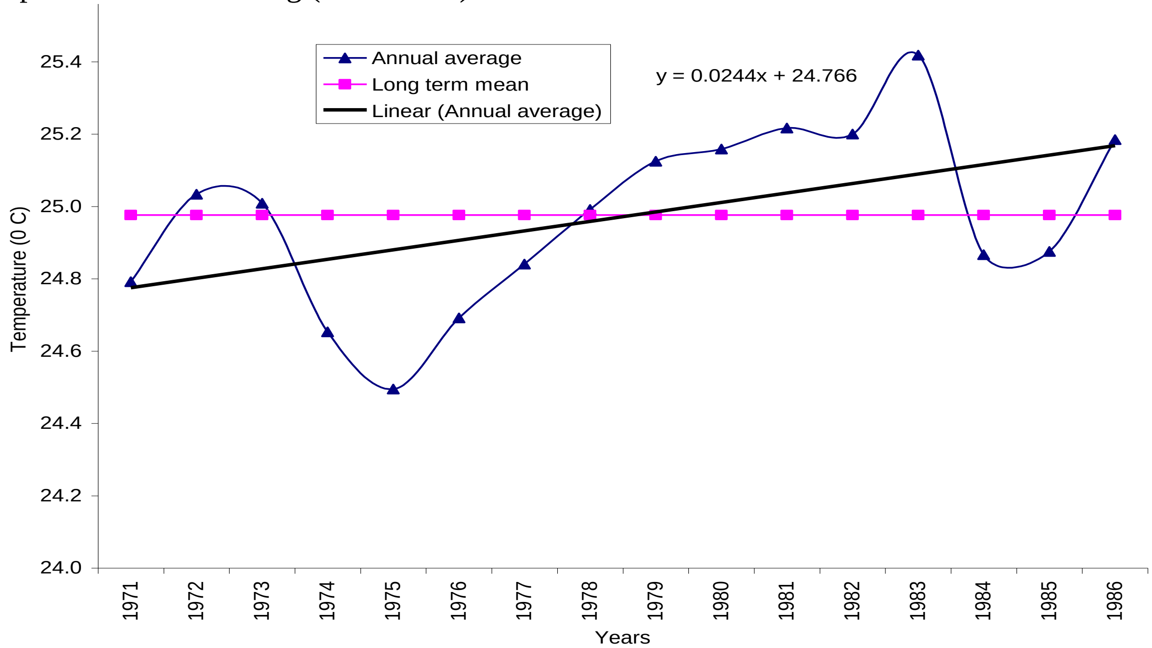


Figure 5.2-3: Tafelberg annual temperature average 1971-1986

There was an upward trend in temperature for Tafelberg (fig.5.2-3) during the period 1971-1986. The trend was observed from around 1979. The regression coefficient is 0.0244.

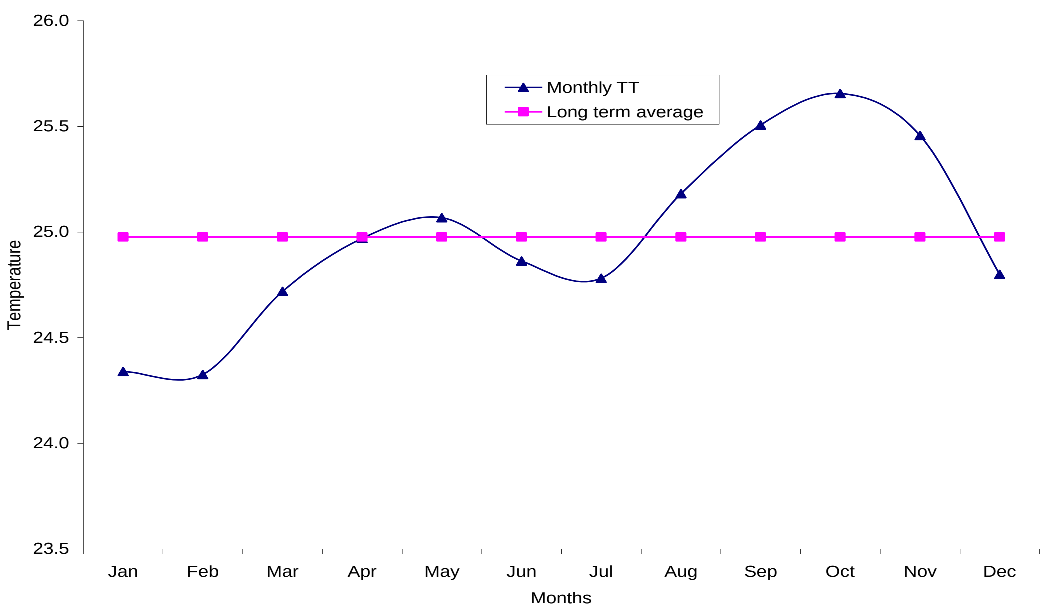


Figure 5.2-4: Tafelberg monthly temperature 1971-1986

High temperatures are observed during the long dry season for Tafelberg (fig.5.2-4). The long term average temperature, 25.0 ^{0} C is used as the norm for Tafelberg.

5.3 The Southern part of Suriname

This part of the country is represented by the stations Kwamalasoemoetoe and Sipaliwini, close to the border with Brazil. The temperature data for Kwamalasoemoetoe covers the period 1977-2005 and figure 5.3-1 illustrates the annual average temperature for this selected station.

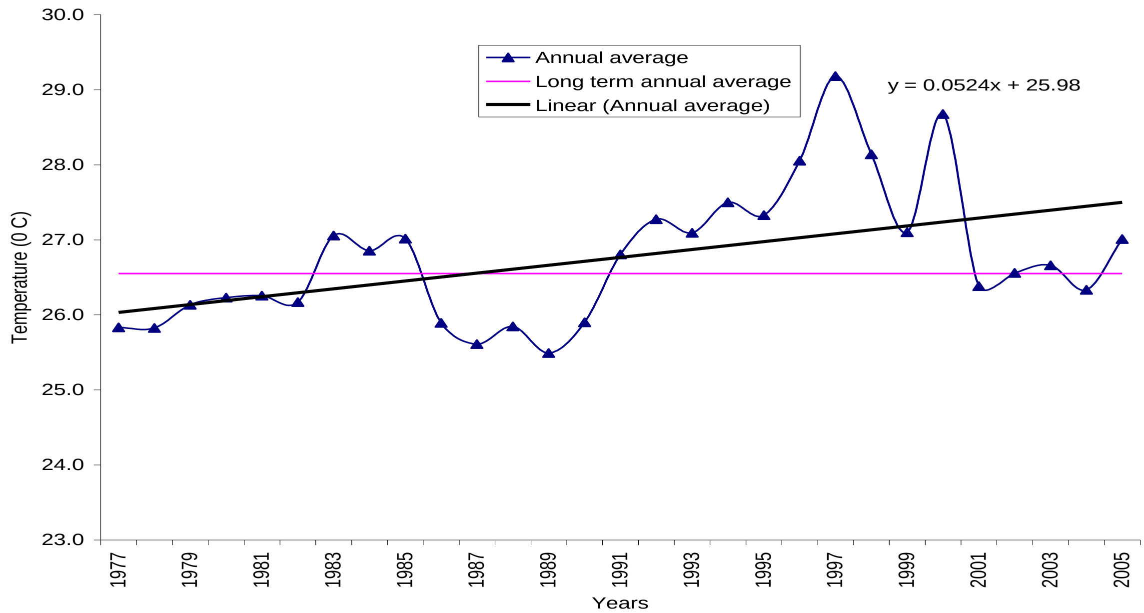


Figure 5.3-1: Kwamalasoemoetoe average annual temperature 1977-2005

The slope of the temperature graph (fig.5.3-2) shows that the temperature has increased for Kwamalasoemoetoe over the period covered by the data. The regression coefficient is 0.05.

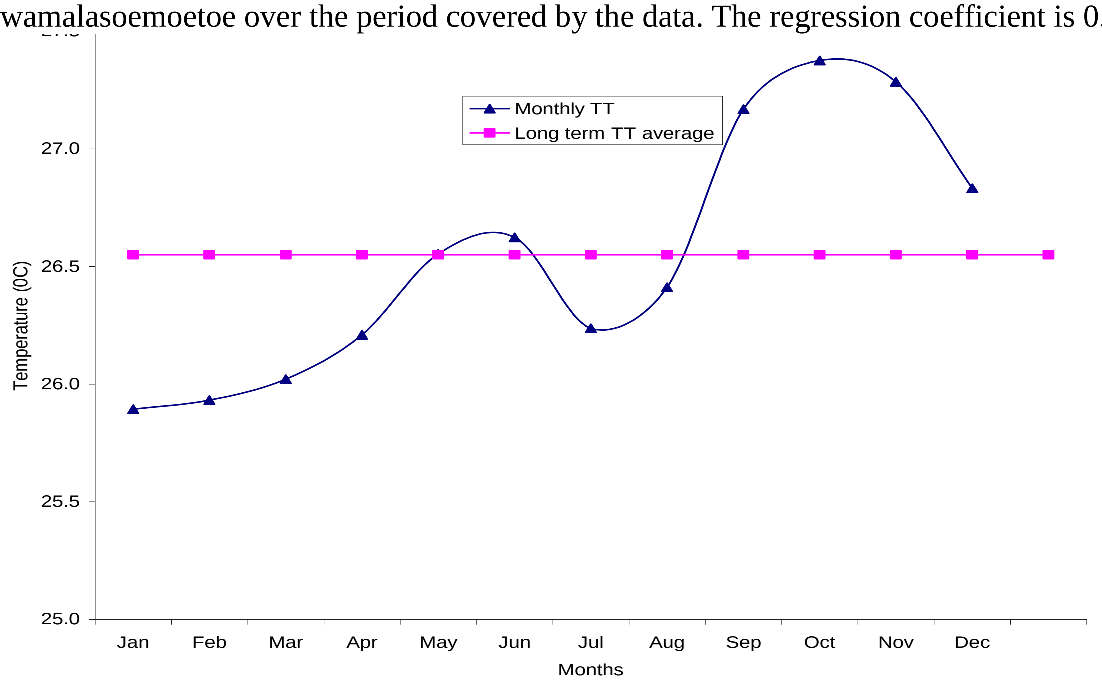


Figure 5.3-2Figure: Kwamalasoemoetoe monthly temperature 1977-2005

The highest temperature at Kwamalasoemoetoe occurs in the month of November (fig.5.3-3). Sipaliwini is the second selected station in the Southern part of Suriname and the data covers 1971-2008. The annual average temperature 1971-2008 is illustrated in figure 5.3-3.

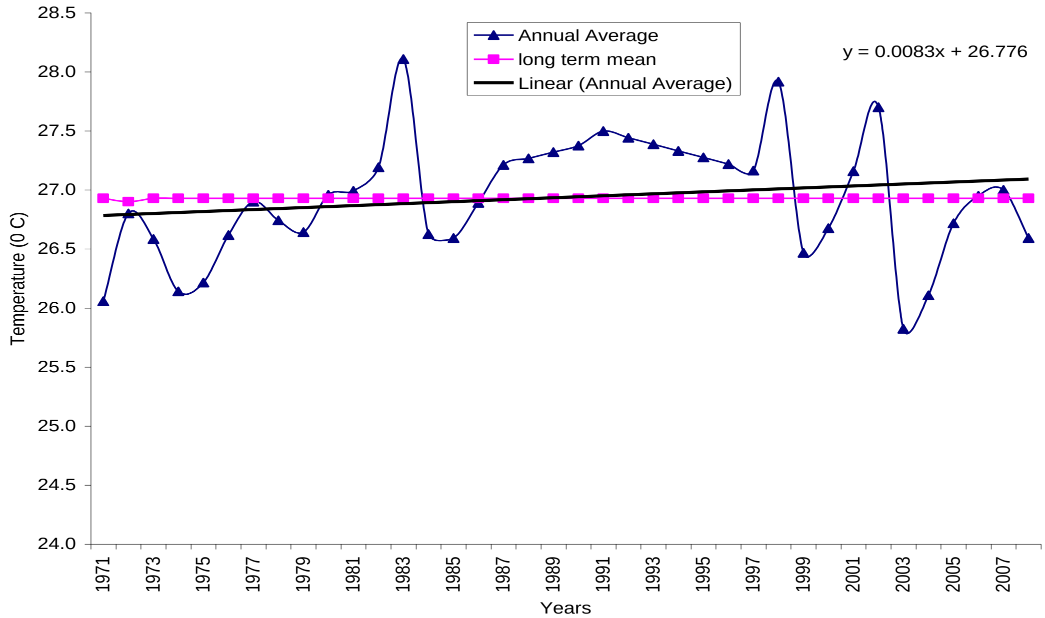


Figure 5.3-3: Sipaliwini average annual temperature 1971-2008

The temperature has also been increasing at Sipaliwini (fig. 5.3-3) in the period 1971-2008, although there is a data gap from 1987-1997. The missing values were derived using linear interpolation in order to get a complete data series.

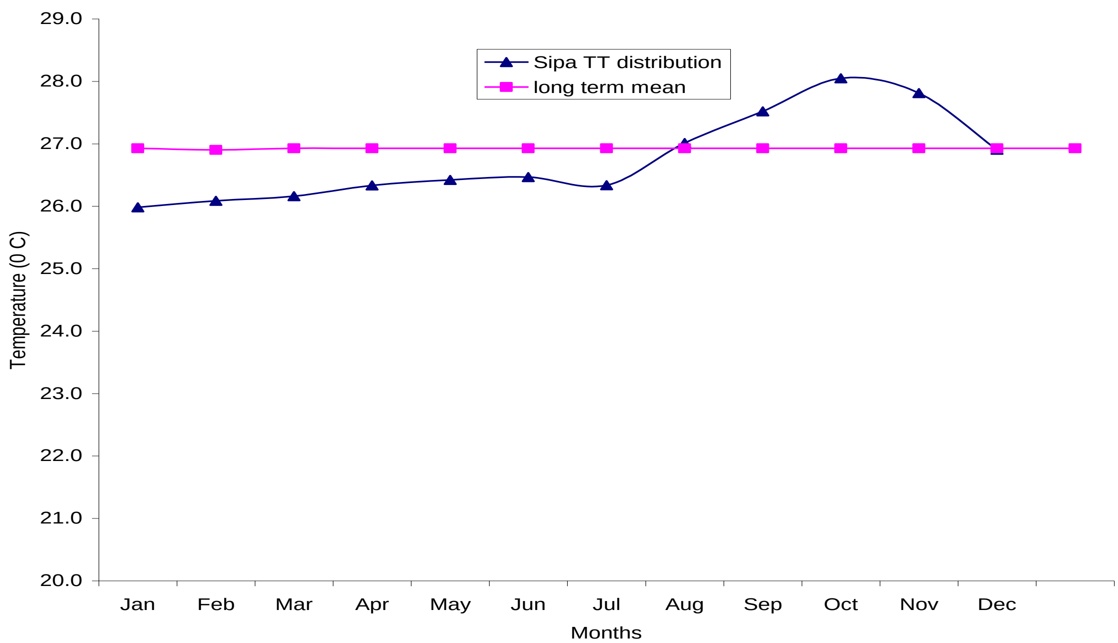


Figure 5.3-4Figure: Sipaliwini average monthly temperature 1971-2008

High temperatures were observed during the dry season (fig.5.3-4). All the other seasons experienced low temperatures, when the long term average of T=26.9 ^{0}C is used as the norm.

5.4 Discussion and results

The monthly and annual temperatures 1971-2008 of the seven selected meteorological stations were examined (Appendix C: table C1). The length of the time series varies from 16 to 37 years. Tafelberg had only 16 years of data (1971-1986), however because of its location in the central of Suriname, it was decided that the station should not be excluded from the analysis. Missing data were derived using linear interpolation. The monthly temperature pattern is similar for all stations, with the highest temperatures observed during the long dry season at all stations.

Table 5.4-1: Observed average seasonal temperature for selected meteorological stations in Suriname

Station	Period	DJF	MAM	JJA	SON
Nickerie	1971-2008	26.8	27.1	27.3	28.0
Cultuurtuin	1971-2008	26.6	27.1	27.3	28.1
Zanderij	1971-2008	26.6	27.1	27.4	28.6
Stoelmans Eiland	1971-2005	26.3	26.7	27.0	28.2
Kwamalasoemoetoe	1977-2005	26.2	26.3	26.4	27.3
Tafelberg	1971-1986	24.5	24.9	24.9	25.5
Sipaliwini	1971-2008	26.3	26.3	26.6	27.8

Table 5.4-1 presents the observed seasonal temperature for the selected meteorological stations, most of the low temperatures are recorded during December – February (DJF), and high Temperatures are recorded during September – November (SON).

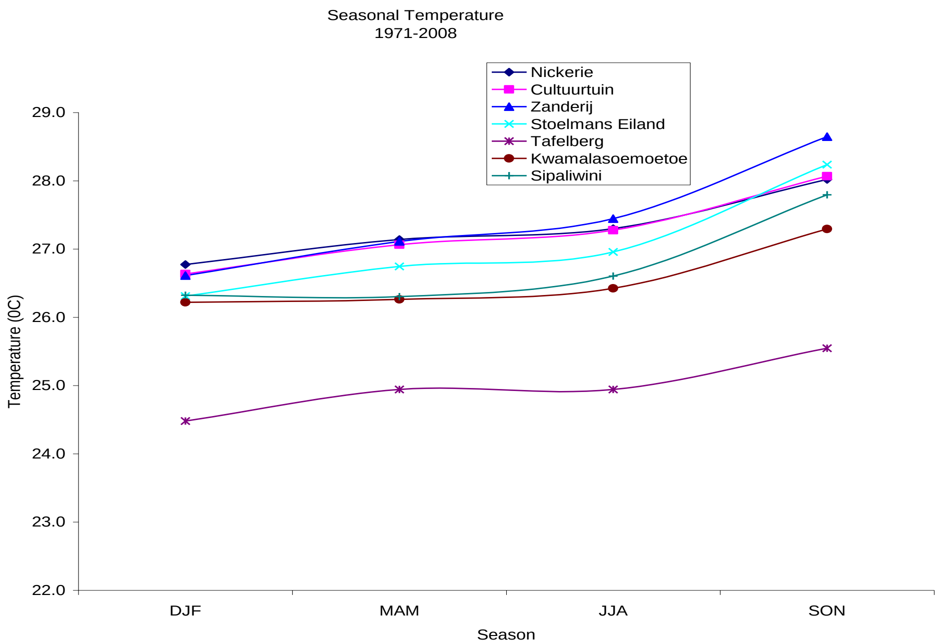


Figure 5.4-1: Average seasonal temperature for the selected meteorological stations in Suriname 1971-2008

The seasonal temperature patterns for the stations are similar (fig.5.4-1). The analysis shows that higher temperatures are observed in the coastal region. They decrease toward the central part of

Suriname, but increase again in the southern region of the country. The lowest temperature at any of the stations, during any season, was recorded at Tafelberg (table 5.4-1).

Table 5.4-2: Observed average monthly temperature (0C) data for selected meteorological stations in Suriname.

Station	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nickerie	1971-2008	26.6	26.7	27.0	27.3	27.2	27.0	27.2	27.7	28.1	28.1	27.8	27.0	27.3
Cultuurtuin	1971-2008	26.5	26.6	27.1	27.2	27.0	26.8	27.2	27.9	28.2	28.3	27.7	26.8	27.3
Zanderij	1971-2008	26.4	26.6	27.0	27.3	27.1	26.9	27.3	28.1	28.8	28.9	28.2	26.9	27.5
Stoelmans Eiland	1971-2005	26.1	26.3	26.7	26.9	26.7	26.5	26.8	27.5	28.2	28.5	27.9	26.6	27.1
Kwamalasoemoetoe	1977-2005	25.9	25.9	26.0	26.2	26.6	26.6	26.2	26.4	27.2	27.3	27.4	26.8	26.5
Tafelberg	1971-1986	24.3	24.3	24.7	25.0	25.1	24.9	24.8	25.2	25.5	25.7	25.5	24.8	25.0
Sipaliwini	1971-2008	26.0	26.1	26.2	26.3	26.4	26.5	26.3	27.0	27.5	28.0	27.8	26.9	26.9

The observed average monthly temperatures for the selected meteorological stations are presented in table 5.4-2. The coldest month is January and the warmest month is October for all stations (table 5.4-2). Low temperatures are recorded in January, which is within the short wet season and high temperatures are recorded in October that is within the long dry season.

Table 5.4-3: Temperature statistics f or selected meteorological stations 1971-2008

Station	Annual average	Long term average	Maximum	Minimum
Nickerie	27.3	27.3	28.1	26.8
Cultuurtuin	27.3	27.3	28.1	26.6
Zanderij	27.4	27.4	28.5	26.8
Stoelmans Eiland	27.1	27.1	27.9	26.6
Tafelberg	25.0	25.0	25.5	24.5
Kwamalasoemoetoe	26.8	26.8	29.2	25.5
Sipaliwini	26.9	26.9	28.1	25.8

The temperature statistics presented in table 5.4-3 shows that the temperatures vary between 24.5^0 C and 29.2^0 C for the selected meteorological stations. Tafelberg has recorded the lowest temperatures for all stations.

Table 5.4-4: Linear trends (0C/year) in annual average temperatures for selected meteorological stations in Suriname

Station	Time range	Regression coefficient (R)	Trend	Result
Nickerie	1971-2008	0.0087	Positive(+)	Warmer
Cultuurtuin	1971-2008	0.0162	Positive(+)	Warmer
Zanderij	1971-2008	-0.0007	Negative (-)	Colder
Stoelmans Eiland	1971-2008	0.0174	Positive (+)	warmer
Tafelberg	1971-1986	0.0244	Positive (+)	warmer
Kwamalasoemoetoe	1977-2005	0.0524	Positive (+)	warmer
Sipaliwini	1971-1986 1998-2008	0.0083	Positive (+)	warmer

Table 5.4-4 shows the temperature trends for the selected stations are presented and a negative trend is identified for Zanderij during 1971-2008. Therefore, Zanderij experienced a decrease in temperature for the past 39 years. All the other stations experienced an increase in temperature.

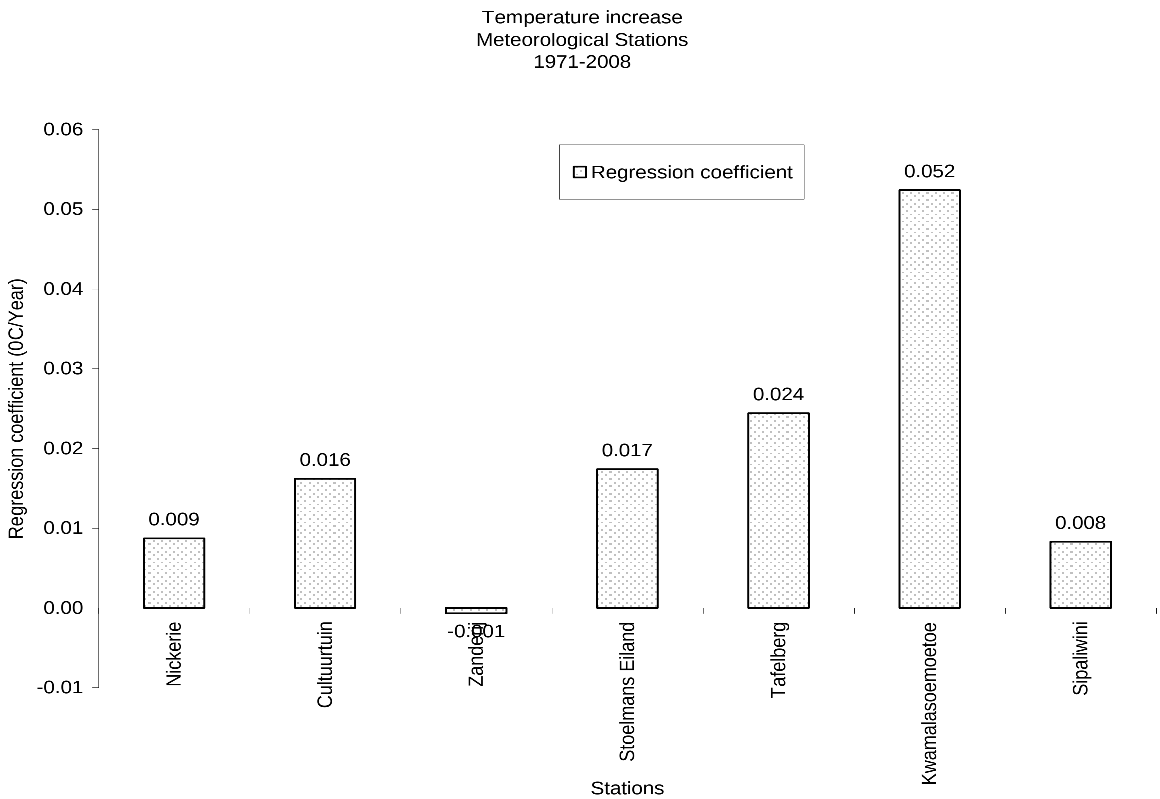


Figure 5.4-2: Regression coefficient of the temperature (^{0}C/year) for selected meteorological stations 1971-2008

All the stations, except Zanderij, showed an increase in the temperature for the time series 1971-2008 (fig. 5.4-2). Even though Tafelberg had only 16 years of data, a temperature increase of 0.024 ^{0} C/year is detectable at that station. The temperature increase varied from 0.01^0 C/year – 0.05 ^{0}C/year, with the highest rate of, 0.05^0 C/year increase, occurring at Kwamalasoemoetoe. The temperature increase was lower in the coastal area. With the exception of Zanderij, a greater increase was found in the central region and thereafter the rate decreased again in Sipaliwini, which is in the southern part of Suriname.

During at least the last century, the tropics experienced a temperature increase of nearly 1^{0}C and the southern hemisphere experiences a temperature increase varying between 0.2 ^{0}C and 0.6 ^{0}C (WMO, 2005). Suriname is a part of the Guiana Shield region, and this region experienced an increase in temperature of approximately 1^{0}C (Watson et al., 2001). The trends observed for the stations in Suriname therefore support the temperature trend reported for the Guina Shield.

The analysis indicates that Suriname has become warmer in the past 37 years, which appears to reflect the influence of the global warming due to the doubling of carbon dioxide in the atmosphere. Over the 37 years covered by the data, temperatures at the selected meteorological stations in Suriname increased by between 0.37^0 C -1.85^0 C, which is an average increase of 1.1^{0}C.

6 THE INFLUENCE OF THE SUBTROPICAL HIGH PRESSURE SYSTEM ON THE RAINFALL AND THE TEMPERATURE

6.1 The subtropical high pressure systems

The subtropical high-pressure system is a high-pressure surface area, which moves between 380 North and 350 South (fig.6.1-1). The high-pressure surface areas over the Atlantic Ocean have two centres: the North Atlantic Subtropical High, and the South Atlantic Subtropical High. The North Atlantic High also called the Azores High or Bermuda High and the South Atlantic High, also known as the St. Helena High. The focus of the study is on the surface sea level pressure over the North Atlantic, the South Atlantic and its influence on the rainfall and temperature of Suriname.

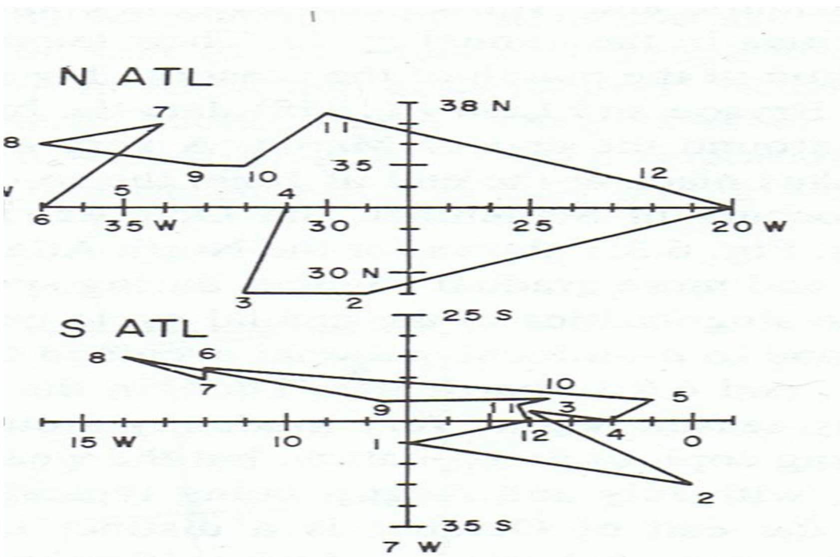


Figure 6.1-1: Meridional movement of the subtropical high-pressure systems

Source: Hastenrath, 1990

Low-pressure areas lie between these high-pressure zones and air masses rise in the low-pressure areas. High temperature near the earth’s surface causes low pressure and the rising of air masses. On the other hand, lower temperature produces high pressure near the surface and subsiding air movement. A pressure gradient often develops between the zones at 20-30 degrees latitude and the equatorial areas (Newel, 1977). Warming sea surface temperature and low pressure in the Atlantic brings increased precipitation, while high-pressure systems cause lower precipitation (Nurmohamed, 2008). The Inter-Tropical Convergence Zone (ITCZ) is a low-pressure zone in which air masses rise, and is a major factor that determines the amount and distribution of rainfall over Suriname.

The trade winds (North East and Southeast trades) coincide at the ITCZ. The ITZC moves from North to South and back once a year. During its passage, twice over Suriname (fig.1.3-1), air rises causing a low-pressure area at the surface, and therefore the conditions that can produce rain. As a result, the rainy season in Suriname starts when the ITZC is passing over Suriname. The first passage occurs when the ITCZ is moving to the South (Short rainy season) and the second passage takes place when the ITCZ is moving to the North (Long rainy season). At some times the ITCZ remains over Suriname for a longer period than normal, and thus causes more rain during the rainy season.

6.1.1 The South Atlantic High pressure system

The centre of this high-pressure system is located above the South Atlantic, its pressure centre expands to the equator, and back, thus the displacement is from south to north and back. Figure 6.1.1-1 illustrates the average annual sea level pressure of the South Atlantic High 1971-2008. The pressure centre is between 25 S and 35 S. The annual average South Atlantic High pressure ranged from 1014.7mb – 1015.7 mb during the period 1971-2008 (appendix B: table B1). The long-term average pressure is 1015.24 mb.

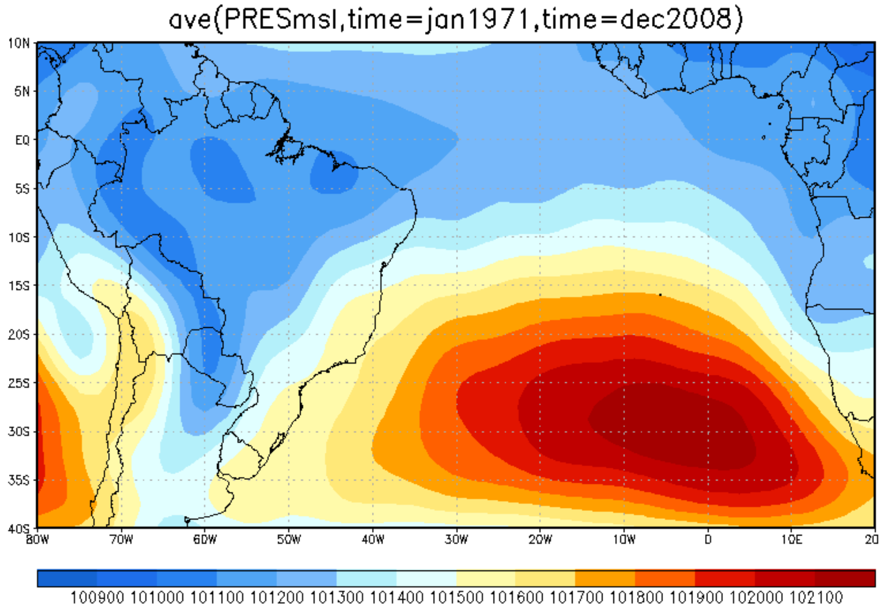


Figure 6.1.1-1 Average Sea Level Pressure of the South Atlantic High 1971- 2008

Adapted: http://nomad3.ncep.noaa.gov, NOAA\NCEP\NCAR, 2009

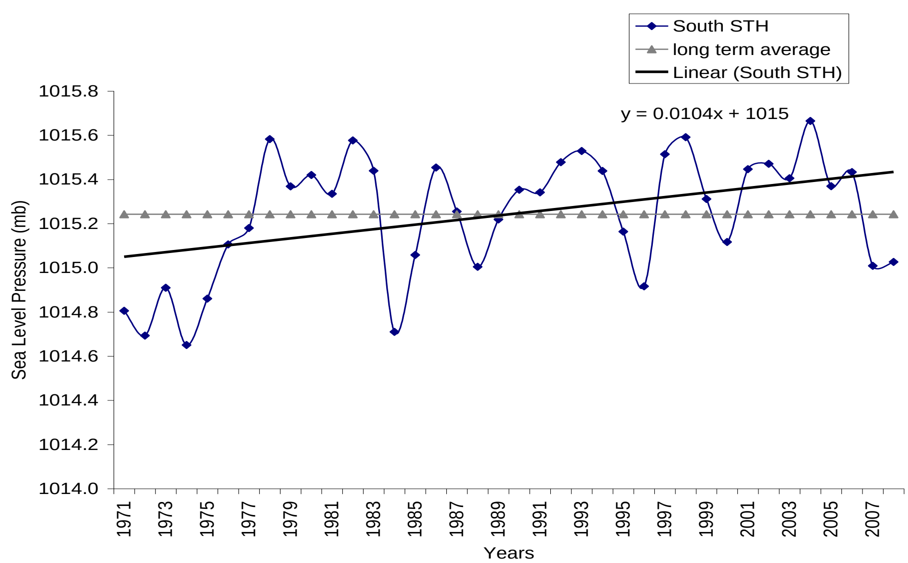


Figure 6.1.1-2: South Atlantic subtropical high-pressure system annual average pressure 1971-2008

The course of the South Atlantic Subtropical High pressure, 1971-2008, is presented in figure 6.1.1-2. The regression coefficient is 0.0104, thus, the slope of the regression line is positive for the SSTH 1971-2008 (fig.6.1.1-2).

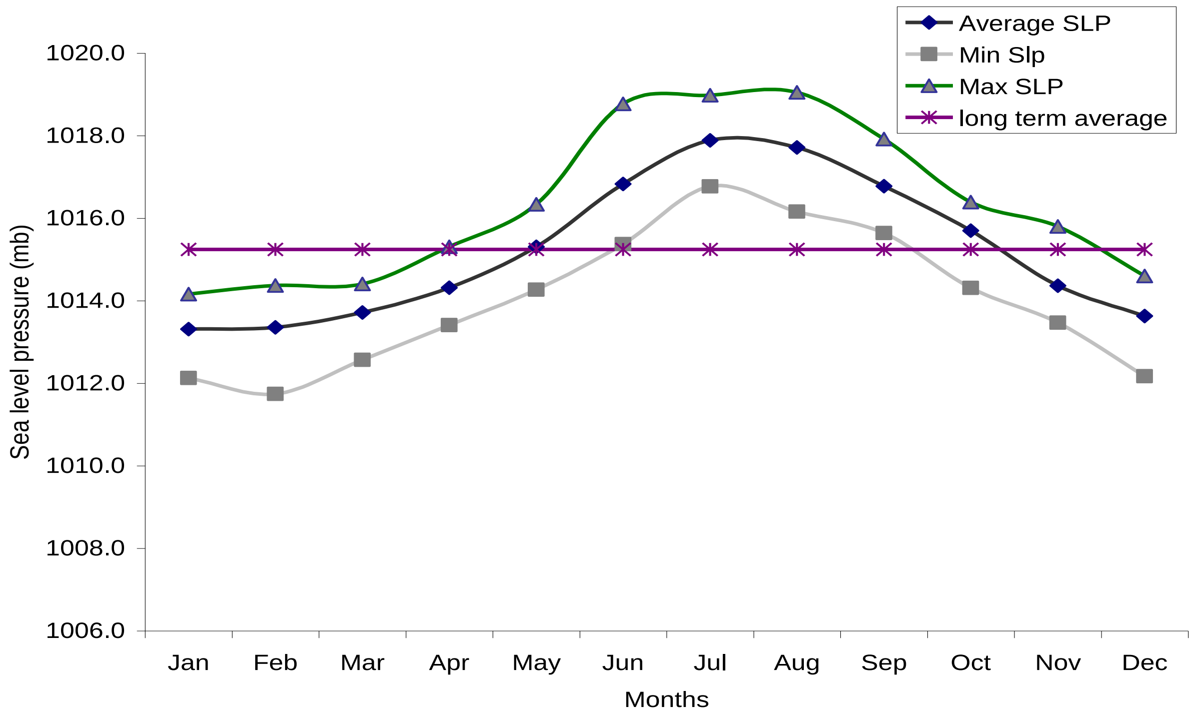


Figure 6.1.1-3: South Atlantic Subtropical High monthly average pressure Mean Sea Level 1971-2008

The long term mean monthly Sea Level Pressure (SLP) over the period 1971-2008 was 1015.24 mb (fig.6.1.1-3). This average is used as the normal to determine the strong and weak Subtropical high in the South Atlantic (fig.6.1.1-3). All the SLP values above the Long Term monthly mean are 'strong highs' and the SLP values less than the long term mean are 'weak highs'. The strong highs occur between April and December and the strongest Subtropical High, 1017.9 mb, occurs in July for the South Atlantic Subtropical system. The 'weak highs' tend to occur mostly between October and May on average and the weakest high, 1013.3 mb occurs in January (Appendix B: table B2).

6.1.2 The North Atlantic Subtropical High

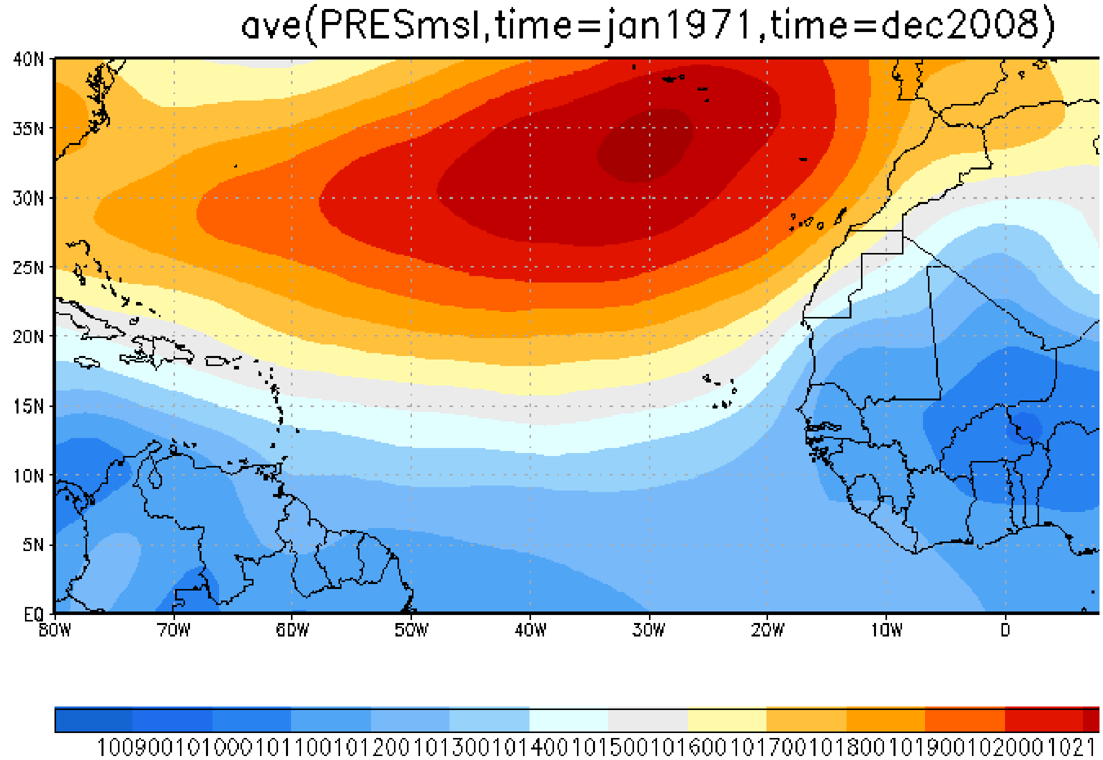


Figure 6.1.2-1: Figure: Average sea level pressure of the North Atlantic High 1971-2008

Adapted from: http://nomad3.ncep.noaa.gov/, NOAA/NCAR/NCEP, 2009

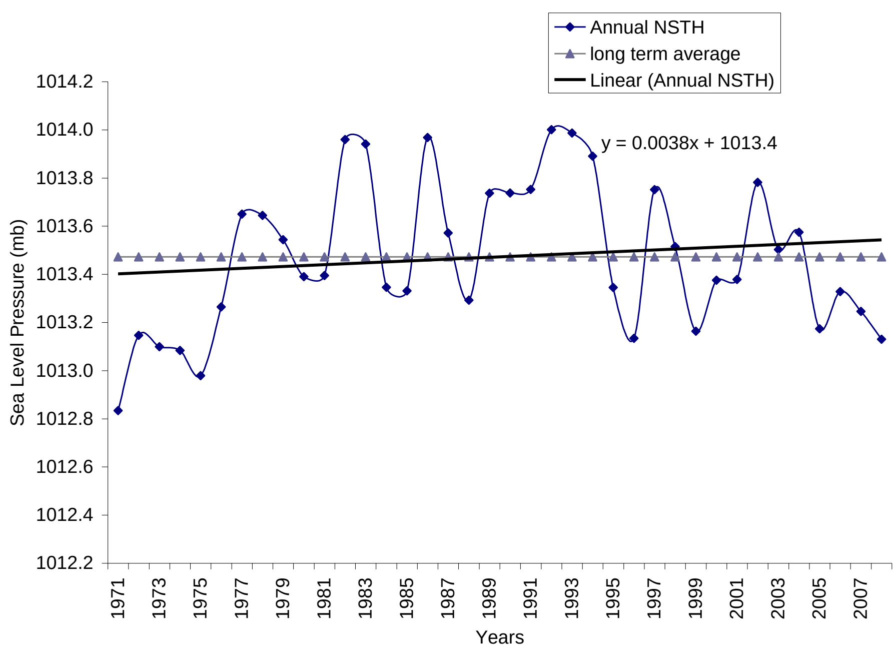


Figure 6.1.2-2: North Atlantic subtropical high-pressure system annual average pressure 1971-2008

The pressure centre of the North Atlantic Subtropical High (NSTH) is between 30 N – 40 N (fig.6.1.2-2) and the long-term average pressure for this high is 1013.5 mb (Appendix B). The North Atlantic high-pressure centre is above the North Atlantic and its displacement is southward and back. The pressure values vary between 1012.8 mb and 1014.0 mb (Appendix B: table B3). The course of the NSTH central pressure 1971-2008 is illustrated in figure 6.1.2-2. The regression coefficient is 0.0038 for the NSTH 1971-2008, thus, the slope is positive for the regression line (fig.6.1.2-2).

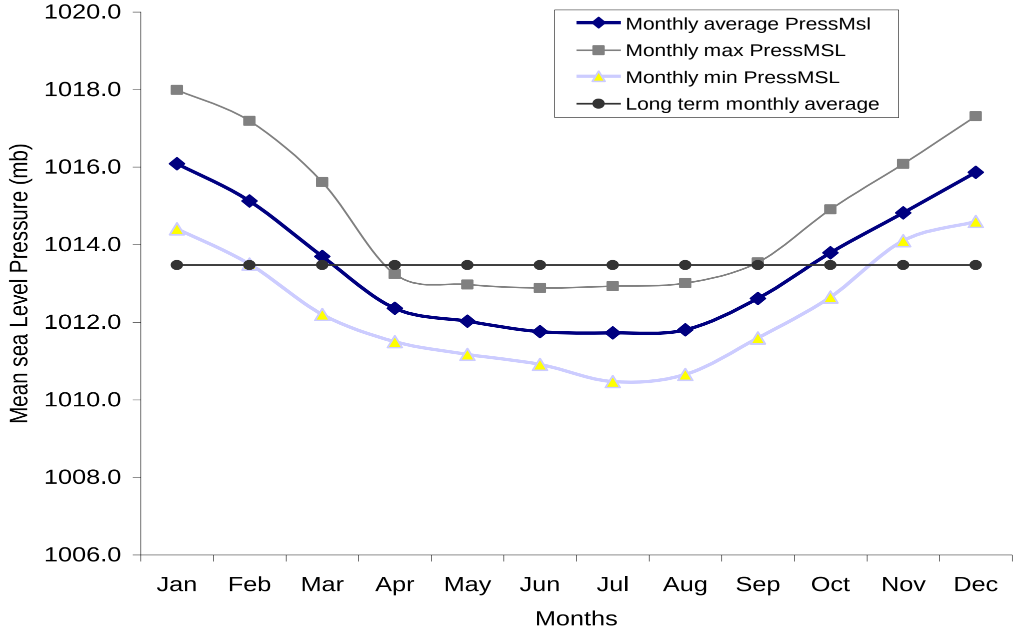


Figure 6.1.2-3: North Atlantic subtropical High monthly average of the sea level pressure 1971-2008

The long-term monthly average pressure for the years 1971-2008 for the North Atlantic Subtropical High is 1013.47 mb (fig.6.1.2-3). This long-term average is used as the normal for determining the strong and weak highs. The 'strong highs' occur between September and April. The strongest high for 1971-2008, with a SLP value of 1016.09 mb occurs in January. However, on average 'strong highs' tend to occur mostly between October and March. The 'weak highs' occur on average between March and October and the weakest high occurs in July with an average Sea Level Pressure (SLP) of 1011.7mb (Appendix B: tableB3).

6.1.3 Results and Discussion

The North and South Atlantic High pressure system 1971-2008 and its location are between 40S and 40N (fig.6.1.3-1).Table 6.1.3-1 presents the statistics for the subtropical high pressure systems, followed by the linear trends for these systems in table 6.1.3-2 and furthermore, this linear trend is illustrated in figure 6.1.3-2.

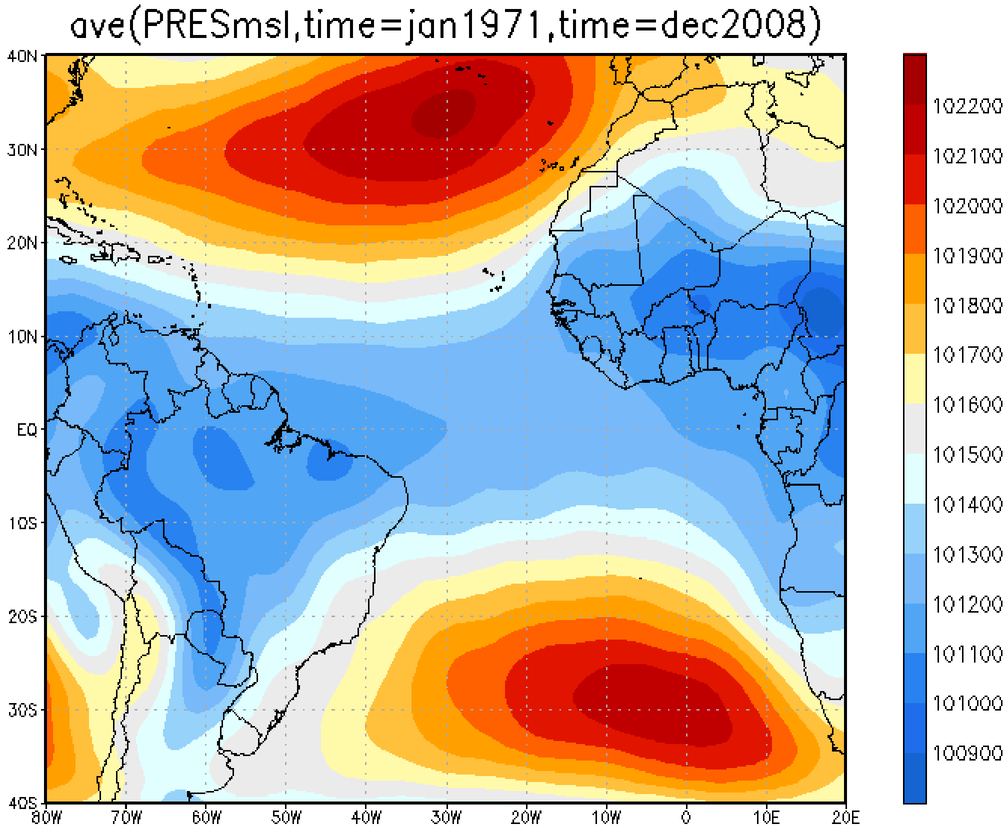


Figure 6.1.3-1: The subtropical high-pressure system 1971-2008

Adapted from http://nomad3.ncep.noaa.gov/ NOAA/NCAP/NCAR, 2009

Table 6.1.3-1: Monthly averages mean sea level pressure north – south Atlantic subtropical high 1971-2008

Months	Subtropical high South Atlantic Average pressure (mb)	Maximum pressure (mb)	Minimum pressure (mb)	Subtropical high North Atlantic Average pressure(mb)	Maximum pressure (mb)	Minimum pressure (mb)
Jan	1013.3	1014.2	1012.1	1016.1	1018.0	1014.4
Feb	1013.4	1014.4	1011.7	1015.1	1017.2	1013.5
Mar	1013.7	1014.4	1012.6	1013.7	1015.6	1012.2
Apr	1014.3	1015.3	1013.4	1012.4	1013.2	1011.5
May	1015.3	1016.3	1014.3	1012.0	1013.0	1011.2
Jun	1016.8	1018.8	1015.4	1011.8	1012.9	1010.9
Jul	1017.9	1019.0	1016.8	1011.7	1012.9	1010.5
Aug	1017.7	1019.1	1016.2	1011.8	1013.0	1010.7
Sep	1016.8	1017.9	1015.6	1012.6	1013.5	1011.6
Oct	1015.7	1016.4	1014.3	1013.8	1014.9	1012.7
Nov	1014.4	1015.8	1013.5	1014.8	1016.1	1014.1
Dec	1013.6	1014.6	1012.2	1015.9	1017.3	1014.6
Annual	1015.2	1015.7	1011.7	1013.5	1018.0	1010.5

Table 6.1.3-2: linear trend (mb/year) of the subtropical high-pressure systems 1971-2008

Pressure system	Period	Regression coefficient	trend	result
South Atlantic Subtropical high	1971-2008	0.010	positive(+)	Stronger
North Atlantic Subtropical high	1971-2008	0.004	positive(+)	Stronger

The subtropical high-pressure systems show a positive trend thus, it has become stronger (table 6.1.3-2) for the past 39 years (1971-2008).

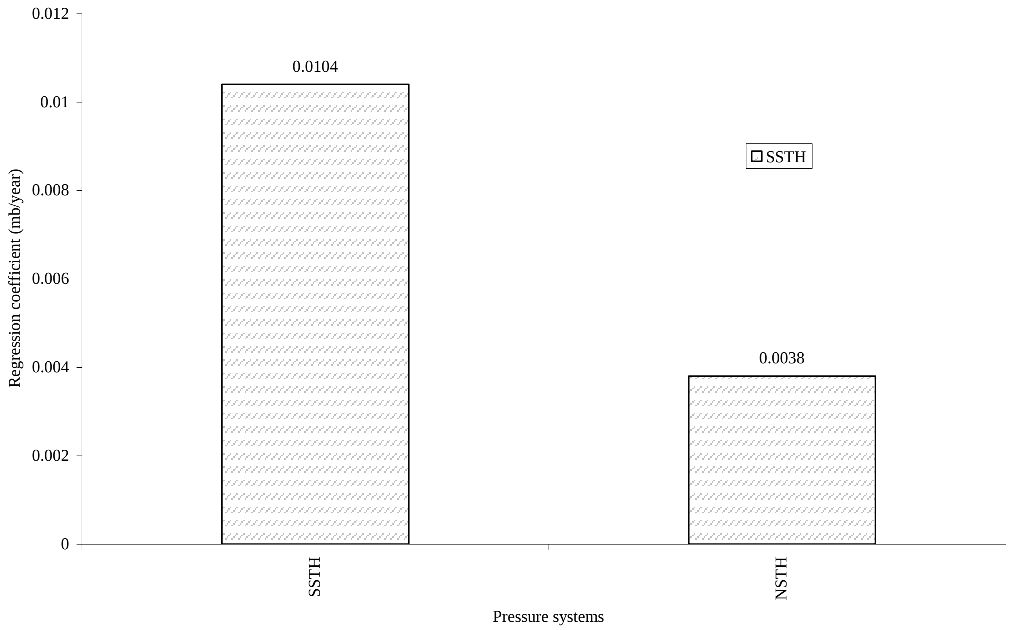


Figure 6.1-2-2: Linear trend (mb/year) of the subtropical high-pressure systems 1971-2008

The trends for both the SSTH and the NSTH are positive for 1971-2008 (table 6.1.3-1, fig.6.1.3-1, and fig. 6.1.3-2). The analysis suggests that pressure associated with the South Atlantic subtropical High-pressure system has been increasing since 1991, at a rate of about 0.01 mb/year (figure 6.1.3-2).

With regard to the North Atlantic High, the positive slope of the graph (fig.6.1.2-2) indicates that the central pressure of the North Atlantic subtropical high-pressure system is increasing. The trend has been occurring since 1992, at a rate of 0.004 mb/year (fig.6.1.3-2). This development of the subtropical highs indicates that the central pressure of the systems has become stronger in the past 39 years and it is still increasing until the present.

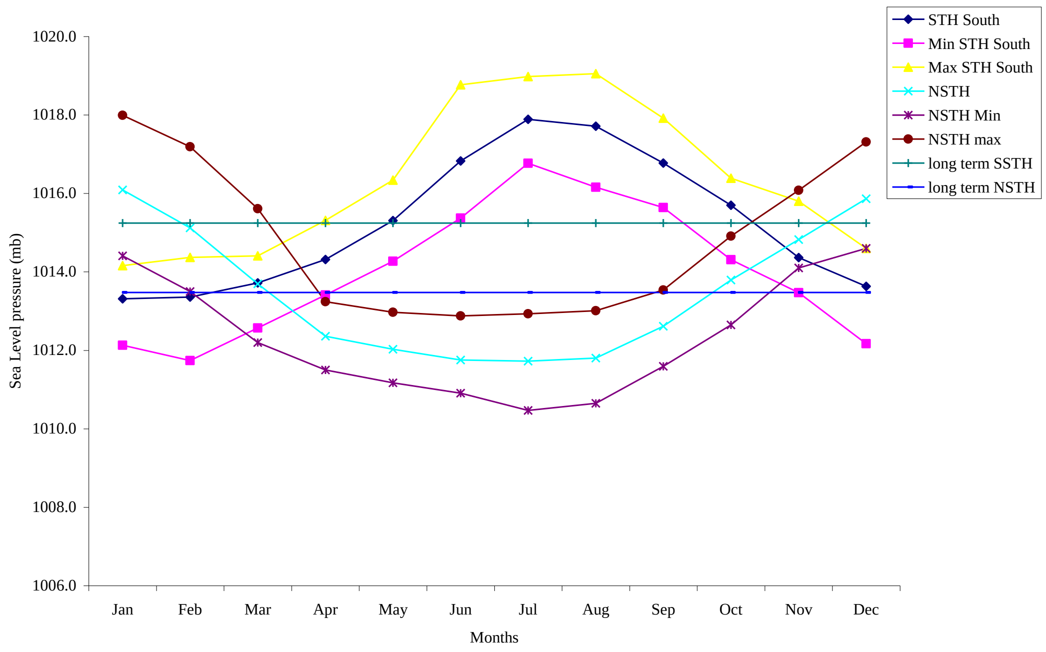


Figure 6.1.3-3: Monthly average of the North Atlantic –South Atlantic pressure 1971-2008

The seasonal course of the High Pressure Systems is illustrated in figure 6.3-1. The North Atlantic and the South Atlantic Highs usually coincide for the first time in March-April, but the timing might vary from the 3rd week of March – 2nd week of April. The second coincidence occurs in November, and this timing may vary between the 3rd week of November – last week of November (fig.6.1.3-3). While the South Atlantic High-pressure system reaches its maximum in July, the North Atlantic High-pressure system reaches its minimum in July. The maximum pressure for the South Atlantic High is 1015.67 mb, the minimum is 1014.65 mb, and the average pressure is 1015.24 mb during 1971-2008 (Appendix B). The South Atlantic High reaches its minimum in January and the North Atlantic High reaches in the meantime its maximum pressure. The statistics for the North Atlantic High pressure system, 1971-2008, are 1014.0 mb (maximum), 1012.8 mb (minimum) and the average pressure is 1013.5 mb (Appendix B).

6.2 The influence of the Subtropical highs on the rainfall

A Correlation analyses was used to determine the relationship between the mean sea level (MSL) pressure above the North and South Atlantic and the rainfall for the seven selected meteorological stations. This relationship between the average annual South and North Atlantic subtropical High pressure and the annual rainfall 1971-2008 for the selected stations is illustrated in scatter diagrams in Appendix D: figure D1-D7. The correlation coefficient (R) between the annual rainfall and the annual average South Atlantic high pressure is presented in table 6.2-1 and it is illustrated in figure 6.2-1.

Table 6.2-1: Relationship between South Atlantic subtropical high-pressure system and the average annual rainfall for the selected meteorological stations in Suriname 1971-2008

Stations	period	Coefficient of determination ($R^{2)}$ SSTH	Correlation Coefficient (R) RR - SSTH	Relationship
Nickerie	1971-2008	0.22	-0.47	Negative (-)
Cultuurtuin	1971-2008	0.05	-0.22	Negative (-)
Zanderij	1971-2008	0.02	-0.14	Negative (-)
Stoelmans Eiland	1971-2008	0.09	-0.31	Negative (-)
Tafelberg	1971-1986	0.40	-0.63	Negative (-)
Kwamalasoemoetoe	1977-2008	0.11	-0.33	Negative (-)
Sipaliwini	1971-2008	0.12	-0.35	Negative (-)

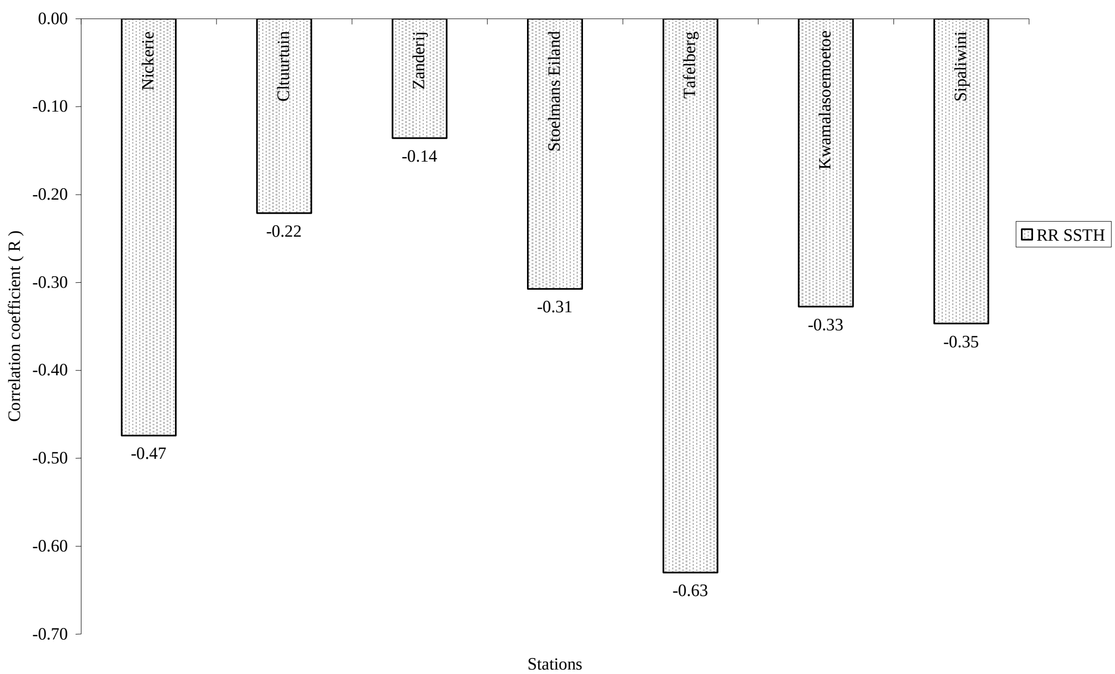


Figure 6.2-1: Relationship between the South Atlantic subtropical high and the average annual rainfall for selected meteorological stations 1971-2008

Based on the above findings (table 6.2-1), illustrated in the figures D1-D7 (Appendix D), and figure 6.2-1 it is clear that the annual average South Atlantic subtropical high pressure is negatively correlated with the annual average rainfall for all the selected meteorological stations in Suriname for the period 1971-2008 and 1971-1986 for Tafelberg. The South Atlantic

Subtropical High-pressure system has a strong negative correlation with the rainfall at Nickerie and Tafelberg, with R = -0.41 and the R = -0.63, respectively. The negative relationship indicates that while the central pressure of the Subtropical High increases the rainfall at the stations decreases.

Table 6.2-2: Relationship between the Monthly average South Atlantic Subtropical high-pressure system and the monthly average rainfall for the selected meteorological stations in Suriname 1971-2008

Stations	period	Coefficient of determination (R^2) SSTH	Correlation Coefficient (R) RR - SSTH	Relationship
Nickerie	1971-2008	0.128	0.36	Positive (+)
Cultuurtuin	1971-2008	0.049.	0.22	Positive(+)
Zanderij	1971-2008	0.057	0.24	Positive(+)
Stoelmans Eiland	1971-2008	0.006	-0.08	Negative(-)
Tafelberg	1971-1986	0.002	-0.04	Negative(-)
Kwamalasoemoetoe	1977-2008	0.017	0.13	Positive(+)
Sipaliwini	1971-2008	0.005	0.07	Positive(+)

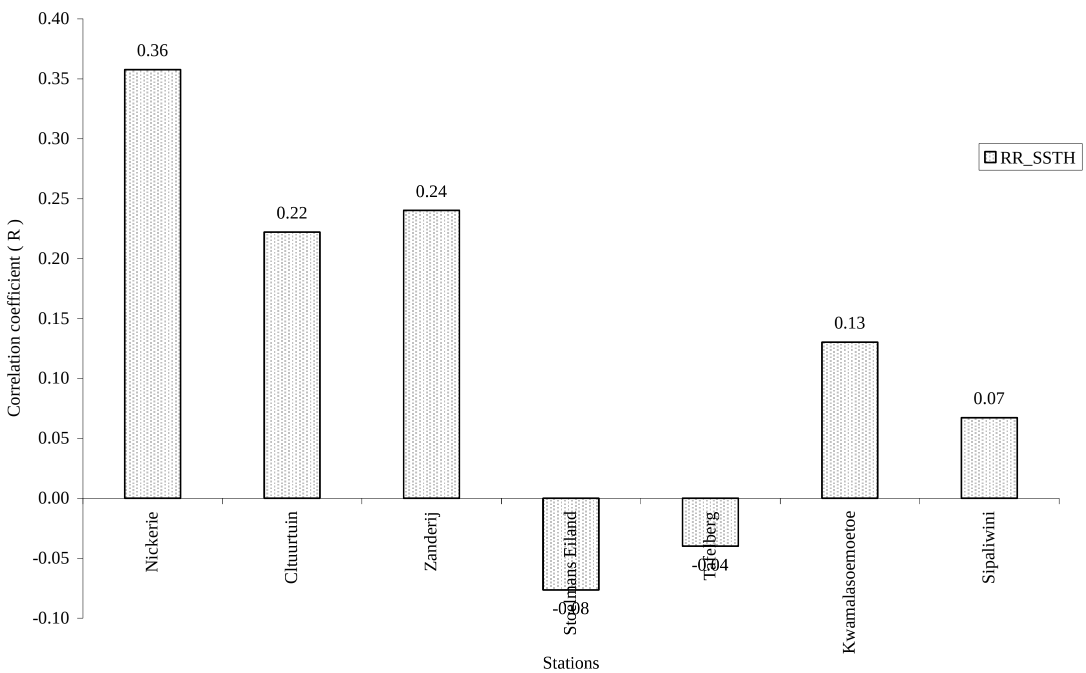


Figure 6.2-2: Relationship between South Atlantic subtropical high and the average monthly rainfall for selected meteorological stations 1971-2008

The monthly average South Atlantic subtropical pressure is positively correlated with the monthly average rainfall of the stations in the north, negatively associated with the stations in the central part of the country, and positively correlated again with the stations in the south (table 6.2-2 and fig. 6.2-2). The influence of the South Atlantic subtropical high on rainfall is therefore not uniform, but varies from place to place across Suriname. The relationship is *positive for Nickerie, Cultuurtuin, Zanderij, Kwamalasoemoetoe, Sipaliwini, and negative for Stoelmans Eiland and Tafelberg (fig.6.2-2*

Table 6.2-3 : Relationship between North Atlantic High-pressure system and the average annual rainfall for the selected meteorological stations 1971-2008

Stations	period	Coefficient of determination (R^2)	Correlation coefficient (R) RR-NSTH	Relationship
Nickerie	1971-2008	0.02	-0.35	Negative (-)
Cultuurtuin	1971-2008	0.05	-0.22	Negative (-)
Zanderij	1971-2008	0.03	-0.17	Negative (-)
Stoelmans Eiland	1971-2008	0.08	-0.27	Negative (-)
Tafelberg	1971-1986	0.66	-0.81	Negative (-)
Kwamalasoemoetoe	1977-2008	0.33	-0.57	Negative (-)
Sipaliwini	1971-2008	0.35	-0.59	Negative (-)

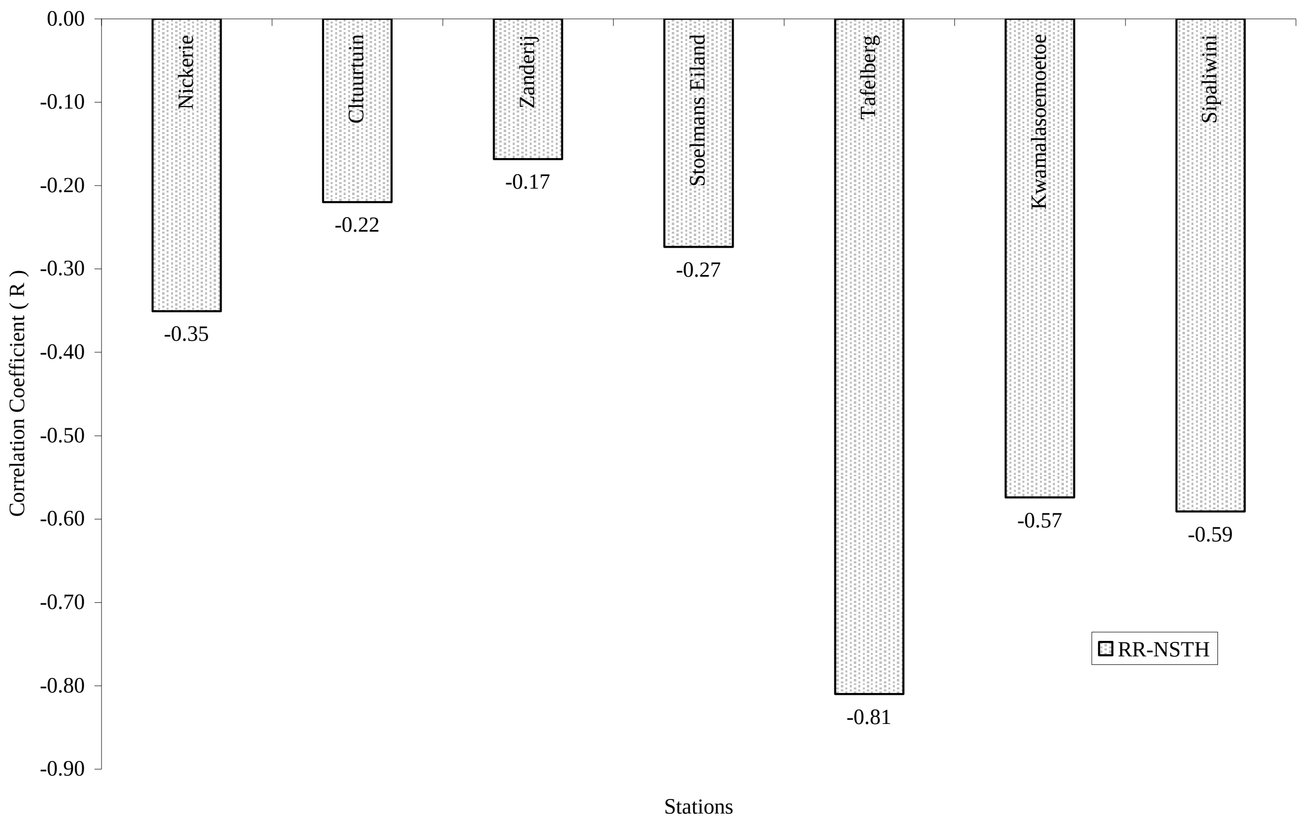


Figure 6.2-3 : Relationship between annual average North Atlantic subtropical high and the annual average rainfall for the selected meteorological stations in Suriname 1971-2008

The relationship between the North Atlantic Subtropical High and the annual average rainfall for the selected meteorological stations is negative for all stations (table 6.2-3). The strongest negative relationship is between the North Atlantic subtropical high and the annual average rainfall of Tafelberg where R = -0.81, followed by Sipaliwini with R=-0.59 (fig.6.2-3). Table 6.1-

4 and figure 6.1-4 present the relationship between the North Atlantic Subtropical High and average monthly rainfall.

Table 6.2-4: Relationship between North Atlantic subtropical high and average monthly rainfall for the selected meteorological stations 1971-2008

Stations	Coefficient of determination (R^2)	Correlation coefficient (R) RR-NSTH	Relationship
Nickerie	0.23	-0.48	Negative (-)
Cultuurtuin	0.18	-0.41	Negative (-)
Zanderij	0.23	-0.47	Negative (-)
Stoelmans Eiland	0.07	-0.27	Negative (-)
Tafelberg	0.12	-0.35	Negative (-)
Kwamalasoemoetoe	0.32	-0.57	Negative (-)
Sipaliwini	0.28	-0.53	Negative (-)

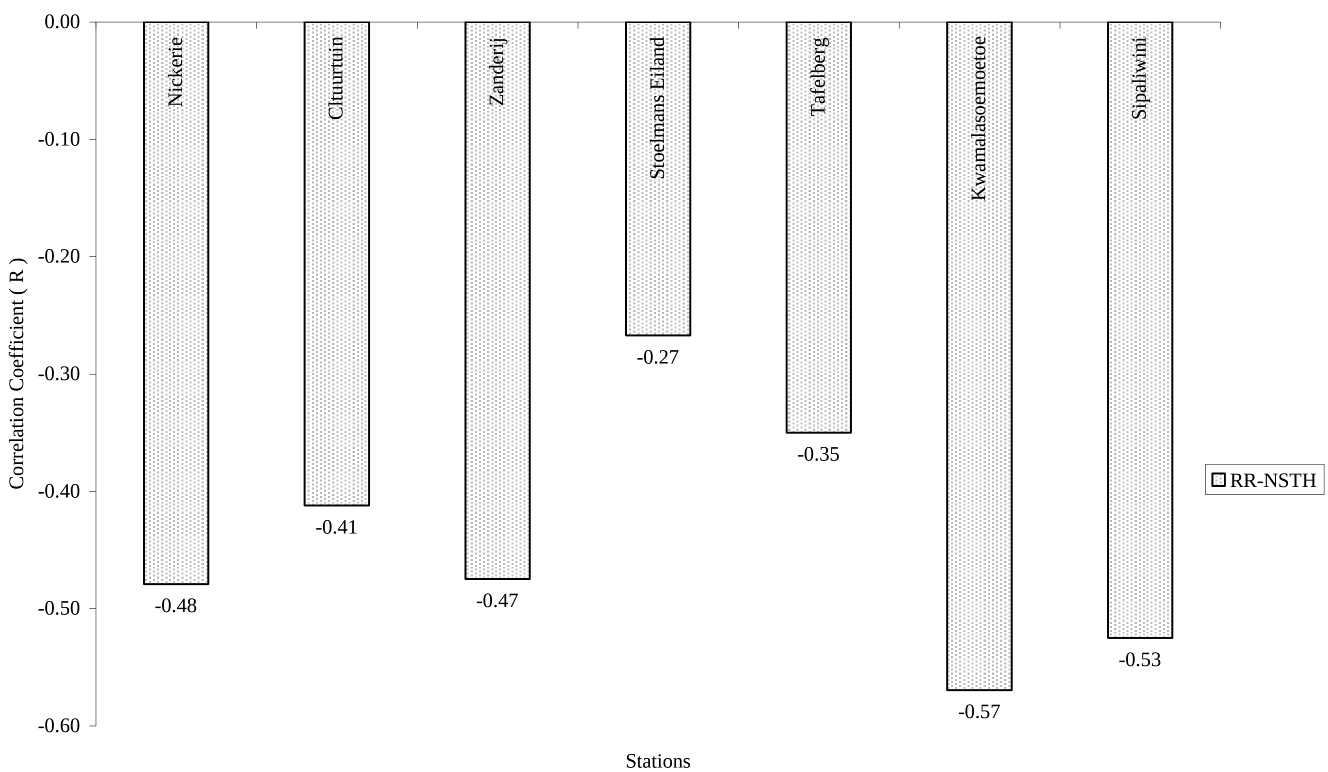


Figure 6.2-4: Relationship between North Atlantic subtropical high and average monthly rainfall for the selected meteorological stations 1971-2008

With regard to the North Atlantic Subtropical High, a consistently negative relationship is identified between the pressure system and the monthly average rainfall. The strongest negative correlation is between NSTH and the monthly rainfall of Kwamalasoemoetoe (table 6.2-4 and fig.6.2-4). Thus, an increase in pressure results in reduced monthly rainfall.

6.2.1 Discussion

The subtropical high-pressure systems, the South Atlantic and the North Atlantic High pressure, are negatively correlated with the annual average rainfall for all stations (table 6.2-1 and table 6.2-3). For the North Atlantic High-pressure system (NSTH) the coefficient 'R' varies from -0.17 to -0.81. The strongest negative relation is between NSTH and Tafelberg with R= -0.81. This negative correlation indicates that while the central pressure increases, the rainfall decreases over the stations. In the case of the South Atlantic High-pressure system (SSTH) the R varies from -0.14 to -0.63. Again the strongest negative relationship is with Tafelberg, where R = -0.63.

It might therefore be concluded that the Subtropical High exerts the greatest influence on rainfall at Tafelberg, where the rainfall will decrease as the central pressure increases. The overall negative relationships between the variables, the annual average rainfall, and the surface pressure show that while the central pressure of the Subtropical High-pressure systems increases, the annual rainfall decreases. Thus, a strong subtropical high-pressure centre will result in less annual rainfall for the selected stations in Suriname.

The relationship between the Subtropical High-pressure system and the monthly rainfall is therefore not uniform (table 6.2-2 and table 6.2-4). The South Atlantic High pressure system (SSTH) is positively associated with rainfall received at stations near the coast (Nickerie, Cultuurtuin, Zanderij), negatively related to precipitation at stations in the central regions (Stoelmans Eiland, Tafelberg), and positively correlated with rainfall at the stations in the south of the country (Kwamalasoemoetoe, Sipaliwini). The positive relationship indicates that while the pressure of the South Atlantic high-pressure system increases, the monthly rainfall increases as well at the stations (Nickerie, Cultuurtuin, Zanderij, Kwamalasoemoetoe, Sipaliwini). Furthermore, the negative relationship point out that while the South Atlantic Subtropical High (SSTH) pressure increases, the monthly rainfall decreases at the stations (Stoelmans Eiland, Tafelberg). The correlation coefficients range between R = -0.04 and R= 0.36.

On the other hand, the North Atlantic High-pressure system (NSTH) is negatively correlated with average monthly rainfall for all stations (table 6.2-4). Accordingly, an increase in the pressure system results in a decrease of rainfall at the selected stations. The correlation coefficients (R) vary between -0.27 and -0.57. A strong relationship, R = -0.57, is identified between the North Atlantic High-pressure system and the monthly rainfall for Kwamalasoemoetoe. Hence, an increase in the pressure system results in a higher rainfall increase rate for this station.

The South Atlantic subtropical high-pressure pattern shows a seasonal cycle that is similar to that of the rainfall pattern for Suriname during the period April –November. The rainfall pattern of Nickerie is used as an example (fig. 6.3-2). It is during this period that the South Atlantic High reaches its maximum pressure, usually in July.

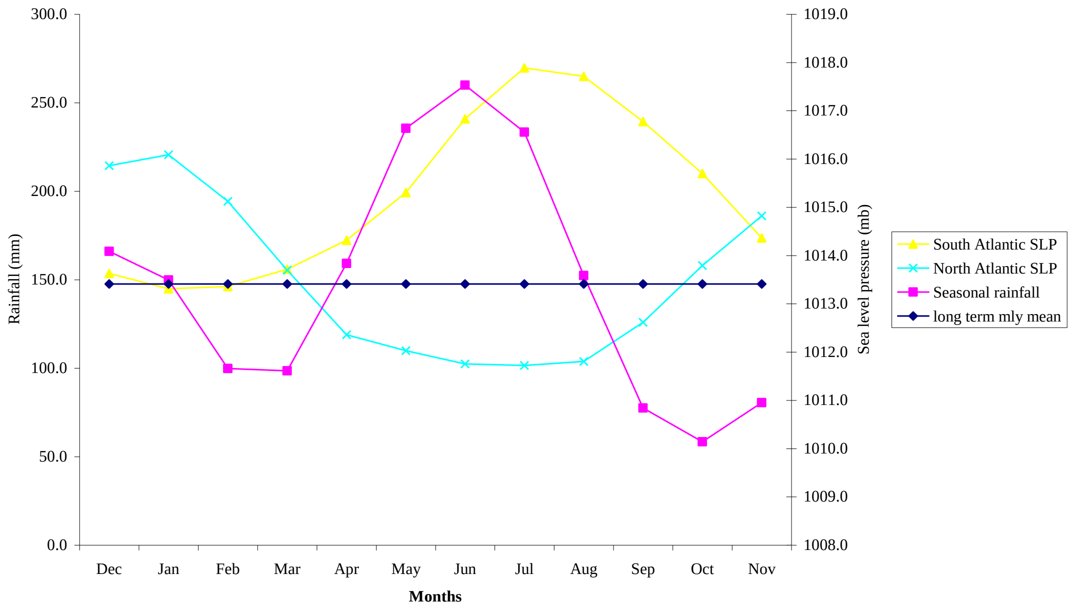


Figure 6.2.1-1: Nickerie monthly average rainfall and the monthly average subtropical high pressure system 1971-2008

The relationship between the monthly average rainfall of the selected stations and the South Atlantic High Pressure system is positive as well negative. Therefore, an increase of the central pressure will cause an increase of rainfall for the coastal and southern part of the country, but a decrease in rainfall for the central stations. While the pressure centre of the SSTH expands toward the equator (northward), and further increases in pressure would push the ITCZ toward the north. In view of the fact that the ITCZ is one of the main factors that determines the rainfall for the country, Suriname will therefore experience a rainy period while the ITCZ is above the country. After reaching its maximum in July, the central pressure will decrease again and in the meantime, the North Atlantic central pressure increases until the systems coincide again in November. The short wet and dry seasons last from the end of November –April. It is during this period that the North Atlantic High reaches its maximum pressure and the South Atlantic attains its minimum pressure, usually in January (fig.6.2.1-1).

The North Atlantic subtropical high-pressure system is negatively related to the average monthly rainfall for all the selected meteorological stations. Thus, an increase of the central pressure of the North Atlantic Subtropical high-pressure system will result in a decrease in the monthly average rainfall for the selected stations. While the central pressure of the North Atlantic High pressure increases, it will expand toward the equator southward. As a result, it would push the ITCZ toward the South and therefore the rainfall season in Suriname is activated. The North Atlantic subtropical High-pressure system pattern shows a similar seasonal cycle to that of the rainfall pattern during this period November – April. An increase of the central pressure of the North Atlantic Subtropical High-pressure system will therefore cause less rainfall, or suppress the rainfall. The coincidence of the Subtropical High-pressure systems also determines if there is a late or early start of the rainy season. The Subtropical High coincides for the first time in March –April, but the timing might vary from the 3rd week of March – 2nd week of April. The timing of the second coincidence is in November and may vary between the 3rd week of November – last week of November (fig.6.3-1).

6.3 The influence of the Subtropical High pressure systems on the temperature pattern

The Subtropical High-pressure centres are positioned above the North Atlantic and the South Atlantic Ocean, respectively. These pressure centres is moving westward toward the equator and back (Hastenrath, 1990). Correlation analyses were utilized to find out whether there is a relationship between the subtropical highs and the temperature for the selected stations.

The relationships between the SSTH and the annual average temperatures are illustrated in scatter diagrams, which are presented in Appendix D. Table 6.4-1 presents the relationships between the South Atlantic Subtropical High (SSTH) and the annual average temperature 1971-2008 and the relationship is illustrated in figure .6.3-1.

Table 6.3-1: Relationship between South Atlantic subtropical High-pressure system and the average annual temperature for the selected meteorological stations 1971-2008

Stations	period	Coefficient of determination (R^2)	Correlation coefficient (R) TT-SSTH	Relationship
Nickerie	1971-2008	0.161	0.401	Positive (+)
Cultuurtuin	1971-2008	0.229	0.479	Positive (+)
Zanderij	1971-2008	0.075	0.274	Positive (+)
Stoelmans Eiland	1971-2005	0.333	0.577	Positive (+)
Tafelberg	1971-1986	0.423	0.655	Positive (+)
Kwamalasoemoetoe	1977-2005	0.002	-0.044	Negative (-)
Sipaliwini	1971-2008	0.171	0.413	Positive (+)

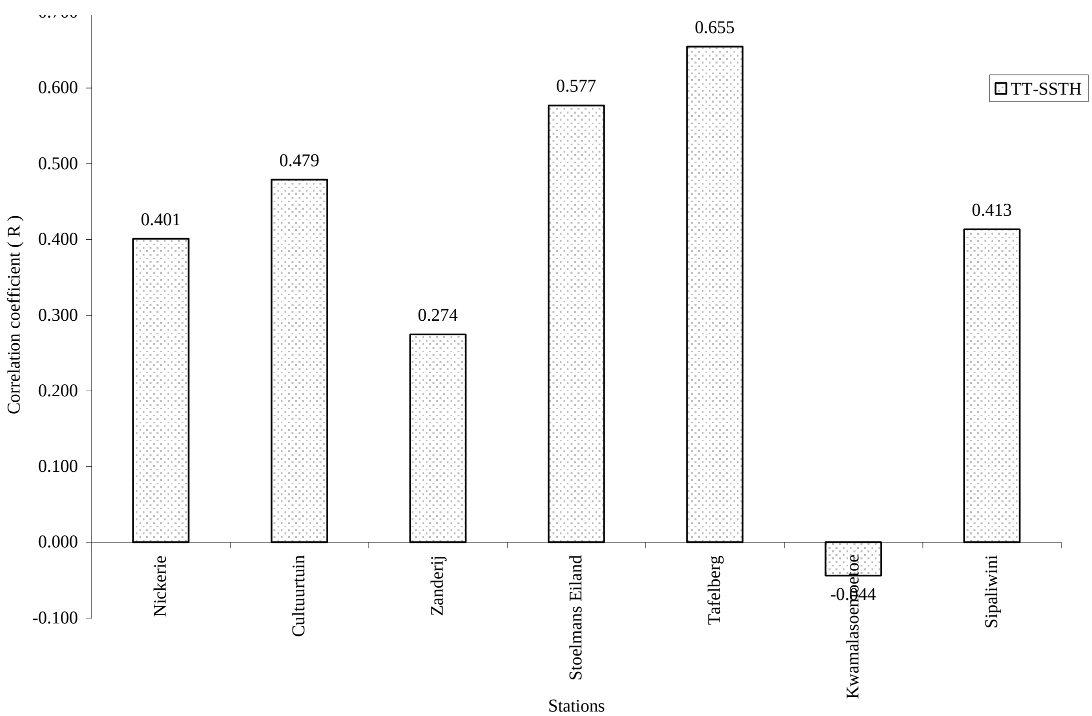


Figure 6.3-1: Relationship between South Atlantic subtropical High (SSTH) pressure and the annual temperature for the selected meteorological stations in Suriname 1971-2008

The relationship between the South Atlantic Subtropical high and the annual average temperature is positive for the selected meteorological stations except for Kwamalasoemoetoe (table 6.3-1 and fig.6.3-1). The correlation coefficients (R) vary between -0.044 and 0.655 where the highest correlation of R=0.655 is identified for Tafelberg.

Table 6.3-2: Relationship between South Atlantic subtropical high- pressure and the average monthly temperature for the selected meteorological stations 1971-2008

Stations	Period	Coefficient of Determination R^2	Correlation coefficient (R) TT-SSTH	Relationship
Nickerie	1971-2008	0.254	0.504	Positive (+)
Cultuurtuin	1971-2008	0.260	0.510	Positive (+)
Zanderij	1971-2008	0.251	0.501	Positive (+)
Stoelmans Eiland	1971-2005	0.174	0.417	Positive (+)
Tafelberg	1971-1986	0.206	0.454	Positive (+)
Kwamalasoemoetoe	1977-2005	0.067	0.259	Positive (+)
Sipaliwini	1971-2008	0.078	0.280	Positive (+)

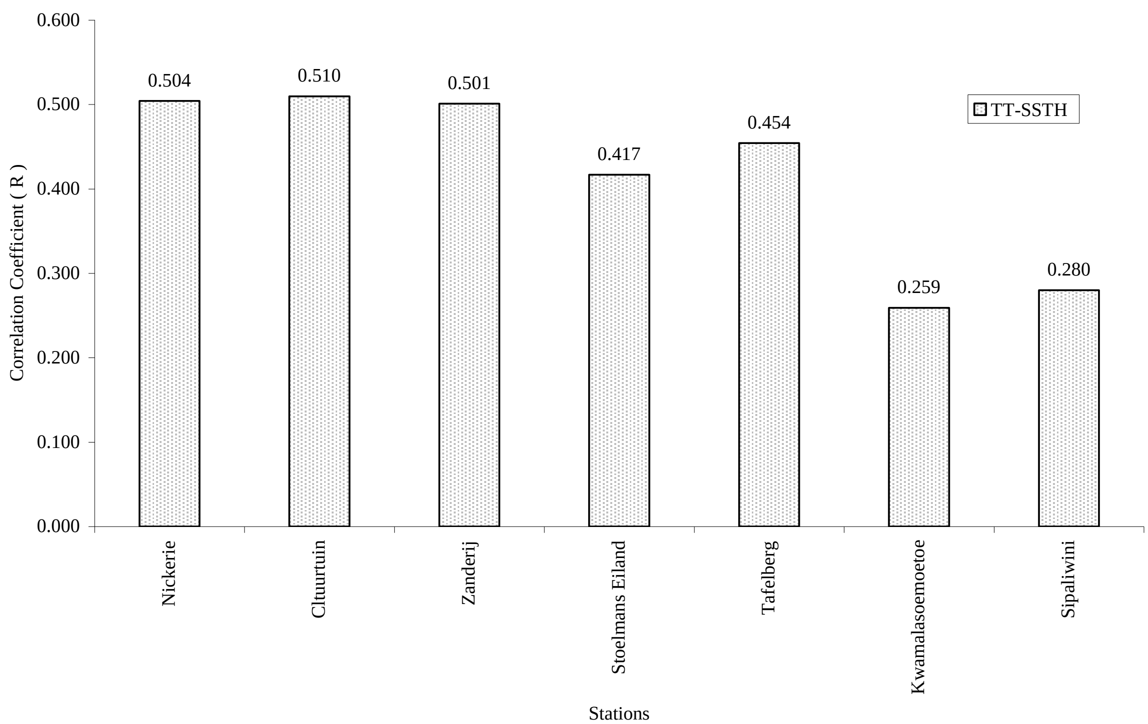


Figure 6.3-2: Relationship between South Atlantic Subtropical high-pressure system and monthly average temperature for the selected meteorological stations 1971-2008

The monthly average temperature for all the selected stations is positively related with the South Atlantic Subtropical High (table 6.3-3 and fig.6.3-3). The correlation coefficients (R) vary between 0.259 and 0.510. The correlation coefficient (R) for Cultuurtuin is the highest and is equal to 0.510.

Table 6.3-3: Relationship between North Atlantic Subtropical High-pressure system and the average annual temperature for the selected meteorological stations 1971-2008

Stations	period	Coefficient of determination (R^2)	Correlation coefficient (R) TT-NSTH	Relationship
Nickerie	1971-2008	0.029	0.173	Positive (+)
Cultuurtuin	1971-2008	0.096	0.310	Positive (+)
Zanderij	1971-2008	0.074	0.272	Positive (+)
Stoelmans Eiland	1971-2005	0.032	0.181	Positive (+)
Tafelberg	1971-1986	0.474	0.688	Positive (+)
Kwamalasoemoetoe	1977-2005	0.015	-0.123	Negative (+)
Sipaliwini	1971-2008	0.363	0.603	Positive (+)

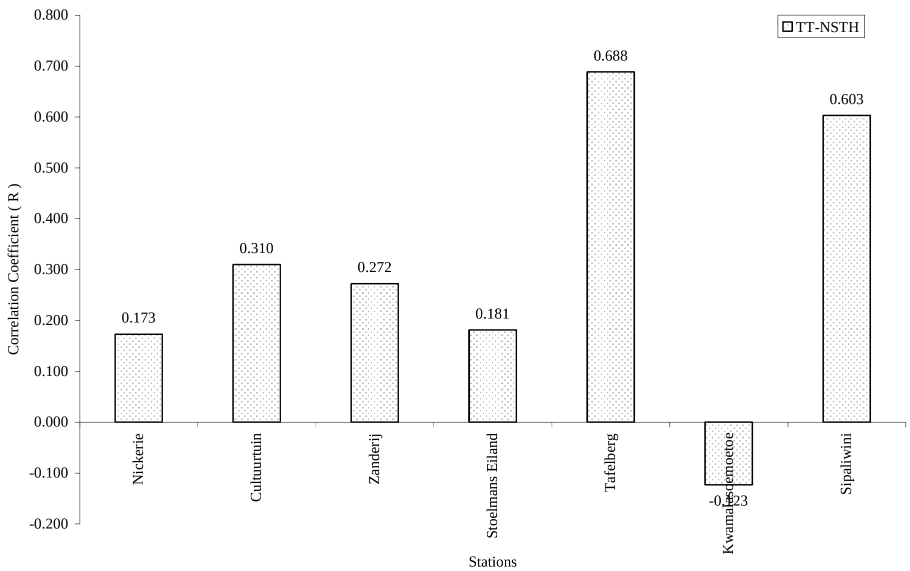


Figure 6.3-3: Relationship between North Atlantic Subtropical High pressure and the annual average temperature for the selected meteorological stations in Suriname 1971-2008

The annual average temperature of the selected meteorological stations is positively related to the North Atlantic High pressure system (table 6.3-2 and fig.6.3-2) except for Kwamalasoemoetoe. The correlation coefficients vary between -0.123 and 0.688 and the highest correlation is recognized for Tafelberg with R = 0.688.

Table 6.3-4: Relationship between North Atlantic Subtropical high-pressure system and monthly average temperature for the selected meteorological stations 1971-2008

Stations	Period	Coefficient of determination R^2	Correlation coefficient (R) TT-NSTH	Relationship
Nickerie	1971-2008	3E-06	-0.326	Negative (-)
Cultuurtuin	1971-2008	0.106	-0.325	Negative (-)
Zanderij	1971-2008	0.088	-0.297	Negative (-)
Stoelmans Eiland	1971-2005	0.045	-0.213	Negative (-)
Tafelberg	1971-1986	0.135	-0.368	Negative (-)
Kwamalasoemoetoe	1977-2005	0.001	-0.029	Negative (-)
Sipaliwini	1971-2008	8E-06	0.003	Positive (+)

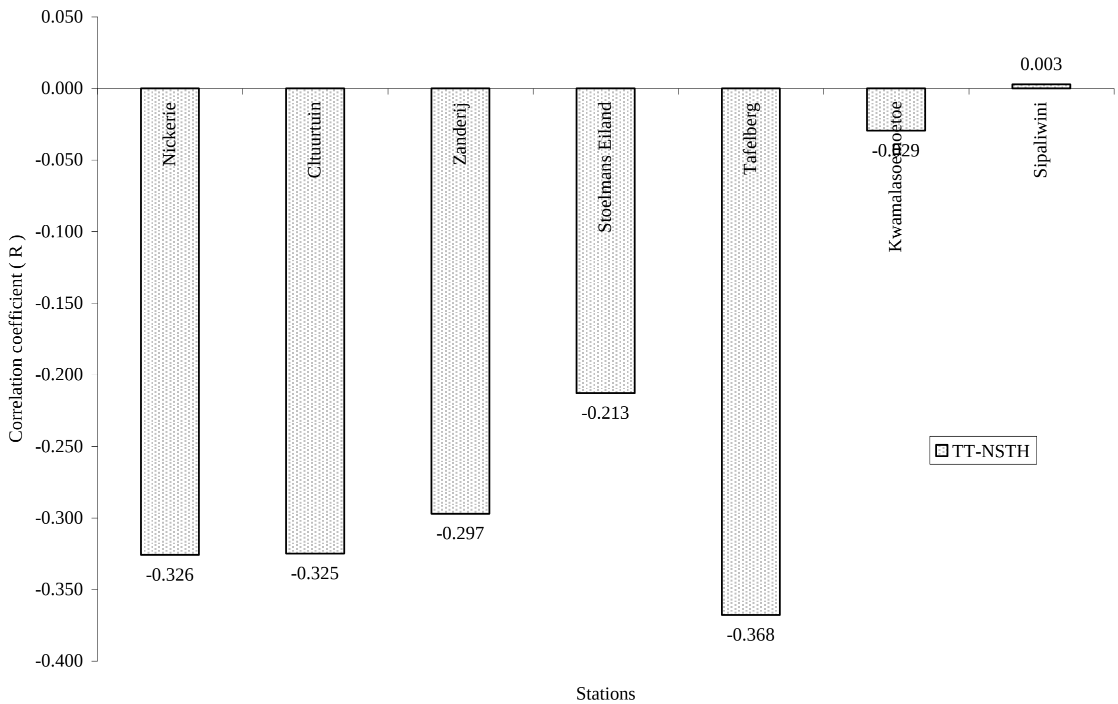


Figure 6.3-4: relationship between North Atlantic Subtropical high-pressure system and monthly average temperature for the selected meteorological stations 1971-2008

The monthly average temperature for the selected stations is negatively correlated with the North Atlantic Subtropical High-pressure system, except for Sipaliwini (table 6.3-4 and fig. 6.3-4). The correlation coefficient (R) varies between -0.368 and 0.003.

6.3.1 Discussion

The relationship between the Subtropical High Pressure systems and the annual average temperature is not uniform. The South Atlantic as well the North Atlantic High-pressure system is positively related to the annual average temperature for the selected stations, except for Kwamalasoemoetoe. Hence, an increase in the central pressure of the systems will result in an increase of the annual average temperature for the stations, except for Kwamalasoemoetoe. Strong correlation is recognized for Tafelberg. Therefore, the Subtropical High-pressure systems exert the greatest influence on the temperature at Tafelberg. The correlation coefficient (R) for Tafelberg varies between 0.655-0.688.

The relationship between the South Atlantic Subtropical High pressure system and the monthly average temperature for all the selected meteorological stations is a positive one. Consequently, an increase of the pressure centre results in an increase of the temperatures at the selected stations. The correlation coefficient (R) between the monthly average temperature and the South Atlantic High-pressure system varies from 0.26 to 0.51. Strong relation exists between the SSTH and the monthly average temperature at Cultuurtuin with R = 0.510. The correlation between the monthly average temperature and the South Atlantic High-pressure system is strong along the coastal region (Nickerie, Cultuurtuin, Zanderij), but it is weaker for stations in the south of the country.

On the other hand, negative correlation exists between the central pressure of the North Atlantic Subtropical High-pressure system and the monthly average temperature for all stations, except for Sipaliwini. Hence, an increase of the central pressure will cause a decrease in monthly average temperature at six stations (Nickerie, Cultuurtuin, Zanderij, Stoelmans Eiland, Tafelberg, Kwamalasoemoetoe), and an increase in temperature at Sipaliwini. The correlation coefficient between the monthly average temperature and the North Atlantic High-pressure system varies between -0.368 – 0.003.

7 THE IMPLICATION ON THE RICE PRODUCTION IN NICKERIE DISTRICT

7.1 Introduction

Rice is the most important crop in Suriname and the main farming area for rice is the Nickerie District in the northwestern part of the country. Rice farming is done on the heavy soils of the young coastal plain. Rice cultivation in the Nickerie District is irrigated and mechanized (Kamerling et al., 1974). The tropical rainy climate of Suriname is characterized by a bimodal rainfall pattern and therefore two rice crops can be grown annually. The main crop starts in the long rainy season and the harvesting time is during the long dry season. The second crop begins in the short rainy season and the harvest is during the short dry season (Keiser, 1987). However, especially in the short rainy season additional water is needed for the rice farming. Harvesting and tillage are done during the dry seasons (Kamerling et al., 1974).

Climatic factors affect the rice yield in two ways namely directly and indirectly. Direct effects include those that have to do with the processes involved in grain yield formation, while among the indirect effects are those that affect the yield through factors such as the incidence of diseases and pests (Keiser, 1987). Rice yields tend to decrease due to the lack of water availability (Nurmohamed, 2008). The drought that lasted from August 1977 until March 1998 in the North Western part of Suriname had a negative effect on rice production in the Nickerie District. While conducting this research, the student was able to obtain valuable information from local rice farmers about their experiences relating to loss of the rice yield during that year. An investigation such as this one, which examines the effect of climatic factors such as rainfall and temperature on rice production, would be useful for planning future adaptation strategies in this agricultural sector.

In the previous sections, the association between the Subtropical High pressure systems and temperature and rainfall for seven meteorological stations in Suriname was examined. The implications, which those findings have for rice production in the Nickerie District, will be examined in the following sections.

7.2 Rice production in Nickerie District

The average production area for rice farming during 1971-2008 was 49493.6 hectares, which produced a total yield of 192338.6 tonnes of rice. Therefore, the average production per hectare was approximately 3.9tonnes/hectare (table 7.2-3). The varieties used for the rice farming are ADRON 111, ADRON 117, ADRON 125, ADRON 130 and GROVENI, but the main variety used by the farmers is ADRON 125, which reaches maturity after 100 days (ADRON, 2008). The Nickerie District has two rice crops yearly (table 7.2-1).

Table 7.2-1: Crop calendar for rice farming in Suriname

Activity	Months May Jun	Jul	Aug	Sep-Oct	Nov-Dec	Jan	Feb	Mar-Apr
Sowing	1/2 May - End June				1/2 Nov- End Dec			
Harvest				Sept- Oct				Mar-April
	Second crop				First crop			

Source: Rice research centre ADRON

The climatic conditions of Nickerie during 1971-2008 are presented in table 7.2-2.

Table 7.2-2: Monthly averages of temperature (0C), Monthly average of rainfall (mm), average wind velocity (Beaufort), average evaporation (mm) of Nickerie District 1971-2008

Month	Monthly Temperature (^{0}C)	Monthly rainfall (mm)	Monthly wind velocity (Beaufort)	monthly evaporation (mm)
Jan	26.6	149.8	2.9	127.1
Feb	26.7	99.8	3.0	128.9
Mar	27.0	98.4	3.0	140.0
Apr	27.3	159.2	2.9	125.4
May	27.2	235.6	2.7	116.1
Jun	27.0	259.9	2.3	104.5
Jul	27.2	233.4	2.2	120.7
Aug	27.7	152.3	2.3	141.1
Sep	28.1	77.5	2.8	147.1
Oct	28.1	58.4	2.7	149.9
Nov	27.8	80.5	2.7	138.2
Dec	27.0	166.0	2.7	127.9

Source: Meteorological Service Suriname

Table 7.2-3 presents the average rice production of Nickerie.

Table 7.2-3: Nickerie rice production 1971-2008

Period	Average Production area (ha)	Average Rice yield (tonnes)	Rice yield per Hectare (tonnes/ha)
1971-2008	49493.6	192338.6	3.9

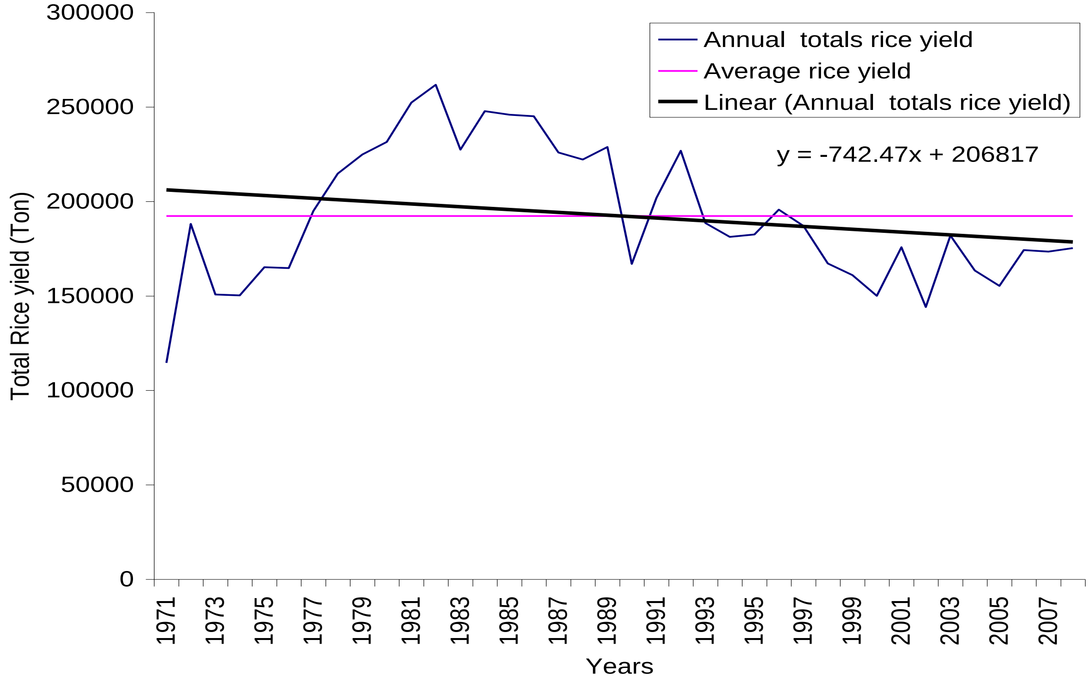


Figure 7.2-1: Annual rice yield production in tonnes for Nickerie 1971-2008

Figure 7.2-1 shows the annual rice yield and the graph (fig.7.2-1) shows a negative trend through the years (1971-2008). Furthermore, the decline of the rice yield started about 1990-1991, where the slope of the regression line is below the long-term annual average rice yield. The long-term annual average rice yield is 192338.6 tonnes.

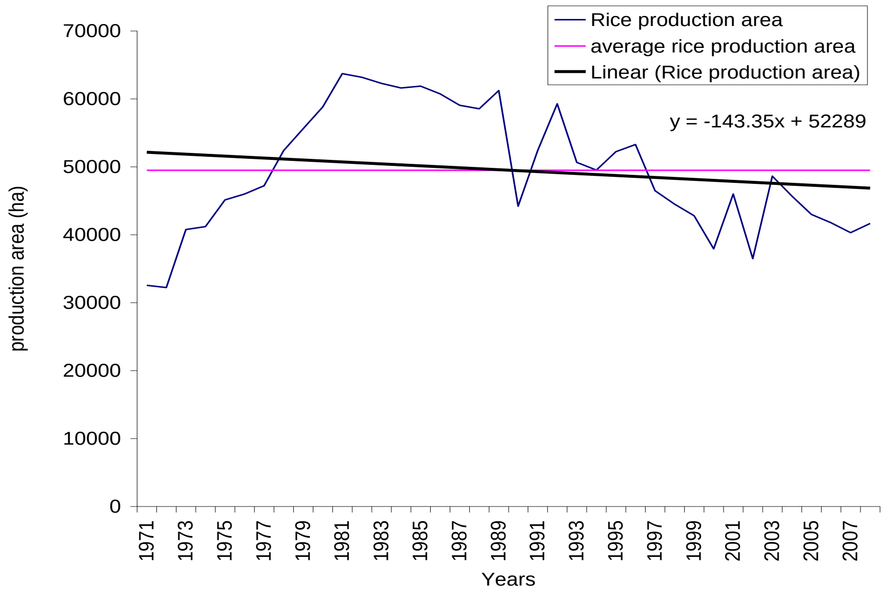


Figure 7.2-2: Annual rice production area in hectare (ha) 1971-2008

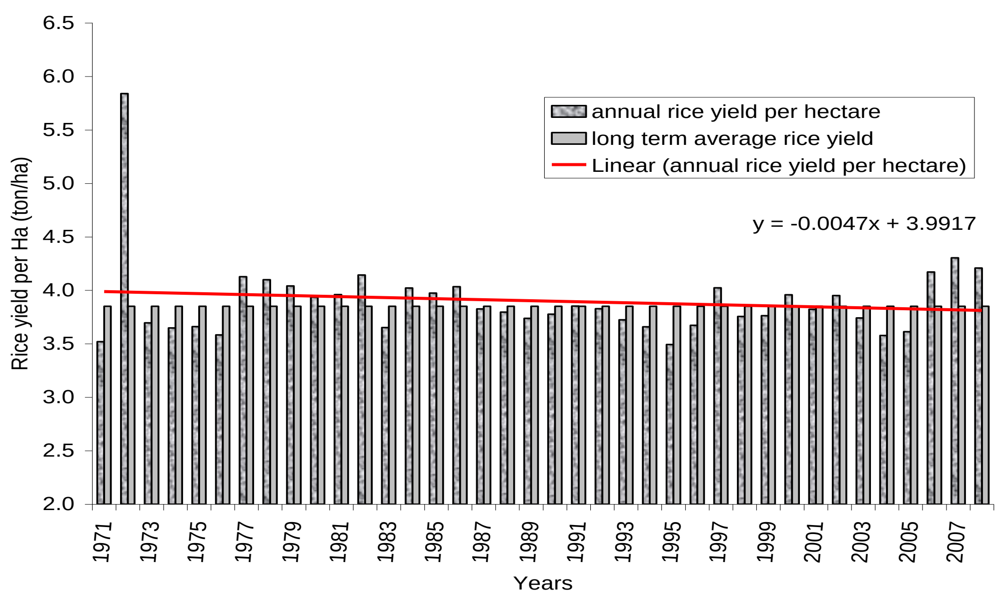


Figure 7.2-3: annual rice yield per area (tonnes/ha) 1971-2008

Figure 7.2-2 shows the amount of land under rice production (in hectares) and its decline through the years (1971-2008). A negative trend for the rice production is also observed during these years.

The graph (fig.7.2-3) shows a negative trend, which means that the annual rice yield per area is decreasing over time (1971-2008). The maximum yield of 5.8 tonnes/ha was reached in 1972, and the minimum yield of 3.5 tonnes/ha was recorded in 1995. The long-term annual average rice yield is 3.9 tonnes/ha.

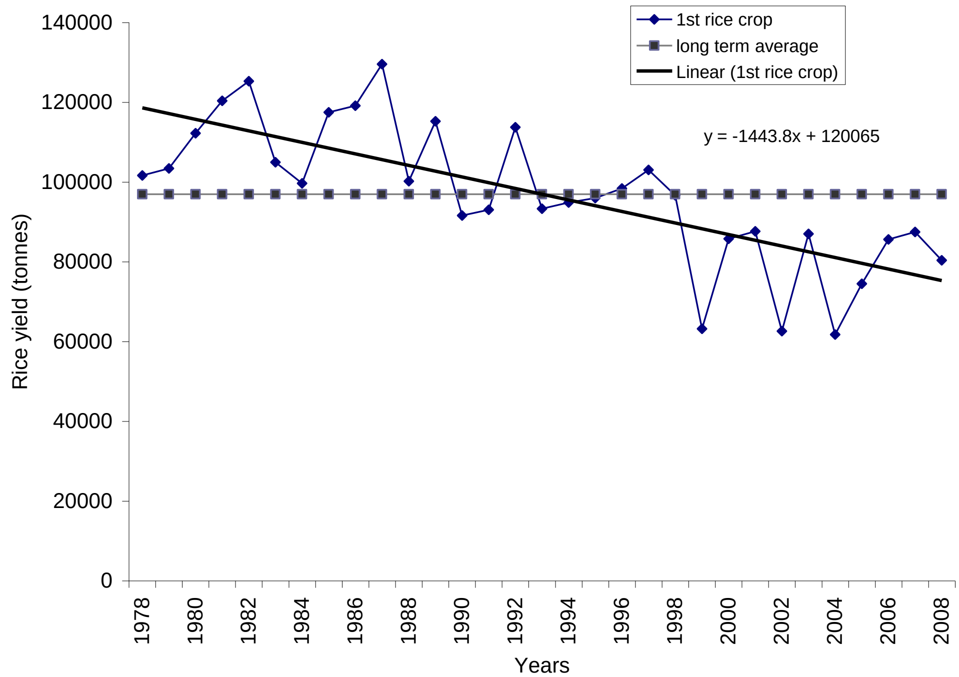


Figure 7.2-4: Annual rice yield 1st crop 1978-2008

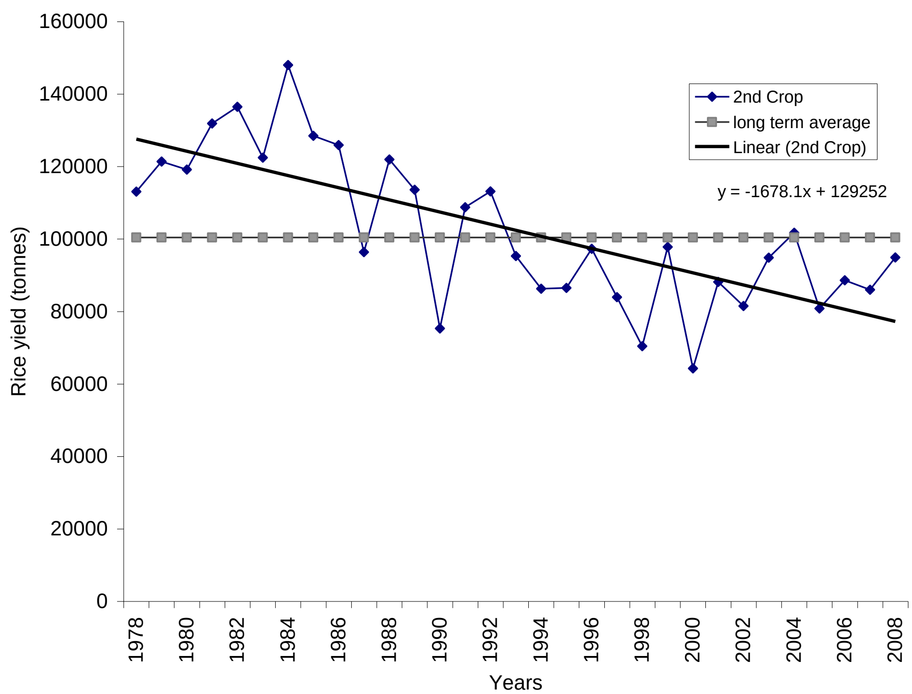


Figure 7.2-5: Annual rice yield for the 2nd crop 1978-2008

The figures 7.2-4 and 7.2-5 presents the annual rice yield for the 1st and the 2nd crop. The total annual rice yields for the 1st as well the 2nd crop have also decreased through the years (1971-2008). The long-term average for the 1st crop is 96965.3 tons and the average for the 2nd crop is 100431.7 tons. Even though that the total production for the 2nd crop is higher than the 1st crop, the yield per ha for both crops is still the same.

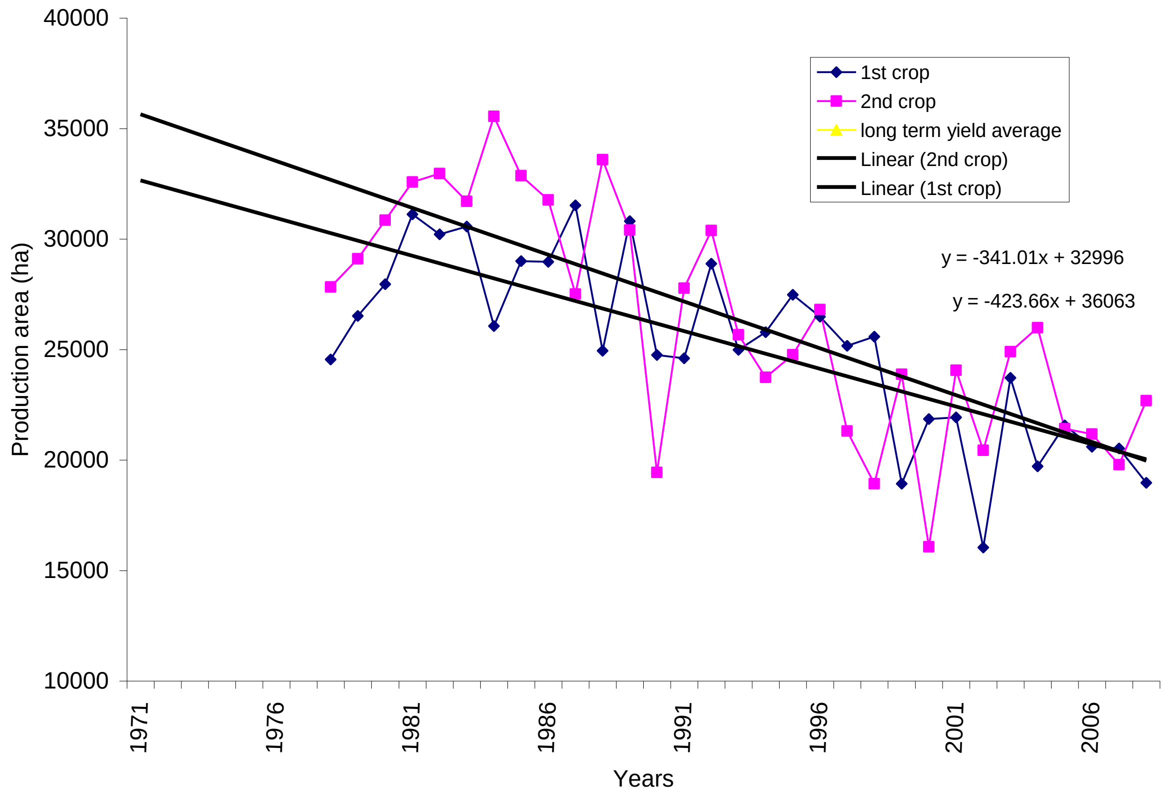


Figure 7.2-6: Total rice production area 1st and 2nd crop 1978-2008

Figure 7.2-4 and figure 7.2-6 shows declines in area under rice production and the total yield for the 1st and 2nd crops. The reduction in cultivated land through the years (1971-2008) has been associated with a decrease in the rice production. The average area under cultivation for the 1st crop is 25152.3 ha and 26318.9 ha for the 2nd crop. Although more land is used for rice farming for the 2nd crop, the yield (production per hectare) is still the same.

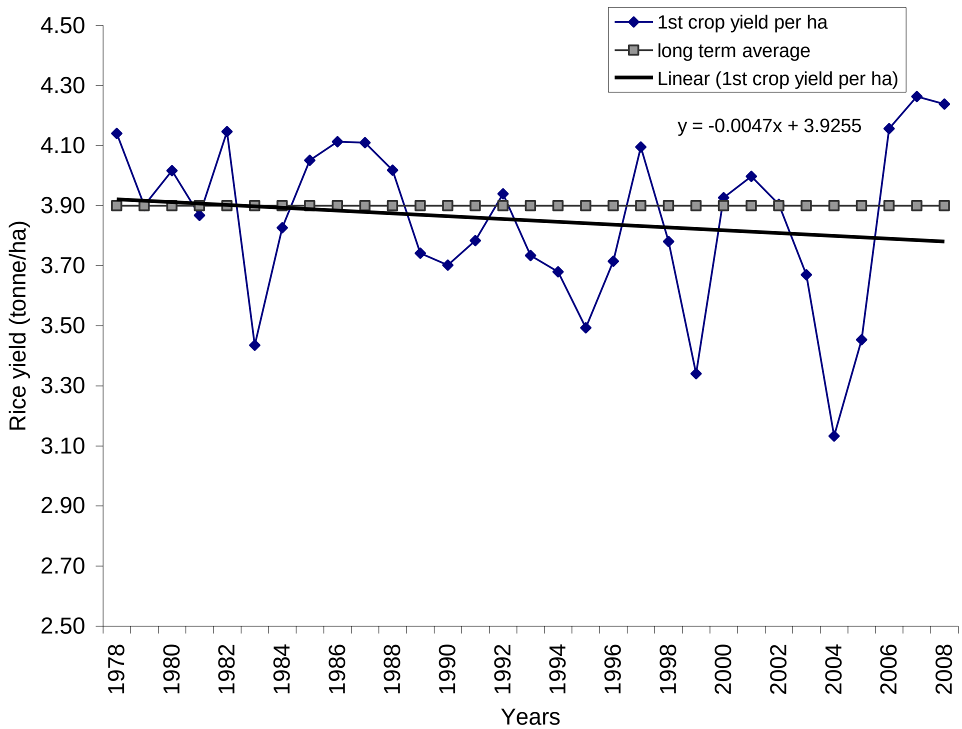


Figure 7.2-7: Annual 1st crop rice yield per acre 1978-2008

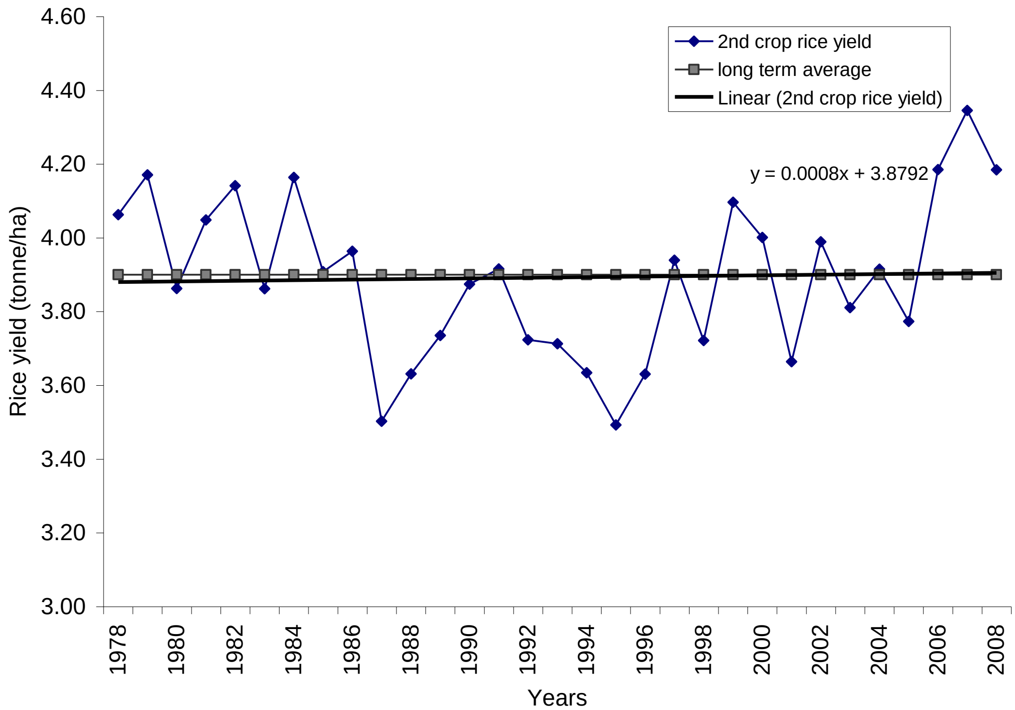


Figure 7.2-8: Annual 2nd crop rice yield per acre 1978-2008

The 1st and 2nd crops graph (fig.7.2-7 and fig. 7.2-8) shows the course in yield through the years (1971-2008). The average yield for the two crops is 3.9 tonne/ha. The first crop experienced 0.005 tonne/year decreases, whereas the second crop had 0.001 tonne/year increase in rice yield.

7.2.1 Summary of findings

Table 7.2-4: The average of rice production area and rice yield 1971-2008 for Nickerie

Activity	Period	Average Production area (ha)	Total rice yield (tonnes)	Rice yield per hectare (tonnes/ha)
	1971-2008	49493.6	192338.6	3.9
1st Crop	1978-2008	25152.3	96965.3	3.9
2nd Crop	1978-2008	26318.9	102402.1	3.9

Source: Ministry of Agriculture husbandry and fishery

The graphs (fig.7.2-1 – fig.7.2-6) show that the area under rice cultivation, as well as rice yield has declined over the years (1971-2008). As the land under production declined, so too did the yield. In addition, there was a decrease in yield of 0.005tonnes/year, over the same period. The average amount of land under cultivation per year was 49493.6 ha; while average production was 192338.6 tonnes (192338.6 x 1000 kg) (table 7.2-4). The long term annual average production was 3.9 tonne/ha (3900kg/ha) for both, the 1st as well the 2nd crop. There was no difference in the rice yield between the 1st and the 2nd crops, even though more land is cultivated during the 2nd crop. In addition, the first crop experienced 0.005 tonne/hectare/year declines in rice yield, and the second crop had 0.001 tonne/hectare increases yearly. Overall, however, the increase and decrease are very small and can be considered negligible.

7.3 The relationship between rice production and rainfall

Climatic factors, especially rainfall can have effect on the rice production, since water is an important production factor for rice farming. In the next paragraphs, .close attention will be paid whether there is a relationship between the precipitation and the rice production. The rainfall data for Nickerie 1971-2008 and the rice production data for this District are examined in the following paragraphs.

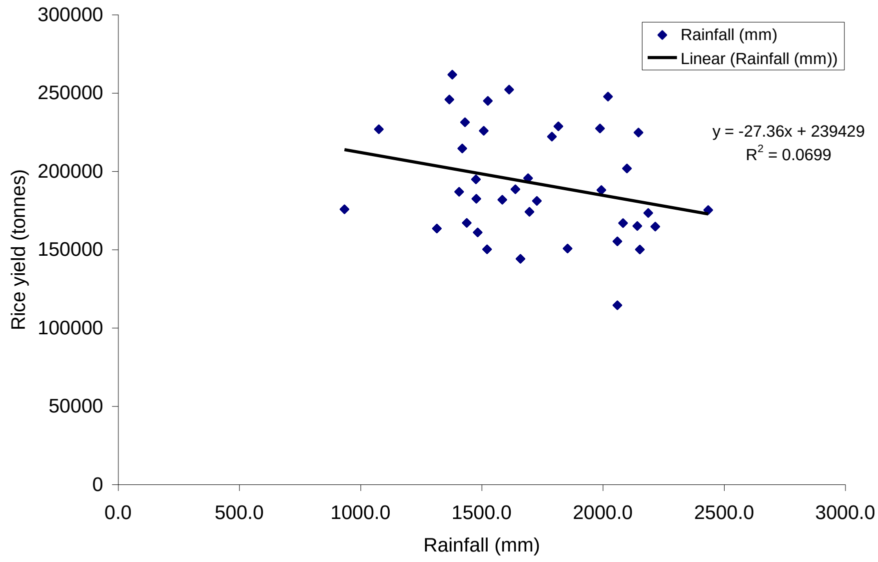


Figure 7.3-1: The relationship between annual average rainfall and rice production for Nickerie 1971-2008

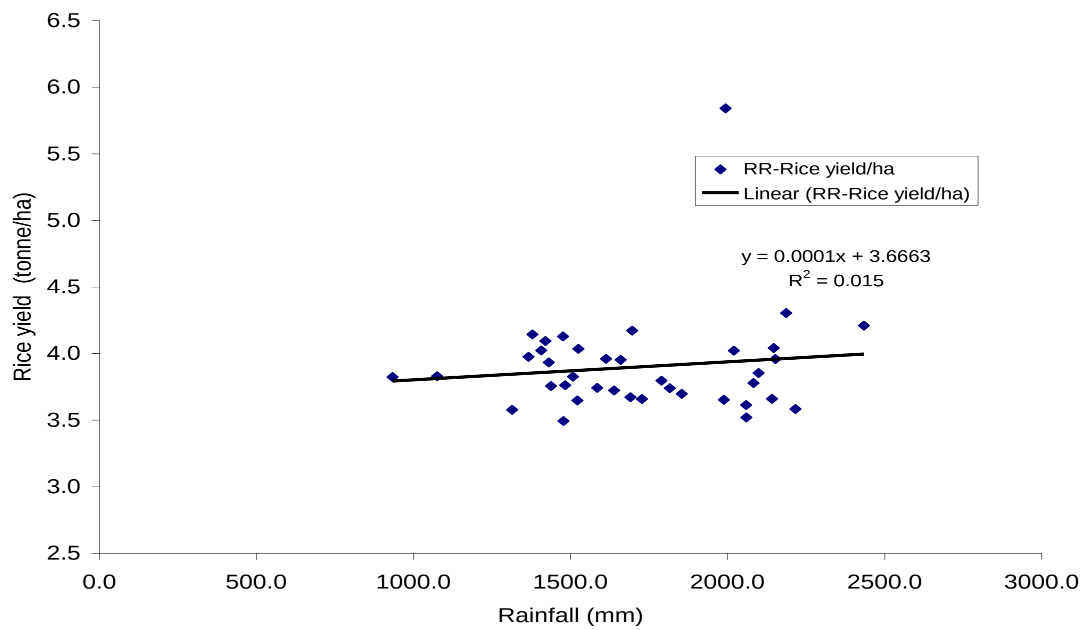


Figure 7.3-2: Relationship between annual rainfall and the rice yield per hectare 1971-2008

According to the illustration in figure 7.3-1, there appears to have been a decrease in rice production as the rainfall increases. Annual rice production was negatively correlated with annual rainfall for the period, which the data set covers (1971-2008). However, the relationship is weak.

The annual rainfall and the rice yield show a positive relation, however, an increase of 0.00001 tonne/mm is very small, and probably not statistically significant (fig.7.3-2). The significance testing of the correlation coefficient at a significance level 0.05 shows that the null hypothesis "there is no relationship between the variables rainfall and rice production" should not be rejected since the t-value (0.75063) is less than the t (0.05), 37 = 2.0262. Therefore, this relationship is not statistical significant.

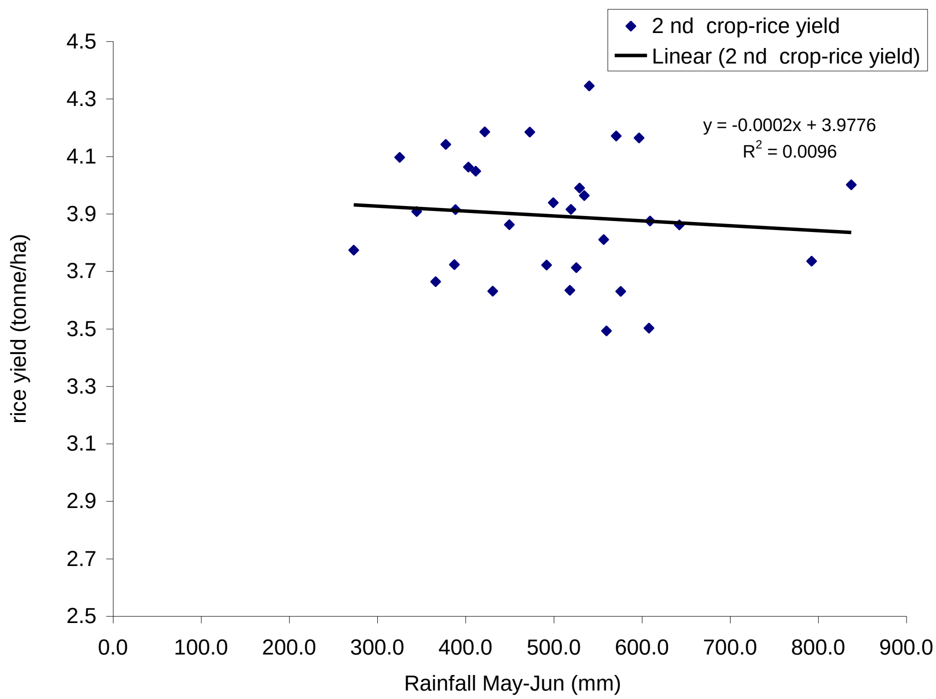


Figure 7.3-3: The relationship between the rainfall May-June (2nd sowing) and the 2nd crop rice yield per hectare 1978-2008

A weak negative relationship is identified between the May-June rainfall and the 2nd rice yield per hectare (fig. 7.3-3). The negative relationship between the rainfall May-June and the rice yield indicates that if rainfall increases during the 2nd sowing period (May-June) a decline occurs in the rice yield production.

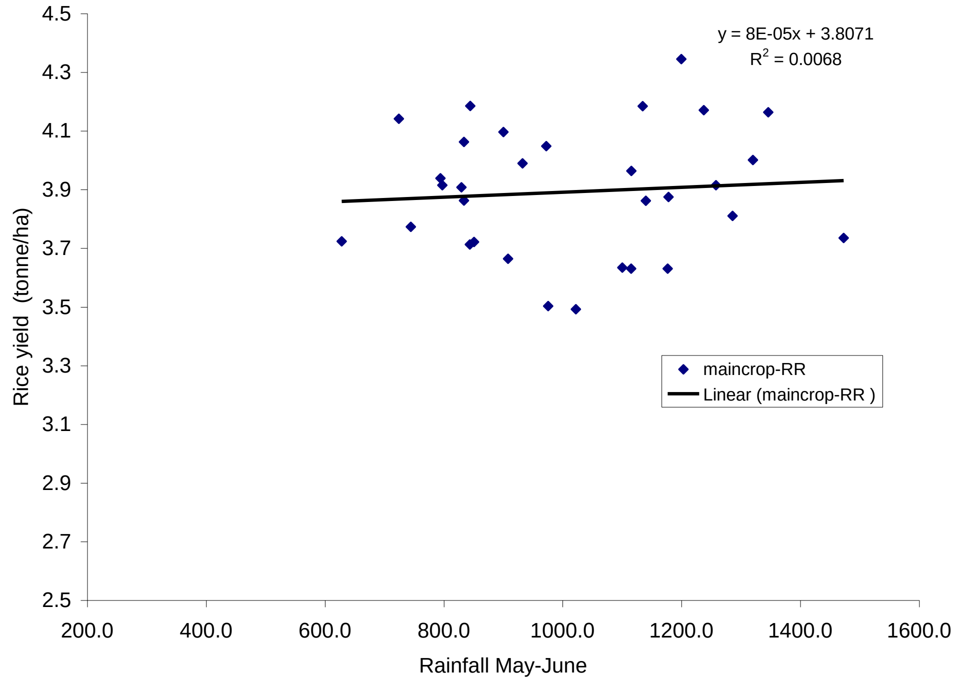


Figure 7.3-4 : The relationship between the rainfall (May-Oct) and the rice yield per hectare for the 2nd crop 1971-2008

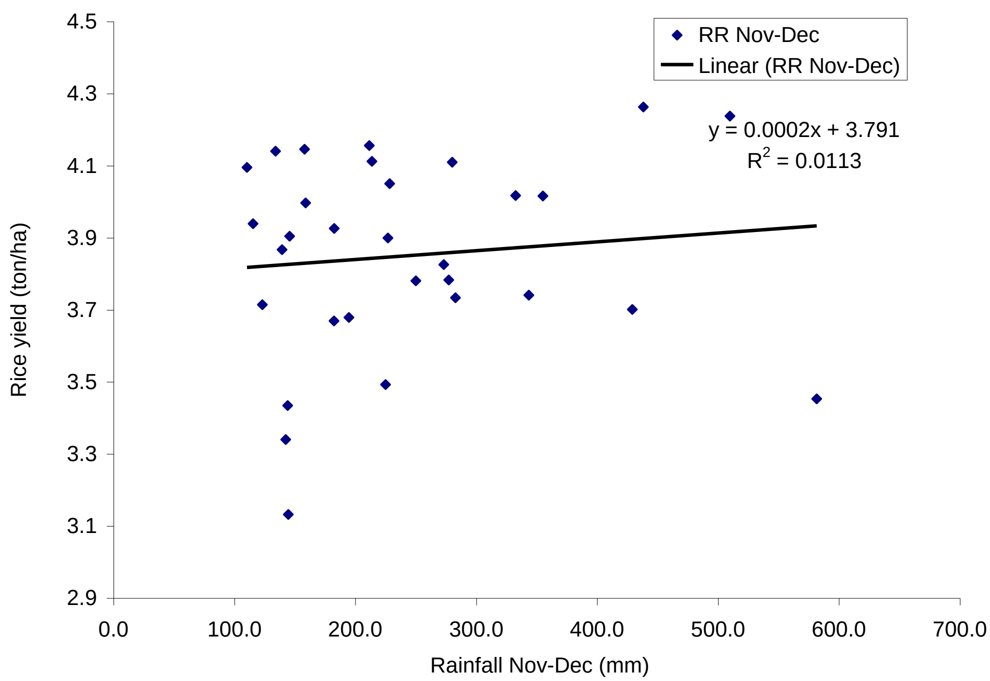


Figure 7.3-5: The relationship between the rainfall November-December and the rice yield per hectare for the 1st crop 1978-2008

The relationship between the rainfall of May-October and the rice yield per hectare for the 2nd crop illustrated in figure 7.3-4 is positive however, the relationship is positive weak.

The association between the rainfalls of November-December (cultivation of the 1st crop) is positive, as illustrated in figure 7.3-5.

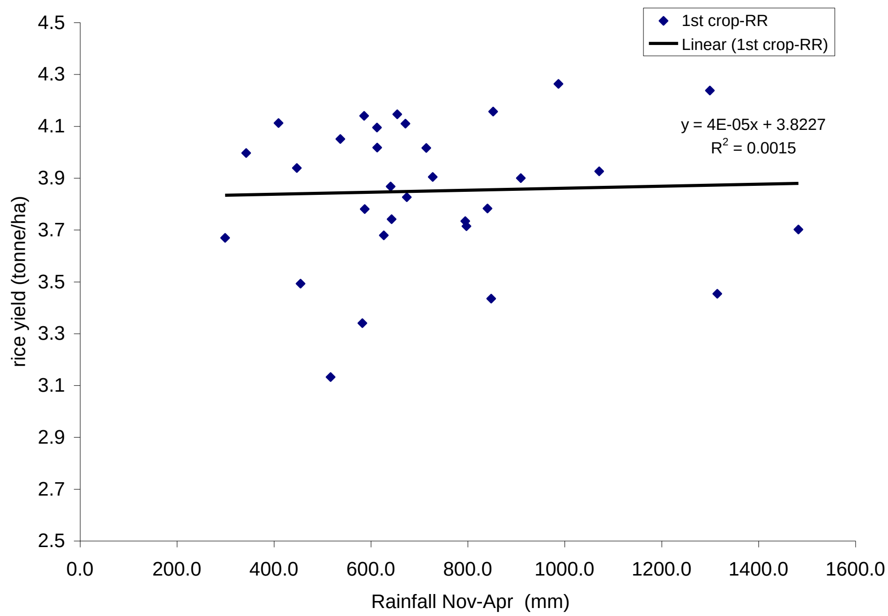


Figure 7.3-6: The relationship between the rainfall November-April and rice yield per hectare for the 1st crop 1978-2008

The correlation between the rainfall of November-April and the 1st rice crop is positive as illustrated in figure 7.3-6 however, it is weak.

7.3.1 Discussion

The correlations for the 1st and 2nd crop and the rainfall for the seasons are displayed in table 7.3-1.

Table 7.3-1: The correlation coefficient for rainfall and rice production 1971-2008

1st crop November-April		**2nd crop May-October**		**Annual**	
R (RR Nov-Dec vs. Rice yield per hectare)	R (RR Nov-Apr vs. Rice yield per hectare)	R (RR May-Jun vs. Rice yield per hectare)	R (RR May-Oct vs. Rice yield per hectare)	R (Anly RR vs. rice yield per ha)	R (Anly RR vs. annual rice yield)
0.11	0.04	- 0.1	0.1	0.122	-0.2643

Table 7.3-2 presents an overview of the statistics for the rainfall and the rice crops during 1971-2008.

Table 7.3-2: The average rainfall 1st and 2nd crop and the average yield per hectare 1971-2008

1st crop (November-April)			**2nd crop(May-October)**		
Average RR Nov-Dec (mm)	Average RR Nov-Apr (mm)	Average rice yield per hectare (tonne/ha)	Average RR May-Jun (mm)	Average RR May-Oct(mm)	Average rice yield per hectare (tonne/ha)
240.52	744.81	3.9	497.15	1026.56	3.9

The relationship between rainfall and rice production is positive except during the sowing period for the 2nd crop (table 7.3-1). However, the relationship is weak since the correlation coefficients are between -0.3 - 0.2. The relationship between annual rainfall and the annual rice yield is negative, thus, an overall increase in rainfall will result in a decline of the rice yield.

The period May-June is within the long wet season and much rain should be expected during this period. For this reason, high rainfall tends to occur in May and June. Hence, too much rain during the sowing period in the 2nd crop causes a decline in the rice production for that season. Much rain is observed during May – October than during November – April (table 7.3-2). On the other hand, the positive relationship between the rainfall in November –December and the 1st crop indicates that if the rainfall increases during the sowing period, an increase in the yield might also be expected. It is in this period that water is not sufficiently available for rice farming. The long dry season ends at the end of November and the short rainy season starts at the beginning of December. Therefore, a shortage to water is very likely during this period.

The rice farming in Nickerie District is irrigated and thus the farmers depend on irrigation water. If there is not sufficient irrigation water or sufficient rain for the rice farming, as a result it will cause a decline in production. In addition, the water resources, used for the irrigation, are rain fed and less rain is observed during the long dry season. Thus, decreases occur in the water resources water levels, since these resources are rain fed. Moreover, for this reason it can happen that the water is not flowing with the gravitation into the rice fields due to low water levels. If this happens, workers are needed to activate the water pumps to force the water into the irrigation canals, in order to get the water into the rice fields.

7.4 The relationship between temperature and rice production

The annual and monthly average temperature for 1971-2008 for Nickerie was examined to determine the relationship between the temperature and the rice production. Annual rice production data for the years 1971-2008 for the Nickerie District (Appendix E) were used to determine the relationship between the two variables. Temperatures in the lower part of their range may influence grain yield in a positive way, but may have a negative effect when the temperature are in their higher ranges (Evans et al., 1976).

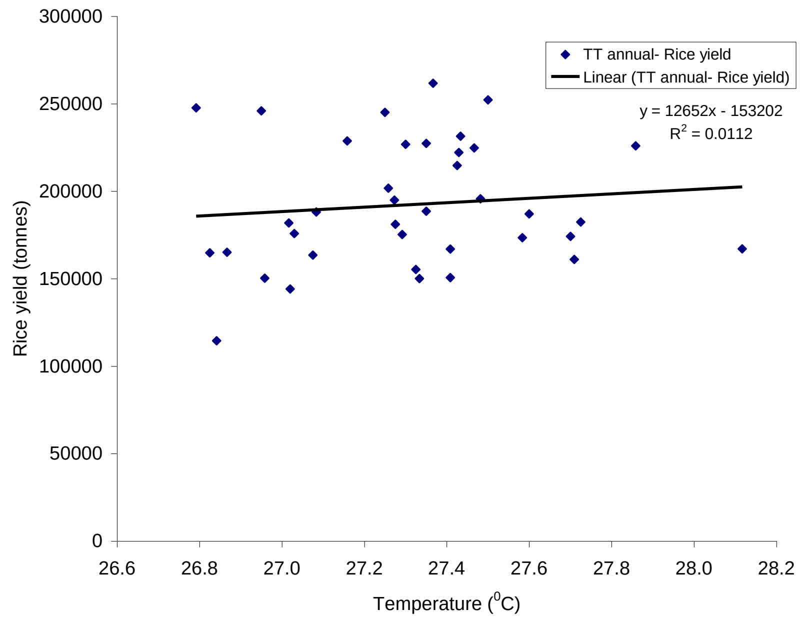


Figure 7.4-1: The relationship between annual average temperature and rice production

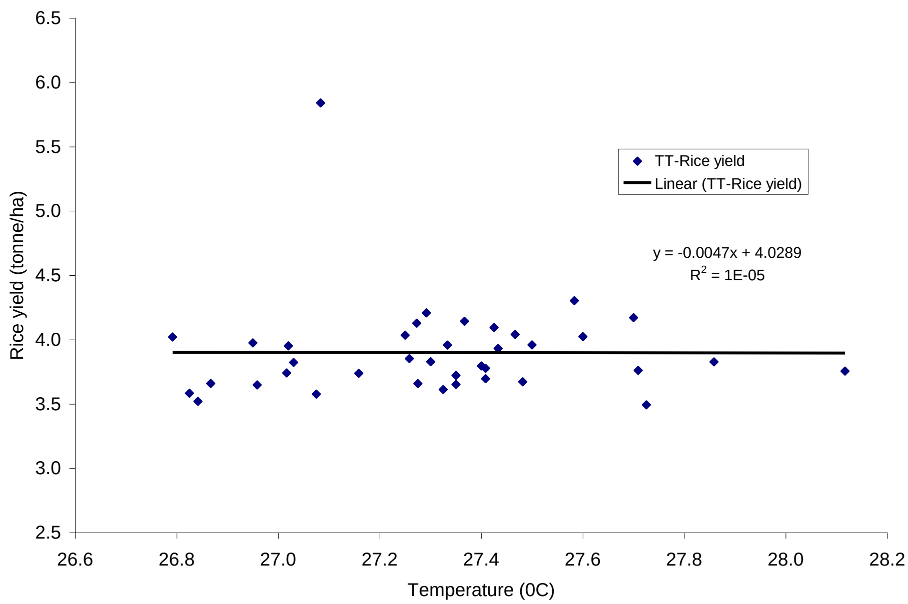


Figure 7.4-2: The relationship between the annual average temperature and the average rice yield per hectare 1971-2008

The rice production is positively related to the annual average temperature and this is illustrated in figure 7.4-1 however, the relationship between the variables is positive weak.

The illustration in figure 7.4-2 above shows a slight decrease of the annual average rice yield. Thus, the relationship is negative weak between the annual average temperature and the rice yield per hectare.

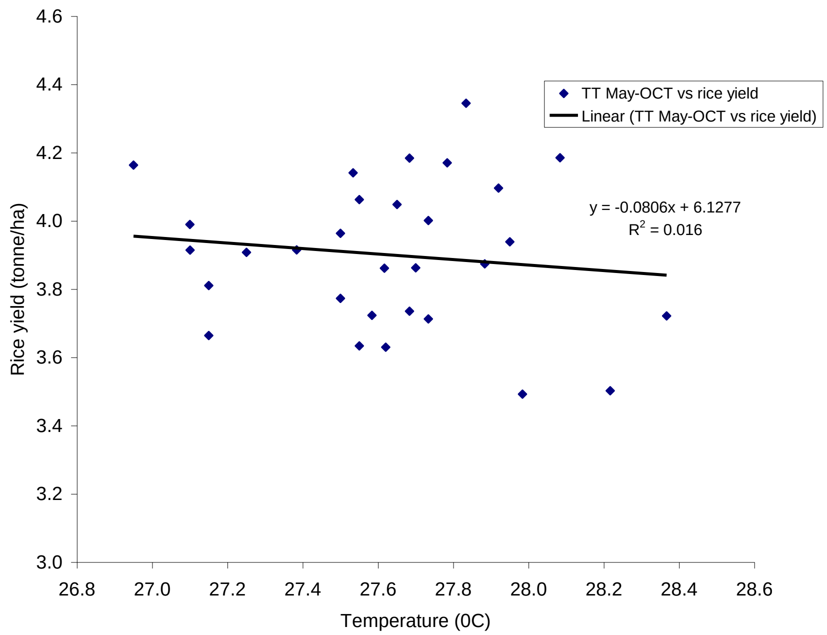


Figure 7.4-3: The relationship between the temperature May-October and the annual average rice yield per hectare 1971-2008

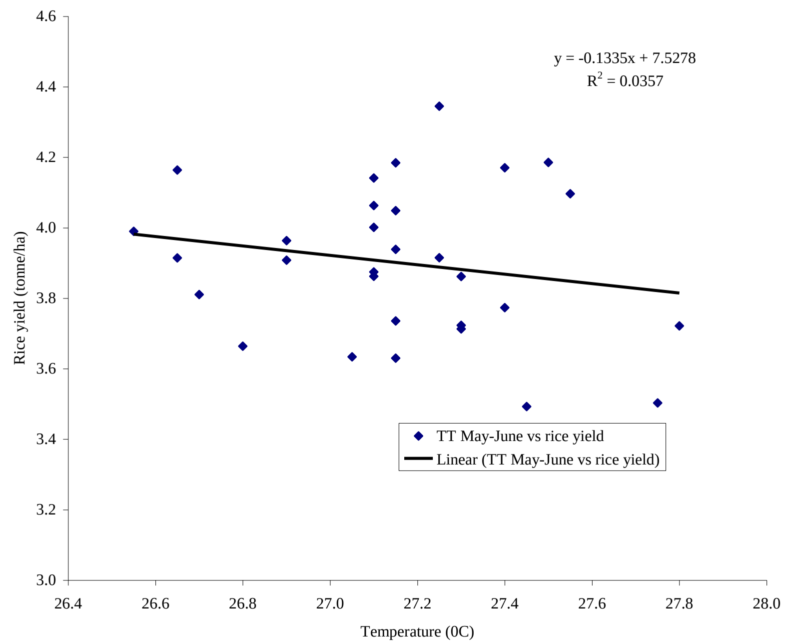


Figure 7.4-4: Relationship temperature May-June vs. rice yield 2nd crop 1971-2008

The relationship between the temperature May-October and the annual average rice yield is negative as illustrated in figure 7.4-3). The graphs (fig.7.4-3 and fig. 7.4-4) show a decrease of the crop while the temperature increases thus; the relationship between the temperatures May-June vs. the 2nd crop is negative. As a result, a temperature increase causes a decrease in the rice yield.

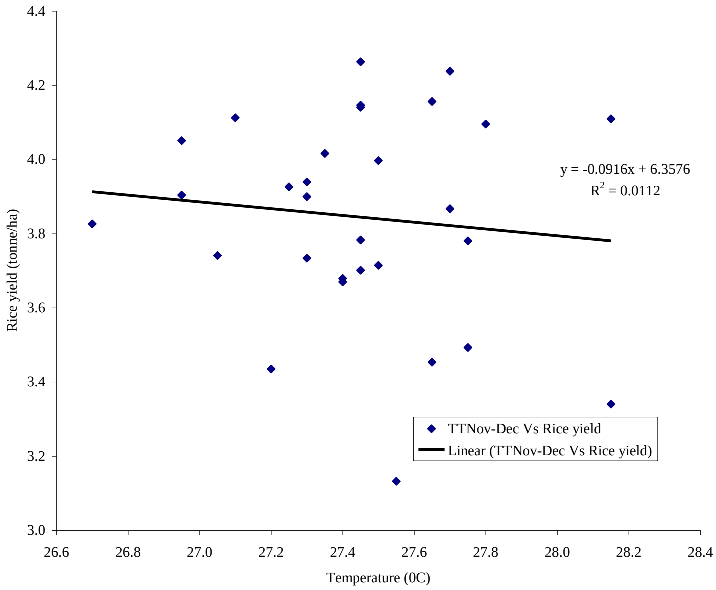


Figure 7.4-5: The relationship between the temperature November-December and the rice yield per hectare for the 1st crop 1971-2008

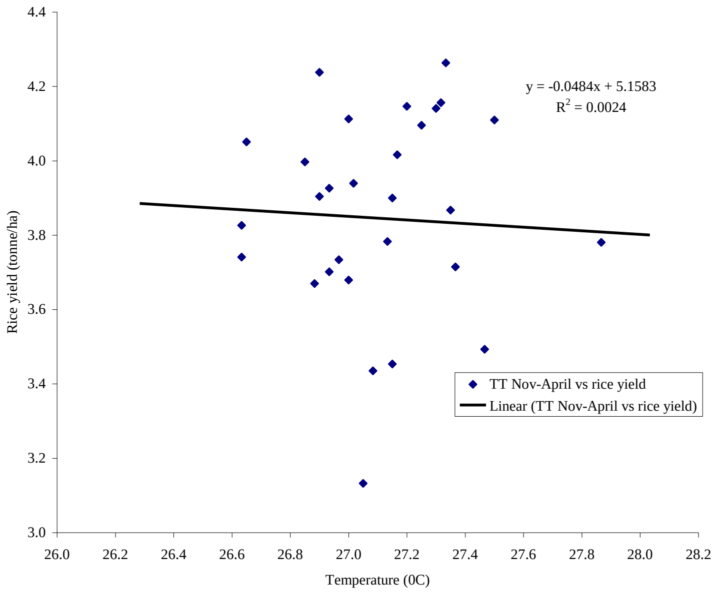


Figure 7.4-6: The relationship between the temperature November-April and the rice yield per hectare for the 1st crop 1971-2008

The illustration displayed in figure 7.4-5 shows a negative relationship between the temperature November-December and the rice yield per hectare for the 1st crop. Thus, rice yield decreases while the temperature increases.

The temperature November-April is negatively related to the rice yield for the 1st crop as illustrated in figure 7.4-6. Therefore, a negative relationship between the variables indicates that while the temperature increases, the rice yield decreases.

7.4.1 Discussion

Table 7.4-1 gives an overview of the correlation for the 1st, the 2nd crop, and the temperature during 1971-2008.

Table 7.4-1: correlation coefficient between the temperature and the rice yield 1971-2008

1st crop (November-April)		2nd crop (May-October)		Annual	
Corr R TT Nov-Dec vs. Rice yield/ha (1st crop)	Corr R TT Nov-Apr vs. Rice yield/ha (1st crop)	Corr R TT May-June vs. Rice yield/ha (2nd crop)	Corr R TT May-Oct vs. Rice yield/ha (2nd crop)	Corr R – annual TT-Rice (annual)	Corr R-annual TT-rice yield/ha
-0.18048	-0.09122	-0.1889	-0.12632	0.10370	-0.00369

The temperature is negatively correlated with rice yield for both rice crops. Thus, an increase of temperature will cause a decline in the rice yield. The correlation for the annual average temperature and the total rice yield is positive, but the total rice production also depends on the area under cultivation. An increase in the area farmed results in an increase in production.

The relationship between the temperature and the rice yield is considered weak since the correlations values vary between -0.2 and 0.2.

7.5 Conclusion

Based on the above findings the conclusion can be drawn that the total rice production has declined through the years, 1971-2008. Rice production is positively correlated with rainfall except during the 2nd sowing period. In addition, the 2nd sowing period occurs during the long rainy season when there is not an abundance of rainfall. In addition, a negative relationship exists between the temperature and rice yield for both crops. In consequence, an increase of the temperature will cause a decline in grain yield. Although a positive relationship is recognized between the annual average temperature and annual rice production, it should be pointed out that other factors, such as amount of land under cultivation, also affect total production.

In previous sections of the paper, the relationships between the Subtropical High pressure systems, rainfall, and the temperature pattern are discussed. The central pressure of the Subtropical High pressure systems increased during the past 39 years, while the rainfall for Nickerie decreased and the temperature increased.

In addition, annual average rainfall at Nickerie is negatively correlated with the North Atlantic Subtropical High as well as with the South Atlantic High pressure system, but the monthly average rainfall is positively related to the South Atlantic Subtropical High and negatively correlated with the North Atlantic Subtropical High. As a result, an increase in the central pressure of the North Atlantic Subtropical High is associated with a decrease in the rainfall for Nickerie. Thus, overall, it might be concluded that as the central pressure of the Subtropical High increases, it is accompanied by a decrease in rainfall, an increase in temperature, a decrease in freshwater resources, and is therefore likely to have a negative effect on the rice farming in the Nickerie District. The result is consequently a decrease in the rice yield.

8 ADAPTATION TO CLIMATE CHANGE IMPACTS IN THE RICE SECTOR

It is believed that the findings presented in the previous sections of this paper can be used to help develop a broad strategy for reducing the negative effects of climate and weather related changes on rice production in the Nickerie District. Given the changes in climate that are projected to occur over Suriname in coming decades, it would be sensible to identify effective measures that farmers can implement in order to reduce the negative effects on rice production. The recommendations below are being suggested as elements of a preliminary adaptation framework for the consideration of the authorities and farmers in the Nickerie District.

Seasonal prediction and climate change scenarios:

The use of seasonal prediction and climate change scenarios are important in agricultural production, with respect to rice farming, and food security systems. Agricultural production is an economical business, thus it is a risky one. Agriculture is very much subject to the weather. As a result, the provision of services to agriculture can avoid waste and spoilage. There after seasonal prediction and climate change scenarios is of economic value for the rice farmers. Because of this, promotion of insurance in rice farming is recommendable.

More efficient use of the water resources:

The rainfall of Nickerie District has decreased for the last 37 years, hence this will put a stress on the water resources, which are rain fed. A decline in rainfall causes lowering level in the Nannie Swamp and the rivers, thus, a reduced amount of freshwater will be available for rice farming. Global rainfall projection shows that a decline will occur in precipitation mean, and drought will occur in different areas of the world. Since rice farming in Suriname is based on irrigation, it is recommendable that a greater effort is made to use and allocate the irrigation resources more efficiently. With projected decreases in rainfall, less water will be available for the rice farming and therefore no water should be wasted. The use of trickle irrigation is recommended in preference to systems that irrigate less efficiently and waste water. Furthermore, an improved drainage system and the recycling of irrigation water in the rice farming are recommendable. Irrigation water in the rice farming is free. For that, reason an introduction of metering and pricing of the water in rice farming in order to prevent waste of water.

Introduction of heat resistant rice varieties:

The analysis of the temperature reveals that it has increased during 1971-2008. Since Nickerie District is a major rice farming area, it is recommendable to pay attention to this. . Increasing temperature will cause greater stress on the rice plants. Higher temperature for example will cause an increase in evaporation from the soil, and wilting of the plants. Such effects might cause a reduction in rice yield. Therefore, the development of heat resistant rice varieties is recommended.

The introduction of rice varieties that is more resistant to pests and insect whose population may increase due to changed climatic conditions:

Information obtained from field observations and from the farmers shows that rice farming is experiencing many challenges from the occurrence of red rice in the fields, and various pests and insect attacks on the rice cop. Therefore, varieties of rice that are more resistant to these outbreaks would be highly recommended.

Education

An improved farmer's education would be beneficial to accelerate adaptation to climate change. Therefore, awareness programme should be created in order to make the farmers familiar with climatic changes. The provision of guidance to the farmers in scheduling farming operation such as planting, irrigation and harvesting in order to avoid waste and loses. Furthermore, an education for the farmers in sustainable water use is highly suggested.

Farm practices.

Promote and develop alternative crops and adjustment of plantation and harvesting schedule. Introduce the use of chemical controls and application of biological control in rice farming

In order to reduce the negative effects of climate change and weather related events on the rice sector in Suriname, it is recommendable to give thought at the above mentioned preliminary adaptation framework.

9 CONCLUSION AND RECOMMENDATION

Rainfall

The rainfall trend is not uniform for the selected stations. Over the 39 year (1971-2008) period, the coastal stations Nickerie and Zanderij experienced a decrease in rainfall, while Cultuurtuin recorded an increase in rainfall. The central part of Suriname recorded a decrease in rainfall, while there was increased precipitation in the southern region of Suriname (Sipaliwini). Tafelberg, located in the central part of Suriname, recorded the highest annual average rainfall of all the stations. Similar to what is being observed globally, rainfall distribution and change over Suriname is not uniform, but varies from place to place. Drier conditions have been observed at six of the stations studied, while wetter have been recorded at the other location.

The South Atlantic Subtropical High pressure system is negatively related to the annual average rainfall for all the selected stations. The Subtropical High-pressure system is strongly negatively correlated with rainfall at Nickerie and Tafelberg, with R = -0.41 and the R = -0.63, respectively. As the central pressure of these high-pressure systems increases, a decrease in rainfall tends to occur in Suriname. The central pressure of the systems is positively related to the monthly average rainfall at the northern part of the country (Nickerie, Cultuurtuin, Zanderij), negatively correlated with the stations in the central region (Stoelmans Eiland, Tafelberg) and positively associated with the southern area of the country (Kwamalasoemoetoe, Sipaliwini). The influence of the South Atlantic Subtropical High is not uniform with respect to the monthly average rainfall for the selected meteorological stations. There was an increase in monthly rainfall in the north and south of the country, while a decrease in monthly rainfall was observed in the central regions

The North Atlantic Subtropical High pressure system is negatively correlated with the annual average rainfall for all stations: the strongest relationship is noted for Tafelberg (R=-0.81), followed by Sipaliwini (R=-0.59). Thus, overall the results suggest that a strong subtropical high-pressure centre will result in reduced annual rainfall in Suriname. Likewise, a consistent negative relationship is identified between the North Atlantic Subtropical High pressure system and the monthly average rainfall. While the central pressure of the SSTH increases toward the equator, it will push the ITCZ to the north. Since the ITCZ is one on the main factors that determines the rainfall distribution over Suriname, the country will experience a rainy period while the ITCZ is over the country. After reaching its maximum pressure in July, the central pressure of the South Atlantic High will decrease, while the central pressure of the North Atlantic Subtropical High increases until the systems coincide again in November. The minimum pressure for the North Atlantic Subtropical High is recorded in July. The North Atlantic Subtropical High pressure system expands southward toward the equator due to the increase of its centre pressure The short wet and dry seasons extend over the period end November –April. It is during this period, in the month of January, that the North Atlantic High pressure system reaches its maximum pressure and the South Atlantic High records its minimum pressure. The coincidence of the two subtropical high pressure systems determines if there will be a late or early start to the rainy season.

Temperature

The temperature trend for the selected stations is positive except for the Zanderij. The monthly temperature pattern is generally similar for all stations, and the highest temperatures are observed at all stations during the long dry season. The temperature pattern shows a seasonal cycle that is similar for all stations. The highest temperature is observed in the coastal areas, decreasing toward the central region, and increasing again in the southern part of the country. Tafelberg experiences the lowest average temperature for any station, in any season.

All stations except Zanderij experienced an annual increase in temperature over the years 1971-2008. The rate varied from 0.010 C/year – 0.05 0C/year, with the highest regression coefficient of 0.05 0C/year calculated for Kwamalasoemoetoe. The rate of temperature increase is lower in the coastal area (with the exception of Zanderij). A higher rate of increase was observed in the central region, but a reduced rate toward the south at Sipaliwini.
The increase in temperature over Suriname during the last 39 years reflects the observed global trend, attributed to increased emissions of greenhouse gases into the atmosphere (IPCC, 2007). The temperature increase for the seven meteorological stations in Suriname varied between 0.37 ^{0}C -1.85 ^{0}C over the period. The average temperature increase was around 1.1 ^{0}C. Except for Kwamalasoemoetoe, there was a positive correlation between annual average temperatures and both subtropical high-pressure systems.

In addition, the South Atlantic Subtropical High is positively correlated with the monthly average temperatures. In contrast, the relationship between temperature and the North Atlantic Subtropical High (except for the station at Sipaliwini) is negative. The correlation coefficient (R) between the monthly average temperature and the South Atlantic pressure system varies from 0.26 to 0.51 and for the North Atlantic Subtropical High the coefficient ranges between -0.37 and - 0.003. Moreover, strong relations exist between the South Atlantic high-pressure system and the monthly average temperature of the coastal stations (Nickerie, Cultuurtuin, and Zanderij) and the relation becomes weak towards the south of the country.

The Subtropical High Pressure Systems

The study shows that a positive trend is identified for both systems. Thus, the subtropical high pressure is increasing and it has started about 1991-1992 and it is still increasing up to the present.

Rice

The analysis shows total rice production in Nickerie district has declined through the years, 1971-2008, but that yield is positively correlated with the rainfall except during the 2nd sowing period. It should be noted that the 2nd sowing period occurs during the long rainy season and therefore the abundance of rain is not favourable factor during the sowing period. A negative relationship is identified between the temperature and the rice yield for both crops. Although a positive relationship exists between the annual average temperature and the annual rice production, it should be remembered that other factors, including the amount of land under cultivation, also influence total production.

The study also found that an increase in the central pressure of the Subtropical High is associated with a decrease in rainfall, an increase in temperature, and a decrease in available water resources. This is likely to have a negative effect on the rice farming in the Nickerie District. Consequently, this could result in a decrease in the rice yield in Nickerie District. Examination of the rice production data shows that a decline in both production and yield has occurred in the years covered by this study.

Changes in the rainfall distribution and average annual rainfall in Suriname will affect the freshwater resources and in turn will likely have a negative impact on rice cultivation. Since rice is the most important foreign exchange earner in the agriculture sector, the socio economic implications for the country would be serious. Recommendations for improving the resilience of the rice industry in light of these changes are provided. It is hoped that these suggestions can form part of a preliminary adaptation framework for the sector. Finally, it is recommended that further research on these topics should be carried out, since this study is one of the first to be undertaken for Suriname.

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