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The Impact of Climate Change and Climate Variability on The Agricultural Sector in Nickerie District

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Abstract

Rice is a very important agriculture product for Suriname, not only for local consumption but also for export. The Intergovernmental Panel on Climate Change states that the global averaged surface temperature will increase by 0.3°C–1.7°C under RCP2.6 and 2.6°C–4.8°C under RCP8.5, and extreme precipitation events over wet tropical regions will very likely become more intense and more frequent. This might significantly impact the rice yield in the future. The first objective of this study was therefore to analyze historical changes in the climate and hydrology in Nickerie district. The second objective was to study the impact of projected climate change on the rice sector in Nickerie district by 2070-2100. Analysis has shown that the trend in the historical annual rainfall and the annual temperature have been non-significant (T-test, 95%). Historical El Niño and La Niña events, but also the reverse impacts, have affected the rainfall in Nickerie district. The regression models represent no or a negligible relationship between the rice yield, and temperature and rainfall. The water-balance studies have shown that less rainfall will be available by 2070-2100 at the beginning of the second crop season (April-May) and the beginning of the first crop season (October, November, December). This means that more irrigation water will be required in the future and new freshwater resources need to be developed.

Keywords: Agriculture, climate change, climate variability, Nickerie

Introduction

Agriculture is one of the top 3 fastest growing sectors of the economy in Suriname (Reusche and Atanasov, 2014). Rice is a major component of Suriname's agricultural exports representing on average 38% of total foreign exchange earnings from agricultural exports (Derlagen et al., 2013; Ministry of Agriculture, Animal Husbandry and Fisheries, 2013). Nickerie district in the northwest of Suriname is the largest producer of rice for local consumption and export to the Caribbean region and EU countries.The total annual cultivated area of rice in Nickerie district is about 51,747ha (1978-2013). The total annual rice production is about 203,605 tons and the total annual rice yield is about 3.93 tons/ha (Ministry of Agriculture, Animal Husbandry and Fisheries, 2009, 2013). This is a little below the world average of 4.43 tons/ha. The rice production per ha varies from 4.36 tons (> 20ha) to 4.47ha (6-10ha) and from 4.36 tons (> 20ha) to 5.03 (1-3ha) (Ramadhin, 2014). Rice production is a source of greenhouse gas (CH4) due to flooding of paddies. The agriculture emissions due to rice cultivation in Nickerie district are about 314.9 gigagrams CO_2eq (2010) (IPCC, 1997; FAOSTAT, 2015). Rice fields also emit nitrous oxide (NO_2) due to the excessive use of chemical fertilizers and pesticides.

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Rice cultivation in Nickerie district is irrigated (wet rice cultivation).Farmers struggle with many problems such as inefficient irrigation, saltwater intrusion in the coastal rivers especially during the two dry seasons (February-April and September-November), the effects of climate change (shift in seasonal rainfall) and climate variability (e.g. El Niño), poor hydraulic works, weak institutional arrangements at polder level. Poor quality of paddy and low paddy prices also exert a negative pressure on the rice production.Mungroo (2014) has shown that climate events in the past in Nickerie district particularly reduced food production through reduced water availability and drought. The International Food Policy Research Institute (IFPRI) indicates that by 2050 rice prices will have increased by between 32% and 37% as a result of climate change. It also indicates that yield losses in rice could be between 10% and 15%. TheIntergovernmental Panel on Climate Change IPPC (2013) reports that globally the averaged surface temperature data show a warming of 0.85 [0.65 to 1.06] °C over the period 1880 to 2012. By the end of the 21st century (2081-2100) relative to 1986-2005, the global mean surface temperature is likely to have increased by 0.3°C–1.7°C under RCP2.6 and 2.6°C–4.8°C under RCP8.5. The mean precipitation for 2081–2100 relative to 1986-2005 will likely decrease (between -20% and +10%), but extreme precipitation events over wet tropical regions will very likely become more intense and more frequent. The mean sea level will rise by about 0.44-0.74m by 2100 relative to 1986-2005 levels (IPCC, 2013). Observations from tidal gauges surrounding the Caribbean basin indicate that SLR in the Caribbean will increase from 0.13m up to 1.45m by 2100 relative to 1980-1999 (Meehl et al., 2007).

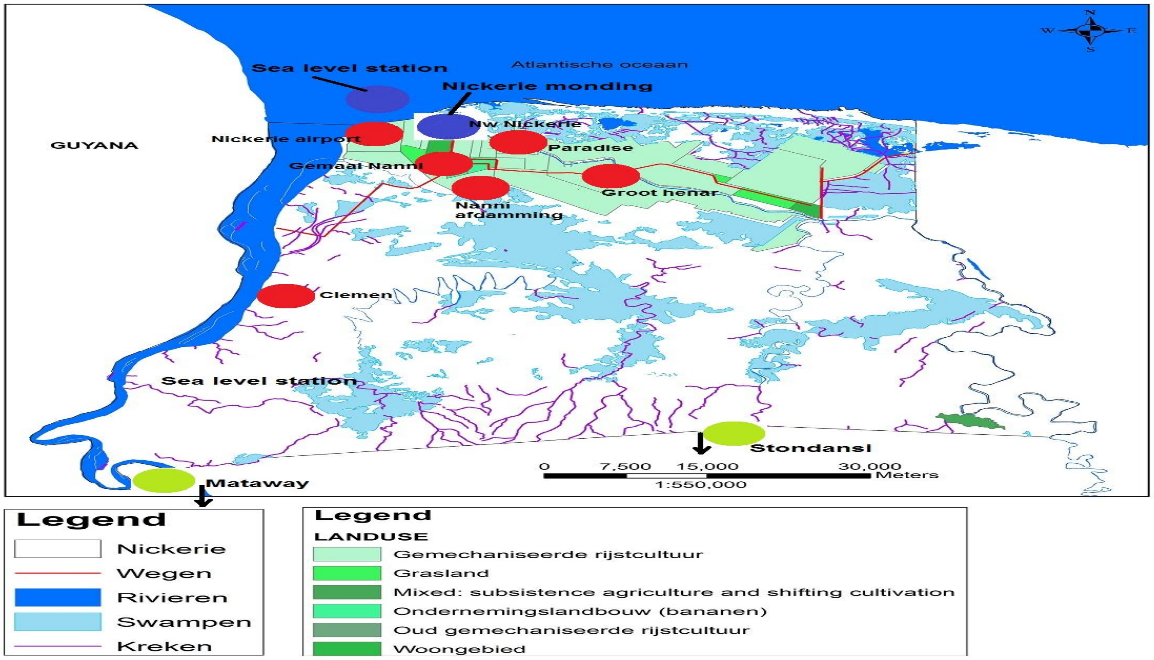
Climate change will have a significant effect on crop growth, development and yield (productivity) by the increasing temperature and uncertainty in rainfall (Biscay, 1984; Hasanuzzaman, et al., no year; Nimos, 2005; Peng et al., 1995, Rahman et al., 2012; Vaghefi et al., 2014). An increase in temperature may shorten the length of the growing period in tropical regions, and thus reduce yield. The range of temperatures for seed germination of rice is optimal between 20-35^{o}C (min. 10^{o}C and max. 45^{o}C). The International Rice Research Institute (IRRI) indicates that a rise in night-time temperature by 1^{o}C may reduce rice yields by about 10%(Retrieved Jan 10, 2015, from http://irri.org/). According to the Philippine Rice Research Institute (2011), grain yield of major crops including rice is reduced by 5-7% for every 1^{o}C rise in mean daily temperature. A separate study shows that rice yield declines by 10% for each 1^{o}C increase in minimum or night-time temperature during the dry season, whereas the effect of the maximum temperature was found insignificant. Higher temperatures can also decrease rice yields as they can make rice flowers sterile, meaning no grain is produced. Moreover, a change in the climate will affect the distribution and the degree of infestation of insects including rice diseases and pests.

The full impact of climate change on rice production is still unknown, nor is it fully clear what measures should be taken to reduce the impact. The different predictions for temperature, carbon dioxide levels, changes in humidity, and the interaction of these factors make forecasting future rice yields under these conditions challenging. Crop modelling has become a critical tool to get insights into the physiological and ecological processes, assessing the relationships between crop yield and environmental factors and evaluating the impacts of climate change on rice production (Lobell and Field, 2007; Lobell and Burke, 2010; Mahmood et al., 2012; Ogbuene, 2010; Peprah, 2014; Rahman et al., 2012; Rowhania et al., 2011; Sarker et al., 2012; Tazhibayeva, and Townsend, 2012; Vaghefi et al., 2014). In general, there are several methods to study theimpact of climate change on agriculture (CCCCC, 2010). These are: a) expert judgment, b) analogous procedures, c) actual statistical relationships, d) climatic and bioclimatic indexes, e) biophysical and ecological impact models/agronomic-economic models e.g. DSSAT, EPIC, CENTURY, RICEMODE, WARM, and f) integrated assessment models e.g. DICE, RICE.Various studies have been conducted to study the impact of climate change on the agricultural sector, especially rice(CCCCC, 2010, 2014). 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. Karn (2014) studied the effect of climate on rice production, using a regression function on rice harvest (yield) and weather variables (e.g. temperature) in Nepal. Monteiro et al. (2013) estimated rice yield based on weather conditions and on the technological level of production systems in Brazil using a regression relationship. Biscay (1984) has made an assessment of on-farm practices for improved rice production in Nickerie district. According to his findings, there is an increase in grain yield with an increase in solar radiation. The National Oceanic and Atmospheric Administration Center for Environmental Assessment Services and Atmospheric Science Department of the University of Missouri-Columbia (1979) also used a linear regression model based on rainfall and yields to predict the rice yields in Nickerie district.The objectives of this studyareto analyse the historical climate and hydrologyand to study the impact of projected climate change on the rice sector in Nickerie district by 2070-2100.

Methodology

The study area, Nickerie district, is about 5,353 km^2 (about 3% of Suriname) and is situated in the northwest of Suriname, between 56°8’-57°4’ WL and 5°2’-6°0’ NL (Figure 1). The following data were available for this study: meteorological data (e.g. rainfall, temperature), hydrological data (e.g. sea and river-water levels, river discharges), CMIP5 climate data from global circulation models (e.g. rainfall, temperature) and climate data from the PRECIS regional climate model (e.g. rainfall, temperature) (Alves and Marengo, 2009; Campbell et al., 2010). Socioeconomic data have been provided by the Algemeen Bureau voor de Statistiek (ABS, 2014). Data about the agricultural production (e.g. rice areas, rice yields) in Nickerie district have been provided by the Ministry of Agriculture, Animal Husbandry and Fisheries (LVV) and ABS. Only stations with sufficient and complete data (covering at least 25 years) were considered for analysis of climate variability. Stations with long-time series (e.g. more than 50 years) will be considered for climate change analysis. For this study, 7 rainfall stations were available with monthly and daily series. Based on the location of the rice areas, only Paradise station was considered. For temperature and evaporation analysis, only one station (Nickerie airport) had useful daily data.Two river discharge stations (Mataway and Stondansi) with daily data located in different rivers were considered in this study. Two water-level stations (close to the river mouth) and one seawater-level station (with daily data) were considered in this study. Other stations in the study area were not considered, as they had poor observations and the time series were too short (< 10 years). Figure 1 shows the locations of these stations. The monthly observed sea surface temperatures (SSTs) (1950-2003) are adapted from the National Oceanic and Atmospheric Administration (NOAA-CIRES Climate Diagnostics Center) for the Tropical Northern Atlantic-TNA (5.5o-23.5oN, 15o-57.5oW), the Tropical Southern Atlantic-TSA (0o-20oS, 10oE-30oW), the Extreme Eastern Tropical Pacific ENSO-Niño 1+2 (0o-10oS, 90o-80oW) and East Central Pacific ENSO-Niño 3+4 (5oN-5oS, 160oE-150oW). The monthly Atlantic Niño SSTAs (3oS-3oN, 20oW-0o) and SSTAs in the Tropical Atlantic (“dipole index”) are obtained from Dr. Wang, C. (NOAA).

Figure 1: Study area, Nickerie district. Note: borders are indicated in a purple line (Narena, 2008). Location of the meteorological, hydrological and hydraulic stations in Nickerie district are indicated in different circles. Note: the red circles show the location of the meteorological stations; the blue circles show the location of the water level stations;the green circles show the location of the discharge stations.



The complete monthly and annual time series were used to calculate the mean rainfall, temperature and evapotranspiration in the study area. Out of the available rainfall stations, 3 were considered, i.e. the stations at NW Nickerie, Paradise and Groot Henar. For the past/ current trend and variability analysis, monthly average data (observed) were used from the years 1961 through 1987, with the exclusion of 1970 and 1971 (no records). Out of the 3 stations, Paradise station had the most complete series for the considered period (1961-1987). Small gaps were filled with data available from the 2 other stations, given the strong correlation (confirmed by regression tests performed).Insufficient observed evaporation data were substituted by modelled baseline evaporation data. Future evaporation climate series were developed by applying linear regression between evaporation and temperature, considering observed evaporation data (long-term monthly mean values based on available observations (1973-2008)) relative to observed and modelled baseline temperature data. Perturbation factors derived for temperature, which are considered to be a measure for the change signal, were used to perturb the modelled baseline evaporation series to obtain the future evaporation series.

For detecting climate change of hydrological time series (randomness, stationary and homogeneity) the regression test will only be used (McCuen, 2003; Mamdouh et al, 1993). To investigate the relationship between the rainfall anomalies in Nickerie district and the Atlantic and Pacific SSTAs on an inter-annual scale, cross correlation analyses were used. These analyses were carried out on a seasonal scale (December-February DJF; March-May MAM; June-August JJA; September-November SON), using the Anclim model (Stipanek, 2003) and the KNMI Climate Explorer (http://climexp.knmi.nl/). The SST anomaly was obtained by subtracting the annual (monthly) climatologies (for 12 months) for each data series for the individual annual (monthly) data. The common period 1961-1985 (25 years) is further used to identify temporal changes in the annual rainfall.

To generate climate scenarios, CMIP5 global climate model output (RCP2.6 and RCP8.5 scenarios) and regional climate model output from the PRECIS regional climate model (A2, B2 and A1B scenarios) are usedfor rainfall, temperature and evapotranspiration for the agricultural sector in Nickerie district (IPCC, 2013; Taylor et al, 2012). CMIP5 uses more than 50 GCM models at resolutions of 25x25 or 50x50 km, while the PRECIS model uses three global models (HadAM3P, ECHAM4 and ECHAM5) at a resolution of 25x25 km. The statistical models used in this research are: MSExcel (Data analysis) and the KNMI Climate Explorer (Retrieved January 5, 2014 from http://climexp.knmi.nl/).

Because of the limited availability of meteorological data (e.g. for temperature, evapotranspiration), a regression model was used to model the rice yield. Regression lines can have a linear, parabolic, exponential or other relationship. If the yield time series are longer than 30–35 years, second degree polynomial can be used. For shorter time series, linear approximation is sufficient to satisfy the minimum criteria (Rahman et al., 2012). XLStatistics (Carr, 2000) is used to develop the regression models. General linear regression models have the form of:

$$Y = \alpha + \beta_1 X_1 + \ldots + \beta_k X_k + \varepsilon \qquad (1)$$

where,

Y is the predicted yield (dependent variable)

α, β_k are estimated regression constants; α represents the deterministic component (trend) and is estimated using the least squares method; these parameters are estimated from observed data using the method of least squares$X_1, \ldots, X_k$ is k_{th} least squares estimated for the k_{th} predictor X_k; X_k is e.g. rainfall, temperature (independent variables)ε is the residual term which represents the composite effect of all other types of individual differences not explicitly identified in the model

Polynomial regression models have the form of:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2^2 + \ldots \beta_k X_k^k \qquad (2)$$

Because of the shortness of the data, the results presented here should be used as an indication of climate variability and climate change in Nickerie district. For consistency and uniformity, all tests used will be performed at a 5% significance level (α), because of the availability of statistical tables.

Results and discussion

Figure 2 shows the anomalies in annual rainfall at Paradise station for the periods 1915-1985 and 1961-1985 respectively. Figure 3 shows two annual cycles of rainfall for the period 1961-1985 at Paradise station. It appears from this figure that annual rainfall is concentrated in June-July, with an average of about 300mm and 95% interval from 175mm to 550mm. This is quite variable.

Linear trend analysis shows that the annual rainfall has increased by about 30.7 mm/10 years since 1961 (1961-1985), but this trend is non-significant (T-test, 95%). The trend of the annual rainfall for the whole period (1915-1985) shows a slightly decreasing trend (less than 1mm/10 years; non-significant (T-test, 95%)). Application of the Kolmogorov-Smirnov test has shown that the annual rainfall time series (1915-1985) at Paradise show a normal variability (stationary) (D=0.242; p=0.0). The results of the tests to detect discontinuity (change point) in the annual rainfall time series at a 95% confidence interval show that for the Cumulative Deviation test, year 1929, for the Standard Normal Homogeneity test SNHT test (shift in mean and standard deviation), year 1980, for the double shift in annual rainfall mean, year 1970 and 1972, and for the regression F-test, year 1950. It is unlikely that 1929, 1970-1972, 1980, could be the years when the climate changed in Suriname. But it is clear from figure 2 that after year 1950 the mean annual rainfall decreased. However, the 1940-1980 period is a period when the global mean surface temperature was more or less stable. Global climate change may not be the cause of the climatic shifts. Figures 3 and 4 show that there has been great variation in the seasonal rainfall between 1915 and 1985 with an increase in rainfall between 1930 and 1960 for the seasons DJF, MAM, JJA.

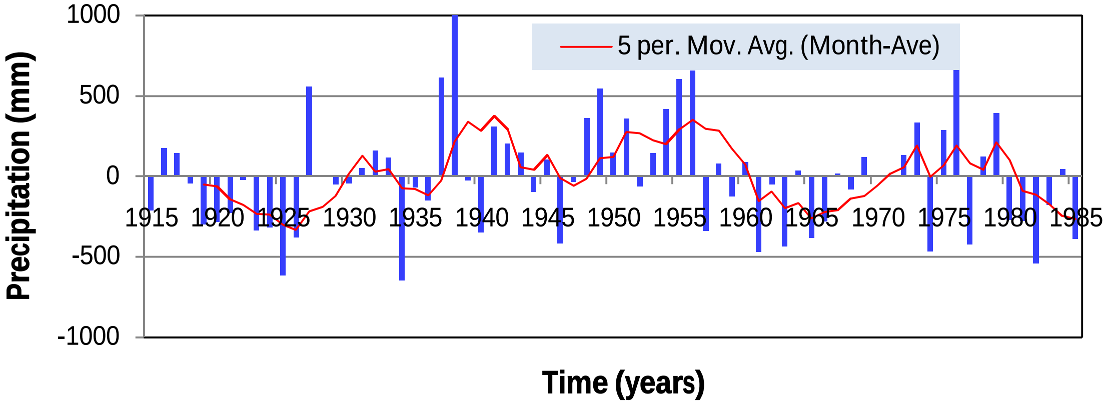


Figure 2a: Anomaly in annual rainfall for the period 1915-1985 (71 years) Paradise station

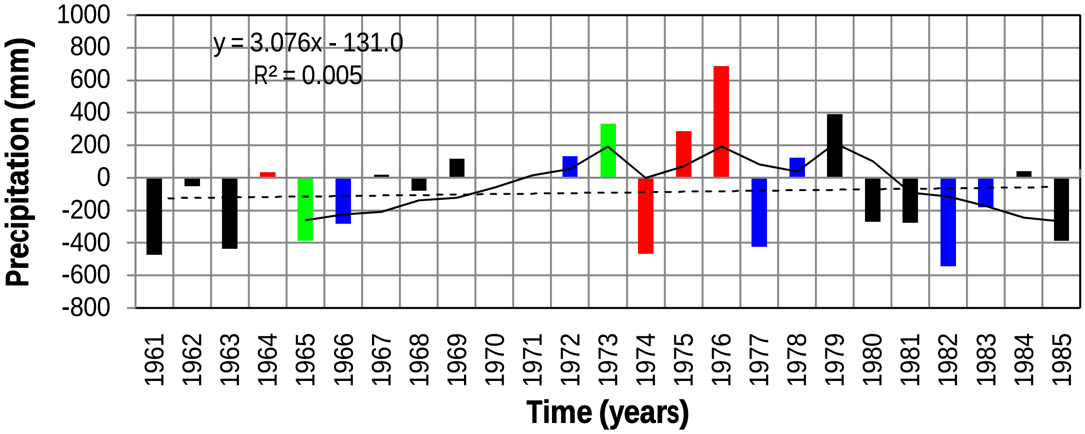


Figure 2b: Anomaly in annual rainfall compared to normal years, during El Niño and La Niña years for the period 1961-1985 (25 years) at Paradise station. Note: the blue columns indicate moderate to strong El Niño events/years, the red columns indicate moderate to strong La Niña events/years, the green columns are both El Niño and La Niña years. The period is Nov-March of the following year. The linear dotted line is the trend line and the black line is the 5 year moving average.

Figure 3: Two annual cycles of rainfall for the period 1961-1985 at Paradise station

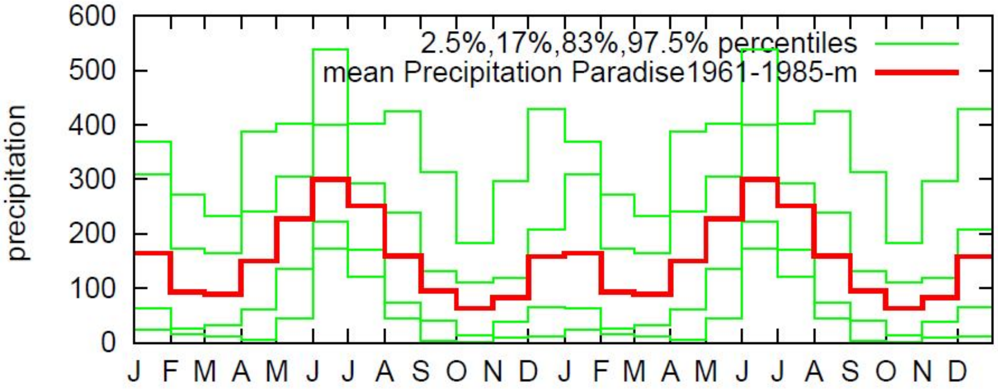
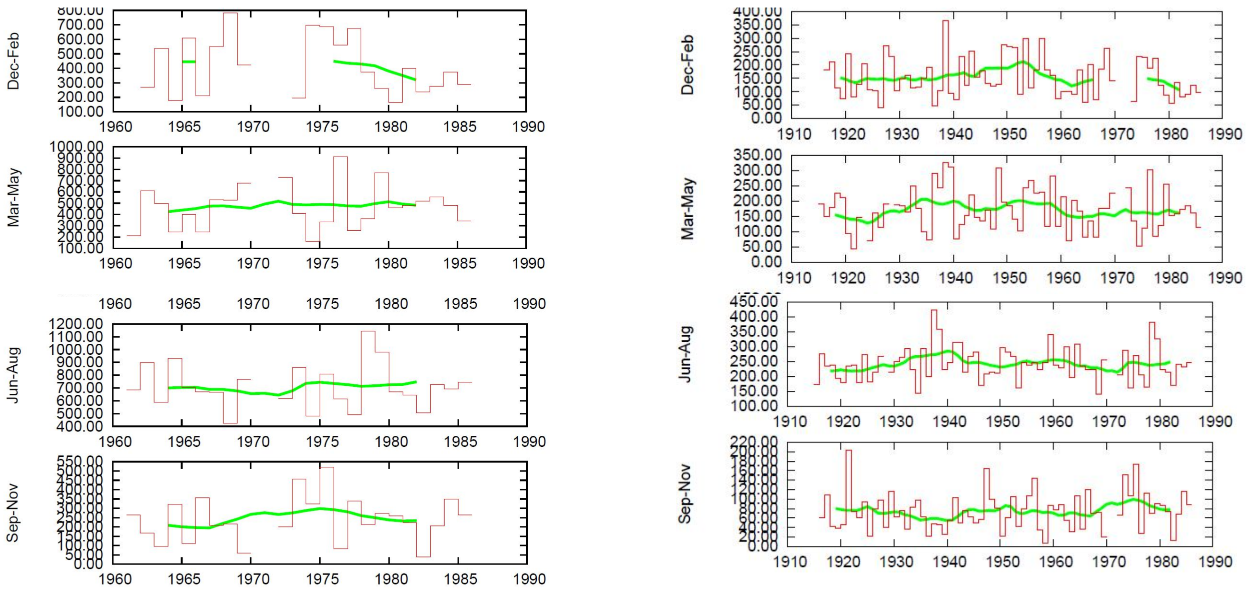


Figure 4: Seasonal rainfall pattern and moving average (5 years) at Paradise station for two periods (a) 1961-1985 and (b) 1915-1985

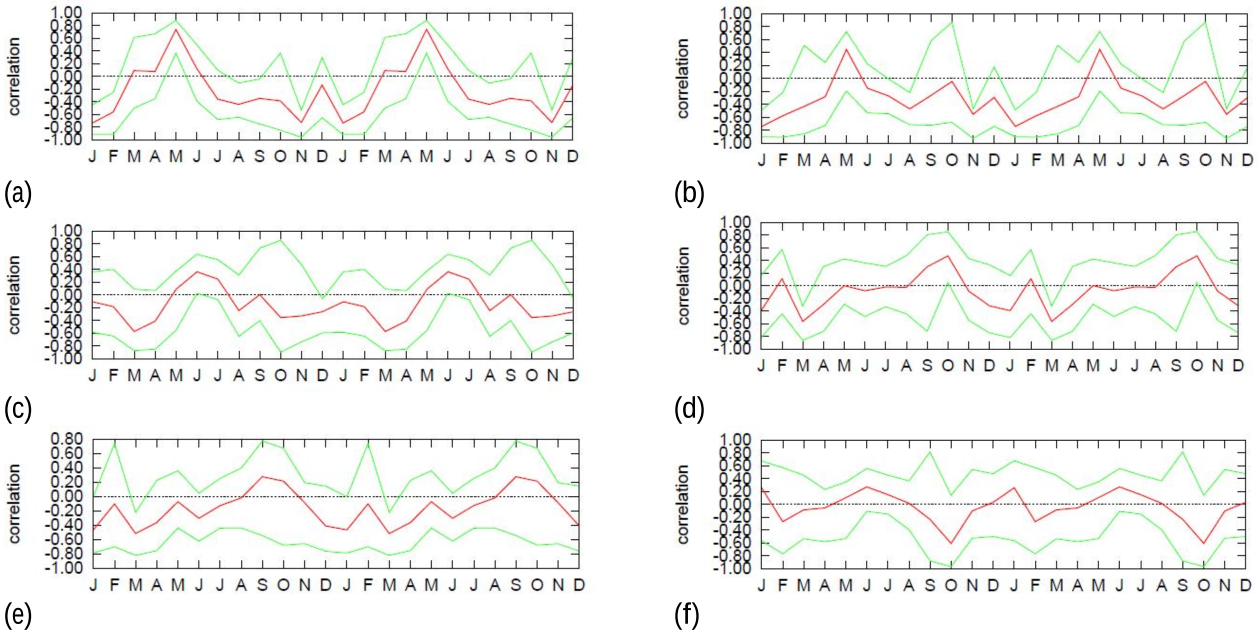


(a) (b)

Based on the results of the moving average (see figure 2a), six periods can be distinguished at Paradise station: a decrease in annual rainfall in the period of 1920-1930, an increase between 1938-1944, an increase between 1948-1960, and a decrease between 1960-1973, an increase between 1973-1980, and a decrease after 1980. The lower rainfall during 1960-1973 could be associated with the warmer than normal SSTs in the TNA region in those years. This may have caused the ITCZ to stay south of the equator longer especially in March-May. The increase in rainfall during 1973-1980 may have been caused by the cooler than normal SSTs in the TNA region in those years. The decrease in rainfall in 1980-1985 is more strongly related to the warmer SSTs in the Niño1+2 and Niño 3+4 regions.From figure 2b, it can be concluded that the El Niño events (1966, 1972, 1973, 1977, 1978, 1982, 1983) cause lower annual rainfall than normal in Nickerie district.

During El Niño events, the SSTs are warmer than normal in the Niño 1+2 and Niño 3+4 regions. For La Niña events it is difficult to draw a conclusion, but in general it seems that La Niña events (1964, 1965, 1973, 1974, 1975 and 1976) cause higher annual rainfall than normal in Nickerie district. We can conclude that there are also years when there was more rainfall than normal (e.g. 1979) or less rainfall than normal (e.g. 1963), which was not related to El Niño events or La Niña events. During the warm ENSO events, the SSTs also increase in the TNA, reaching their maximum during December-February and March-May.

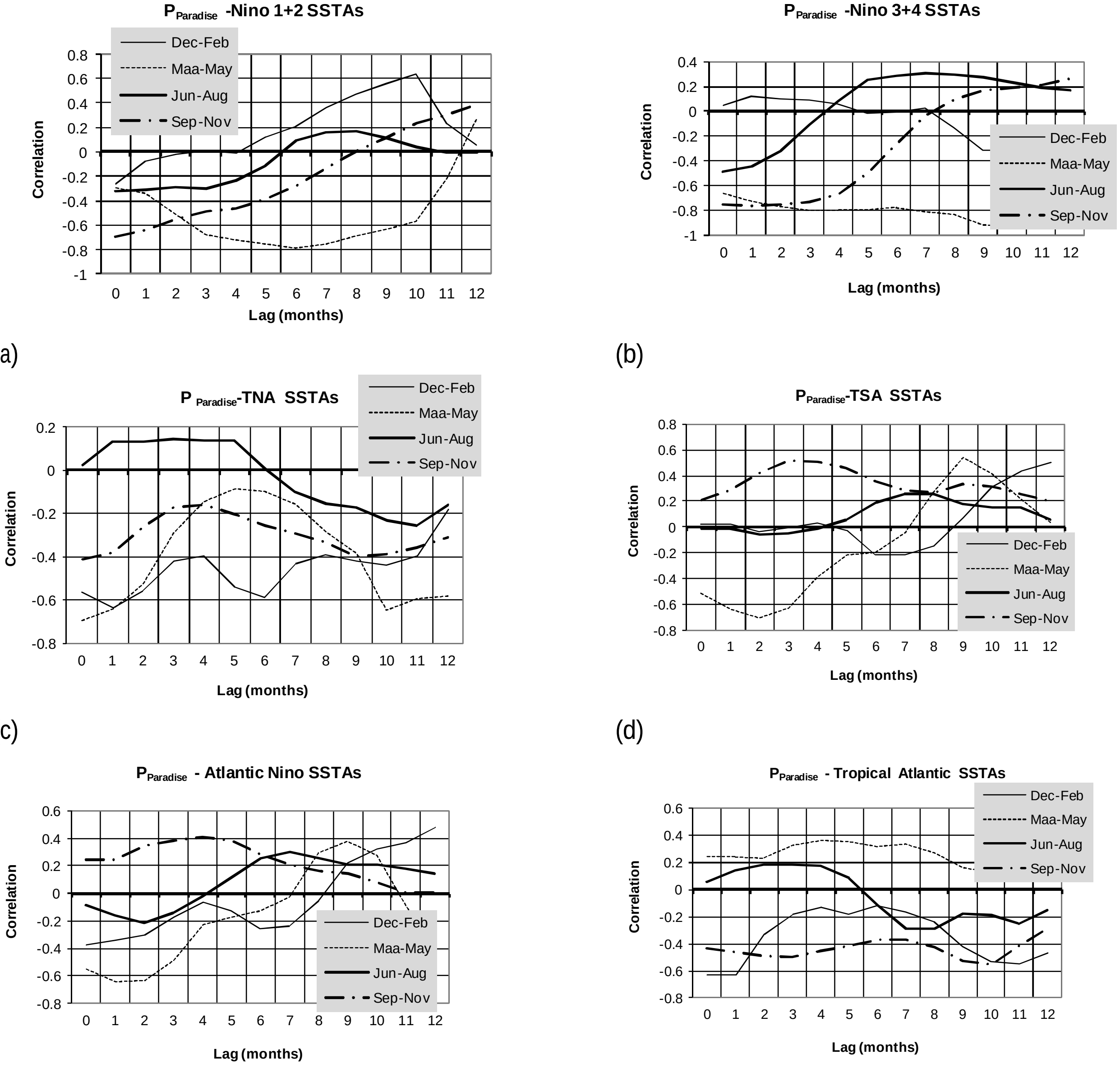
During these periods, rainfall deficits are experienced in northeast South America such as in 1972-1973, 1982-1983 and 1997-1998. During La Niña events, SSTAs in the equatorial Pacific are negative and reach their peak between June-September. Rainfall excess is then experienced in northern South America during December-February and March-May such as in 1973-1974, 1975-1976 and 1988-1989. The lower than normal rainfall in the year 1982 in Nickerie district corresponds with global impacts in northern South America. For the years 1965, 1966, 1974 and 1977 no global impacts were reported in northeast South America. The dry years 1965 and 1974 may have been caused by the reverse impact of the strong La Niña event in those years due to the absence of the ITCZ especially during March-May. The higher than normal rainfall in the years 1973, 1975 and 1976 in Nickerie district corresponds with global impacts in northern South America.



(a) (b) (c) (d) (e) (f)

Figure 5: Correlation analyses (lag = 0 months) of the monthly rainfall anomalies (1961-1985) at Paradise station with the monthly (a) Niño 1+2 SSTAs, (b) Niño 3+4 SSTAs, (c) TNA SSTAs, (d) TSA SSTAs, (e) Atlantic Niño SSTAs and (f) Tropical Atlantic dipole SSTAs predictors (1961-1985). Note: lag in months, lag positive: predictor leading rainfall. The rainfall anomalies are taken as the first series and the SSTAs as the second time series. A positive lag indicates that the SSTAs are the leading index and a positive (negative) correlation indicates that large (small) rainfall anomalies are related to large SSTAs

Figure 5 shows the Pearson's correlation coefficients for lag = 0 months of the monthly rainfall anomalies (1961-1985) at station Paradise with the monthly (a) Niño 1+2 SSTAs, (b) Niño 3+4 SSTAs, (c) TNA SSTAs, (d) TSA SSTAs, (e) Atlantic Niño SSTAs and (f) Tropical Atlantic dipole SSTAs predictors.From figure 5 it appears that the monthly rainfall at Paradise shows a stronger correlation with the Niño 1+2 SSTAs (-0.73 to 0.74) and the Niño 3+4 SSTAs (-0.74 to 0.45) than with the other predictors (TNA SSTAs (-0.57 to 0.36), TSA SSTAs (-0.57 to 0.48), Atlantic Niño SSTAs (-0.51 to 0.28) and Tropical Atlantic dipole SSTAs (-0.61 to 0.27)).



(a) (b) (c) (d) (e) (f)

Figure 6: Lag correlations of seasonal rainfall anomalies (1961-1985) at Paradise station for December-February (DJF), March-May (MAM) and June-August (JJA) with the predictors (a) Niño 1+2 SSTAs, (b) Niño 3+4 SSTAs, (c) TNA SSTAs, (d) TSA SSTAs, (e) Atlantic Niño SSTAs and (f) Tropical Atlantic dipole SSTAs (1961-1985). Note: lag in months, lag positive: predictor leading rainfall. The rainfall anomalies are taken as the first series and the SSTAs as the second time series. A positive lag indicates that the SSTAs are the leading index and a positive (negative) correlation indicates that large (small) rainfall anomalies are related to large SSTAs

Figure 6 shows the lag correlations of seasonal rainfall anomalies at Paradise station. January and May show the highest correlation with the Niño SSTAs; these are the wettest months (within the wet season) of the year. March shows the highest correlation with the TNA and TSA SSTAs; this is normally a dry month (within the dry season). The difference in correlations between the rainfall anomalies and the Atlantic and Pacific SSTs anomalies may be explained by the high variability in the annual rainfall at Paradise station in Nickerie district, but perhaps also local influence of Atlantic and Pacific SSTs and local climate effects.During DJF, the ITCZ has a small rainfall belt and is displaced to the south of Suriname and causes a reduction in precipitation that reaches its peak in February-March (short wet season).

The beginning of the long wet season (MAM), shows the strongest correlation with the Niño SSTAs ($c_{lag\ 6}^{\text{Niño1+2}} = -0.79$; $c_{lag\ 9}^{\text{Niño3+4}} = -0.91$), followed by the TNA ($c_{lag\ 0}^{TNA} = -0.70$) and TSA SSTAs ($c_{lag\ 2}^{TSA} = -0.70$), the Tropical Atlantic Niño SSTAs ($c_{lag\ 0}^{TA} = -0.64$) and the Atlantic Niño SSTAs ($c_{lag\ 1}^{\text{Atlantic Niño}} = -0.64$). One can notice that the correlations are of the same magnitude, only the lag is different. During JJA (long wet season), the rainfall shows the strongest correlation with the Niño 3+4 SSTAs ($c_{lag\ 0}^{\text{Niño3+4}} = -0.48$). During SON (long dry season), the rainfall shows the strongest correlation with the Niño SSTAs ($c_{lag\ 0}^{\text{Niño1+2}} = -0.70$; $c_{lag\ 0}^{\text{Niño3+4}} = -0.76$), followed by the TA regions ($c_{lag\ 0}^{TNA} = -0.41$; $c_{lag\ 3}^{TSA} = -0.52$). During the period mid-August to November (the long dry season), the SSTs in the TNA (TSA) are the highest (lowest) and the rainfall maximum has passed over Suriname and is found north (5°N-10°N) above the Atlantic Ocean (Webster, 2005). During this period, the trade winds south of the equator increase surface winds and cause surface evaporative cooling and, as a result, less rainfall over Suriname. Correlations with the other predictors are weak (maximum 0.32). The fact that monthly rainfall in Nickerie district shows stronger correlations with the Pacific SSTAs makes Nickerie indeed vulnerable to strong changes in rainfall due to El Niño and La Niña events.

A linear regression of the annual temperature at Nickerie airport station (1961-2013) shows that the annual temperature has increased by less than 0.01°C/10 years in Nickerie district.No statistically significant trend (39 mm/10 years) was found for the annual evapotranspirationat the Nickerie Airport station.To characterize the discharge volumes for the area of interest, awater-balance assessment has been made as presented in equation 3,

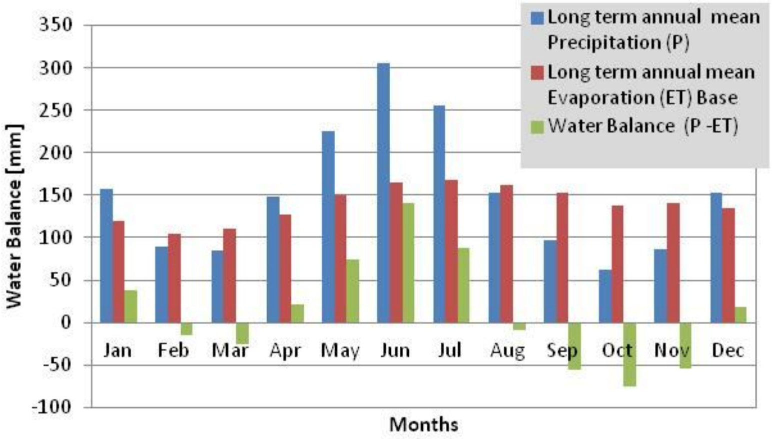
$$P - E = Q \qquad (3)$$

where,

P is precipitation, E (ET) is evaporation and Q is the rainfall fraction that contributes to discharge, as part of the total water budget for the area of interest.

Figure 7 shows the mean water balance for the period of 1961-1987. This figure shows that shortage of rainfall existed in the months Feb-March and Sept-Oct-Nov. Both periods are the dry seasons and the latter period (Sept-Nov) is the beginning of the first rice season, when a lot of water is required.

Figure 7: Water Balance (P – ET) for the period 1961-1987



The maximum water levels (1961-1984) at Nickerie stationshow a slight increase in the historical water levels (0.74 cm/10 years). The trend of the annual seawater level (2000-2013) at Nickerie station (river mouth) shows a clear increase; the Pearson's correlation coefficient r at a 95% reliability level is 0.9, while the hypothesis test value p =9.67E-05. The annual seawater trend is consistent with the monthly seawater trend. From the historical observations in the coastal part of the Nickerie River we can conclude that if climate change continues in this way and the linear trend continues, the water level could increase by about 4.7 and 85.1cm by 2050 and 2100 respectively. Based on the historical observations of the annual seawater level, the seawater level could increase by about 28.8 and 68.8cm by 2050 and 2100 respectively if the trend continues. These values (4.7-85.1mm) are in the range of the projected increases in sea-level rise (44-74mm) from the IPCC AR5.

For the rise in sealevel and river-water level, values between 4.7 and 85.1mm are found. Flooding may also take place by the Nickerie and Corantijn Rivers as a result of backwater effect (CST, 1999). In case of flooding by the Nickerie River the damage will be more extensive than from flooding by the Corantijn River. The difference is that the development of rice cultures along the Nickerie River is concentrated on both sides of the river and is further upstream than along the Corantijn River. Higher water levels in the rivers due to the higher sea level will force the boundary between saltwater and freshwater to move upstream. As a result, locations for water intake for irrigation purposes should be replaced, which in turn will require the entire rehabilitation of the irrigation infrastructure.

Out of the climate models used from PRECIS, only the GCM ECHAM4 was useful, given the precondition that it is only warranted to use a model effectively for future climate predictions, if the model is able to represent the current climate correctly, in terms of extremes, with special emphasis on the temporal variability (seasonal patterns) of the climatic variables of interest. As for rainfall, the seasonal patterns for simulated temperature are reasonably consistent with the observations. Considering the monthly average values, however, there is a slight underestimation. Bias correction was made using the statistical downscaling step,referred to as the Quantile Perturbation principle(Willems and Vrac, 2011).The water-balance assessment results for the future predictions are presented in figures 8a, 8b and 8c, representing the scenario periods/scenarios: 2020-2050-A2, 2070-2100-A2 and 2070-2100-B2. From these results it is clear that for all scenarios greater shortages in water are expected for the months of August-October. For the 2070-2100 scenarios, shortages of water are also expected in the months of February-March.

Figure 8a: Water balance for 2020-2050 A2

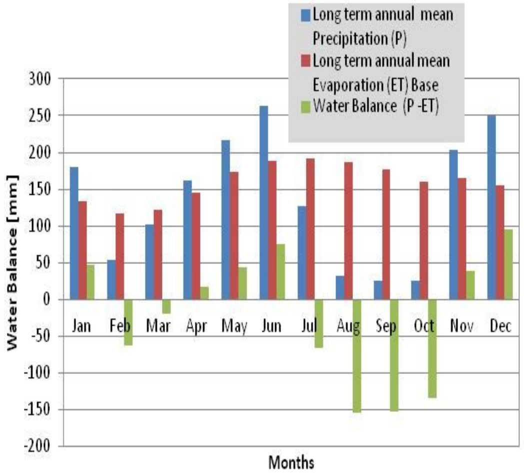


Figure 8b: Water balance for 2070-2100 A2

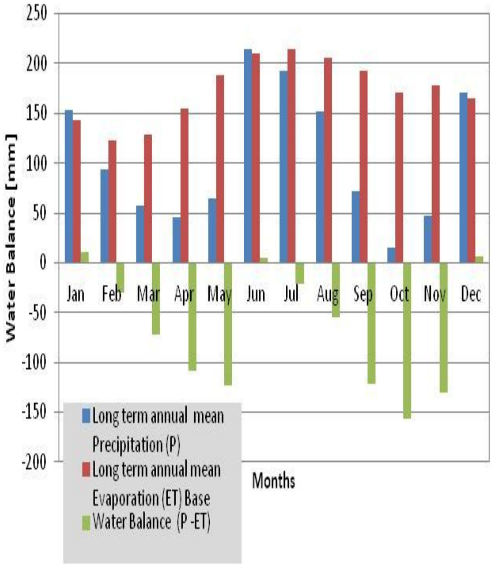


Figure 8c: Water balance for 2070-2100 B2

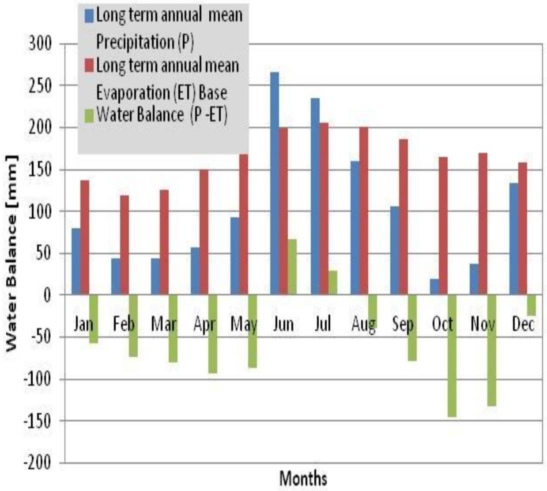


Figure 9a: Temporal trends of annual cultivated areas of rice (ha) and annual rice yield (tons) for the first and second crops over the period of 1978-2013. Note: cultivated area is shown on the left axis and rice yield is shown on the right axis (Ministry of LVV, 2015)

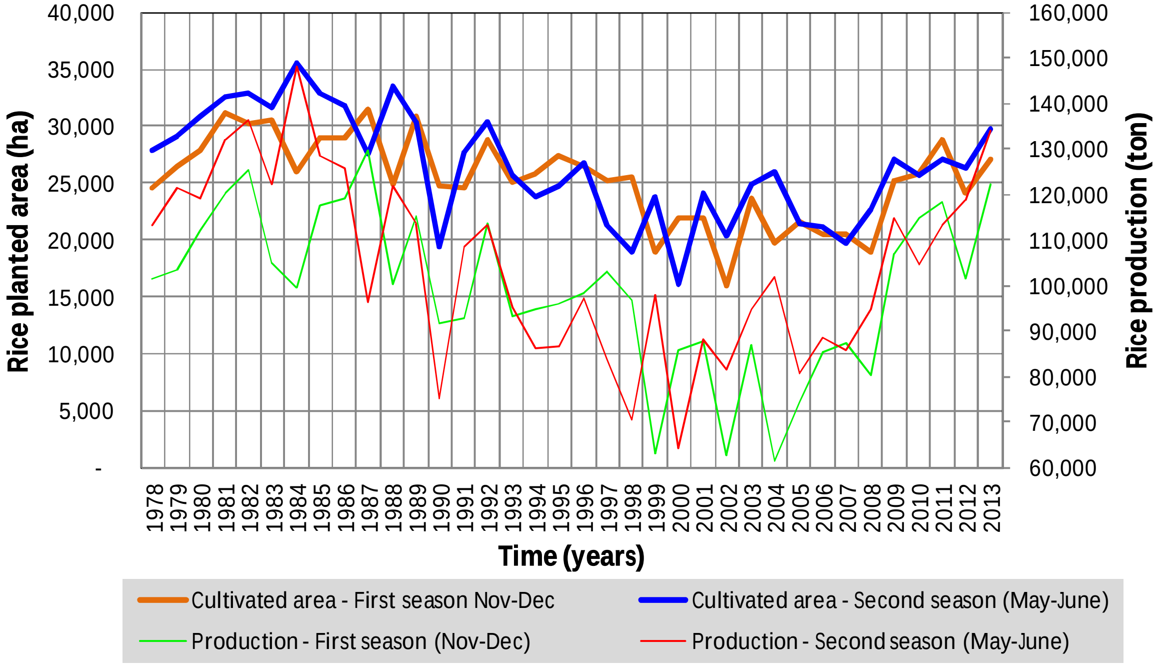


Figure 9b: Temporal trends of annual cultivated areas of rice (ha) and annual rice yield (tons) for both seasons over the period 1978-2013. Note: cultivated area is shown on the left axis and rice yield is shown on the right axis (Ministry of LVV, 2015)

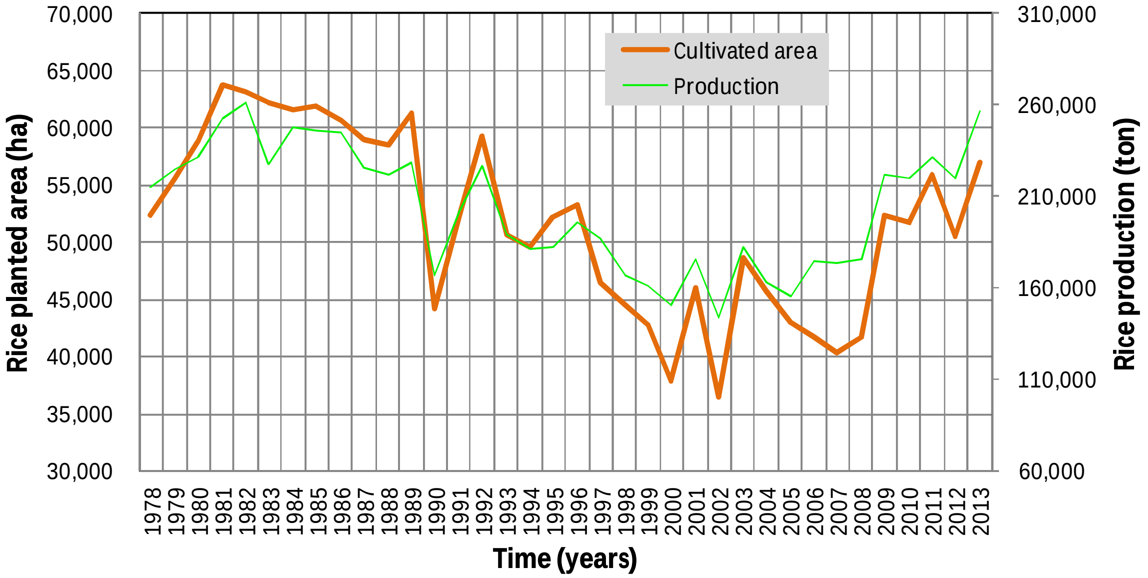


Figure 9c: Temporal trends of annual rice yield (tons/ha) for the first and second crops, and for both crops, over the period 1978-2013 (Ministry of LVV, 2015)

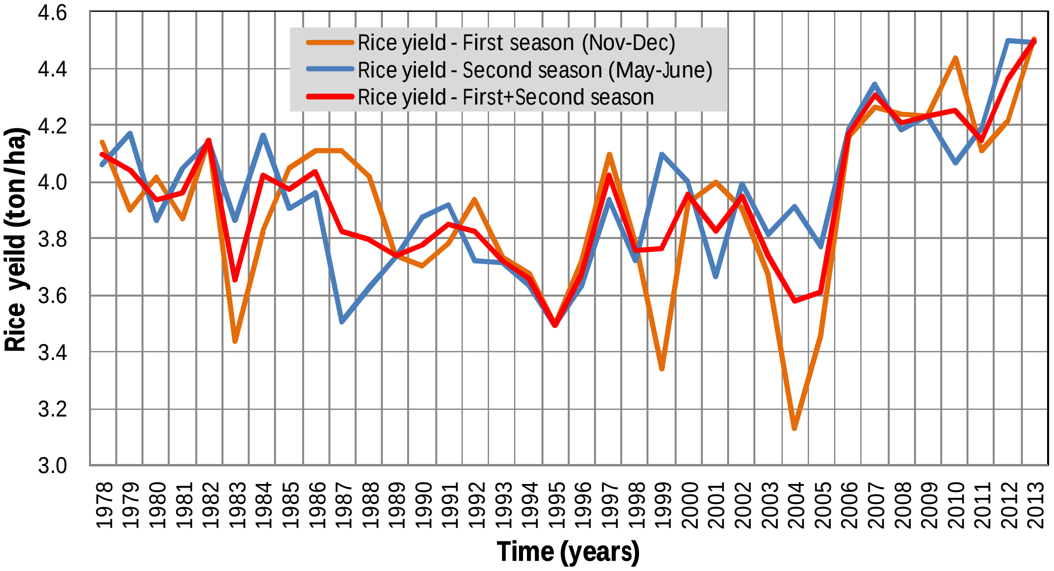
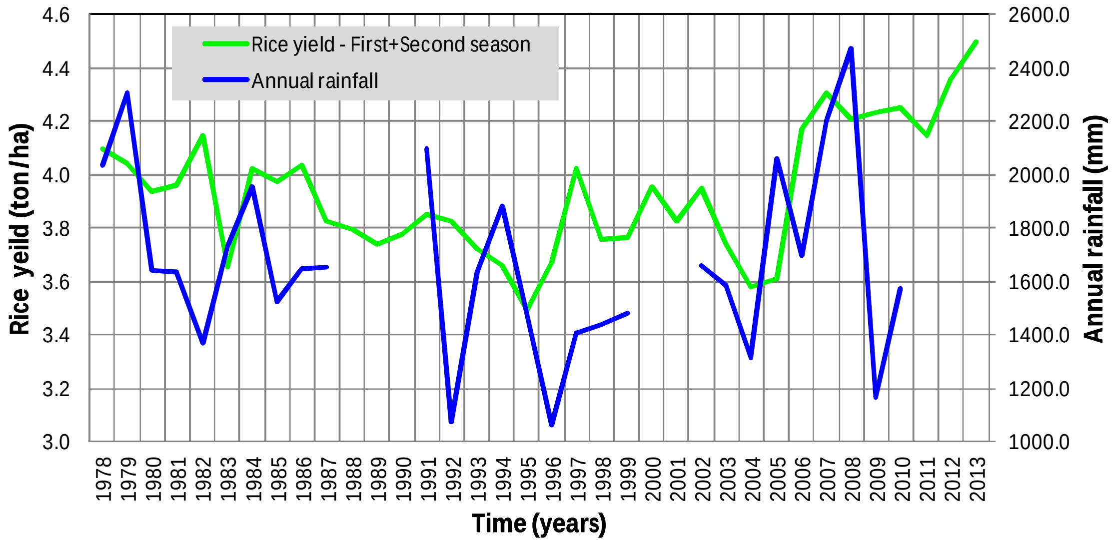


Figure 9d: Temporal trends of annual rice yield (tons/ha) and annual rainfall over the period 1978-2013. Note: left site yield, right site rainfall



The rice production and rice yield in Nickerie district from 1978 to 2013 are shown graphically in figure 9.From figure 9a, b and c it appears that the cultivated rice area and/or rice production decreased from 1980 to 2003 and since 2003 it has been increasing. Figure 9shows that there have been peaks in the rice production, decreases and increases. Some can be explained by climate factors. The significant drop in rice cultivated area in 1983 may have been caused by El Niño (drought conditions). Mungroo(2014) states that it could have been caused by the suspension of Dutch Development Aid at the end of 1982. There were more drops as in 1998 and 2004. The 1998 event was probably also caused by the El Niño event. The heavy rains in 2004 could have damaged the production. The decrease in paddy production after 1987 could have been a result of a shortage of fertilizer and pesticide (Mungroo, 2014). In 2009 there was a drastic increase in cultivated area and paddy production, which was fuelled by a rise in world market prices. It seems that the climate does not have a direct effect on the rice production. It is, however, short-term climate variability such as extreme events that might cause decreases in production. The decline in cultivation and production can be attributed to external factors rather than internal and climate factors of the rice sector.

Looking at the impact of rainfall (figure 9d) and rice yield, no clear relation exists, because water comes mainly from irrigation water.Figure 10shows the relationship between the two crop seasons rainfall/temperature and the yield for that season. There is no clear relationship.The multiple linear regression model based on temperature and rice yield data for Nickerie district (period 1978-2013) for the months April-August (y_{AA} second crop season) and Nov- March (y_{NM} first crop season) were found:

$Y_{AA} = -0.23.X_1 + 10.1$, with $R^2 = 0.14$ (4)

$y_{NM} = -0.13.X_1 + 7.28$, with $R^2 = 0.02$ (5)

Both models represent no or a negligible relationship between the yield and temperature. The regression analysis indicates an R square of 0.14 and 0.02 implying that rainfall accounts for only 14 and 2% of rice yield respectively, while 86 and 98% variation respectively in rice yield is explained by other factors.It is more likely that the relationship between climate variables and crop yield is nonlinear as crop growth increases with a rise in temperature up to a certain limit; after that, crop growth may be adversely affected by an increase in the temperature; the same applies to rainfall impact on crop productivity.

Figure 10a: Rice yield (tons/ha) vs rainfall (mm) for the two crop seasons Apr-Aug (AMJJA) and Nov-March (NDJFM) for the period 1978-2013

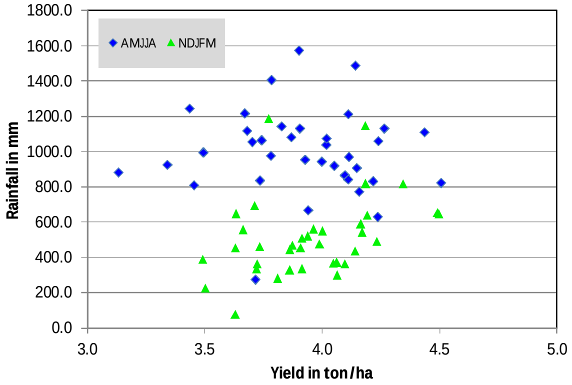
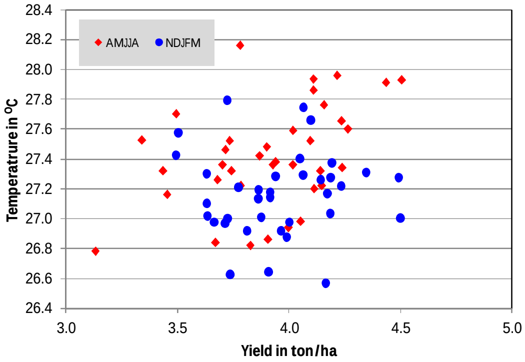


Figure 10b: Rice yield (tons/ha) vs temperature (°C) for the two crop seasons Apr-Aug (AMJJA) and Nov-March (NDJFM) for the period 1978-2013



Most rice yields in Nickerie district of between 3.5 and 4.5 tons/ha are obtained between average temperatures of 26.5 and 28.2°C. Based on the projected changes in average temperature by 2070-2100, it is clear that the maximum average temperature would reach about 33.9°C. This is a change of about 6.6°C in July and could mean that the rice production could decrease slightly (about 5-10% for every 1°C rise). As mentioned before, the range of temperatures for seed germination of rice is optimal between 20-35°C (min. 10°C and max. 45°C). The water-balance studies show that less rainfall will be available by 2070-2100 at the beginning of the second crop season (Apr-May). This also applies to the beginning of the first crop season (Oct, Nov, Dec). This means that more irrigation water will be required.

Conclusion

Climate change does not have a direct impact on rice production. Short-term climate variability such as extreme climate events is more likely to cause a decrease in rice production. Based on projected changes in average temperature from 2007-2010, the maximum temperature is estimated at 33.9°C. This translates into a temperature change of about 6.6°C in July and could mean that rice production could decrease slightly.Damage to the rice production would be greater along the NickerieRiver as rice fields are concentrated around this river and fields are located further upstream in the Corantijn River.In addition,salt water will also intrude further upstream. In areas vulnerable to flooding, river-water levels will exceed irrigation canal levels and surplus water will accumulate. If the amount of rainfall decreases and the sea-level rise continues as projected, salt intrusion will proceed further inland and less fresh water will be available for irrigation of rice fields. However, if rainfall increases and the sea-level rise continues as projected, salinity will decrease and more water will be available for irrigation.

The ongoing expansion of rice fields in the direct vicinity of the Corantijn River will exhaust the existing possibility for irrigation within the next few years and further expansion of rice fields will be halted because of freshwater shortage, especially during the long dry season. To increase the amount of freshwater in above cases for the rice production there are three options: 1) expansion of the capacity of pumps at Wakay or the establishment of new pumping stations, 2) to extract water from the Nanni swamp, 3) to extract water from the Nickerie River basin (Stondansi project) (CST, 1999; HTSPE Limited, 2009).

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