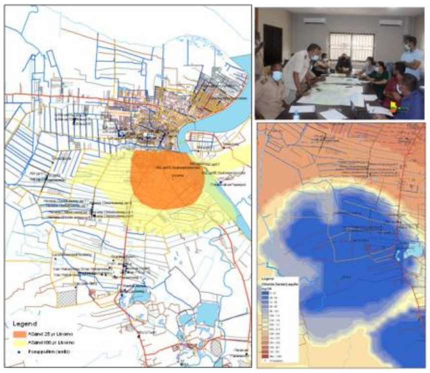
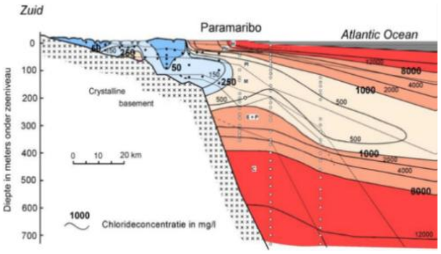
The United Nations Environment Programme (UNEP) on behalf of the Climate Technology
Centre and Network (CTCN)

Report on Drought Risks And Water Demand in Suriname



Consultancy services for

Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge



Acronym: ***ARADIS***

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Table of content

Table of Tables

Table of Figures

Appendices

No table of contents entries found.

1 Introduction

This drought risk assessment is part of the project titled “Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge.” For practical purposes the title is shortened to “Aquifer Recharge Against Droughts In Suriname” with the acronym ARADIS.

This report is part of phase 2 – i.e. the analysis phase of the project. Seasonal and interannual droughts will be investigated under current and future climate. This will be based on historical records in Suriname and results from existing climate models and remote sensing datasets.

1.1 Objectives

The primary objectives of this drought assessment report are:

1. To identify and map areas in Suriname that are most at risk to droughts and water shortages.
2. To analyze the potential impacts of drought on critical sectors such as agriculture, energy, and water supply.

1.2 Methodology

The analysis starts with the determination of a **meteorological drought indicator**. This includes the acquisition of precipitation data from ground stations as well as remote sensing datasets.

Based on the acquired data a **drought hazard index (DHI)** will be calculated for the entire country. The DHI will provide information on the climatological likelihood of the occurrence of a drought event. The DHI is based on the **Standard Precipitation Index (SPI)**.

Subsequently, the **impacts of droughts** on groundwater reserves and the derivative effects of droughts on the critical sectors of agriculture, water supply and energy are assessed. This feeds into the vulnerability of the assets that are exposed to droughts. Special emphasis will be put on the water supply sector for which we will look at **water use and demand** in the project area (coastal area of Suriname) into the future.

Drought vulnerability is defined as the damage to a certain asset that may occur as a consequence of a drought event. We will look at the land use types and the previously determined impacted sectors to determine the vulnerability to droughts.

The **drought risk** combines both hazard and vulnerability into a score which shows the actual risk of damages occurring as a consequence of drought events.

2 Meteorological drought indicator

Drought indicators are tools used to monitor and quantify drought conditions by assessing various components of the hydrological cycle and environmental impacts. In this report – the main focus will be on the meteorogological drought indicators.

Rainfall data are the main and primary information for studying the meteorological drought hazard. Rainfall patterns are standardized in an index called the Standardized Precipitation Index (SPI).

2.1 The standardized precipitation index (SPI)

2.1.1 Drought characterization

Drought characterization is a critical aspect of hydro-climatological research, focusing on understanding the complex dynamics of water scarcity. The methodology developed by Yevjevich provides a comprehensive framework for analyzing drought characteristics through three primary parameters:

1. Duration: The length of time a drought event persists
2. Severity: The cumulative magnitude of water deficit
3. Intensity: The rate of water deficit occurrence

Central to this approach is the concept of a "truncation level" or threshold, which can be either a constant value or a time-varying function. By examining how hydrological variables intersect with this threshold, it is possible to identify and quantify drought runs—continuous periods where water measurements remain consistently below (or above) the specified level. The truncation level can be deterministic, stochastic, or a hybrid, allowing for nuanced analysis of drought patterns. This statistical methodology makes it possible to develop more precise drought assessments, supporting better predictive models and water management strategies in regions vulnerable to water scarcity (Yevjevich, 1967).

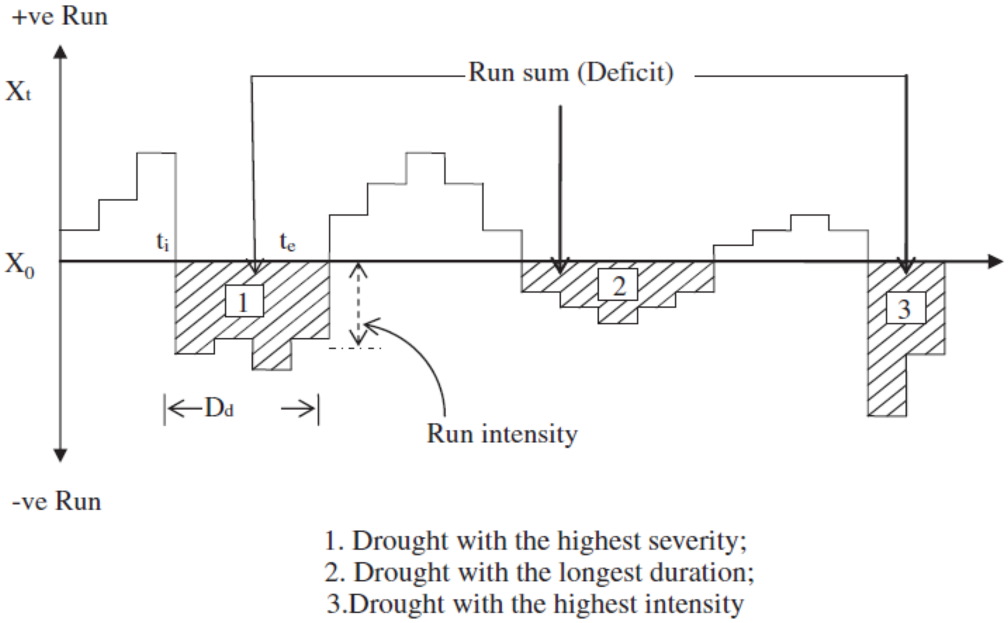


Figure 2-1: Definition of drought severity, intensity and duration

2.1.2 SPI theory

This approach is directly related to the Standardized Precipitation Index (SPI), which is a widely used method for characterizing meteorological drought. The SPI is based on the same fundamental concepts but improves upon Yevjevich's method by standardizing precipitation data, allowing for comparisons across different locations and time scale. In addition, the SPI allows for the analysis of drought duration, severity, and intensity.

The SPI is designed to measure precipitation deficits across multiple timescales, reflecting how drought impacts different water resources. Soil moisture responds quickly to precipitation changes, while groundwater, streamflow, and reservoir storage reflect longer-term precipitation patterns. For this reason, McKee and others (1993) originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month timescales (McKee, Doesken, & Kleist., 1993).

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location is zero. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, it allows for comparing wetter and drier climates in the same way, enabling monitoring of both wet and dry periods.

2.1.3 SPI classification for droughts

McKee et al. (1993, 1995) proposed a seven-category classification for the SPI: extremely wet (z>2.0), very wet (1.5 to 1.99), moderately wet (1.0 to 1.49), near normal (−0.99 to 0.99), moderately dry (−1.49 to 1.0), severely dry (−1.99 to 1.5), and extremely dry (<−2.0) (Table 1).

McKee and others (1993) used the classification system shown in Table 2-1 to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive.

Table 2-1: drought characterization according to SPI

SPI>2.0	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-.99 to .99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and less	Extremely Dry

This standardization allows the SPI to determine the rarity of a current drought, as well as the probability of the precipitation necessary to end it (McKee et al., 1993). It also allows the user to confidently compare historical and current droughts between different climatic and geographic locations when assessing how rare, or frequent, a given drought event is.

2.1.4 Advantages and limitations of SPI

The SPI has the following advantages:

- The SPI is uniquely related to probability.
- The precipitation used in SPI can be used to calculate the precipitation deficit for the current period.
- The precipitation used in SPI can be used to calculate the current percent of average precipitation for time period of i months.
- Simplicity of use since it needs only rainfall data.
- Its variable time scale, which allows it to describe drought conditions important for a range of meteorological, agricultural, and hydrological applications. This temporal versatility is also helpful for the analysis of drought dynamics, especially the determination of onset and cessation, which have always been difficult to track with other indices.
- Its standardization, which ensures that the frequency of extreme events at any location and on any time scale are consistent.

The SPI has the following limitations:

- The assumption that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. An associated problem is the quantity and reliability of the data used to fit the distribution. McKee et al. (1993) recommend using at least 30 years of high-quality data.
- A second problem may arise when applying the SPI at short time scales (1, 2, or 3 months) to regions of low seasonal precipitation. In these cases, misleadingly large positive or negative SPI values may result.
- The SPI presents the relative dry or wet events for a certain location rather than the absolute precipitation amounts. The SPI normalizes precipitation data by comparing every precipitation entry to the long-term average. This normalization transforms precipitation into standardized units, making it possible to compare wet and dry periods across different climates or precipitation regimes. However, this also means that SPI values reflect relative anomalies rather than absolute precipitation amounts. The SPI is therefore sensitive to variability within a given dataset. In wetter scenarios, where the mean precipitation is higher, deviations from the norm (either increases or decreases) can lead to larger swings in SPI values. This could make dry periods in wet environments appear more severe compared to dry periods in drier environments where variability is naturally lower.

2.1.5 Time scales of SPI

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero the fundamental strength of SPI is that it can be calculated for a variety of time scales. (Edwards & McKee, 1997). The following SPI scales are distinguished:

- **SPI1-6:** The 1 to 6 months SPI allows to monitor short-term water supply, such as soil moisture – which responds to precipitation anomalies on a relatively short scale. This is mainly important for rainfed agricultural production.
- **SPI12:** The 12-month SPI allows for the comparison of the cumulative precipitation of 12 consecutive months every year within the selected study period. Groundwater, streamflow, and reservoir storage are best reflected by these long-term precipitation anomalies.

Since this study focusses on droughts in relation to Managed Aquifer Recharge technologies, the 12-month Standard Precipitation Index (SPI-12) is proposed as the basis for the analysis of the meteorological drought episodes.

2.2 Data availability

To be able to perform this drought analyses, daily precipitation measurements over a period of longer than 30 years – to allow for a significant result of the SPI are required. Ideally, precipitation should be measured at different locations to allow for a spatial assessment of drought conditions. The same holds for daily evaporation measurements. This data can be acquired through:

- Data from meteorological stations in Suriname
- Data from remote sensing datasets – such as CHIRPS

The meteorological data from Suriname includes measurements from various stations. The raw acquired data of 10 stations are presented in Figure 2-2. Some of the stations – e.g., Groningen and Tijgerkreek – show significant outliers which are interpreted as meter errors. After deleting the outliers of the Groningen and Tijgerkreek meteo stations – the data can be summarized as per Table 2-2.

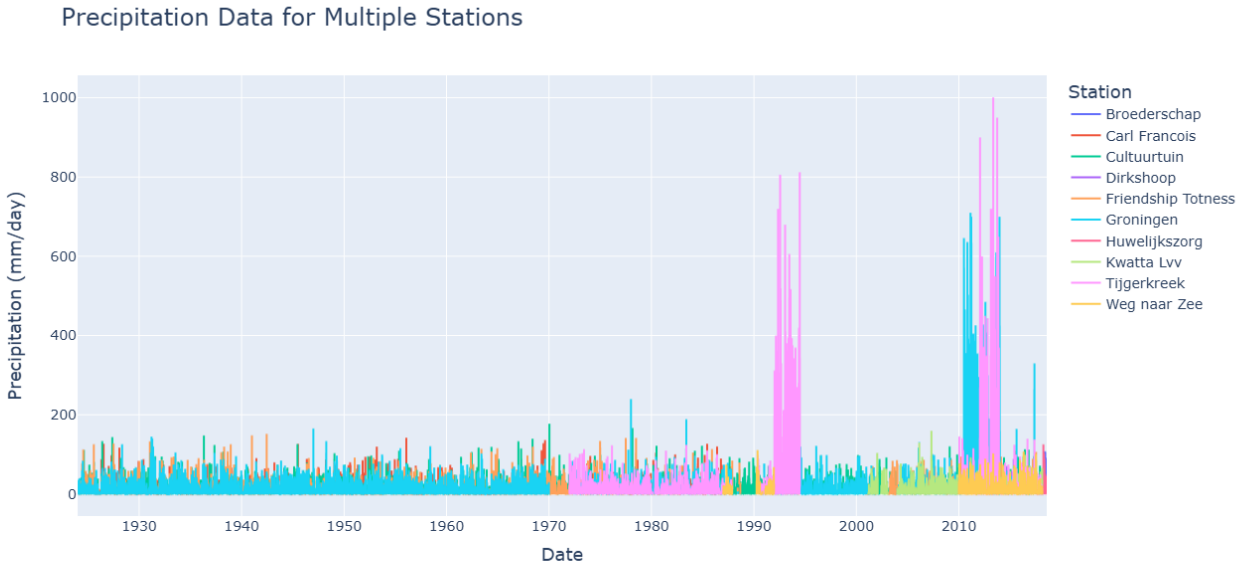


Figure 2-2: Raw precipitation data from meteo stations in Suriname

Table 2-2: Available meteodata

Station	Start Date	End Date	# Measurements	Max daily precipitation (mm)	Average yearly precipitation (mm)
Broederschap	1/15/2018	7/31/2018	198	108.21	833.33
Carl Francois	1/1/1924	12/31/1986	23011	142.5	1948.2
Cultuurtuin	1/1/1924	2/28/2018	34393	178	2104.77
Dirkshoop	9/1/2012	2/28/2018	2007	138.8	1415.84
Friendship Totness	1/1/1924	3/1/2018	34394	152	1255.74

Groningen	1/1/1924	2/28/2018	33110	330	1959.86
Huwelijkszorg	12/12/2017	7/31/2018	232	125.73	1023.56
Kwatta Lvv	1/1/2001	2/28/2018	6268	220	1757.34
Tijgerkreek	1/1/1972	2/28/2018	15262	145.5	1118.12
Weg naar Zee	1/1/1987	2/28/2018	11382	111.5	650.63

Not all stations have records spanning 40 years or more, and many datasets contain significant gaps. This lack of long-term, continuous data limits the reliability of drought analyses based solely on local station data. To address these limitations, we have opted to use the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) dataset as our primary input. CHIRPS is a quasi-global rainfall dataset that combines satellite imagery with in-situ station data to create gridded precipitation time series. It spans from 1981 to near-present and provides high spatial resolution (0.05°), making it particularly useful for regions with sparse or incomplete station data.

To validate the CHIRPS dataset, the results are cross-referenced with available ground-based meteorological data where possible. For three stations, the coordinates have been availed and the precipitation measurements from these stations are compared to the reported values as per CHIRPS. Since this study focusses on seasonal changes in precipitation, the monthly aggregated values are analysed.

The statistical parameters in Table 2-3—correlation, RMSE, and bias—are used to evaluate the agreement between CHIRPS precipitation estimates and observed data from the meteorological stations. Correlation measures the strength and direction of the linear relationship between the two datasets, ranging from -1 to 1. In this case, values like 0.82 for Cultuurtuin indicate a strong positive relationship, meaning CHIRPS captures the temporal patterns of precipitation fairly well. Bias represents the systematic difference between CHIRPS estimates and observed values, calculated as the mean difference (CHIRPS minus observed). A negative bias, such as observed for all locations in Table 2-3, indicates that CHIRPS tends to underestimate precipitation compared to observations. Finally, RMSE (Root Mean Square Error) quantifies the average magnitude of errors between the observed and estimated values, expressed in the same units as the variable being measured (i.e., millimeters of precipitation). Smaller RMSE values indicate closer agreement. In this case the errors in the monthly precipitation amounts are still substantial – meaning that the exact amount of precipitation is not always well reflected. On another note, the analysis is performed using raw data values from the meteo stations. Validated results will allow for a more meaningful comparison.

Table 2-3: Statistical parameters for comparing CHIPRS results with measured precipitation for meteo stations in Suriname

Station	Correlation	Bias	RMSE
Cultuurtuin	0.82	-14.63	62.91
Groningen	0.77	-14.95	74.99
Tijgerkreek	0.79	-21.52	72.53

3 Drought hazard

3.1 Drought Hazard Index (DHI)

3.1.1 Introducing the concept of DHI

Based on the values of the SPI-12, the drought episodes within the reference period can be identified in each precipitation series. A drought episode is identified when the SPI-12 first falls below zero (onset of the episode) and continues to increase (higher negative values) reaching a value equal or less than -1. When SPI-12 reaches again its first positive value this event has ended. If an SPI-12 value equal or less than -1 has not been reached, then this event is not characterized as drought (i.e. it is just low precipitation event but cannot be characterized as a drought episode).

Four sub-indicators that reflect the severity, duration, and recurrence of the drought hazard for each precipitation series are calculated. The focus of this meta-analysis is to derive operational indicators each one reflecting common drought hazard characteristics, easy to reproduce, and blend into a Drought Hazard Index. The following sub-indicators have been defined, to be computed at each rain gauge. A visual interpretation is added to Figure 3-2.

1. **FRQ**: Number of drought episodes (events) observed within the reference period (expressed as absolute number or as % over the total duration of the period of analysis). This sub-indicator is used as metrics of “recurrence”.
2. **FRQ24**: Number of drought episodes with duration greater than 24 months, within the reference period. This sub-indicator is used as a sensible descriptor of prolonged drought and thus metrics of “severity”.
3. **DMmax**: Maximum drought magnitude observed within the reference period. This sub-indicator is used as metrics of “severity” – see Figure 2-1.
4. **dmax**: Maximum duration (in months) among the drought episodes observed within the reference period. This sub-indicator is used as metrics of “duration”.

Following the calculation of the four sub-indicators, a classification is developed. The classification used in this study is presented in

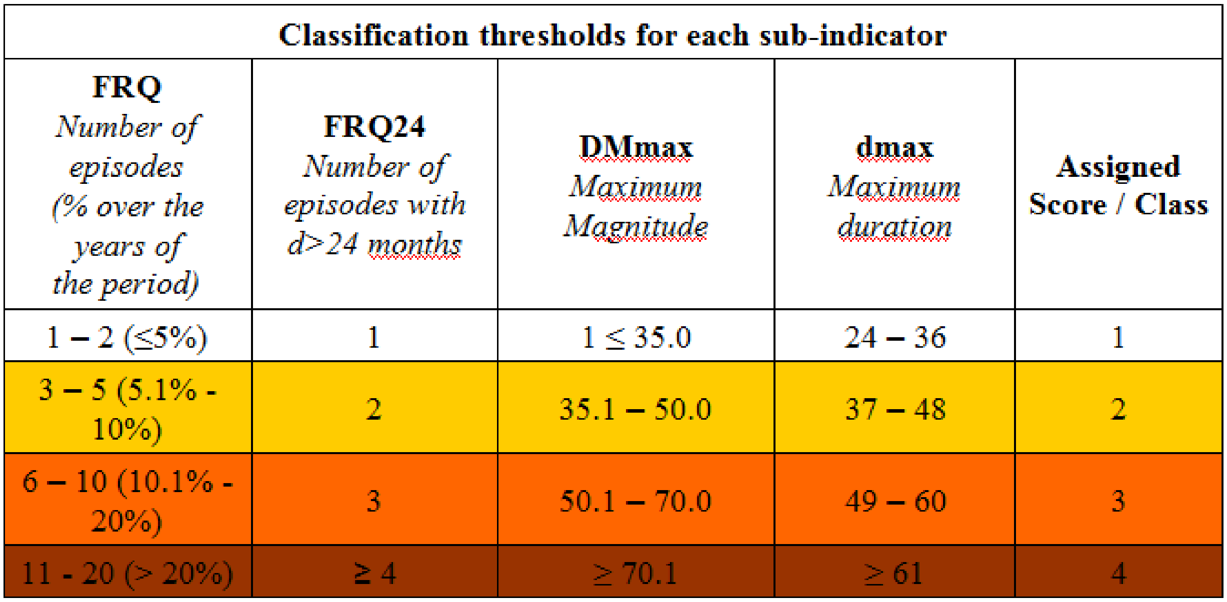
Table 3-1. The thresholds for each sub-indicator are following international literature (Kossida, 2015). The second sub-indicator (FRQ24) is linked to a number of drought events according to the whole duration of our data series. That means that the length of the used dataset matters for the classification of the score. A period of around 40-50 years is required for this classification.

Equal weights are assigned for all four sub-indicators. A DHI value is calculated based on the following equation:

$$DHI = (\theta_1 \times score_{FRQ}) + (\theta_2 \times score_{FRQ24}) + (\theta_3 \times score_{DM\,\max}) + (\theta_4 \times score_{d\,\max})$$

where θ_i are the equal weights of the sub-indicators ($\theta1=\theta2=\theta3=\theta4=0.25$).

Table 3-1: Classification thresholds for each sub-indicator



Classification thresholds for each sub-indicator

FRQ *Number of episodes (% over the years of the period)*	**FRQ24** *Number of episodes with d>24 months*	**DMmax** *Maximum Magnitude*	**dmax** *Maximum duration*	**Assigned Score / Class**
1 – 2 (≤5%)	1	1 ≤ 35.0	24 – 36	1
3 – 5 (5.1% - 10%)	2	35.1 – 50.0	37 – 48	2
6 – 10 (10.1% - 20%)	3	50.1 – 70.0	49 – 60	3
11 - 20 (> 20%)	≥ 4	≥ 70.1	≥ 61	4

The DHI values are subsequently classified as:

DHI value	Drought hazard
1 – 2	Low
2 – 3	Moderate
3 – 4	High

3.1.2 Data used for calculating DHI

CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) is employed in this study due to its comprehensive spatial coverage and complete time series for Suriname. This dataset offers a high spatial resolution of 0.05 degrees (approximately 5.5 km at the equator), enabling detailed analysis of precipitation patterns across the entire country. The CHIRPS dataset spans from 1981 to near-present, providing a robust historical context for the drought hazard analysis.

CHIRPS data from 1984 to 2024 is used to ensure a statistically significant sample for calculating long-term averages. The average annual precipitation based on CHIRPS data is presented in Figure 3-1.

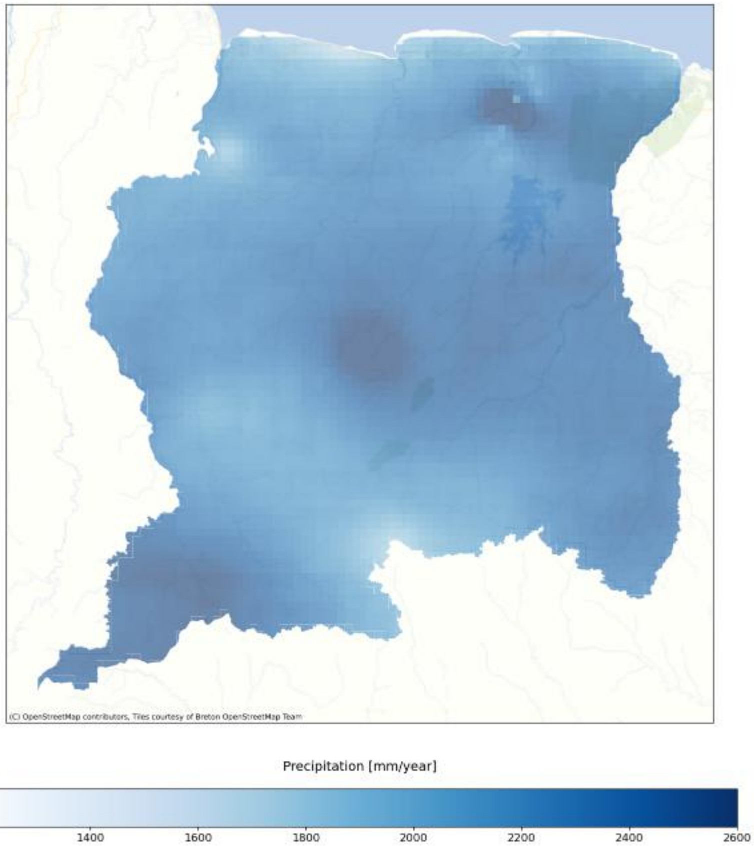


Figure 3-1: Average annual precipitation sums (1984 - 2024)

3.1.3 Assessing DHI sub-indicators from SPI

For each 0.05-degree pixel within Suriname's borders, the complete 1984-2024 time series is extracted. Using this data, the Standardized Precipitation Index (SPI) for each pixel is calculated. An example of an SPI graph is presented in Figure 3-2 – showing the SPI for the spatial average of all CHIRPS pixels within Surinam's borders.

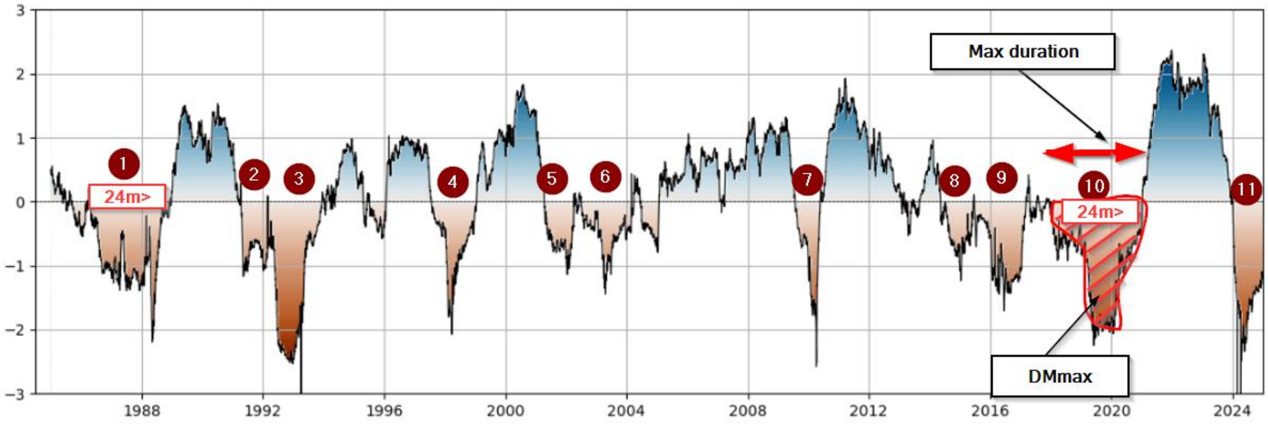


Figure 3-2: Example SPI-12 for the mean precipitation series in Suriname. The integers present the number of drought events (FRQ, I.e. 11). The red 24m> present the number of drought events longer than 2 years (FRQ24, i.e. 2). The magnitude is assessed by multiplying the time and the anomaly score for the drought

event, the maximum magnitude (DMmax) is therefore presented by the biggest area of the drought event. The max duration (dmax) is presented by the red arrows (I.e. slightly more than 2 years).

3.1.4 How droughts relate to the El Niño or La Niña events

To assess the relationship between dry periods in Suriname and El Niño/La Niña phenomena, the Oceanic Niño Index (ONI) (NOAA, 2025) is compared with the SPI derived from spatial averages of CHIRPS rainfall data across Suriname (Figure 3-3). Over the past 40 years,11 major droughts have been recorded in Suriname (see Figure 3-2), with many aligning with El Niño or La Niña events. These climate patterns, known to drive global weather anomalies, influence Suriname's precipitation variability through shifts in atmospheric circulation and sea surface temperatures in the Pacific Ocean.

As observed in Figure 3-3, a significant portion of Suriname's droughts correlate with El Niño (associated with reduced rainfall) and, to a lesser extent, La Niña (which can amplify dry conditions in specific regions). For instance, the 1997–1998 El Niño event coincided with a drought causing critical water shortages, ecosystem stress, and agricultural losses. Similarly, the 2023–2024 El Niño triggered widespread bushfires and strained water resources. However, not all droughts align with ENSO phases, indicating contributions from regional climate variability or other teleconnection patterns (e.g., Atlantic Ocean dynamics).

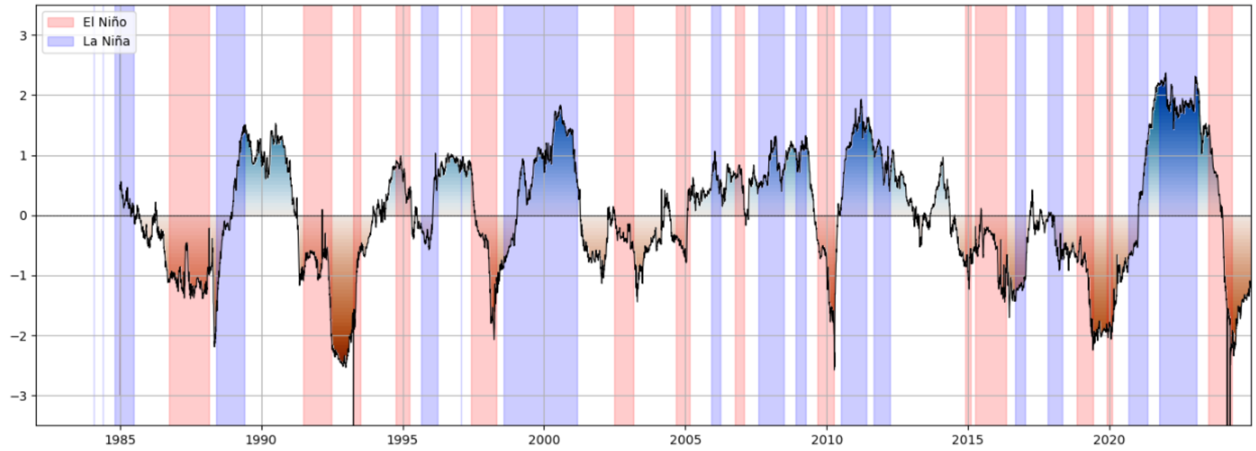


Figure 3-3: SPI graph including El Nino / La Nina effects. Blue and red periods are relating to an absolute ONI of more than 0.5.

3.1.5 Spatial variations in DHI

Subsequently the DHI sub-indicators as described in section 3.1.1 are calculated for each pixel. The four indicators together allow for the calculation of the DHI per CHIRPS pixel. Using

Table 3-1, this results in a DHI value for each value based on the 1984 – 2024 time series. The resulting DHI for Suriname is presented in Figure 3-4.

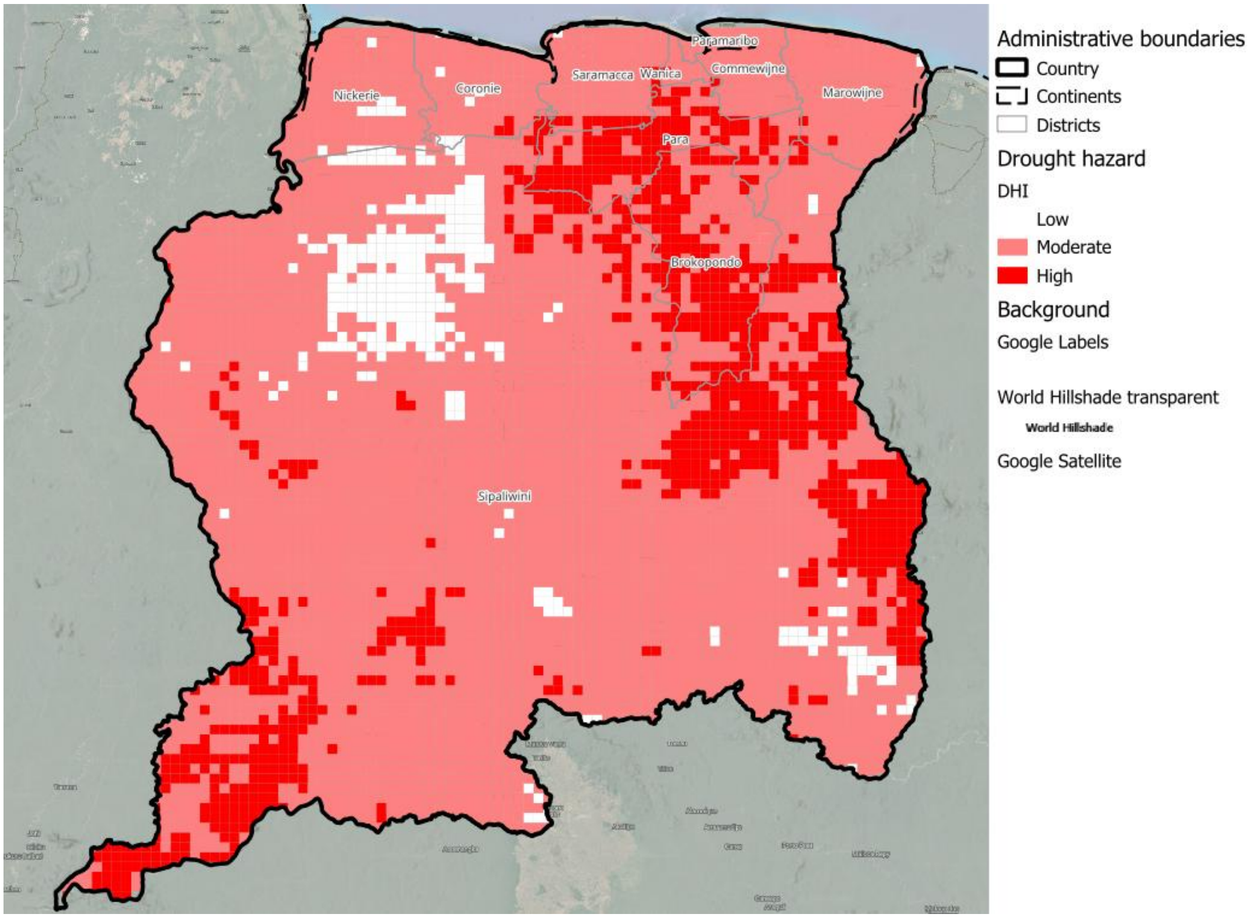


Figure 3-4: DHI for Suriname

According to the presented methodology, a major part of Suriname is classified as yielding a moderate drought hazard (DHI value between 2 and 3). In the districts Para, Brokopondo and the south-east of Sipalwini the drought hazards are classified as high. In the western parts of Sipalwini and in some parts of Nickerie and Coronie, there are some areas with a low drought hazard.

3.2 Climate change effects

To quantify the effects of climate change on the drought hazard, the results of the CMIP6 are used. The current conditions (reference period of 1995 – 2014) are compared to the long-term (2081 – 2100) changes under climate scenario SSP5-8.5. This is a high-emissions climate change scenario representing a fossil fuel-intensive world with significant mitigation challenges.

The changes in the annual averaged precipitation sums for Suriname are presented in Figure 3-5. Note that for the entire country, the annual precipitation sums will decrease under this scenario. In the northern parts this decrease is modelled to be approximately 21%. In the southern part of the country, the modelled decrease in precipitation is slightly less, i.e. around 16% in the far west to approximately 19 % in the far east.

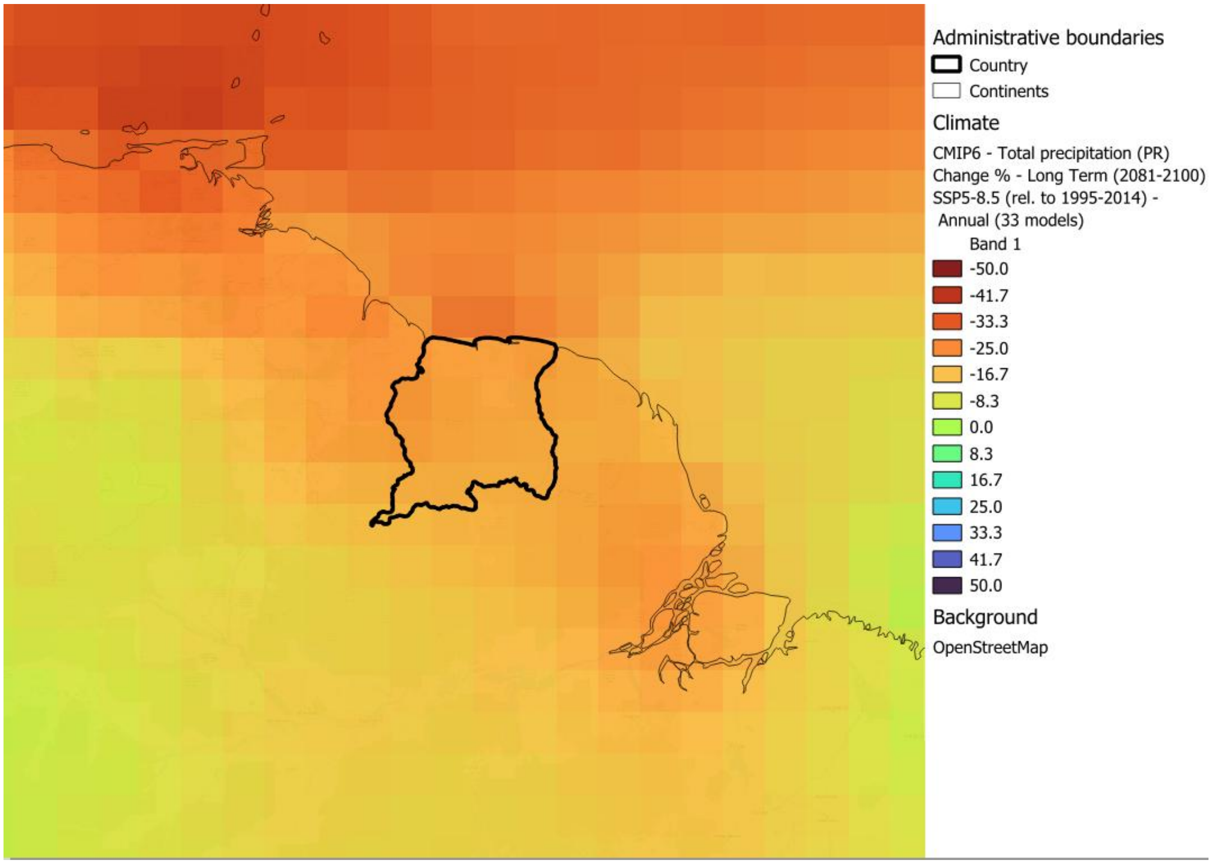


Figure 3-5: percentage of annual precipitation changes according to CMIP6 under climate scenario ssp5-8.5

The biggest changes in precipitation are likely to occur from January to March – see Figure 3-6 and Figure 3-7 – when the precipitation amounts are almost halved. This coincides with the short rainy season (early December to late January) and the short dry season (early February to mid-April). The changes in the long rainy season (mid-April to mid-August) are relatively limited.

Therefore, under this climate scenario, the intensity of droughts will increase significantly and the total yearly precipitation will be much lower. This will exacerbate the drought hazard for Suriname. However, the yearly precipitation patterns in terms of when the dry and rainy season occur are mostly unchanged.

This is supported by (IDB, 2021) - which states that annual precipitation patterns in Suriname are projected to shift, with an increase in the number of dry days across all regions, particularly along the coast and over the long term. In northern locations such as Paramaribo, Albina, Brokopondo, and Bigi Pan MUMA, total precipitation is projected to decrease during the short dry season but slightly increase during the long dry season, indicating a seasonal shift caused by the narrowing influence of the ITCZ. For interior areas like Kwamalasamutu, Upper Tapanahony, and Tafelberg, both the shorter rainy and dry seasons are expected to become much drier, while the rainy season will intensify during its peak months (IDB, 2021).

Note that the presented SPI methodology is not applicable to map the DHI under the climate change scenario. As explained in section 2.1.4, SPI values reflect relative anomalies rather than absolute precipitation amounts. This will make dry periods under the new SSP5-8.5 scenario look less pronounced whereas the actual drought hazard has increased.

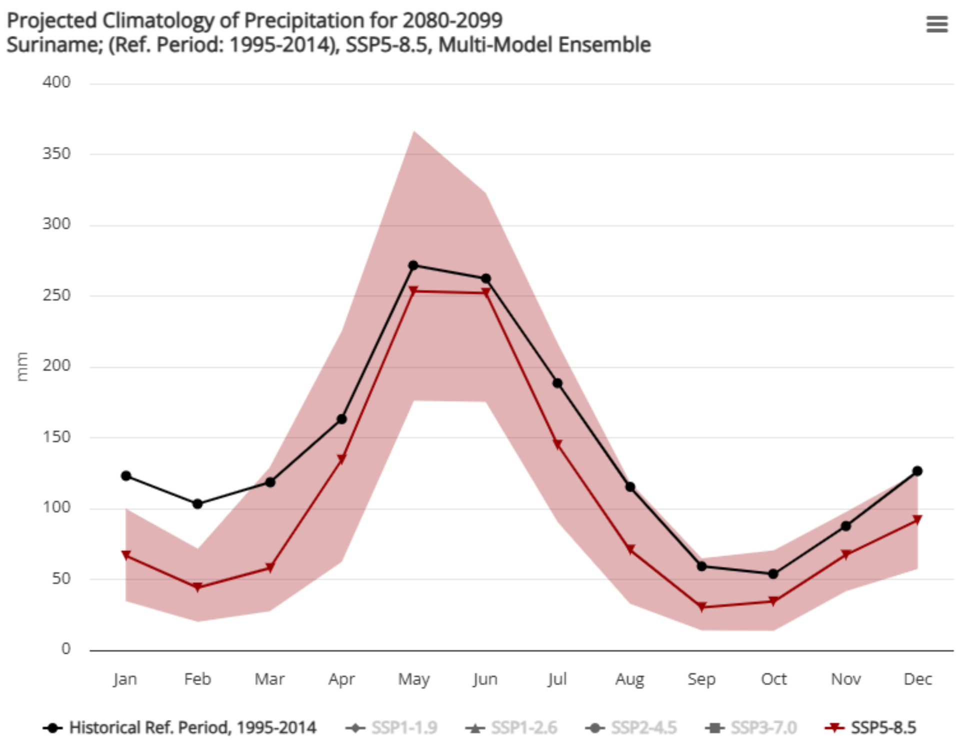


Figure 3-6: Projected annual precipitation according to CMIP6 under historical conditions (1995 – 2014) and under the SSP5-8.5 climate scenario.

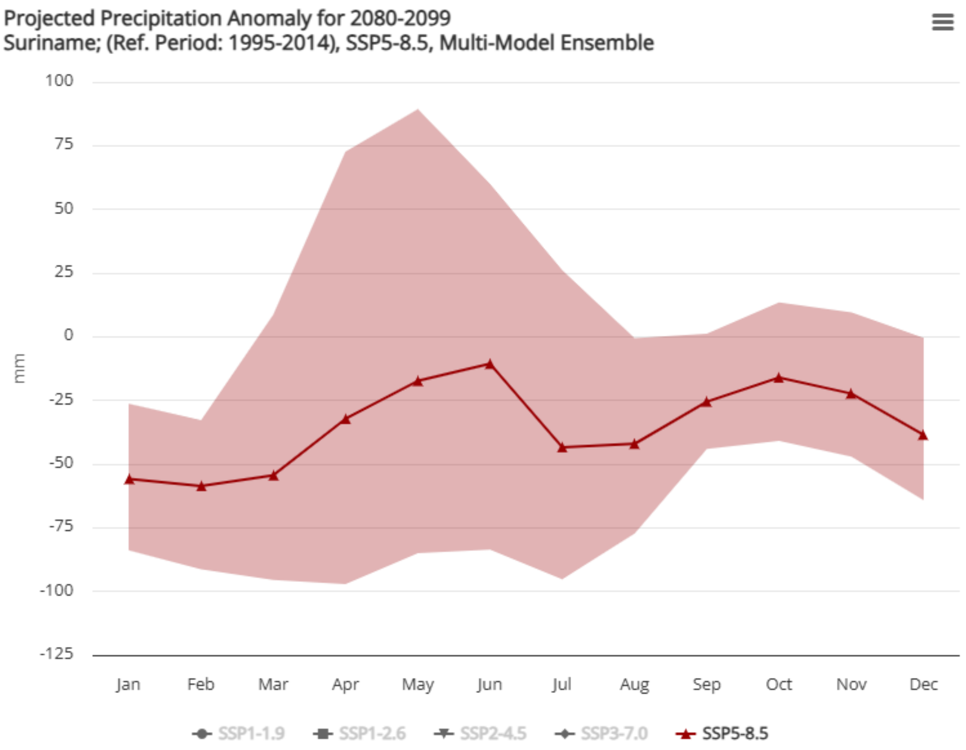


Figure 3-7: Projected changes in annual precipitation according to CMIP6 under historical conditions (1995 – 2014) and under the SSP5-8.5 climate scenario.

3.3 Trend analysis

In order to assess whether the projected decrease in precipitation has already presented itself over the past decades, a trend analysis is performed using a Mann-Kendall test.

The Mann-Kendall test is a widely used non-parametric statistical method for detecting trends in time series data. It is particularly useful in environmental and climate studies, where data may not follow a normal distribution. The test assesses whether there is a monotonic upward or downward trend in the data over time.

The Mann-Kendall test does not require the data to be normally distributed or linear, making it robust against outliers and missing values. It works by comparing each data point with all subsequent data points in the series. A positive trend is indicated if later values tend to be higher than earlier values, while a negative trend is suggested if later values tend to be lower.

The test provides a p-value to indicate the statistical significance of the trend. A p-value less than the chosen significance level (typically 0.05) suggests a significant trend, while a higher p-value indicates that there is not enough evidence to conclude a significant trend (Kendall, 1975).

The trend analysis is performed for all stations taking the cumulative rainfall sums of three periods:

1. The short rainy season – from the 1st of December to the 31st of January
2. The long rainy season – from the 1st of April until the 15th of August
3. A whole year – from the 1st of January to the 31st of December

It is assumed that for each period the number of NoData entries can only be 20% of the total number of readings – assuring that there is no bias in the trend analyses.

The results, as presented in Table 3-2, reveal two significant trends identified through the analysis: an increasing trend at the Dirkshoop station and a decreasing trend at the Friendship Totness station. It is important to note that the Dirkshoop station provides data only for the period 2013–2017, which is insufficient for assessing long-term climatic changes and instead reflects short-term weather variability. Conversely, the Friendship Totness station offers nearly a century of data (1924–2017), providing a robust basis for analysis. The observed decreasing trend in precipitation during the long rainy season at this station – see Figure 3-8 - suggests significant changes in rainfall patterns over time.

However, this trend is not backed up by other stations with similarly extensive datasets, indicating that it cannot be generalized as a nationwide pattern of declining precipitation during the long rainy season. Furthermore, no significant trends were detected for precipitation during the short rainy season or in annual totals across all stations analysed. This finding indicates that over the past century, there has been no consistent trend of decreasing precipitation patterns in Suriname.

The projected changes outlined in Section 3.2 have not yet manifested in Suriname's precipitation patterns over this nearly 100-year period. However, the recent droughts of 2024 are reported to be perceived as unprecedented and extreme. Note that the impacts of rainfall and drought may now be more severe under similar weather conditions due to various environmental and human factors. These include the expansion of paved surfaces, increased mining activities, larger agricultural areas, poor maintenance of waterways, and spatial planning that fails to account for water management. These developments amplify the vulnerability of affected regions, making them less resilient to changing precipitation patterns.

Table 3-2: Results of precipitation trend analyses

Station	Period	Trend	Slope (mm/year)	P-value	Significance	Data Years
Broederschap	Short Rainy Season	Insufficient Data			N/A	
Carl Francois		no trend	0.0	1.00	Not Significant	1923-1986
Cultuurtuin		no trend	-0.5	0.42	Not Significant	1923-2017
Dirkshoop		no trend	39.2	0.31	Not Significant	2012-2017
Friendship Totness		no trend	-0.9	0.15	Not Significant	1923-2017
Groningen		no trend	0.0	0.97	Not Significant	1923-2017
Huwelijkszorg		Insufficient Data			N/A	
Kwatta Lvv		no trend	-9.1	0.60	Not Significant	2000-2017
Tijgerkreek		no trend	-0.2	0.91	Not Significant	1971-2017
Weg naar Zee		no trend	0.4	1.00	Not Significant	1986-2017
Broederschap	Long Rainy Season	Insufficient Data			N/A	
Carl Francois		no trend	-0.7	0.55	Not Significant	1924-1986
Cultuurtuin		no trend	-1.5	0.06	Not Significant	1924-2017
Dirkshoop		increasing	158.9	0.03	Significant	2013-2017
Friendship Totness		decreasing	-2.3	0.01	Significant	1924-2017
Groningen		no trend	-0.2	0.89	Not Significant	1924-2017
Huwelijkszorg		Insufficient Data			N/A	
Kwatta Lvv		no trend	-54.8	0.39	Not Significant	2001-2017
Tijgerkreek		no trend	1.3	0.89	Not Significant	1972-2017
Weg naar Zee		no trend	10.1	0.28	Not Significant	1987-2017
Broederschap	Yearly Sums	Insufficient Data			N/A	
Carl Francois		no trend	2.9	0.32	Not Significant	1924-1986
Cultuurtuin		no trend	-0.2	0.89	Not Significant	1924-2018
Dirkshoop		no trend	14.7	1.00	Not Significant	2012-2018
Friendship Totness		no trend	-2.7	0.06	Not Significant	1924-2018
Groningen		no trend	1.5	0.33	Not Significant	1924-2018
Huwelijkszorg		Insufficient Data			N/A	
Kwatta Lvv		no trend	48.9	0.60	Not Significant	2001-2018
Tijgerkreek		no trend	3.7	0.78	Not Significant	1972-2018
Weg naar Zee		no trend	21.0	0.59	Not Significant	1987-2018

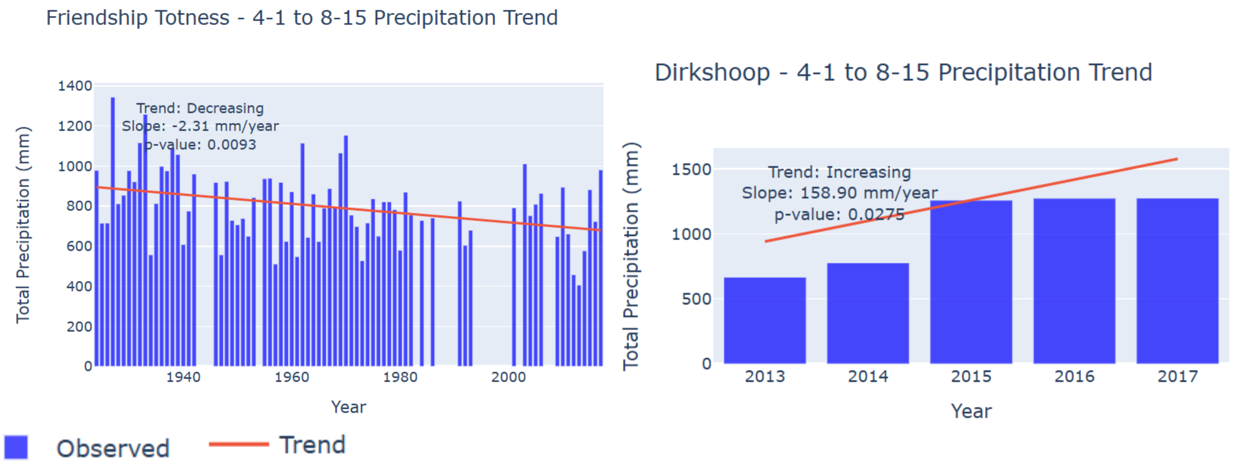


Figure 3-8: Observed sums during long rainy season and trend lines (Mann-Kendall) in left: Friendship Totness and right: Dirkshoop

4 Impact of droughts

As presented in section 3.3, the precipitation patterns are projected to decrease under climate change scenario SSP5-8.5. This is expected to lead to an increase in droughts and its negative effects. In this chapter the hydrological effects (HEs) of droughts and their derivative effects are described.

4.1 Hydrological effects of droughts

4.1.1 HE1: Depletion of soil moisture

Drought conditions in Suriname significantly affect the hydrological balance by depleting soil moisture, which is a critical component of the water cycle. Reduced precipitation and increased temperatures lead to lower infiltration rates, limiting the replenishment of water stored in the soil. This results in diminished soil water availability for plants. The depletion of soil moisture also reduces the capacity of the soil to retain water during subsequent rainfall events, increasing surface runoff and limiting groundwater recharge. These hydrological changes exacerbate water scarcity for agriculture, ecosystems, and human consumption, especially in regions where soil moisture plays a key role in sustaining vegetation and maintaining water flow to nearby wetlands and streams.

4.1.2 HE2: Lowering of water levels in trenches and swamps

The prolonged drought in Suriname will result in a significant lowering of water levels in trenches and swamps, which are vital components of the country's hydrological system. These water bodies serve as critical habitats for biodiversity, natural flood regulators, and sources of irrigation for agriculture. Reduced rainfall diminishes their recharge rates, while elevated evaporation rates due to higher temperatures exacerbate water loss.

4.1.3 HE3: Reduced recharge rates leading to lowering of groundwater levels

Since all climate projections project a decrease in the amount of precipitation and an increase in the temperatures for Suriname, the recharge rates will decrease if climate change effects are not mitigated. In addition, rivers will carry less water due to decreases in precipitation in their catchment areas. Their reduced discharge in freshwater sources such as wetlands will result in a lower percolation and recharge of aquifers. This will lead to a lowering of groundwater levels and a reduction of the available water for abstraction from the aquifers.

Note that currently water is abstracted from three aquifers (A-sand, Coesewijne and Zanderij Aquifers). Currently, only the Zanderij aquifer is directly recharged by precipitation and therefore vulnerable to reduced precipitation rates as a consequence of climate change effects.

4.1.4 HE4: Reduced base flow of rivers and creeks

The combined effects of reduced annual rainfall, increased evapotranspiration, and prolonged dry periods will significantly impact the hydrological cycle in Suriname. These factors will lead to a reduction in the base flow towards the rivers, creeks, and streams that flow directly into the Atlantic Ocean.

4.1.5 HE5: Upstream intrusion of saline water in rivers and creeks

The issue of upstream intrusion of saline water in rivers and creeks in Suriname is becoming increasingly critical due to climate change-induced drought conditions and their impact on freshwater discharge. This problem is particularly acute in the coastal regions, where the delicate balance between freshwater and saltwater is easily disrupted. The decrease in freshwater discharge exacerbates saltwater intrusion in two primary ways (Government of the Republic of Suriname, 2023):

i. Reduced base flow of rivers and creeks

As a result of reduced base flow towards rivers and creeks, the natural barrier that freshwater provides against saltwater intrusion is weakened, allowing saline water to penetrate further inland. In some cases, this intrusion can extend up to 20 km inland, affecting coastal farms and industries that rely on river estuaries.

ii. Tidal Effects and Upstream Freshwater Discharge

The tidal influence of the Atlantic Ocean plays a crucial role in saltwater intrusion, particularly during periods of low freshwater discharge from upstream. The semi-diurnal tides of the Atlantic Ocean form salt wedges that penetrate far into the Coastal Plain through rivers and creeks. The location of these salt wedges is not only determined by the magnitude of the tide but also by other factors, with freshwater river discharge being the most significant.

During dry seasons, when freshwater discharge is at its lowest, the 300 mg/l chlorinity levels can be found further upstream, potentially affecting irrigation water quality for agricultural areas such as the Wageningen polder. This situation is exacerbated by the extraction of water from rivers for irrigation purposes, further reducing the freshwater flow that counteracts saltwater intrusion.

4.2 Derivative effects

4.2.1 Agricultural sector

Despite Suriname's high annual rainfall, irrigation is widely practiced due to the uneven distribution of rainfall throughout the year. Rice and bananas are the primary irrigated crops, with rice cultivation being particularly dependent on consistent water availability. During prolonged droughts, freshwater scarcity becomes a critical issue, especially for rice farming in districts like Nickerie. Irrigation water for these areas is sourced from the Nani swamp and the Nickerie and Corantijn Canal. However, increased evapotranspiration caused by higher temperatures during dry periods significantly reduces water stored in these sources, limiting freshwater availability for irrigation (HE2). This problem is most acute during the second rice crop cycle, which coincides with the dry season when rainfall decreases and irrigation demand peaks.

In addition to irrigated crops, rainfed crops in Suriname are highly vulnerable to soil moisture depletion during droughts (HE1). Prolonged dry spells reduce soil water reserves, impairing plant growth and productivity. Rainfed crops rely entirely on natural precipitation for their water needs, making them particularly susceptible to the uneven rainfall patterns and extended dry periods associated with climate change

The effects of drought are not limited to rice cultivation. Saltwater intrusion, resulting from low freshwater discharge in rivers, further complicates irrigation for crops like bananas in coastal districts such as Nickerie, Coronie, and Sarammacca (HE4 en HE5). This intrusion not only reduces the availability of freshwater for irrigation but also poses a threat to crop survival, potentially leading to significant losses.

Droughts also affect livestock by causing a lack of forage at the end of the dry season and during prolonged droughts. This can lead to starvation among cattle, further straining the agricultural sector. Overall, the challenges posed by droughts underscore the need for sustainable water management and irrigation practices to ensure the resilience of Suriname's agricultural sector.

4.2.2 Drinking water sector

Droughts have a limited but gradually increasing impact on Suriname's drinking water sector, primarily due to the reliance on fossil groundwater from deep, confined aquifers. These aquifers, which supply 93% of the country's drinking water, do not receive direct recharge and are thus less affected by short-term climate variability.

The shallow phreatic groundwater, which is recharged by rainfall in savannahs and sand ridges, is more vulnerable. A reduction in rainfall, coupled with increased overland flow during intense rainstorms and higher evapotranspiration rates, is expected to reduce recharge rates for these shallow aquifers. This could lead to declining groundwater levels and potential attraction of brackish water (HE3). This can lead to a reduction in productivity of boreholes which target these aquifers – which is relevant risk for utilities, bottling companies, farmers and the tourism industry.

The Surinaamsche Drinkwatermaatschappij (SWM) also relies partially on surface water for its production. At Moengo and La Liberté, surface water is sourced from the Cottica River and the Suriname River, respectively. However, specific challenges arise at La Liberté due to high salinity levels in the Suriname River. During periods of drought and saltwater intrusion (HE5), salinity levels in the Suriname River can increase beyond acceptable limits. This situation necessitates advanced filtration methods, such as reverse osmosis or other membrane-based techniques, to maintain safe drinking water standards.

4.2.3 Energy sector

The Afobaka Dam and its associated Brokopondo Reservoir play a crucial role in the nation's energy production, supplying approximately 46.7% of Suriname's electricity as of 2020 – see Figure 4-1. This hydroelectric facility, with a capacity of 180 MW, has produced a significant part of Suriname's power generation (OLADE, 2021).

The effectiveness of hydropower is increasingly challenged by climate change-induced droughts. Projections indicate that by the end of the century, water inflow at the Afobaka hydropower plant could – under the worst-case climate change scenarios - decrease up to 14 percent due to reduced precipitation which leads to reduced baseflows (HE4). This potential reduction in hydroelectric generation capacity is concerning, especially as energy demand continues to rise (IDB, 2022).

To compensate for hydropower shortfalls during drought periods, Suriname relies more heavily on thermal plants, primarily diesel generators. The country's energy mix as of 2020 included 52.9% fossil fuel-based electricity generation, highlighting the significant role of thermal plants in maintaining power supply stability. These thermal plants serve as a crucial backup, but their increased usage during droughts leads to higher operational costs and increased carbon emissions (OLADE, 2021).

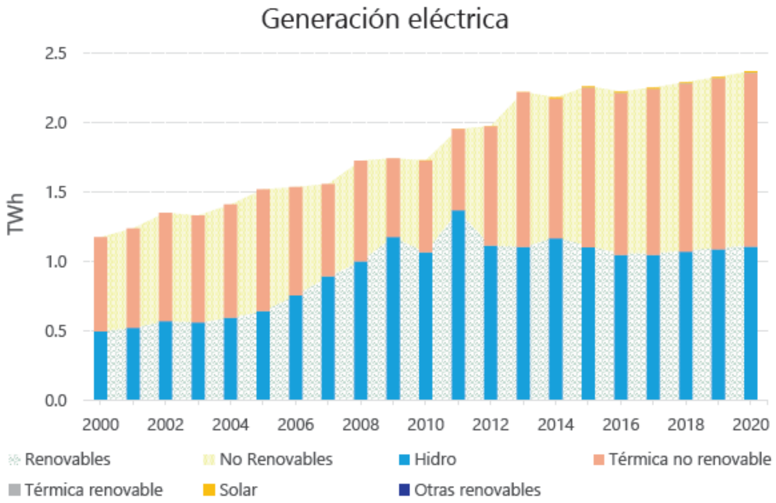


Figure 4-1: Energy production of Suriname (OLADE, 2021)

4.2.4 Ecosystems and tourism

The lowering of water levels in swamps, rivers, and creeks disrupts the natural hydrological balance, leading to significant ecological degradation (HE2). Reduced baseflow to rivers and creeks limits the flushing of pollutants, resulting in increased concentrations of harmful substances and fostering the growth of disease-causing organisms (HE4). This deterioration in water quality not only impacts aquatic ecosystems but also poses health risks to communities relying on these water sources.

Swamps and creeks play a vital role in supporting biodiversity, serving as habitats for fish, birds, and other wildlife. Their drying out due to drought diminishes these habitats, threatening species survival and reducing the ecological integrity of these areas. Additionally, iconic tourist destinations along creeks – including the fishing activities, particularly those located south of Paramaribo, are adversely affected.

Note that in addition to the hydrological effects, drought also increases the risk of wildfires to the forest areas - which take up a large part of Suriname’s surface area (ABS, 2023).

In inland areas, schools and villages became inaccessible for a period because rivers had dried up, significantly reducing navigation possibilities. This disruption not only affected tourism and transport but also exacerbated the challenges faced by the agricultural sector.

5 Water use and demand

The population in Suriname is mainly located in the coastal zone and more specifically centralized around Paramaribo. The population heatmap in Figure 5-1, based on the High-Resolution settlement layer, clearly highlights the urban areas in the coastal zone of Suriname. This means that the demand for potable water is also focussed in these areas.

The projections for the demand for potable water are assessed in this study and provide an update of the Water Masterplan of Suriname from 2011 (Genivar & Ilaco, 2011). For the country of Suriname, the following assumptions are made in the calculation of water demand:

- The UN population projections (medium growth scenario) are used to estimate future population trends
- The census data from 2014 is used to assess how the population is distributed over the districts.
- Average water use per capita varies over the different districts (Urban, rural or interior)
- Both commercial and industrial demands as well as institutional demands are calculated as a percentage of the domestic demand. This varies per district.
- For production losses a flat rate of 2% is used – assuming that all water is produced by boreholes.
- The NRW figures are represented and include an ambition for the improvement of NRW figures towards 2050.

The resulting water demand projections are presented in Figure 5-3 and spatially presented for the projection year of 2050 in Figure 5-1. Note that according to the projections, the demand will steadily increase to a maximum of ~279,000 m^3/day by 2043 and will slowly decrease afterward. This decline in demand is projected due to the decrease in NRW. This means from 2043 the supposed impact of NRW implementation exceeds the impact of population growth. This shows that the demand projections are sensitive to changes in NRW levels. If, for example, none of the NRW measures are implemented the water demand will increase to almost 309,000 m^3/day by 2050.

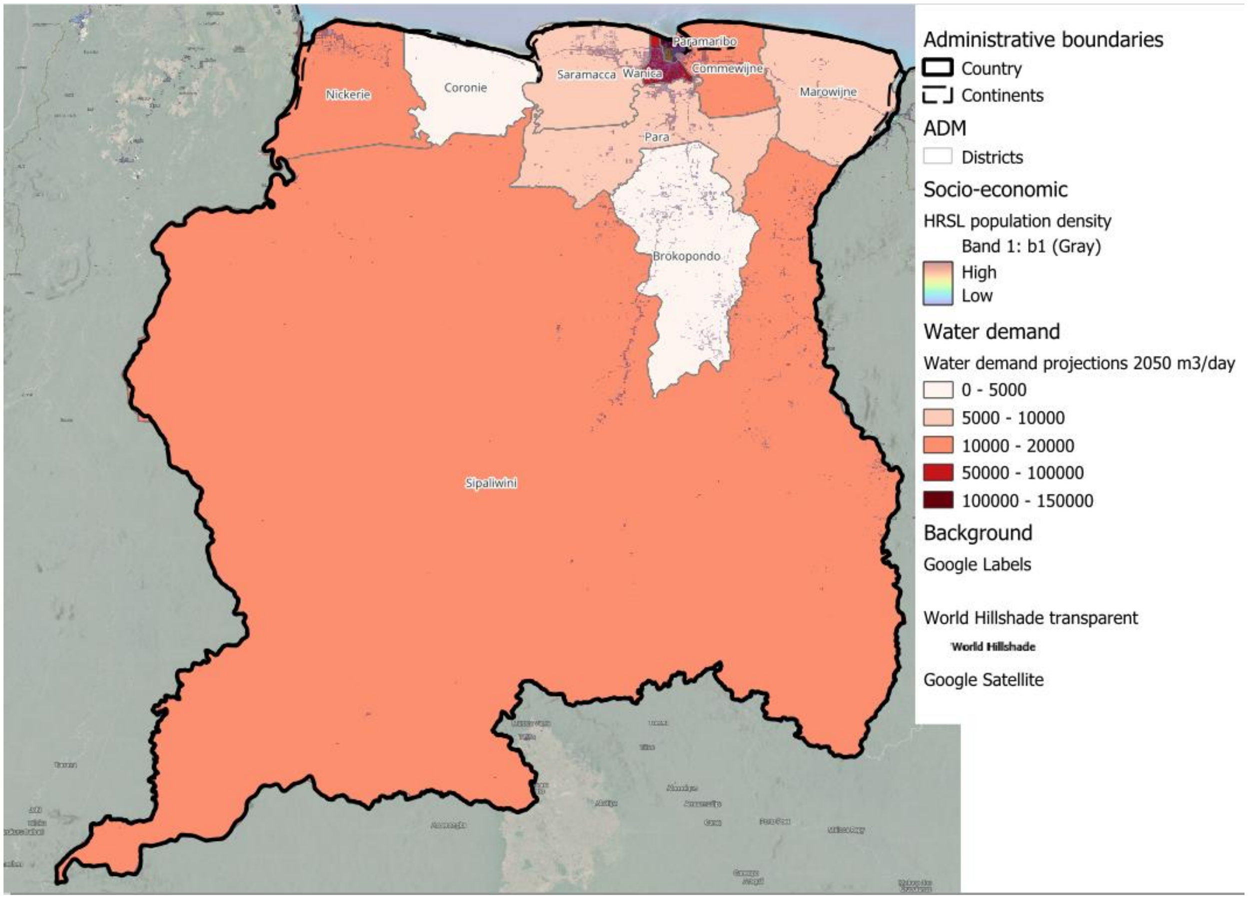


Figure 5-1: Population heatmap of Suriname based on HRSL and water demand projection for 2050 per district

Year	Brokopondo	Commewijne	Coronie	Marowijne	Nickerie	Para	Paramaribo	Saramacca	Sipaliwini	Wanica
	Interior	Rural	Rural	Interior	Rural	Rural	Urban	Rural	Interior	Urban
Average water use per person (L/capita/day)	100	150	150	100	150	150	200	150	100	200
% Commercial and industrial demands	0%	10%	10%	0%	10%	10%	30%	10%	10%	20%
% Institutional demands	0%	5%	5%	0%	5%	5%	15%	5%	10%	15%
Production losses	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
NRW (2024)	50%	50%	50%	50%	50%	50%	40%	50%	50%	40%
NRW (2050)	50%	50%	40%	50%	40%	40%	33%	40%	50%	33%

Figure 5-2: Assumptions for water demand projections

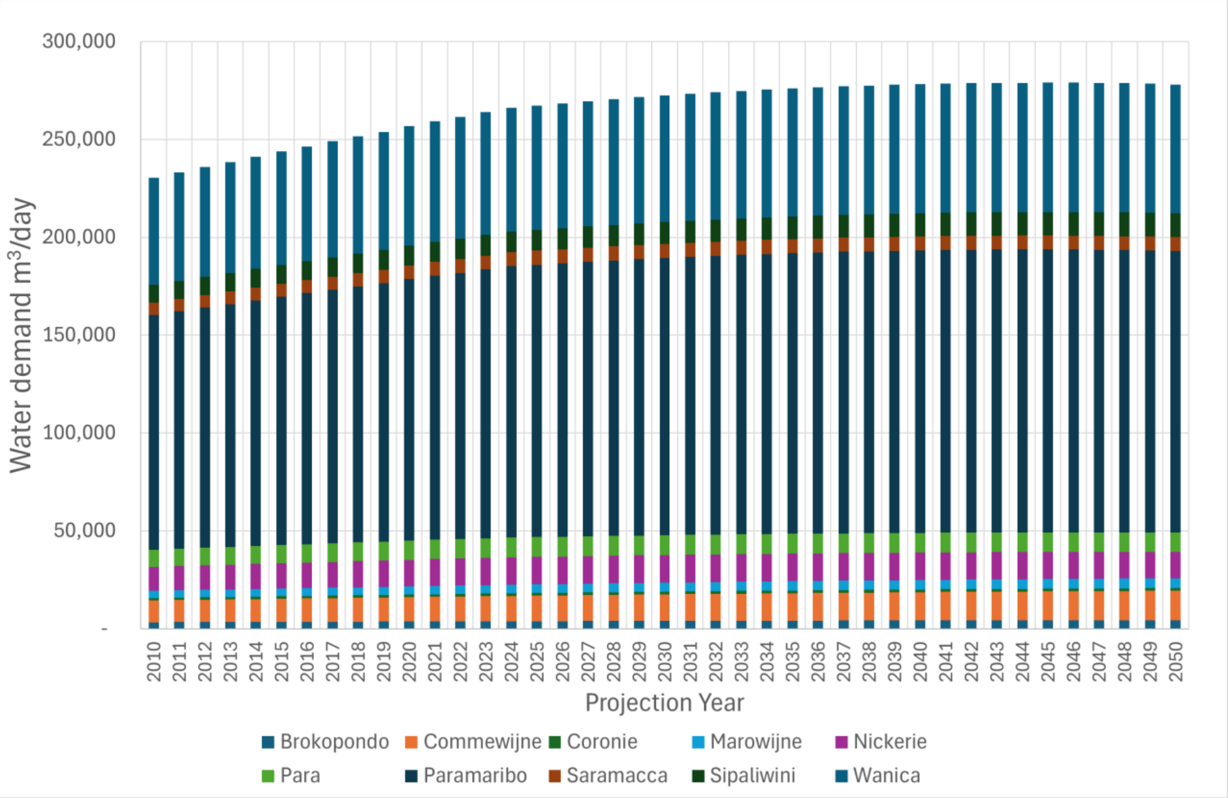


Figure 5-3: Water demand projections Suriname

The drought vulnerability as a result of the demand projections is assessed by using land use maps. I.e., built-up areas are assigned a high vulnerability according to the high demand for water in those areas.

6 Drought vulnerability

6.1 Vulnerability based on land use

Drought vulnerability is defined as the damage to a certain asset that may occur as a consequence of a drought event. In this study, drought vulnerability is assessed by using land use data. An overview of the land use in Suriname is presented in Figure 6-1.

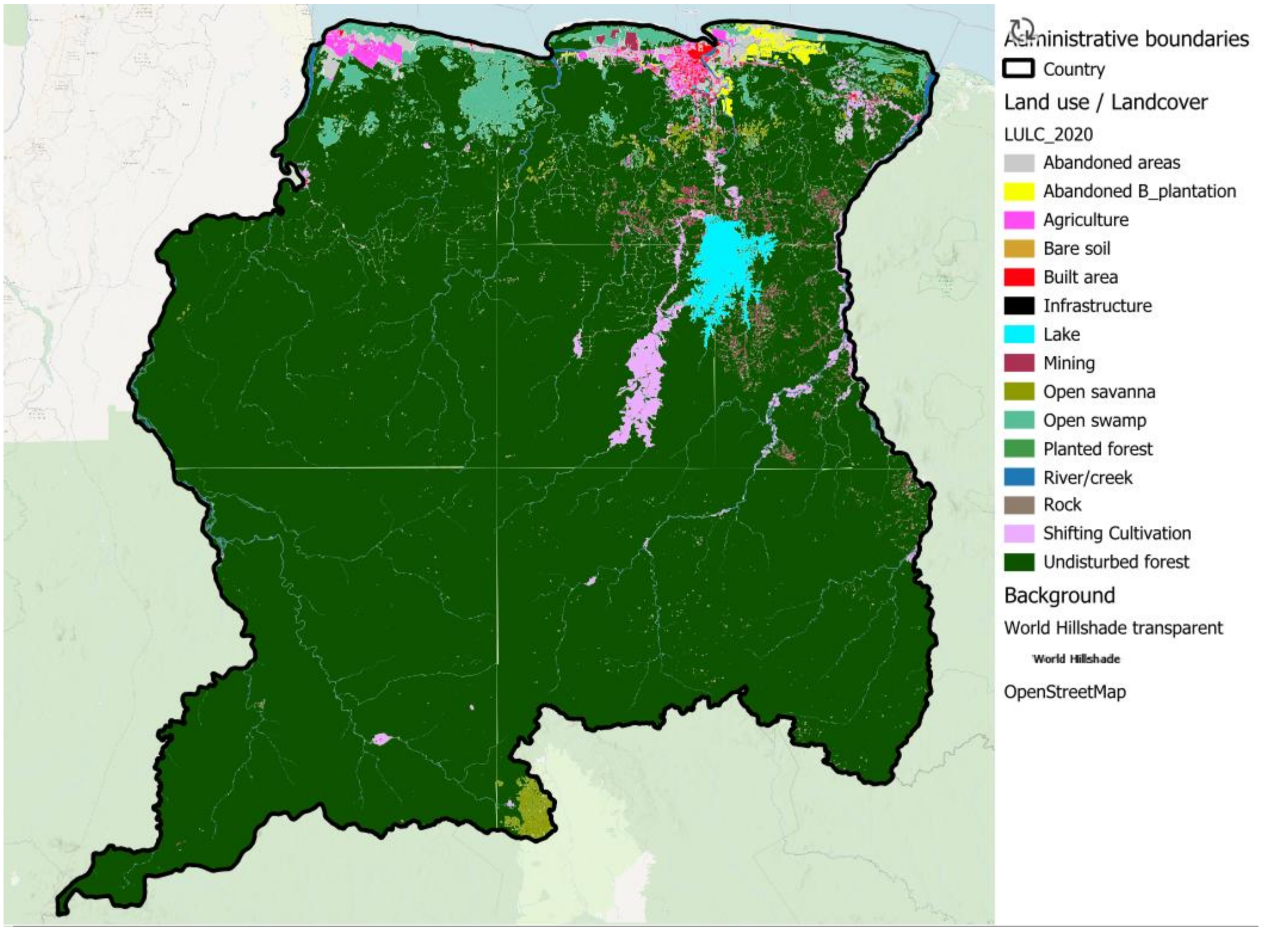


Figure 6-1: Suriname Land Use 2020

Each land use type is linked to a specific sensitivity to droughts, based on the assessed impacts in section 4.2. The rating of high, medium and low vulnerability for each land use class is elaborated in the tables below.

High	Rationale
Agriculture	Most agriculture is rainfed, supplemented by irrigation and the economic importance is high. Droughts may cause significant damage to these assets.
Open swamp	Damage to natural assets is high in case of droughts
Lake	Lakes are highly susceptible to water level changes during droughts

River/Creek	Rivers and creeks can dry up or have significantly reduced flow during droughts leading to reduced navigation possibilities, reduced baseflow resulting in damage to the natural system.
Planted forest	Planted forests are in general young and do not have the resilience of older settled natural systems. Therefore, a shortage of water may cause significant damage.
Built areas	Assuming that these areas coincide with areas of high domestic demand a drought may cause significant economic damage here.

Medium	**Rationale**
Undisturbed forest	Forests have adapted to occasional droughts, but prolonged droughts can still cause damage
Infrastructure	Infrastructure is generally less directly impacted by drought than natural systems
Shifting Cultivation	This practice allows for some adaptation to drought condition
Abandoned banana plantations	Abandoned plantations are less vulnerable as they are not actively used for production, so no direct economic loss occurs in times of drought. However, the area can be considered as undisturbed forest in which case that rationale also holds for this class.

Low	**Rationale**
Mining	Mines usually need to be dewatered; a drought may even be beneficial for mining practices.
Abandoned areas	In this area, there are hardly any water-dependent assets, so drought damage has no negative consequences here.
Open savanna	In this area, there are hardly any water-dependent assets, so drought damage has no negative consequences here.
Rock	In this area, there are no water-dependent assets, so drought damage has no negative consequences here.
Bare soil	In this area, there are no water-dependent assets, so drought damage has no negative consequences here.

This results in a drought vulnerability as presented in Figure 6-2. Note that the most vulnerable areas are located in the coastal zone of Suriname with high water demand for agricultural and domestic use. Another major asset which clearly shows as highly vulnerable on the map is the Brokopondo reservoir. The reservoir is of major importance for the energy supply of Suriname and supplies up to 45% of the energy demand of the city – depending on the season. Most of the country is covered by undisturbed forest which is classified as a medium vulnerable to droughts.

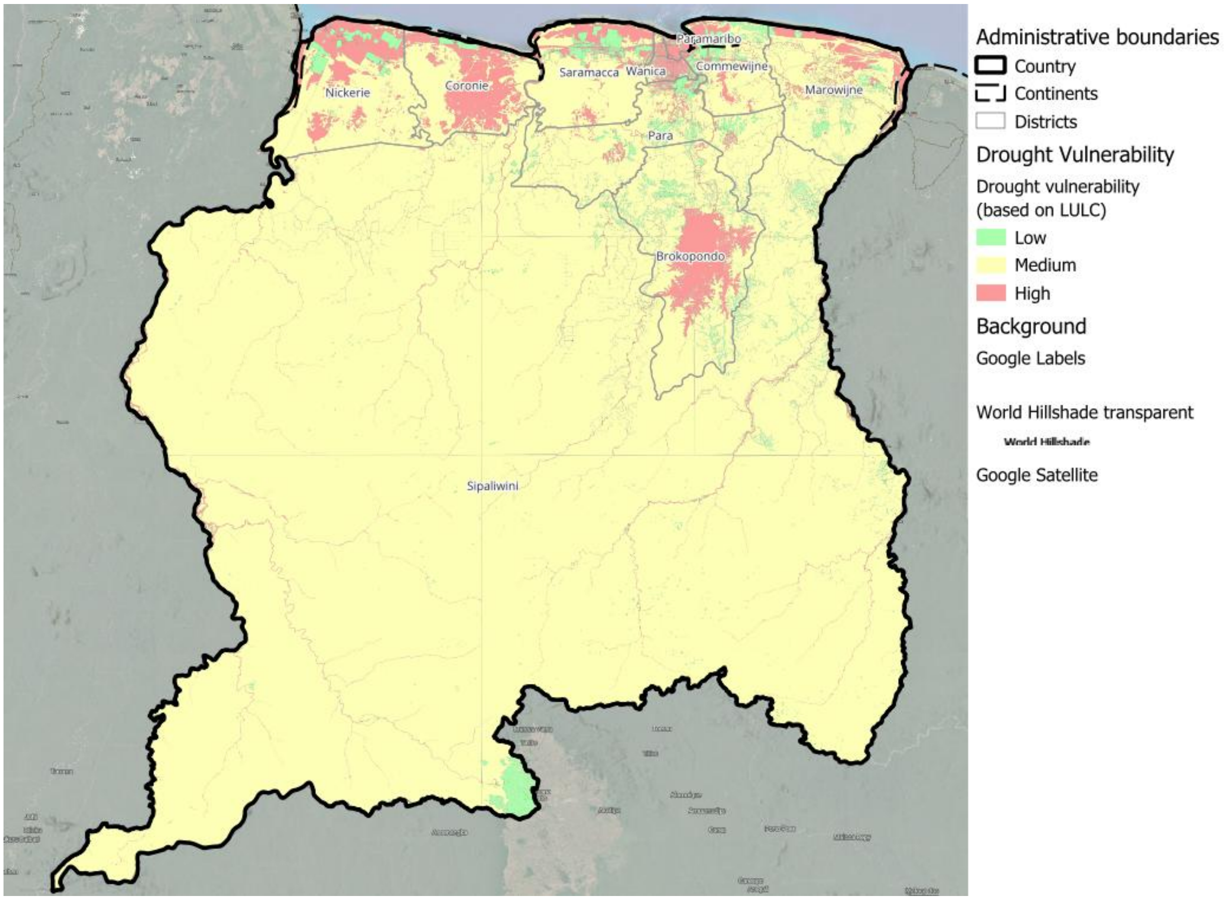


Figure 6-2: Drought vulnerability

7 Drought risk

Drought risk is defined as the hazard times the vulnerability as per the following formula:

$$Drought\ Risk = DHI * Vulnerability\ score$$

Where a vulnerability score of 1, 2 and 3 is respectively assigned to the classes low, medium and high drought vulnerability. This results in a drought risk value which can range from 0 to 12 – where 0 is defined as no drought risk at all and 12 is defined as extreme drought risk.

The resulting drought risk map is presented in Figure 7-1. Several areas stand out:

- The Brokopondo reservoir is categorized as highly vulnerable due to its susceptibility to changing water levels. On top of that the reservoir is located in an area with a higher hazard score – meaning more frequent and severe droughts.
- The agricultural area around Paramaribo – specifically in Wanica also yields high drought risk scores. This is mainly due to its high vulnerability.
- Also, the urban area in Paramaribo itself is characterized by high drought risk scores.
- The central area in Sipaliwini – characterized by undisturbed forests - shows the lowest drought risk scores.
- The coastal zone features open swamps that are highly vulnerable to drought. These areas stand out due to their elevated drought risk, as some of the areas also face a significant drought hazard.

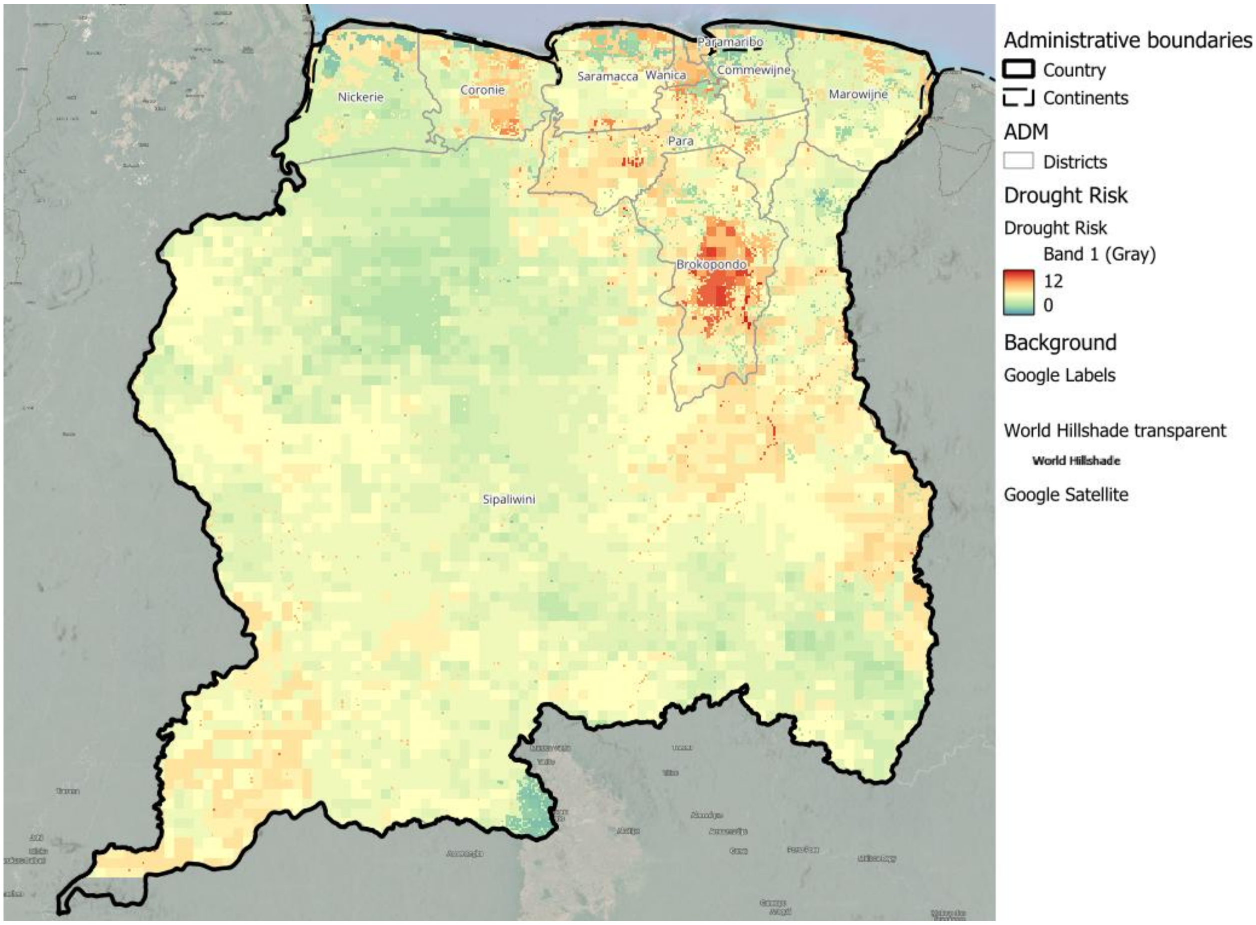


Figure 7-1: Drought risk ranging from 0 (low drought risk) to 12 (extreme drought risk)

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9 Colophon

Client	:	The United Nations Environment Programme (UNEP) on behalf of the Climate Technology Centre and Network (CTCN)
Beneficiary	:	Government of the Republic of Suriname; Ministry of Spatial Planning and Environment
Project	:	Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge.
Subject	:	Report on drought risks and water in Suriname
File/ Code	:	IS-471
Acronym	:	ARADIS project
Author	:	J.J. Pape, B. Bolhuis
Contributions/Validation	:	F. Verhagen, J. Groen, R. Wong Loi Sing, R. Ramkisoen
Authorisation	:	R. Patandin
Date	:	08 May 2025