

Evaluating The Role of Top Soil Properties and Climate on Suitability of Rubber Plantation: A Geographical Study in Badalkumbura Divisional Secretariat Division

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Abstract:

Temperature and rainfall fluctuations, along with soil degradation, significantly impact the rubber plantation distribution, productivity, and economic viability of farmers. This study examines the combined influence of topsoil characteristics and climate on the suitability of rubber plantations in the Badalkumbura Divisional Secretariat Division. Land Surface Temperature (LST) analysis was conducted in 2014 and 2024 to assess temperature trends, while rainfall and temperature variations from 2011–2024 were analyzed using data from the Department of Meteorology and represented graphically. Soil quality was determined through laboratory analysis of samples collected from 25 Grama Niladhari Divisions among 41 Grama Niladhari Divisions in Badalkumbura Divisional Secretariat Division, focusing on parameters such as pH, electrical conductivity (EC), moisture content (MC), and texture. Inverse Distance Weighted (IDW) interpolation was used to generate soil suitability maps. Multiple regression analysis was applied to assess the relationship between climatic and soil variables and rubber plantation patterns. The LST analysis identified a notable increase in land surface temperature from 2014 to 2024. From 2011–2024, minimum temperature consistently met the requirements for rubber, yet maximum temperature occasionally exceeded 34°C, especially in Yala seasons, potentially limiting productivity than the Maha season. Rainfall conditions during some Maha seasons were favorable and corresponded with periods of increasing market prices, encouraging plantation expansion. On the basis of pH, EC, MC, and texture, while none of the GN divisions meet all four suitability parameters, many meet three and are therefore recognized as priority zones for plantation establishment. The areas of Hingurukaduwa, Dewathura, Ankada, Ethpattiya, Ranugalla, and Miyanakandura were identified as highly favorable for rubber. These optimal places fall within Badalkumbura V, particularly "Ihala Kandukaraya". In correlation, temperature, rainfall, and soil quality were found to moderately influence rubber plantation trends in Badalkumbura. Finally, this study provides valuable insights for identifying suitable plantation zones and highlights the importance of integrated climate-soil management and policy support for sustainable rubber cultivation in Badalkumbura.

Keywords: Climatic Variability, Land Surface Temperature (LST), Multiple Regression Analysis, Rubber Plantation Suitability, Top Soil Characteristics

1. Introduction

Far in the tropics, where heat, humidity, and fertile soils converge, a quiet agricultural giant has been constructing livelihoods and economies for centuries—the *Hevea brasiliensis*, or rubber tree. Formerly native to the Amazon

Basin, this remarkable species produces a milky latex that, when processed, is natural rubber, a vital raw material for industries ranging from automotive and manufacturing to healthcare to footwear (Natural Rubber Production, 2021). The story of how rubber came to travel from its South American homeland to the Asian interiors is a history of botanical acclimatization, colonial enterprise, and economic transformation.

Rubber plantations, a long-term yield agriculture system, are today dispersed across the world's humid tropics. The crop grows exceedingly well in regions with high rainfall, well-drained soils, and year-round warm temperatures. Thailand, Indonesia, Malaysia, Vietnam, and India are the chief producers. Among them, Thailand is the largest producer of natural rubber, producing 4.7 million metric tons in the year 2023, nearly one-third of the world's natural rubber (Statistics., n.d.). Despite its Amazonian origins, Asia now accounts for approximately 90% of global production, with Southeast Asian nations collectively accounting for approximately 70% of export value in 2022. The world's largest consumer is China (Natural rubber production,2024).

Sri Lanka has a unique place in the history of rubber. In 1876–1877, the British Colonial Office identified Ceylon as an ideal location to cultivate rubber seedlings before distributing them to the Indian subcontinent. The initial plants were planted under the direction of George Thwaites in the Henarathgoda Botanical Gardens in Gampaha. Commercial cultivation began in 1883, and by 1928, rubber acreage had grown to 214,000 hectares (Natural Rubber and Rubber-Based Products from Sri Lanka, 2021). Although the current extent has decreased to approximately 138,000 hectares, national productivity has been improved by superior varieties and enhanced cultivation practices (Handbook of Rubber—Volume 1).

In Sri Lanka, the Badalkumbura Divisional Secretariat Division (DSD) is a non-traditional but major rubber-growing region. Badalkumbura comprises 4,539.71 hectares of rubber plantations belonging to 8,370 cultivators with 41 Grama Niladhari (GN) divisions (Rubber Development Officer's Office, Badalkumbura, 2025). Planting density averages 108 trees to the acre (162 to the hectare), and optimal productivity is set at 620 metric tons to the hectare. Output quality is categorized into five grades, with Grades 1–3 representing 70% of production and Grade 5 accounting for only 5%. Plantation coverage in Badalkumbura varies annually due to fluctuating soil conditions as well as climatic factors.

Sri Lanka has four major rainy seasons, two of which are inter-monsoon seasons. There is heavy rain during the Southwest Monsoon (May–September) targeting the southwest and the Northeast Monsoon (December–February) targeting the north and east. Widespread thunderstorms constitute the First Inter-monsoon (March–April), and the Second Inter-monsoon (October–November) delivers rainfall to the whole island (Herath C. et al., 2024). Rubber has clearly defined environmental needs. The crop thrives in altitudes below 750 m with more than 1,250 mm rainfall and 20°C to 34°C, preferably 25°C to 28°C, temperature in traditional production regions (Harbor, 2024; Badalkumbura Rubber Development Officer's Record, 2025). Suitable soils are deep, clay-loamy, well-drained, and rich in organic matter content with sufficient sand for aeration and sufficient clay for water retention. Soil quality in terms of pH, organic matter, texture, and moisture directly affects the viability of the plantation (Herath, Badalkumbura Rubber Development Officer's Record, 2025). The both meteorological and agricultural factors important to the drought mitigation strategies (Fasna MRF & Herath HMKCW, 2025). Under the changing climate, the frequency of the drought has been increasing and it is the most disturbing weather event to the livelihood of farmers particularly in the dry zone of Sri Lanka (Herath C, 2024).

Apart from agronomy, rubber cultivation is also a source of rural economic growth. In Badalkumbura, expanding plantation extent has boosted household incomes, consolidated local enterprise, and maintained foreign exchange earnings. Proper planting practices, i.e., maintaining 6–7 m between trees, facilitate sunlight penetration, air circulation, and availability of resources that are critical to healthy growth and optimal latex production (RRI, 2021).

This study situates itself here. It does not attempt to measure yield but instead examines the spatial extent and temporal evolution of rubber plantations in Badalkumbura, focusing attention on the contributions of topsoil

conditions and climatic variables. By identifying the most suitable places for future cultivation, the research seeks to support sustainable agriculture planning in non-traditional rubber cultivation regions so that the legacy of *Hevea brasiliensis* continues to grow in harmony with environmental constraints as well as economic targets.

2. Material and Methods

Primary and Secondary data used for this study. As primary data collection field observations conducted in rubber plantations across Badalkumbura DSD, Interviews with key stakeholders including farmers and rubber plantation officers, Soil sample collection (25 purposive samples taken) across the DSD.

Here, soil sample collected from the study area of covering Badalkumbura DSD. Badalkumbura have five Rubber Divisional Officers Divisions (RDOs). Which means five sub areas. Those are categorized according to the elevation levels. Those are five categories in there, Badalkumbura (I) to Badalkumbura (IV). Among 41 divisions, 25 GN divisions chosen to this study within all the RDO divisions. This 25 sample GNs choose according to the land area of the five RDOs in Badalkumbura DSD.

Equation: Sample size = Land area * 25/100

In field observation physically looks how about the rubber plantation, its physical healthiness, the well growth and distribution of plantation area amount etc. in Badalkumbura DSD. During interviews, the information expected from rubber farmers or residents only includes matters such as whether the areas under rubber cultivation in the relevant GND have expanded more than before. But it was information obtained on factors such as suitable soil, suitable climate, and topography for rubber cultivation during interviews with rubber development officers. In laboratory analysis for topsoil quality assessment, those lab tests done in the Natural Resources (NR) Department's soil laboratory and Biology laboratory in Faculty of Applied Sciences of Sabaragamuwa University of Sri Lanka (SUSL) and the Export Agriculture Department's Chemistry laboratory in Faculty of Agriculture of SUSL. This lab assessment done on various days at both faculty laboratories.

As secondary data sources this study expected to get Rubber plantation areas distribution data from the Rubber Development Officer's Institute, rainfall and temperature data from the Department of Meteorology, Sri Lanka, published research articles, and institutional reports and, resource profile of Badalkumbura DSD.

2.1. Study Area

The study area of this study is Badalkumbura DSD. It is one of the eleven divisional secretariats in the Monaragala District of the Uva Province of Sri Lanka. The relative location of the Badalkumbura DSD is on the western border of the district and is surrounded by various administrative boundaries. To the north, it is bordered by the Madagama DSD and the boundary of the Badulla District. The southern border is shared with the Butthalahala and Wellawaya DSDs, while Monaragala DSD lies to the east; on the western side, it is bounded by the administrative boundary of the Badulla District. The absolute location of the Badalkumbura DSD is 6.87250 N latitude and 81.21750 E longitude. The total land area of the Badalkumbura DSD is 22,941.52 hectares, and it has a population of 50,107. The division is administratively organized into 41 Grama Niladhari (GN) divisions.

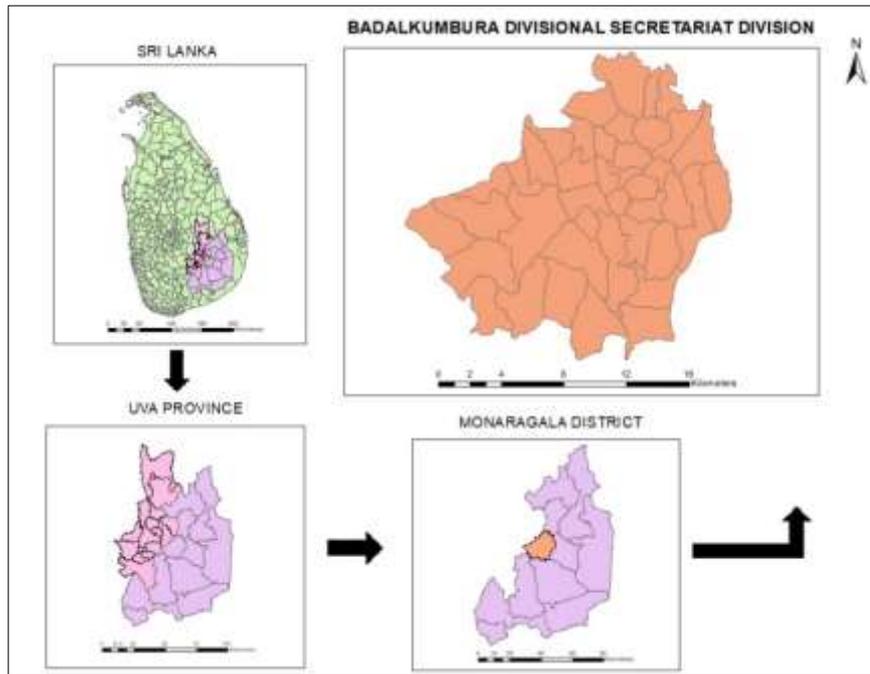


Fig. 1. Study Area Map

Monaragala - Badulla Road is the main road to access Badalkumbura. Apart from that, Badalkumbura can be accessed through Buttala - Badalkumbura road and Medagama - Badalkumbura road. The administrative activities of Badalkumbura Division are organized around Badalkumbura town. The divisional secretariat, regional hospital, regional council, agricultural service center, police, main post office, banks and other major institutions are located in the center of Badalkumbura town. So it has been possible to meet the daily needs of the people.

2.2. Data Collection

Primary and secondary data are expected to be used for this study. As primary data collection field observations were conducted in rubber plantations across Badalkumbura DSD, Interviews with key stakeholders, including farmers and rubber plantation officers; soil sample collection (25 samples taken) across the DSD; and laboratory analysis for topsoil quality assessment, focusing on soil pH levels, texture, moisture content (MC), and electronic conductivity (EC).

As secondary data sources, this study expected to get rubber plantation area distribution data from the Rubber Development Officer's Institute, rainfall and temperature data from the Department of Meteorology, Sri Lanka, published research articles, institutional reports, and the resource profile of Badalkumbura DSD.

2.3. Analysis Techniques

Statistical Analysis: Identifies rainfall and temperature variations using MS Excel. Also in here, Analyzes the relationship between climatic factors and rubber plantation distributed areas through graphical representations.

Laboratory Analysis: In laboratory analysis for topsoil quality assessment, those lab tests done in the Natural Resources (NR) Department's soil laboratory and Biology laboratory in Faculty of Applied Sciences of Sabaragamuwa University of Sri Lanka (SUSL) and the Export Agriculture Department's Chemistry laboratory in Faculty of Agriculture of SUSL. This lab assessment done on various days at both faculty laboratories. Here Laboratory analysis did for topsoil quality assessment, focusing on: Moisture Content, Soil pH levels, Electrical Conductivity and Texture.

Table 1 Soil MC Tested Details

Parameter	Location	Date	Time
Soil Moisture	Biology Laboratory of the NR Department	05/21/2025	09.30 a.m.- 11.30 a.m.
Soil Moisture	Biology Laboratory of the NR Department	05/22/2025	01.30 p.m.- 03.30 p.m.



Fig.2. Moisture Content Testing Process

Equation: $MC = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} * 100\%$

Table 2 Soil Ph and Soil EC Tested Details

Parameter	Location	Date	Time
Soil Ph	Chemistry Laboratory of the Export Agriculture Department	05/23/2025	02.00 p.m.- 5.00 p.m.
Soil EC	Chemistry Laboratory of the Export Agriculture Department	05/23/2025	02.00 a.m.- 05.00 p.m.



Fig.3. Preparation the Soil Samples for Ph and EC Test



Fig.4. Checking the Ph and EC in Soil

Table 3 Soil Texture Tested Details

Parameter	Location	Date	Time
Soil Texture	Soil Laboratory of the NR Department	26/05/2025	11.00 a.m.- 4.00 p.m.
Soil Texture	Soil Laboratory of the NR Department	27/05/2025	9.30 a.m. – 2.30 p.m.



Fig.5. Preparing Soil Samples for Testing Soil Texture



Fig.6. Measuring Soil Layer Levels

GIS Analysis: Used for spatial data analysis of climatic and soil parameters. Analyzes, interprets, and visualizes rainfall and temperature data. Identifies the most suitable areas for rubber plantations based on soil quality. Creates temperature variability maps (LST) using satellite imagery. Develops a suitability map using Inverse Distance Weighting (IDW) interpolation.

Correlation Analysis: Identifies the relationship between soil quality, climatic factors, and rubber plantation areas using SPSS software. Uses multiple regression analysis to determine key influencing factors.

3. Results and Discussion

3.1. Relationship Between Climatic Factors and Rubber Plantation Areas

The temperature-rubber plantation growth relationship in Badalkumbura DSD was evaluated mainly through temperature and rainfall analysis. Land Surface Temperature (LST) satellite data displayed a tremendous increase

between 2014 and 2024. But this LST map can be low accuracy because of the cloud cover and other weather conditions related to satellite images. Therefore, it is important to also use data from the Meteorological Department for get results of this objective.

The minimum temperature for rubber cultivation is 20°C according to the Rubber Research Institute (RRI) and Rubber Development Officer's Department (RDO). During 2011–2017, all months were higher than this, including January 2017 at 22°C. Consistent suitability would likely have sustained plantation stability throughout this six-year interval.

Before 2015, 6131 ha of rubber were cultivated in Badalkumbura, but no specific figures were available annually. After 2015, the cultivation areas fluctuated: the minimum of 6.38 ha in 2016 rose dramatically to 21.47 ha in 2017, and it was the start of a sustained increase. Numbers of farmers also showed similar patterns, depending on climatic suitability and market requirements. Price history between 2000 and 2024 revealed peaks in 2011, 2017, and after 2021. The 2017 price increase coincided with the expansion of plantations, facilitated by a decline in pepper prices, which encouraged farmers to plant rubber instead. Interviews also verified that economic incentives played an important part in planting choices.

The maximum temperature limit for rubber is 34°C. Some months in 2014 and especially in 2016 reached above this (e.g., 35.3°C in July 2016), which contributed to the lower plantation coverage and fewer farmers. Price drops between 2012 and 2016 were another aggravating factor. Conversely, 2017 experienced fewer exceedances, as expected, along with higher prices and greater planting.

From 2018 to 2024, there were different years that had temperature exceedances, particularly for March–October. In 2019, there were six months above 34°C, which led to a 25 ha loss and 47 fewer farmers compared to 2018. Similarly, in 2020, there were different months that exceeded the limit, reducing area and farmers even with changing prices.

On the other hand, 2023 had mostly sufficient maximum temperatures except for June–August. Farming lands and cultivators kept on growing significantly due to overall proper conditions and pre-set prices. By 2024, although four months exceeded the limit, the area totaled 94.39 ha and 193 cultivators with the assistance of rising prices. The Yala season (May–August) was more often in excess of the highest tolerances compared to the Maha season (September–March), although making the latter more generally conducive to rubber. Minimum temperatures, however, were well within the desirable range in 2018–2024, underpinning base potential growth. Annually means never exceeded the 34°C peak level, with the maximum being around 35.5°C and below 32°C at the lowest in graph. This indicates short-term monthly peaks, and not annual means, have a greater effect on limiting plantation growth.

Rubber requires 2,000–3,000 mm of annual and 167–250 mm of monthly rain. During 2011–2017, rainfall months were never normal. Examples are January 2017 (168.7 mm), May 2016 (238.8 mm), and October 2012 (231.1 mm). Five months were exceptional in the year 2017 when the maximum plantation and farmer development happened at this time.

Seasonally, Maha rainfall was generally superior to Yala, which was inordinately short. This difference also impacted plantation timing and success rates.

From 2018 to 2024, rainfall suitability was greatly varying. January 2021 (193 mm), April 2021 (204.3 mm), May 2023 (168.3 mm), and September 2019 (291.7 mm) were the most critical suitable months. The years with more than one suitable month experienced noteworthy area gains. For example, 2021 had the best Maha season rainfall, with an additional plantation of 27 ha and a rise of 56 farmers from 2020. The Yala season again underperformed on rainfall suitability, being only occasionally within the necessary range. This limited growth during years like 2020 and 2022 even with other favorable factors. Years that reached the 2,000–3,000 mm annual mark were 2011, 2015, 2019, 2021, 2022, 2023, and 2024. The peak of the year was in 2023 at 2,512.1 mm and accompanied by enormous plantation development. Price increases consonant with these years also further augmented the cumulative effect of economic and climatic forces.

Results confirm that the dynamics of rubber plantations in Badalkumbura DSD depend on how climatic suitability and market conditions interact. While minimum temperatures were rarely limiting, maximum temperature exceedances and rainfall shortfalls in the dry season—especially in Yala—limited growth in some years. Moderate

climatic constraints are countered by high prices, as in 2023–2024, while low prices heightened unfavorable conditions, as in 2016. The largest increases occurred when climatic favorability combined with high prices, such as in 2017 and 2021. As seasonal observations the Maha Season usually more favorable, with a higher number of months satisfying both temperature and rainfall parameters. Yala Season higher frequency of temperature exceedances and rainfall deficiencies, which restrict planting opportunities.

Key relationships in temperature excess of maximum temperature in specific months reduced area planted, even when annual averages were within range. Rainfall distribution of rainfall by month and season was more effective than annual totals in compelling expansion. Economics Patterns of price had a strong influence on planting, sometimes dominating moderate climatic constraints. Seasonality the Maha season consistently presented better climatic planting conditions than the Yala season.

Outcomes are that rubber plantation development in Badalkumbura must prioritize Maha season planting to optimize climatic windows available. Monitoring monthly maximum temperature heights and rainfall trends can be used to guide planting timing and reduce climate-related hazards. Merging climatic predictions with market prices can optimize planting periods, securing growth during years of good climate and high price. Supporting farmers during unprofitable Yala seasons, e.g., through irrigation or shade management techniques, might also smooth out yields.

The climatic conditions and economic incentives interrelate to decide the spatial and temporal arrangement of rubber cultivation in Badalkumbura DSD. While minimum temperatures are always ideal, withstanding maximum temperature variability and rainfall uncertainty—particularly during Yala—is unavoidable. Timing plantation operations with favorable climatic conditions and strong market prices is the sole promise for sustainable growth in this non-traditional rubber-producing region.

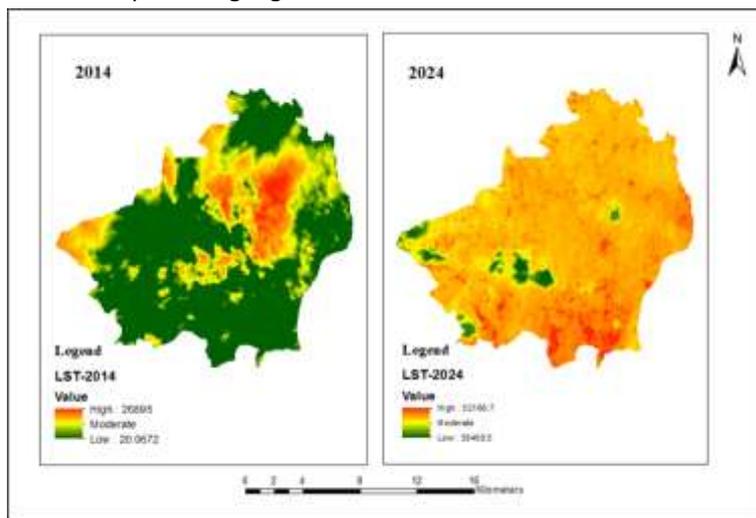


Fig.6. Land Surface Temperature Variations Between 2014 – 2024 in Badalkumbura DSD

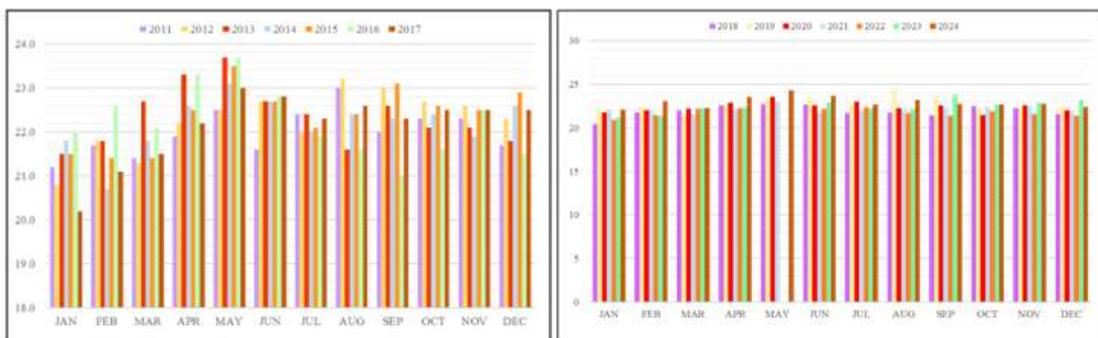


Fig.7 & 8. Monthly Min Temperature Variations of the Badalkumbura DSD in 2011-2024

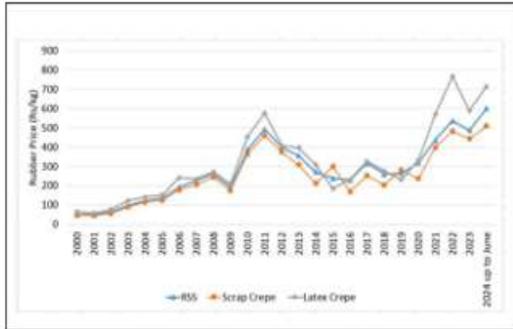


Fig.9. Changes Observed in Yearly Averages of Auction Prices for RSS, Scrap and Latex Crepe from 2000-2024th June, in Sri Lanka

Table 4 Rubber Plantation Area and Farmer's Distribution

Year	Hectares	Farmers
Before the 2015	6131.234	8260
2015	9.565	19
2016	6.375	10
2017	21.47	36
2018	68.752	125
2019	43.611	78
2020	21.262	33
2021	48.508	89
2022	40.668	64
2023	71.14	142
2024	94.388	193

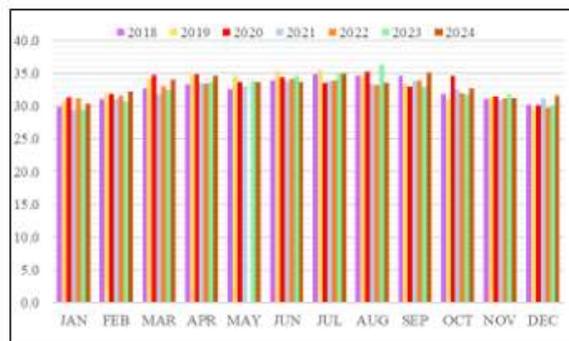
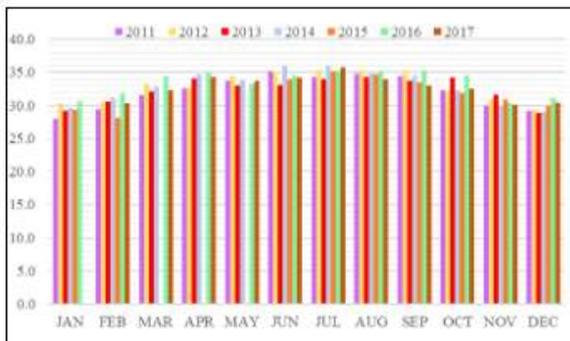


Fig.6. Monthly Max Temperature Variations of the Badalkumbura DSD in 2011-2024

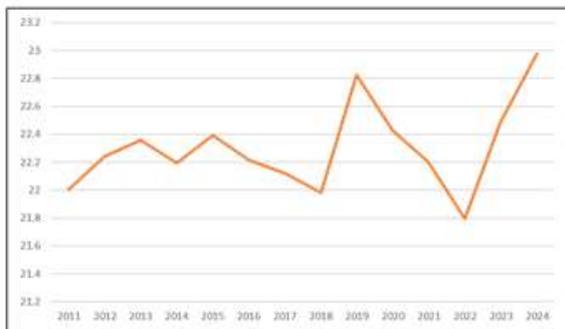


Fig. 7. Annual Min Temperature Variations of the Badalkumbura DSD in 2011-2024

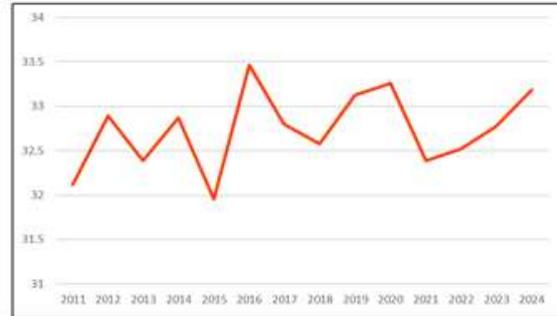


Fig. 8. Annual Max Temperature Variations of the Badalkumbura DSD in 2011-2024

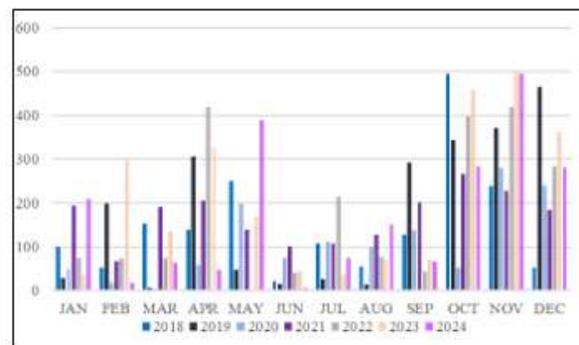
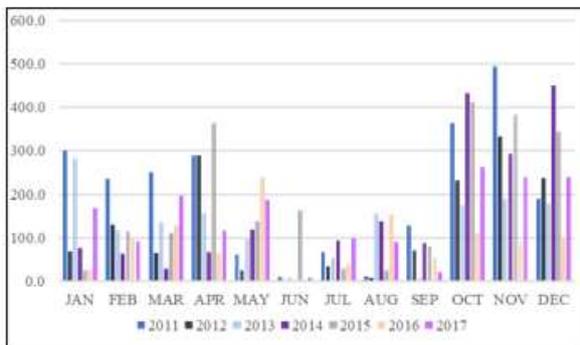


Fig. 9 & 10. Monthly Rainfall Variations of the Badalkumbura DSD in 2011-2024

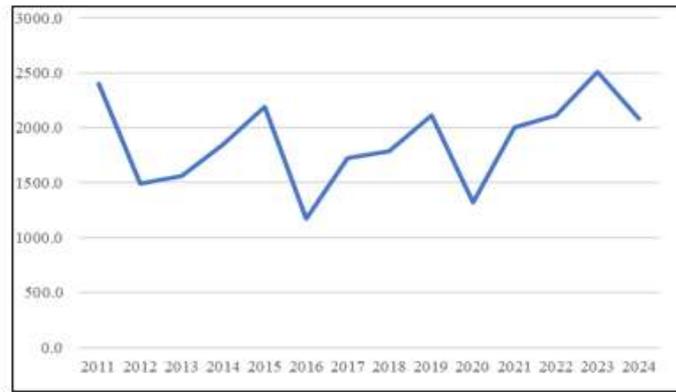


Fig. 11. Yearly Rainfall Variations of the Badalkumbura DSD in 2011-2024

3.2. Topsoil Characteristics and Rubber Plantation Suitability in Badalkumbura DSD

Topsoil parameters are crucial to determine the productivity and success of rubber plantations. Favorable parameters of good-quality soil not only ensure healthy tree growth but also offer higher latex yield, resulting in more revenue for farmers. In this study, four of the most significant soil parameters—pH, Electrical Conductivity (EC), Moisture Content (MC), and Texture were considered to identify the most suitable places for rubber cultivation in Badalkumbura DSD.

pH Value

Crop compatibility is highly influenced by soil pH since it determines nutrient availability and root development. According to Rubber Research Institute standards, the most suitable rubber-compatible pH ranges between 4.0 and 6.0. The spatial map (Figure 12) shows the compatible pH zones colored in light green to cream-green—are patchy along the western border of the DSD. Key GN divisions within suitable pH include Ethpattiya, Dambagahawela, Miyanakandura, Hingurukaduwa, Keliwessa, and Dewathura. The Ankada, Kotamunduna, Madugasmulla, and Ranugalla sections are also under this requirement. Grounds outside of these areas fall outside the range of suggested pH, potentially limiting rubber growth without soil additives.

Electrical Conductivity (EC)

Electrical conductivity, although not having direct influence on plant growth, is an important factor of salinity level and nutrient availability (USDA Natural Resources Conservation Service, 2011). For rubber, soils with EC 0–4 mS/cm are optimum. Figure 13 shows that optimal EC levels, in very dark brown and dark brown, are again predominant in western regions. GN divisions such as Ankada, Ranugalla, Kotamunduna, and some pieces of Miyanakandura, Athpattiya, Dewathura, and Dambagahawela have EC levels at the recommended level. This trend highly overlaps with favorable pH zones, which means western Badalkumbura may have a natural advantage in soil chemistry to grow rubber.

Moisture Content (MC)

Water content is a significant trait for rubber trees since they require constant soil moisture to thrive and yield latex. According to the RRI, 35–45% is a favorable range for rubber. Figure 14 shows favorable MC zones in very light brown, cream, and ash-mixed light blue colors. These areas fall in both the northwest and northeast areas and are scattered in the central-western areas. Suitable GN divisions are Ankada, Kotamunduna, Madukotandarawa, Madugahapattiya, Ella, Pallegama, Karandagama, Dewathura, and some pieces of Dambagahawela, Hingurukaduwa, Alupotha, Gedawila, Ranugalla, Miyanakandura, Waradola, and Ethpattiya. While other areas may support rubber, they lack the optimal MC range and may require irrigation or water management practices.

Soil Texture

Soil texture, the relative proportions of sand, silt, and clay, is a non-variable property that plays an important role in water-holding capacity, drainage, and root penetration. Rubber prefers loams of 23–52% in the most favorable texture range (RRI, 2021). Figure 15 illustrates that favorable textures, light- to medium-orange-colored, are

widespread in the south and west. GN subzones such as Hingurukaduwa, Keliwessa, Lunugala Janapadaya, Muthukeliyawa, Punsisigama, Kalagahakiula, Aththalamulla, and parts of Bogahapelessa, Yakurawa, and Waradola meet these criteria. This indicates that while texture suitability is general, it is not universal throughout the DSD.

Integrated Soil Quality Analysis

By overlaying the four parameters—pH, EC, MC, and texture—a clearer picture is achieved (Figure 16). The maps indicate that no subclassification of GN meets all four parameters in an equal manner, but there are a few that achieve three out of four and are therefore very appropriate for rubber plantations.

The GN divisions that are best compatible with pH, MC, and EC are Ankada, Ethpattiya, Ranugalla, Dewathura, and Miyanakandura. Hingurukaduwa is the only GN division that exactly fulfills the requirement of pH, MC, and texture. It is noteworthy that all these GN divisions fall within the "Ihala Kandukaraya" area of Badalkumbura V, which also meets the required elevation standards for rubber cultivation.

Other subunits miss one or two requirements, where improvement is possible through targeted soil management. Kotamunduna, for example, conforms to EC and MC requirements, whereas Keliwessa and Bogahapelessa are inadequate in pH and texture. Measures such as pH adjustment, the use of organic matter, or irrigation may enhance suitability in such subunits.

The results show an extremely strong geographical pattern: the western half of Badalkumbura DSD is always the most favorably suited for rubber farming, both chemically and in terms of soil structure. This concurs with prevailing patterns of actual plantation area in the region, with existing rubber-growing areas overlapping these high-quality areas of soil.

The significance of pH, EC, MC, and texture cannot be overemphasized. pH influences direct nutrient uptake, EC indicates the level of nutrients and salinity, MC defines the availability of water, and texture influences water retention as well as root development. They are the pillars of a successful rubber plantation.

A deficiency of any GN division meeting all four criteria suggests that even in the most favorable areas, some management is needed to fine-tune conditions for growth. For instance, while Ankada lists pH, MC, and EC requirements, its texture lies outside ideal loamy levels, which could have implications for drainage and root development. Similarly, Hingurukaduwa lacks optimal EC but possesses a suitable texture.

These findings also align with overall environmental and economic patterns in this research. GN divisions of highest soil suitability are generally the same divisions that show resiliency in plantation area and farmer numbers even through periods of climatic stress. This suggests that favorable soil conditions may buffer against adverse weather, maintaining profitability and yield.

It is, however, to be noted that soil quality does not guarantee success on its own. Climatic factors such as temperature and rain patterns, discussed elsewhere in this study, have an impact on soil factors closely. Even a GN division with the best of soils can fail if it is affected by prolonged drought or heat spells. Conversely, those with low-quality soils can thrive sometimes under accommodative weather, although it may come at the expense of long-term sustainability.

Spatial mapping of soil suitability gives good guidance for future plantation planning. Development planning should target intensely suitable places, that is, Ankada, Ethpattiya, Ranugalla, Dewathura, Miyanakandura, and Hingurukaduwa. These areas not only have a strong correlation of soil parameters but also lie in an elevation class favorable for rubber. For other less optimal sites, certain treatments could add to possible areas of plantation. Such soil treatments as organic matter addition (for structure and water improvement), and controlled irrigation (to fill MC deficits) could add more GN divisions to the range that is optimal. In addition, such findings would prove valuable in enabling more efficient allocation of resources by the Rubber Development Department. Extension services could focus training and inputs in areas with high suitability so as to yield maximum returns, while research would look into the cost-effective upgrading of marginal lands.

Joint analysis of pH, EC, MC, and texture provides the basis to conclude that soil quality is a major factor determining spatial distribution and potential productivity of rubber plantations in Badalkumbura DSD. While none of the GN divisions meet all four suitability parameters, many meet three and are therefore recognized as priority zones for plantation establishment. Situated in the "Ihala Kandukaraya" area, these zones offer a

reasonable ground for sustainable rubber cultivation, provided soil management and climatic adaptation strategies are employed.

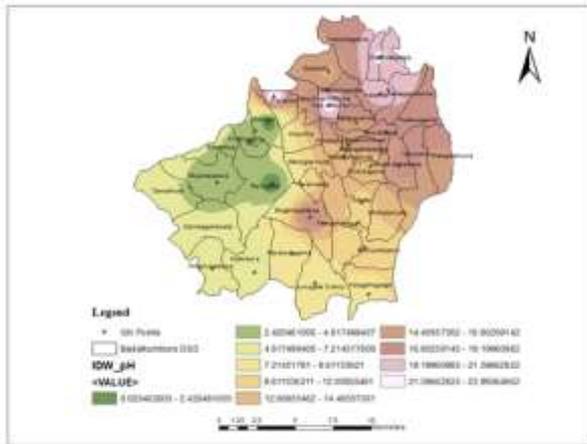


Fig. 12. Soil pH Value of the Badalkumbura DSD

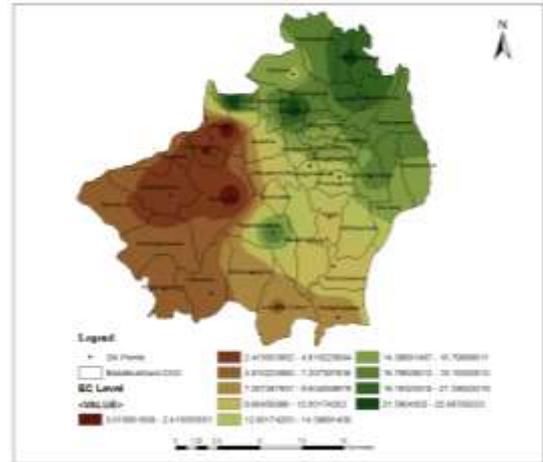


Fig. 13. Soil EC Values of the Badalkumbura DSD

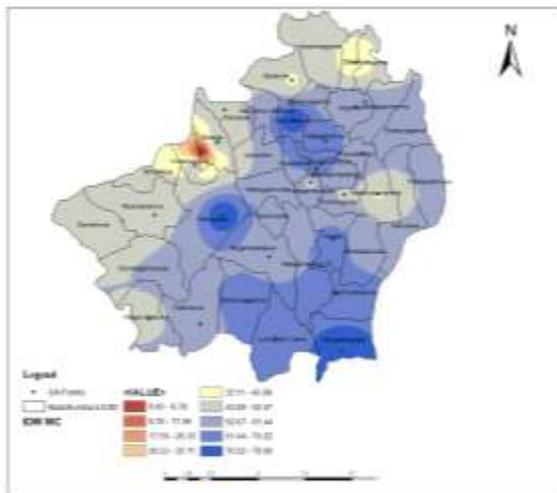


Fig. 14. Soil Moisture Content Levels of the Badalkumbura DSD

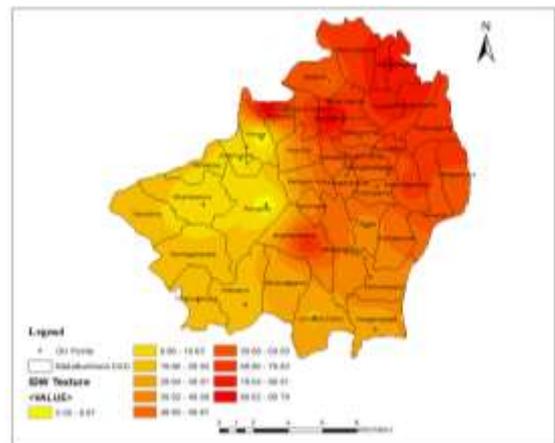


Fig. 15. Soil Texture Values of the Badalkumbura DSD

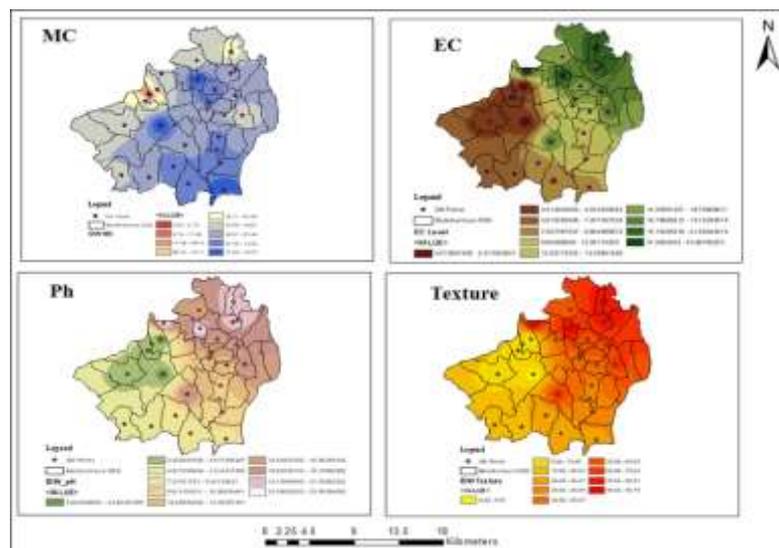


Fig. 16. Soil MC, EC, pH, and Texture Distribution in Badalkumbura DSD

Table 5: Soil Quality Levels for Rubber Plantation

Parameter	pH	EC	Texture	MC
	Power of Hydrogen	Ms/cm	%	%
Suitability Level	Around 4 - 6	0 – 4	23 - 52	35 - 45

3.3. Combined Suitability of Soil Quality and Climate on Rubber Plantation Areas

This study identifies the combined influence of soil quality and climatic conditions on rubber plantation areas within the Badalkumbura Divisional Secretariat Division (DSD), integrating statistical analysis, spatial data, and climatic data from 2011–2024.

Climate Trends and Relationships

The correlation matrix and model summary, supported by scatterplots and P–P plots, show clear relations between year, temperature, and rainfall. Annual temperature has a moderate positive correlation with time ($r = 0.328$) and shows an overall upward trend throughout the period of observation. Annual rainfall has a negative correlation with year ($r = 0.272$) and shows a marginal upward trend. Interestingly, rainfall is negatively correlated with temperature ($r = -0.533$), and hence years of higher rainfall tend to be cooler—a remarkable environmental correlation that will propel rubber development.

The above is graphically validated in Figure 18. It has year vs. temperature – moderate positive trend, year vs. rainfall – weak positive trend and, rainfall vs. temperature – clear downward trend. The ANOVA result for the regression model indicates an overall borderline significance ($p = 0.068$), just above the traditional critical value of 0.05. While the full model explains just 39% of variance in year, the individual predictors are significant:

Rainfall ($B = 0.007$, $p = 0.047$) – Each mm increase is estimated to lead to a 0.007-year increase. Temperature ($B = 6.301$, $p = 0.037$) – Each degree Celsius increase is estimated to lead to a ~6.3-year increase. The P–P plot demonstrates that the errors are normally distributed, justifying the model's reliability despite its moderate explanatory power. The scatterplots also support the linearity assumption of year and climate variables.

Soil Quality and Plantation Areas

The P–P plot of plantation area against soil parameters (pH, EC, MC, and texture) has residuals nearest to following the line as expected, representing normal distribution and high correlation between GN divisions and the quality of soil. The residual scatterplot shows randomness in distribution within ± 2 , indicating no outliers and proving the appropriateness of the model.

The Durbin–Watson statistic of 1.081 is within the desired range (1–3), reflecting independence between observations. The R^2 of the regression model of 0.655 suggests that soil quality explains 65.5% of the variance in plantation areas across the 25 GN divisions—a tremendous influence. The ANOVA table shows statistical significance ($F(4,20) = 3.772$, $p < 0.0005$), confirming the goodness of fit of the model.

Multicollinearity tests show no severe issues (all VIF < 5), while pH and EC are moderately correlated ($r = 0.707$, $p < 0.01$). Among the soil parameters, pH and EC are the strongest predictors that explain most of plantation area differences.

Climate and Soil Effects on Plantation Area

Scatterplot analysis related to the yearly variation in plantation area, indicates wide fluctuations from 2011–2024. Climatic variation, including temperature and rainfall variation, is the cause of the changes but accounts for merely about 39% of the variance. This moderate relationship suggests that although climate contributes to the development of rubber, other variables, including soil fertility, land availability, and agricultural practices, are as significant or even more significant.

After the year 2022, plantation plots show a consistent rising trend along with favorable rainfall and temperature cycles. The climatic–plantation relationship, though moderate, shows that higher rainfall and increasing temperatures can both promote growth under desired environmental conditions.

Soil quality factor parameters exert significant influence on plantation area changes. Places with desirable pH, EC, MC, and texture values consistently exhibit increased plantation cover. Plantation area improvements post-2022 could be partly attributed to soils being present in ideal ranges, as well as desired climatic conditions.

Integrated Suitability Findings

In combining climatic and soil quality data, the results emphasize that the GN divisions most suitable for rubber cultivation—Hingurukaduwa, Dewathura, Miyanakandura, Ethpattiya, Ankada, and Ranugalla—are the ones with favorable soil characteristics and climatic conditions within guidelines suitable for rubber growth. Those GN divisions have the optimal pH and EC – stimulating nutrient absorption and providing proper soil chemistry balance, proper Moisture Content – reducing drought stress and allowing for latex production, proper Texture – with proper drainage and enough moisture holding and, favorable Climate – temperatures ranging from 20°C to 34°C and precipitation more than 1250 mm annually.

Geographical concurrence of favorable climatic conditions and high-grade soils in these areas promises strong potential for rubber cultivation on a sustainable scale. This also aligns with the observation that such GN divisions fall within the "Ihala Kandukaraya" area, which meets elevation specifications for rubber.

The results validate that both climate and soil quality play outstanding contributions in plantation distribution and extent in Badalkumbura DSD, although their relative contribution differs. Climate contributes a noticeable but moderate influence (39% explanatory value), perhaps due to short-term oscillation and sensitiveness of rubber trees in some ranges. Soil quality contributes a more definite and long-lasting influence, explaining 65.5% of plantation variation.

Increased effect of soil parameters suggests that expansion planning requires site-specific land valuation and soil management procedures. While temperature and rainfall are not as controllable, soil conditions can be improved through practices such as liming to adjust pH, adding organic matter to improve structure and MC, or implementing salinity controls where EC is high. Particularly noteworthy is the inverse relationship between temperature and precipitation, a trade-off effect whereby wetter years are cooler, which could be to the benefit of immature plantations but could be to the detriment of tapping activities through over wetness. Drier, warmer years could reduce disease risk but increase drought stress, especially in soils with a low MC retention capability. The joint analysis also indicates that climatic suitability is not enough to ensure plantation success. Even in good climatic zones, adversely conditioned soils may restrict growth and productivity. This observation highlights the need for integrated land evaluation methods, as pursued in this research, taking into account both soil and climate elements at the same time.

The combined spatial and statistical analysis confirms that soil quality is the major driver of rubber plantation area, while climate exerts a moderate but significant influence. The best places—Hingurukaduwa, Dewathura, Miyanakandura, Ethpattiya, Ankada, and Ranugalla—are benefited by best soil characteristics in addition to climatic conditions that meet the standards for rubber plant growth. These results provide a good basis for concentrated development planning, choosing areas of high climatic and soil suitability. Adaptive management and soil enhancement could in less favorable areas lengthen the ranges of productive plantations, but cautious consideration of long-term climate trends is still necessary.

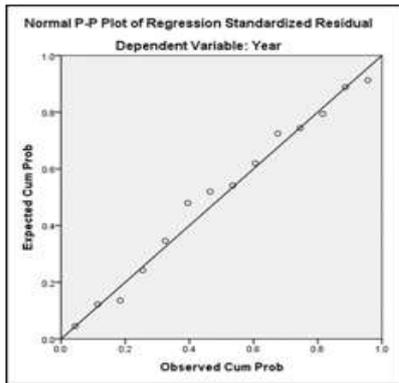


Fig. 17. Normal P-P Plot of Regression Standard Residual Between Year, Temperature, and Rainfall (2011-2024)

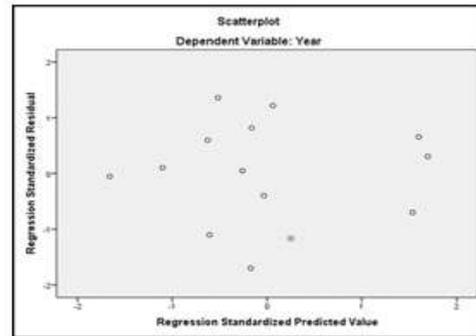


Fig. 18. Scatterplot of the Correlation Between Year, Rainfall and, Temperature (2011-2024)

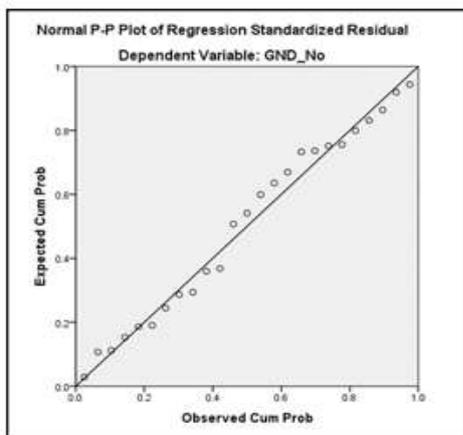


Fig. 19. Normal P-P Plot of Regression Standardized Residual Between Soil EC, MC, pH, and Texture in Badalkumbura DSD

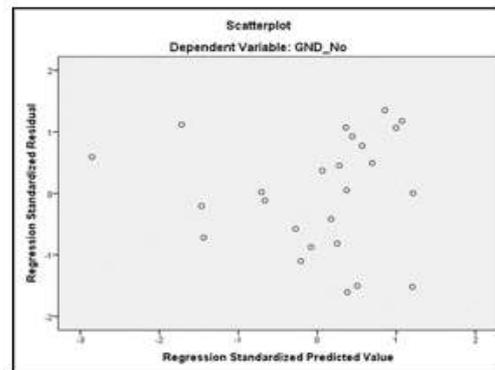


Fig. 20. Scatterplot of Residuals (Usually Residuals vs. Predicted Values)

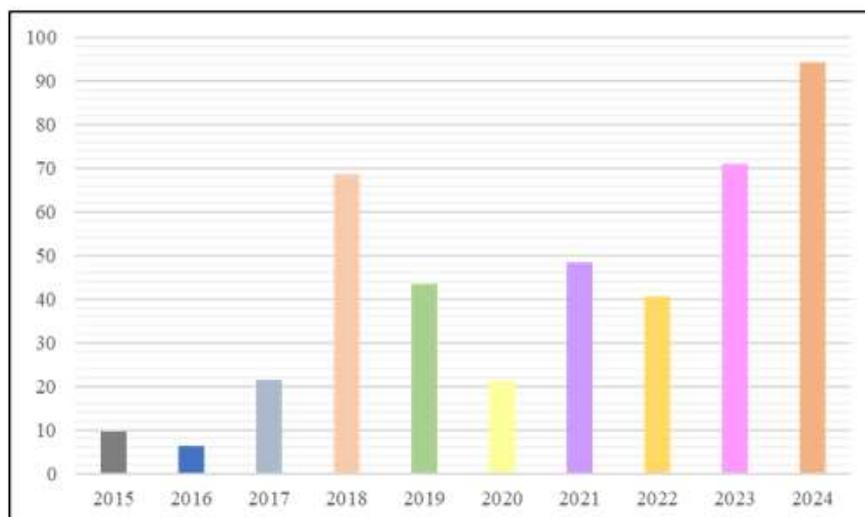


Fig. 21. Yearly Rubber Plantation Areas Distribution in the Badalkumbura DSD by the Hectares

4. Conclusions

The research assessed the effect of topsoil status and climatic status on the suitability and expansion of rubber plantations in the Badalkumbura Divisional Secretariat Division (DSD). The findings show that both climate and soil are drivers of plantation viability, with their intersection determining long-term productivity and sustainability.

Rubber plantations, cultivated primarily for latex, are vital for industries worldwide, and Badalkumbura DSD in Sri Lanka is endowed with vast potential for their cultivation. However, productivity is often undermined due to limited understanding of the environmental conditions required. This study used GIS, remote sensing, analysis of meteorological data (2011–2024), laboratory soil analysis, and multiple regression analysis to determine the cumulative effect of temperature, rainfall, and soil quality parameters (pH, electrical conductivity [EC], moisture content [MC], and texture).

Climatic analysis indicated the apparent warming trend in the recent decade. Land Surface Temperature (LST) comparison between 2014 and 2024 indicated the pronounced shift towards warmer temperatures, with cooler zones shrinking considerably. Maximum temperatures occasionally exceeded the 34°C threshold, negatively impacting plantation growth in certain years (e.g., 2014–2016). The trends of rainfall displayed seasonal variation, with the Maha season relatively more favorable for rubber growth compared to the Yala season. The year 2017 was the turning point when favorable rainfall, moderate weather, and the rising price of rubber triggered significant plantation growth. After 2022, a rise in both climatic and market conditions led to relentless growth. Soil analysis identified main GN divisions with optimum conditions for rubber cultivation: Hingurukaduwa, Dewathura, Ankada, Ethpattiya, Ranugalla, and Miyanakandura. These areas met a number of suitability criteria pH (4–6), EC (0–4 mS/cm), MC (35–45%), and loamy texture (23–52%) and are concentrated within the Badalkumbura V area, locally known as "Ihala Kandukaraya."

Regression analysis indicated that climatic factors explained about 39% of the variation in plantation cover, and both temperature and rainfall were significant predictors. The soil quality indicators explained a higher percentage 65.5% with EC and pH being the most influential variables. This suggests that, as much as climate variability influences short-term change, soil conditions have a more intense and stable influence on plantation suitability.

Together, the findings emphasize that the best plantation sites are where good soil conditions coincide with favorable climatic regimes. While climate trends particularly temperature rise and unpredictable rainfall can both favor and undermine expansion, soil quality determines the fundamental potential for long-term productivity. Strategically focused investment in these high-potential GN divisions, supported by climate monitoring and adaptive farming practices, can maximize yields and economic dividends.

In short, permanent cultivation of rubber in Badalkumbura DSD is a function of integrating both climatic and soil considerations in planning. Priority should be assigned to locations like Hingurukaduwa, Dewathura, Miyanakandura, Ethpattiya, Ankada, and Ranugalla, where the synergistic impact of good climate and suitable soils offers optimum scope for profitable rubber cultivation on a long-term basis.

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How to cite/reference this article: H.M.A. Chalani, H.M.K.C.W. Herath, Evaluating The Role of Top Soil Properties and Climate on Suitability of Rubber Plantation: A Geographical Study in Badalkumbura Divisional Secretariat Division, *Asian. Jour. Social. Scie. Mgmt. Tech.* 2026; 8(1): 111-128.