



Integrating Indicators in Agricultural Vulnerability Assessment to Climate Change

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Abstract Climate change stands as one of the most pressing challenges confronting global ecosystems and human livelihoods. The agriculture sector of Anuradhapura district, Sri Lanka, well renowned for its pivotal role in the nation's food production, faces an increasing threat from the changing climate. This study aims to incorporate the indicator system method which uses a set of indicators to assess the agricultural vulnerability (AV) to climate change in Anuradhapura district. The AV assessment used in this study involves three principal components exposure, sensitivity, and adaptive capacity. The indicators are normalized to allow spatial analysis and smooth integration within a geographic information system (GIS) framework. The AV of Anuradhapura district ranged from 0.32 to 0.67 and was divided among five levels very low, low, moderate, high, and very high. The findings suggest that Anuradhapura's agricultural sector was significantly impacted by climate change as the majority of the total area was found to have very high, high, and moderate levels of AV with 25, 28, and 24%, respectively. The results obtained from this study are essential for formulating plans to improve Anuradhapura's agricultural sector resilience and adaptability to ensure food security and livelihood sustainability considering the ever-changing climate.

Keywords Agricultural vulnerability · Anuradhapura district · Climate change · Resilience and adaptability · Vulnerability assessment

Introduction

Global climate change has drawn the attention of governmental bodies and the academic community worldwide as a serious environmental issue that could impact humanity's existence and future growth [46]. Agriculture is one of the industries most susceptible to future climate change, and it

has been the focus of numerous research in recent years [1, 2, 4, 43]. The largest global user of freshwater resources is certainly agriculture. For the majority of people in developing countries, agriculture serves as their primary source of income and employment which makes a sizable contribution to gross domestic product (GDP). Thus, losses in agricultural output brought on by future climate change

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could significantly harm the living conditions of the poor in rural areas [5]. Agricultural vulnerability (AV) to climate change has significant impacts on loss and damage in terms of crop productivity, food security, and economic consequences. Climate change can lead to a reduction in agricultural production, overgrowth of weeds, increase of parasites, changes to soil water content, and negative impact on production costs and quality [9, 22, 31, 40, 41]. Therefore, identifying the AV due to climate change and its impact is crucial for understanding the magnitude of challenges faced by communities.

The Anuradhapura district in Sri Lanka serves as a primary contributor to the country's paddy production and is recognized as the 'Heart of Sri Lanka's Rice Bowl.' This designation highlights its vital role in the national rice cultivation landscape. Anuradhapura, being located in the dry zone of Sri Lanka, encounters extended periods of drought and a decrease in the annual frequency of rainy days [6, 10, 13, 26]. A study indicates that traditional farming districts in Sri Lanka, such as Nuwara Eliya, Badulla, Monaragala, Ratnapura, and Anuradhapura, display a greater susceptibility to the impacts of climate change compared to other regions. This intensified sensitivity is attributed to their heavy reliance on primary agricultural activities [11]. Therefore, a detailed investigation of AV caused by climate change stands as an immediate challenge in the Anuradhapura district, Sri Lanka. The degree to which an agricultural system is susceptible to or unable to handle the adverse effects of climate change, such as climate variability and extreme occurrences, is known as vulnerability in agriculture [29]. The IPCC defines vulnerability as the degree to which a system is susceptible to adverse effects of climate change, taking into account the character, magnitude, and rate of climate variation to which the system is exposed, its sensitivity, and its adaptive capacity. Thus, vulnerability can be expressed as a function of exposure, sensitivity, and adaptive capacity, as defined by the IPCC [17].

There are various methods to assess AV to climate change. One such method is using statistical analysis where data can be gathered from maps, surveys, measurement stations, or interviews [9, 19]. Although this method is simple and requires less data, it may be difficult to implement this in certain locations [46]. The use of various models is another method adopted in vulnerability studies. Most of the models focus on a set of factors that are the most sensitive to climate change in that particular study area [42]. Models such as the Agricultural Catchments Research Unit (ACRU) model [14, 51], the Soil Water Balance (SWB) model [28, 35], The Agricultural Production Systems Simulator (APSIM) [30, 50], AquaCrop [25, 53], Decision Support System for Agro-technology Transfer model (DSSAT), and Environmental Policy Integrated Climate (EPIC) model [49] have been applied extensively in the field of agricultural management. Assessing AV using these methods in developing countries

like Sri Lanka is a challenging task due to limited data availability.

Therefore, the indicator method, a bottom-up strategy, was chosen to be used in this study based on data accessibility and availability. This approach has been widely used in many studies [16, 32, 34, 36, 44, 52]. Despite the method's proven effectiveness and widespread application, Sri Lanka has not yet seen a sufficient number of in-depth AV research initiatives. Hence this study intends to determine the AV of Anuradhapura district and assess the impact of each indicator on AV. Seven indicators under the three categories of exposure, sensitivity, and adaptive capacity were identified as appropriate for this study. These indicators are the coefficient of variation (CV) of precipitation, heavy rain, and hot days, agricultural land ratio and Topographic Wetness Index (TWI), poverty, and the density of irrigation works. The indicators were normalized as they are measured using different units and scales. The spatial data was processed in a geographic information system (GIS) environment to produce maps for exposure, sensitivity, adaptive capacity, and AV. The findings from this research offer valuable insights for planning and establishing guidelines to assist farmers in Anuradhapura.

Study Area

Anuradhapura district, located in the North Central province of Sri Lanka, is a region that is of great historical, cultural, and agricultural significance. It covers around 2624.19 km² of area which is around 3.8% of Sri Lanka's total land area. Anuradhapura district consists of 21 divisional secretariat divisions (Fig. 1).

The annual rainfall in Anuradhapura typically varies between 1250 and 2000 mm, mainly attributable to the northeast monsoon. The average annual temperature in Anuradhapura is 28.5 °C [10]. Geographically, the district shares its borders with the Vavuniya district to the north, Trincomalee district to the east, Matale district to the south, and Puttalam district to the west. The people who live in the Anuradhapura district primarily make their living from paddy cultivation. Additional revenue streams include the fishing industry, businesses, industries, and service sectors. The region is well known for its irrigation systems based on tanks, especially small rainfed tanks [10, 26]. There are 3365 ha of rainfed paddy fields, 23,922 ha of irrigated paddy fields, 5668 ha of minor irrigated paddy fields, and 21,850 ha of upland areas in the Anuradhapura district. Approximately 34,000 ha are used for paddy cultivation during the Maha season (September to March) and 24,000 ha during the Yala season (May to August) [12]. The land use and land cover map of the Anuradhapura district are shown in Supplementary Fig. 1.

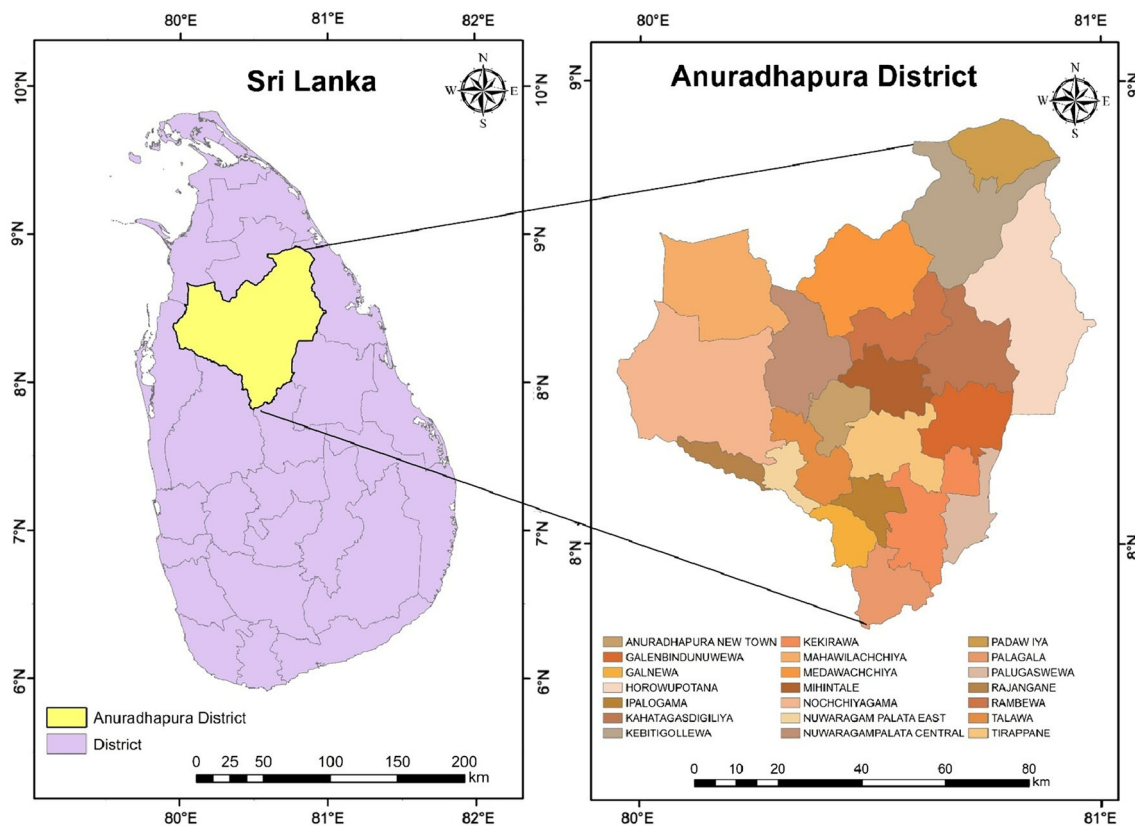


Fig. 1 Anuradhapura district, Sri Lanka

Materials and Methods

Selection of Vulnerability Indicators

Exposure

The indicators of exposure were identified under two main climatic drivers, namely precipitation and temperature. CV of precipitation, heavy rain, and hot days were selected as the indicators of exposure. To assess the CV of precipitation, rainfall data from 2010 to 2020 was collected from three meteorological stations, namely Anuradhapura, Nachchaduwa, and Mahailuppallama. CV of precipitation has a positive functional relationship on AV. Higher CV of precipitation indicates a greater uncertainty in rainfall which can ultimately lead to floods or droughts, where both can negatively impact the crop yield and livestock productivity.

Rainfall is essential for agriculture and farmers commence cultivation onset of monsoonal rains to reduce irrigation water requirements. Cultivations, such as paddy cultivation, are highly vulnerable to fluctuations in rainfall, temperature, and the frequency and intensity of extreme events [7]. According to the meteorological department of Sri Lanka, a day is considered a heavy rainfall day if the

rainfall is above 28 mm/day [3]. Heavy rain has a positive impact on AV. Excess rainfall can harm crop productivity by flooding fields and removing important soils and seeds. Additionally, the growth of fungi and bacteria is encouraged by wet weather, which may result in additional crop damage [18]. A hot day is defined as a day with a temperature above 30 °C [47]. The data used for the average number of hot days was from 2010 to 2020. Hot days have a positive functional relationship on AV. Specifically, high temperatures affect the plant growth stages, and the rate of photosynthesis which will ultimately reduce the crop yields [2, 20, 33].

Sensitivity

The agricultural land ratio and TWI were used to represent sensitivity. The agricultural land ratio is defined as the ratio between the area of agricultural land and the total natural land area. This ratio was evaluated by using satellite images obtained from Landsat 7 and Landsat 8. Agricultural land ratio is positively correlated with AV, where communities that heavily rely on agriculture are more susceptible to the effects of climate change on food security and crop yields. The TWI method specifically examines the topographic characteristics of a given region, particularly

the upper and lower slopes, to evaluate the propensity for water accumulation. Areas with a higher TWI are more vulnerable to climate-related risks because they are more likely to experience waterlogging. Hence, TWI has a positive functional relationship toward AV. Calculations of TWI rely on the topography of the area, which is represented by the digital elevation model (DEM). The DEM used in this study was Shuttle Radar Topography Mission (SRTM) 30 m resolution, and the contour maps were obtained from the Survey Department of Sri Lanka.

Adaptive Capacity

Adaptive capacity depends on factors such as wealth, technology, education, information, skills, infrastructure, access to resources, stability, and management capabilities [15]. Poverty and the density of irrigation works were used as the indicators for adaptive capacity. The poverty indicator in this context was determined by calculating the percentage of households below the poverty line relative to the total population. According to the Department of Census and Statistics of Sri Lanka, a national multidimensional poverty measure has been implemented in the country. This measure utilizes the Alkire-Foster method, which incorporates five key elements: (1) living conditions; (2) income level; (3) access to health and education; (4) access to information; and (5) access to security insurance, social assistance, and average household size [8]. The percentage of households below the poverty line indicates a negative functional relationship toward AV. A higher number of households below the poverty line hinder their ability to invest in adaptive measures in agriculture, making them more vulnerable to climate change. The density of irrigation works was calculated considering the quantity of irrigation works per unit area of agricultural land (per hectare). The density of irrigation works has a positive relationship with AV. Irrigation works play a significant role in agriculture as they contribute to the effective management of water resources in agricultural production. Agricultural systems benefit from irrigation works, which increase resistance to the effects of climate change by reducing excessive flooding during the rainy season and improving drought conditions in the dry season [39]. Therefore in this study, seven indicators under the three categories of exposure, sensitivity, and adaptive capacity were selected, and they were considered to be equally important. Hence, the weights of all indicators were assumed to be equal which will neglect any human subjective errors associated with the indicators.

Data

Data for the study was collected from different sources (Table 1).

Calculation of AV

To calculate AV, the data obtained from each component's indicators was processed in a GIS environment. Since the indicators are measured using different units and scales, they cannot be added together directly. To avoid any scale bias in the final results, they must be converted into standard dimensionless units. Several methods have been proposed in the literature to normalize the influence of units and scales, such as ranking, standardization (i.e., subtracting the mean and dividing by the standard deviation), dividing by its length, and dividing by its mean or any other ideal value. These methods ensure that the final results are not biased by the measurement units or scales used for each indicator.

The spatial data was then interpolated, and a map was created utilizing ArcGIS software (version 10.4) with WGS84 projection. The spatial interpolation method used in this study was the inverse distance weighting (IDW) method. It considers the distance between the neighboring points which builds up the basis for structuring weights for interpolation. Consequently, the final estimate is more heavily influenced by points that are closer to the predicted location [4, 37].

AV was calculated using Eq. (1) [23].

$$AV = \frac{1}{3}(E + S + 1 - AC) \quad (1)$$

where AV: Agricultural vulnerability, E: Exposure, S: Sensitivity, and AC: Adaptive capacity.

The overall methodology framework is presented in Fig. 2.

Results and Discussion

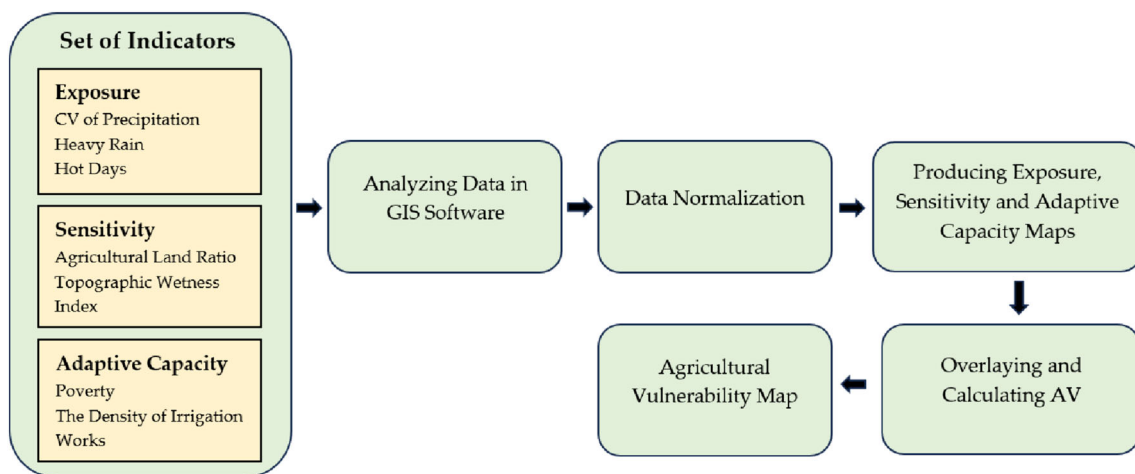
Categorical Assessment Under Exposure, Sensitivity, and Adaptive Capacity

Exposure

The exposure map was generated by combining individual maps of CV of precipitation, heavy rain, and hot days under a GIS environment. Consequently, the CV for precipitation ranges from 33.72 to 24.11% (Supplementary Fig. 2). The highest variability of rainfall was observed toward the southern part of the Anuradhapura district

Table 1 Details of data—vulnerability indicators

Category	Indicator	Data	Unit	Time period	Source
Exposure	CV of precipitation	Rainfall	mm/yr	2010–2020	Department of Meteorology, Sri Lanka
	Heavy rain	Rainfall	mm/yr		
	Hot days	Temperature	°C/yr		
Sensitivity	Agricultural land ratio	Agricultural land area, natural land area	%		USGS—Landsat 7, Landsat 8
	TWI	DEM, contour maps	%		SRTM, Survey Department of Sri Lanka
Adaptive capacity	Poverty	Number of households below the poverty line	%		Department of Census and Statistics, Sri Lanka
	The density of irrigation works	Number of irrigation works per hectare	%		Department of Irrigation, Sri Lanka

**Fig. 2** Methodology framework for AV assessment

which accounted for a frequency of around 34%, whereas other regions showed modest variability.

The number of heavy rain days varied from 6.38 to 18.02 days (Supplementary Fig. 3). The southwestern part of the district experiences frequent heavy rains, whereas the southern part experiences the fewest heavy rain days per year. Figure 3a–c presents the variation of heavy rain days at the three meteorological stations from 2010 to 2020. It was observed that all three stations showed a decreasing trend in heavy rain days during the decade considered.

The third indicator used under the exposure category was the number of hot days per year. Figure 4a–c presents the temporal variation of the number of hot days per year at the three stations considered. All three stations show an increasing trend for the number of hot days from 2010 to 2020. The highest number of hot days per year was around

220 days which was observed toward the southern part of the district (Supplementary Fig. 4). In contrast, the number of hot days in the eastern and western regions ranges from 180 to 190 days. The diminishing occurrence of heavy rainfall days, combined with a rise in the frequency of hot days, indicates an increased susceptibility to extended dry spells and droughts in Anuradhapura. Consequently, the agricultural sector in the region faces an increased risk of adverse impacts from droughts, necessitating better focus and investment in irrigation facilities to safeguard agricultural productivity.

The values obtained under the three indicators were normalized and overlaid to produce the exposure map (Supplementary Fig. 5). The exposure values range from 0.20 to 0.76, and this was classified into five levels, namely very low, low, moderate, high, and very high (Table 2). The highest exposure was mainly concentrated in the

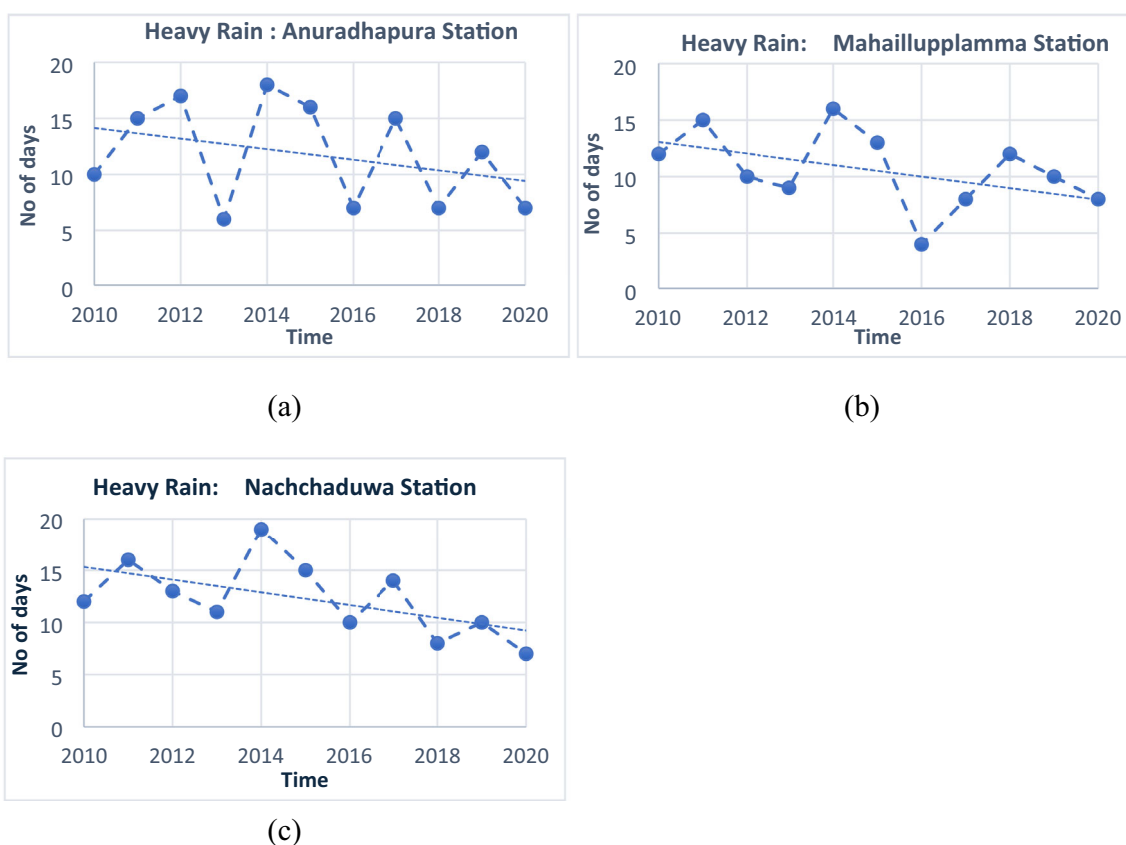


Fig. 3 Heavy rain days **a** temporal variation at Anuradhapura Station; **b** temporal variation at Mahailuppallama Station; **c** temporal variation at Nachchaduwa Station

southern part of Anuradhapura district. This area includes the subdivisions of Galnewa, Kekirawa, Palagala, Ipalogama, and Palugaswewa. The middle range of the Anuradhapura district shows comparatively lower exposure levels. The lowest exposure values were observed at Talawa, Nuwaragam Palatha Central, Nuwaragam Palatha East, Rajanganaya, and Anuradhapura New Town. These areas are less prone to climatic extremes such as droughts, and agricultural systems are less likely to be affected by droughts. Among the 21 subdivisions in the Anuradhapura district, 15 divisions had exposure levels of moderate to very high.

Sensitivity

The indicators used under sensitivity were agricultural land ratio and TWI. The distribution of the ratio between agricultural land and the total natural land area is shown in Fig. 5. Subdivisions starting from the middle toward the southern part of the district were found to have significant concentrations of agricultural land. Areas such as Galnewa, Ipalogama, Rajanganaya, Anuradhapura New Town, and Palugaswewa have a particularly high percentage of agricultural land, exceeding 45%. Among them Rajanganaya,

Galnewa, Ipalogama, and Palugaswewa stand out with large proportions of agricultural land, accounting for 48, 59, 62, and 65%, respectively. Conversely, the western and eastern portions of Anuradhapura show a lower percentage of agricultural land, below 15%, mainly due to the high availability of natural forests and water bodies. The lowest percentage was indicated as 13.5 and 12.4% in Nochchiyagama and Horowupothana.

The distribution of TWI levels across Anuradhapura district is shown in Fig. 6. TWI in Anuradhapura district varies from 6.97 to 23.37%. In the study period considered (2010–2020), the number of hot days is greater than heavy rain days, and hence a moderate range of TWI values was found in Anuradhapura. Higher TWI values were observed mainly near water bodies within the district.

The two indicators under sensitivity were normalized and overlaid to produce the sensitivity map of the Anuradhapura district (Fig. 7). The sensitivity values were classified into five categories depending on the range of values obtained (Table 2). Very high sensitivity levels were observed for areas such as Rajanganaya, Galnewa, Ipalogama, and Palugaswewa. The eastern and western regions of Anuradhapura which includes Nochchiyagama, Kebithigollewa, and Horowpathana were identified as

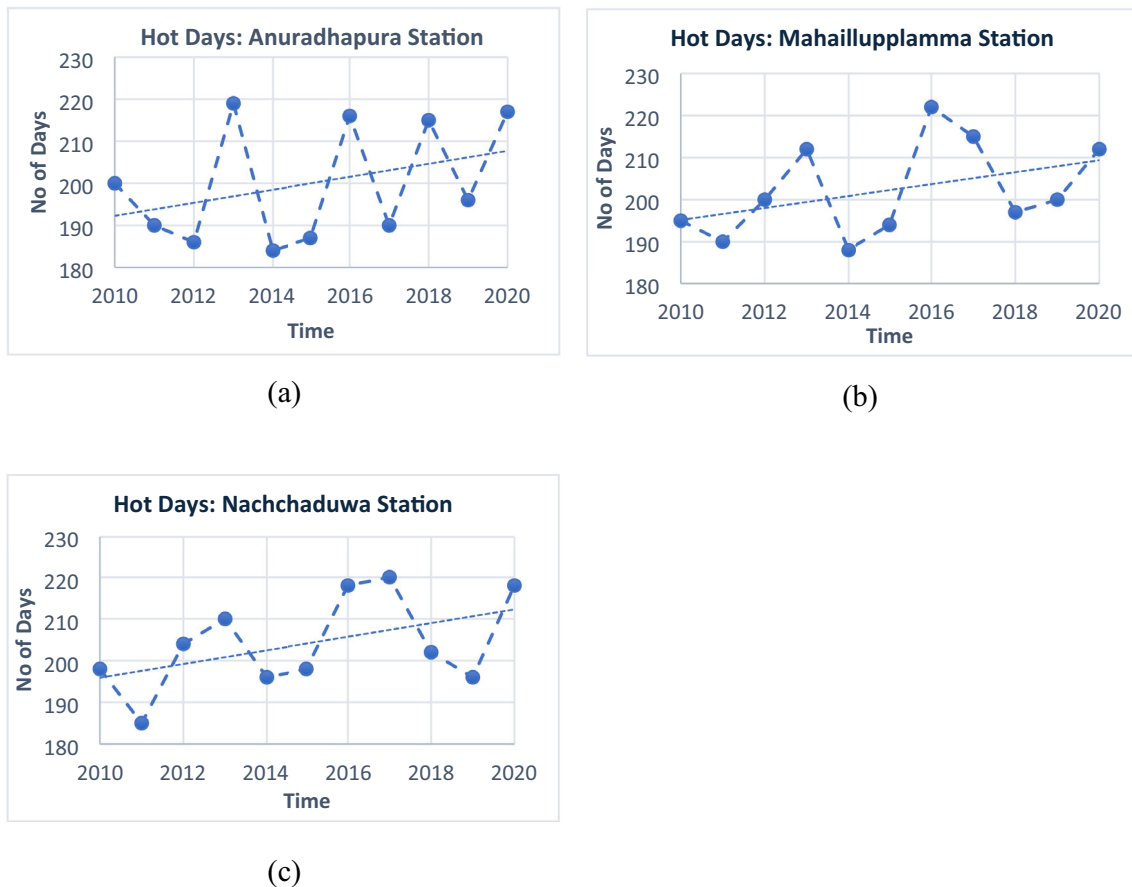


Fig. 4 Hot days **a** temporal variation at Anuradhapura Station; **b** temporal variation at Mahailuppallama Station; **c** temporal variation at Nachchaduwa Station

subdivisions with the least sensitivity values of less than 0.15. The low availability of agricultural lands in Nochchiyagama, Kebithigollewa, and Horowpathana has been the reason for the low sensitivity to AV.

Adaptive Capacity

Adaptive capacity was determined by using two indicators, namely the number of households below the poverty line and the density of irrigation works. The percentage of households below the poverty line is shown in Fig. 8. The Household Income and Expenditure Survey (HIES) conducted by the Department of Census and Statistics, Sri Lanka, once every three years suggests that the minimum expenditure per person per month has increased significantly during the period from 2010 to 2020 but the monthly income levels have not increased substantially during this period. The subdivisions with the highest poverty rates are Kekirawa and Nuwaragam Palatha Central, with values of 7.3 and 7.5%, respectively, while Thirappane shows the lowest poverty rate at 1.2%. High poverty rates were observed due to the low availability of agricultural lands

and irrigation facilities in these areas. Areas with a higher proportion of impoverished households face greater challenges in adapting to climate change.

The second factor considered was the density of irrigation works. Irrigation systems contribute to water resource management and regulation which is a vital factor for agricultural production. In the Anuradhapura district, irrigation is supplied for each season in five main zones, namely Padaviya, Rajanganaya, Anuradhapura New Town, Huruluwewa, and Nachchaduwa. The Irrigation Department of Sri Lanka has conducted several projects to supply water from main canals and lakes to the cultivation lands. Therefore, areas with higher numbers of water bodies have a higher irrigation density than other areas. Figure 9 shows the density of irrigation infrastructure per unit area (hectare), with Rajanganaya, Padaviya, Nuwaragam Palatha East, Talawa, and Anuradhapura New Town having the highest number of projects, which exceed 1.9 works per hectare of agricultural land. In contrast, Nochchiyagama shows the lowest density of irrigation infrastructure which is less than 0.3 works per hectare. It is conclusive that areas with a higher percentage of agricultural land had higher

Table 2 Classification criteria for exposure, sensitivity, adaptive capacity, and AV

Category	Range	Level
Exposure	Less than 0.20	Very low
	From 0.20 to 0.33	Low
	From 0.33 to 0.54	Moderate
	From 0.54 to 0.76	High
	Greater than 0.76	Very high
Sensitivity	Less than 0.15	Very low
	From 0.15 to 0.26	Low
	From 0.26 to 0.51	Moderate
	From 0.51 to 0.78	High
	Greater than 0.78	Very high
Adaptive capacity	Less than 0.1	Very low
	From 0.1 to 0.3	Low
	From 0.3 to 0.5	Moderate
	From 0.5 to 0.7	High
	Greater than 0.7	Very high
AV	From 0.37 to 0.49	Very low
	From 0.49 to 0.55	Low
	From 0.55 to 0.61	Moderate
	From 0.61 to 0.68	High
	From 0.68 to 0.80	Very high

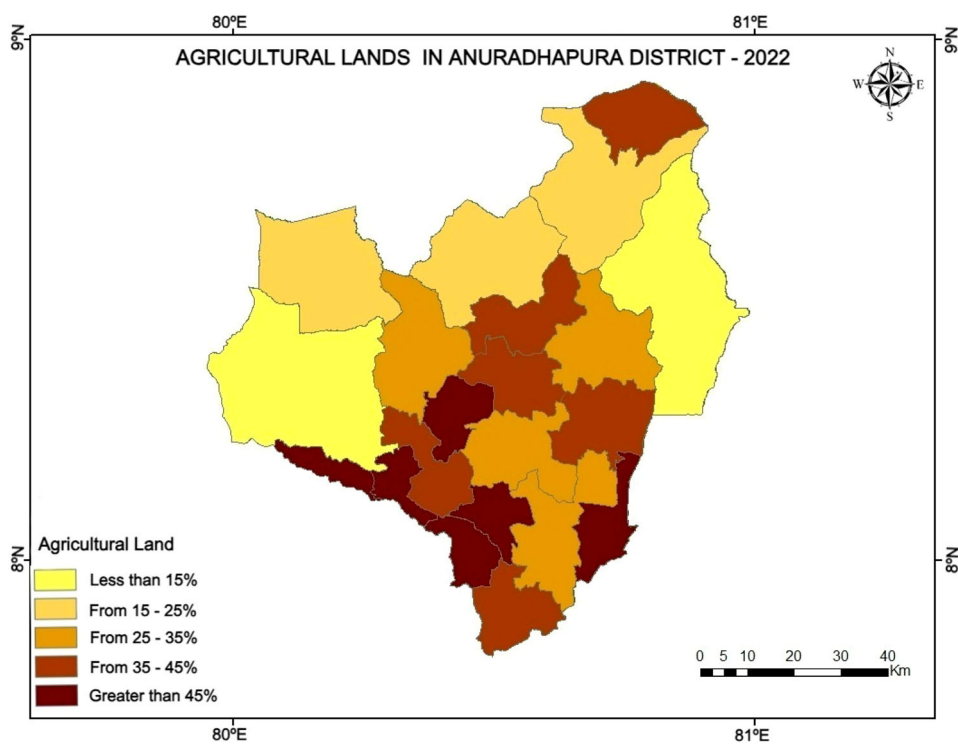
Fig. 5 Agricultural land ratio in Anuradhapura district

Fig. 6 TWI distribution in Anuradhapura district

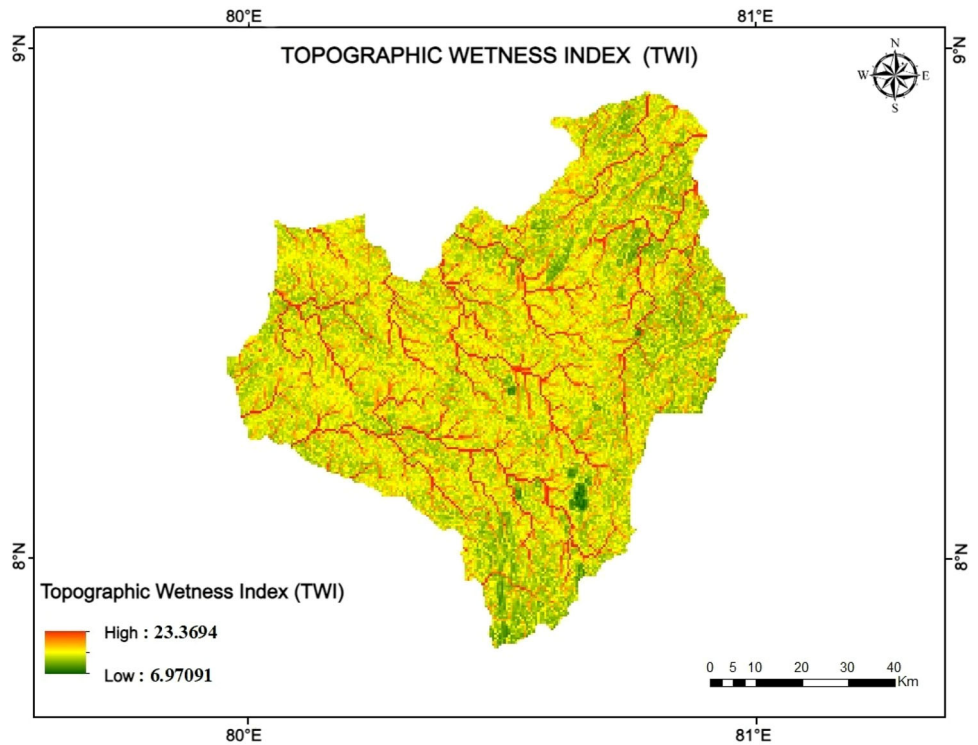
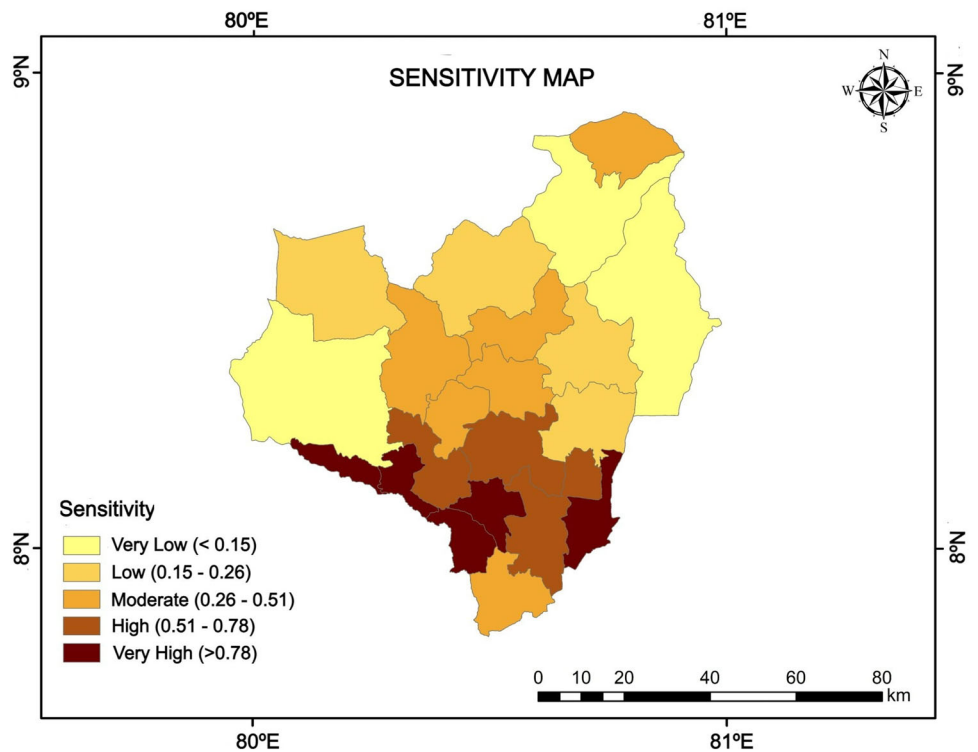


Fig. 7 Sensitivity map of Anuradhapura district



irrigation densities. Higher values of irrigation density indicate greater adaptability, whereas areas with low irrigation density have lower adaptability.

The adaptive capacity map was generated by normalizing the values of the number of households below the

poverty line and the density of irrigation works. After normalization, the maps were overlaid to generate the adaptive capacity map (Supplementary Fig. 6) which ranges from 0 to 1. This was divided into five different categories as listed in Table 2. The highest adaptive capacity

Fig. 8 Distribution of the households below the poverty line in Anuradhapura

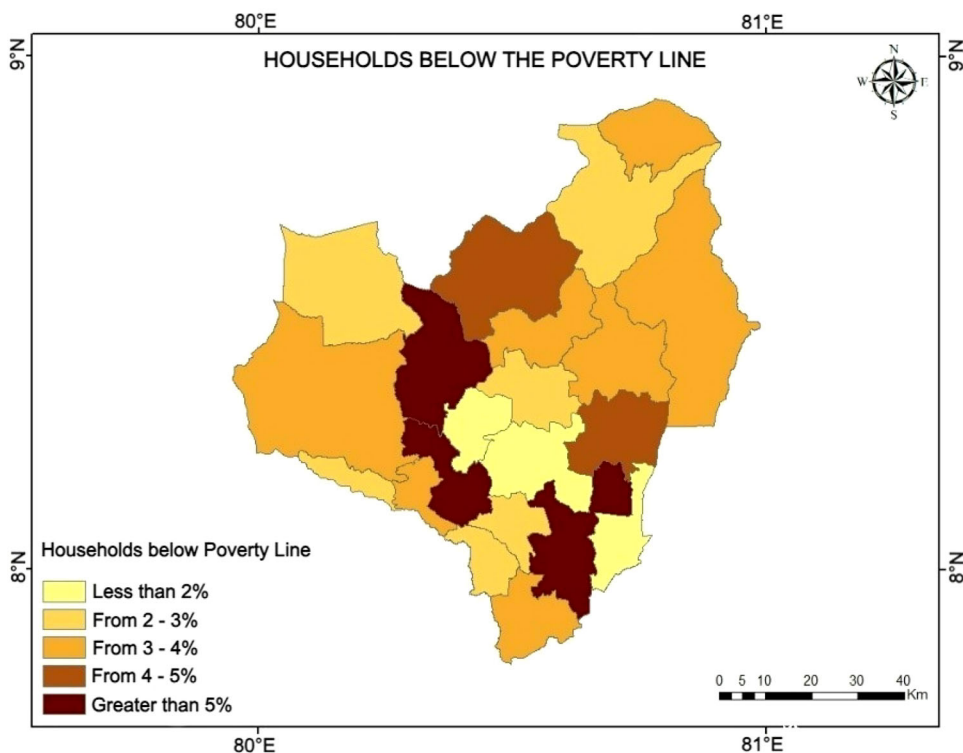
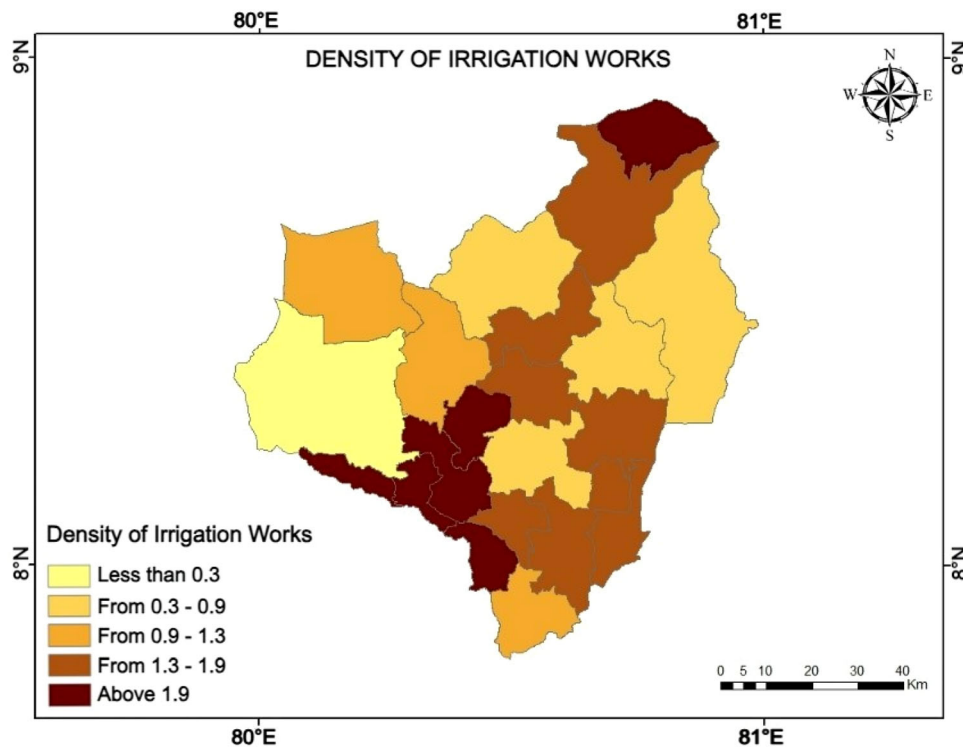


Fig. 9 Density of irrigation works in Anuradhapura



values were observed for Rajanganaya, Galnewa, and Anuradhapura New Town, and the lowest value was given for Nochchiyagama, Kebithigollewa, and Horowpathana divisions.

Among the 21 subdivisions in the Anuradhapura district, in 6 divisions, the adaptive capacity was found to be very high. These areas were mainly urban areas, cities, or towns. The lower values for adaptive capacity can be attributed to the limited availability of agricultural lands and a larger

forest area, contributing to higher unemployment rates. Additionally, the technical efficiency in farming in Anuradhapura is at low levels mainly due to inadequate educational attainment which has resulted in low productivity. The technical efficiency within the district can be improved by raising farmer’s educational status through adult education and agricultural extension services [27].

AV Assessment

The AV of Anuradhapura district was calculated using Eq. (1), resulting in a range from 0.37 to 0.8. This range was divided into five different levels, namely very low, low, moderate, high, and very high as shown in Table 2. The AV zoning map of Anuradhapura is shown in Fig. 10. Nochchiyagama and Horowpathana experience the highest AV whereas divisions such as Rajanganaya, Talawa, Anuradhapura New Town, Rajanganaya, Nuwaragam Palatha East, a part of Thalawa, and north of Padawiya experience lowest AV values. Classification of AV levels into percentages reveals that very high AV levels make up 24.9% of the total area, while areas with high, moderate, low, and very low AV levels account for 28.4, 23.5, 16.2, and 7%, respectively (Fig. 11). Overall, out of the 21 divisional secretariats, more than half were found to have high or very high levels of AV.

The largest areas under very high levels of AV were observed at Nochchiyagama (94,263.3 ha) followed by Horowpathana (84,897.4 ha) (Fig. 12). These two

Agricultural Vulnerability Distribution

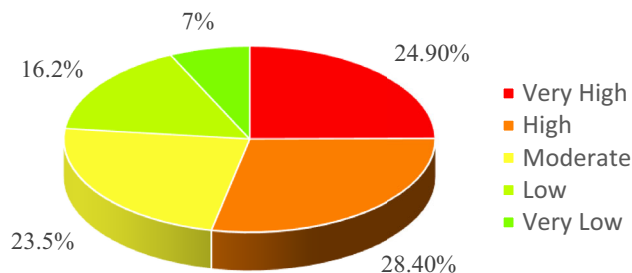


Fig. 11 Percentage-wise distribution of AV in Anuradhapura

subdivisions are highly vulnerable, mainly due to their very low adaptive capacities. Factors such as poor economic background, technology, education, and infrastructure make these areas more vulnerable. On the other hand, Mahavilachchiya and its neighboring division Nochchiyagama face extremely difficult periods during droughts as their irrigation potential is low []. Kekirawa, Ipologama, Kebithigollewa, and Medawachchiya are regions characterized by high levels of AV, covering an area of 29,896.3, 4536.8, 58,868, and 52,921.3 ha, respectively. These areas are heavily influenced by a high number of hot days and subsequent crop failures. This statement gains support from a study that highlights the likelihood of future drought occurrences in Kekirawa and Kebithigollewa, as indicated by the Standardized Precipitation Index [24]. However, the adaptive capacity of these regions is relatively low which

Fig. 10 AV zoning map of Anuradhapura

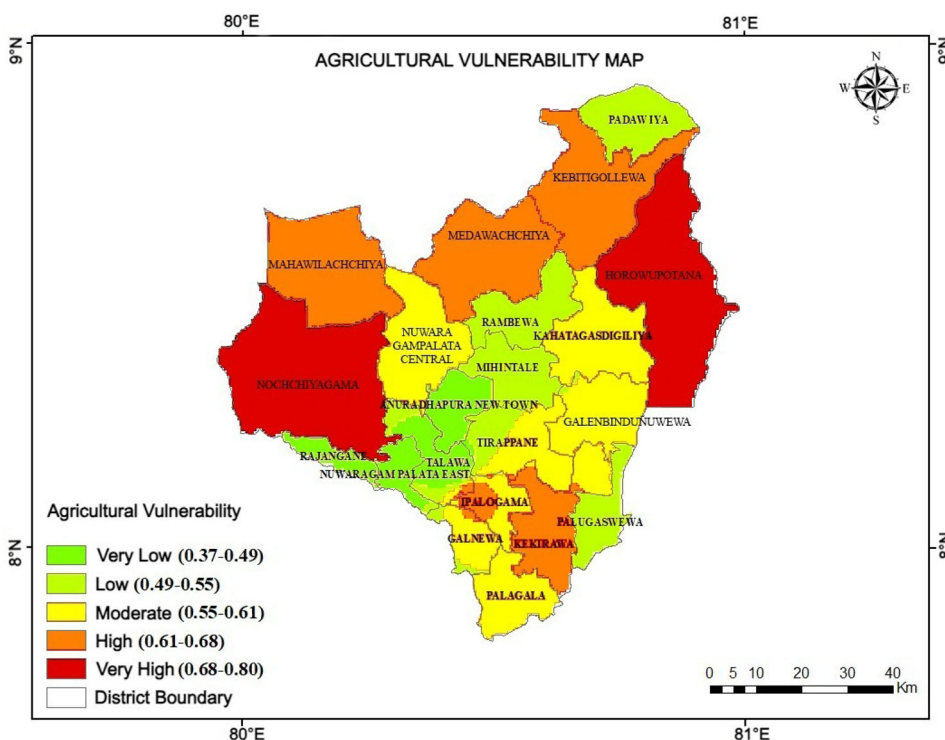
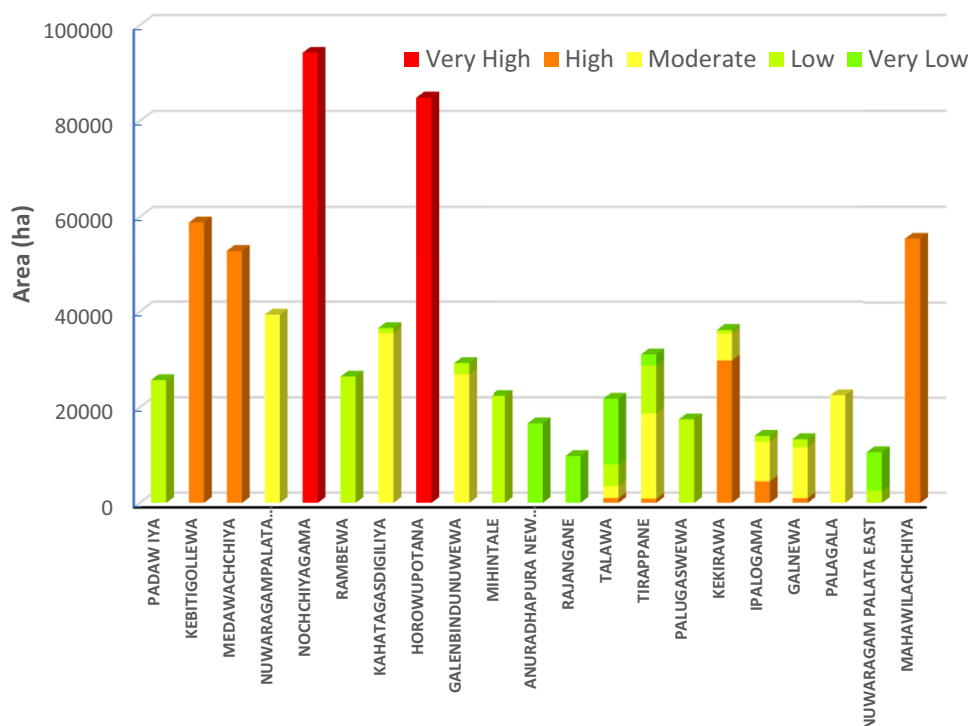


Fig. 12 Area distribution by AV levels



has collectively resulted in high vulnerability levels. Regions characterized as low AV were found in Padawiya, Rambewa, Palugaswewa, and Talawa with respective areas of 25,762.9, 26,522.2, 17,526.4, and 4522.6 ha. The lowest AV was observed at Rajanganaya, western part of Talawa, Anuradhapura New Town, and Nuwaragam Palatha East with areas of 9823, 13,797, 16,682, and 8121 ha, respectively. These areas experience more wet spells and will continue to get wetter in the future [24]. On the other hand, these regions have higher irrigation densities such that agricultural systems are well supported with water. Therefore, these regions are more active in agricultural production.

The findings from the study suggest that the agricultural sector in the Anuradhapura district has experienced a significant impact due to climate change. However, there are some limitations in this study. The choice of indicators was based on available literature and the applicability to the context of the study area but it was restricted by the availability of data. According to the authors' knowledge, although there have been studies conducted to assess the AV in Sri Lanka as a whole this is the first in-depth study to specifically assess the AV in Anuradhapura district, which is the main driver of agriculture in Sri Lanka.

Conclusions

The findings of the current study clearly demonstrate that assessing AV based on the three categories of exposure, sensitivity, and adaptive capacity, as per the IPCC framework, is a reliable approach. The study revealed that more than half of the Anuradhapura district experiences high and very high levels of AV. Exposure and sensitivity show positive relationships, while adaptive capacity is inversely related to AV.

Nochchiyagama and Horowpathana were identified as the regions with highest AV. These areas were observed to have moderate to high exposure levels, low sensitivity, and very low adaptive capacities. Areas such as Galnewa, Kekirawa, and Ipologama experience high AV mainly due to their very high exposure levels. These areas that heavily rely on agriculture are likely to experience droughts as a result of the increase in the number of hot days. Regions characterized by the highest adaptive capacity, such as Rajanganaya, Anuradhapura New Town, Thalawa, and Nuwaragam Palatha East, demonstrate the lowest levels of AV. Enhancing adaptive capacity by using measures such as using supplementary reservoirs for water storage, shifting to shorter cycle crop varieties, planting improved varieties to tolerate climatic variations, developing and

strengthening early warning systems that provide daily and seasonal forecasts, adopting modern irrigation and agricultural technologies, and shifting the harvesting period would help to reduce AV in Anuradhapura [21].

In conclusion, despite the high temperatures, the implementation of effective water management strategies by the government would help in mitigating potential crop yield losses due to increased AV. The findings of this study highlight an increasing risk of AV to climate change in the future. This vulnerability assessment has proven to assist in formulating strategic planning measures aimed at minimizing damage and adverse impacts from climate change, particularly within the agricultural sector and, more broadly, the socio-economic landscape of Anuradhapura.

Author Contributions Conceptualization, resources, writing—review and editing, supervision, and project administration were performed by U.R.; methodology and data curation were done by H.K.J.; software, formal analysis, investigation, and writing—original draft preparation were performed by H.K.J. and C.K.; validation was done by C.K. and M.G.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement Data will be available only for research purposes from the corresponding author.

Declarations

Conflict of interest The authors declare no conflict of interest.

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