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Climate change and farmers' perception in Sivakasi taluk, India: a nexus and a suggestion for sustainable water reuse

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ABSTRACT

Climate change poses a major threat to agriculture and food security, especially in developing countries where farmers depend on rainfall and groundwater for irrigation. This paper investigates how farmers in Sivakasi taluk, Tamil Nadu, India perceive and respond to climate change – rainfall and temperature – and its impacts on agriculture. Actual rainfall and temperature data are analyzed using Mann–Kendall test and Sen's slope estimator test, and the results are compared against the farmers' perceptions obtained through a questionnaire survey. The trend analysis showed an insignificant decrease in rainfall and a significant increase in temperature. Most farmers perceived rainfall change correctly, but not temperature change. It is found that water scarcity is a major challenge for agriculture due to reduced rainfall, increased temperature, and inadequate adaptations. To address this challenge, water reuse is proposed as a sustainable alternate adaptation that involves using treated wastewater (TWW) from a decentralized sewage treatment plant for irrigation. An index named Water Reuse Index (WRI) is developed to estimate the fraction of TWW that can replace freshwater irrigation. This study provides insights into farmers' perception of climate change and suggests a novel way to enhance water security and resilience in agriculture.

Key words: agriculture, climate change, farmer, treated wastewater, water reuse

HIGHLIGHTS

- Trend analyses of rainfall, temperature, and groundwater are performed and the results are compared with farmers' perception of climate change.
- Water reuse, use of treated wastewater (TWW) from decentralized sewage treatment plant for irrigation is suggested as potential sustainable adaptation. Water Reuse Index (WRI) is developed to estimate the fraction of freshwater that can be replaced with TWW for irrigation.

1. INTRODUCTION

Climate change, i.e., change in rainfall and temperature pattern, is due to the long-term atmospheric changes and its intensity varies considerably with geographical locations and anthropogenic activities (Marie *et al.* 2021). The changing rainfall and temperature patterns result in an increased frequency of droughts, groundwater depletion, and global warming (Sathischchandra *et al.* 2014; Rakib *et al.* 2016; Ayanlade *et al.* 2017; Asrat & Simane 2018; Siddig *et al.* 2020; Tabari 2020). Climate change when combined with the stochastic nature of rainfall events has a substantial impact on agriculture (Gebremicheal *et al.* 2014; Asfaw *et al.* 2018; Panda & Sahu 2019; Chombo *et al.* 2020). This reduces agricultural practices, crop yield, and nutritional quality, ultimately leading to food insecurity (Ochieng *et al.* 2016; Jaroensutasinee *et al.* 2023).

The rapid climate change and insufficient adaptation threaten the future of agriculture especially in developing countries (Muhammad *et al.* 2017; Caretta *et al.* 2022; Kumar *et al.* 2023a, 2023b). In a developing country like India, agriculture is the mainstay of the economy as it contributes a significant percentage, 18.8%, of gross value added. In recent years, this sector faces a serious risk due to climate change and makes a mess of the livelihoods of farmers (Syed *et al.* 2022); this situation has to be improved (Qadir *et al.* 2010). The top-notch way to combat the climate crisis in agriculture is adaptation of an integrated – water and wastewater – management (Bahri 2012).

For effective planning of an alternate agriculture adaptation, the local climate change pattern – rainfall and temperature trends – has to be studied (Talanow *et al.* 2021). The Mann–Kendall and the Sen's slope estimator tests are the two most popular methods for trend analysis. The earlier works on rainfall and temperature trends showed that the rainfall trends are decreasing in many regions (Palaniswami & Muthiah 2018; Alemu & Dioha 2020; Tossou *et al.* 2021) and increasing in few regions (Isabella *et al.* 2020) but temperature trends are increasing everywhere (Tabari & Talaee 2011; Jain *et al.* 2013; Alhaji *et al.* 2018; Chand *et al.* 2020).

The analysis on impact of climate change on groundwater is also essential for the formulation of a successful adaptation as more than 50% of the cultivable area depends on well water for irrigation in India (Rajaveni *et al.* 2014; Hasan & Kumar 2019). In addition, climate change leads to more dependency on groundwater and excessive pumping of this resource also reduces its quality (Halder *et al.* 2020; Sahoo *et al.* 2021; Sidhu *et al.* 2021; Nguyen & Huynh 2023). Moreover, a correlation between rainfall and groundwater exists; if rainfall increases groundwater decreases and vice versa (Bharathkumar & Mohammed-Aslam 2018).

The success of any alternate agriculture adaptation merely depends on how well the farmers perceive and respond to the climate change (Jiménez & Asano 2008; Wolf & Moser 2011; Arbuckle *et al.* 2015; Niles & Mueller 2016; Talanow *et al.* 2021; Datta *et al.* 2022). Insufficient knowledge of the climate crisis and lack of preparedness for mitigation will not lead to successful implementation of climate actions. Some of the farmers' perceptions are consistent with the actual climate change, yet a difference in opinion persists among the farmers (Dhanya & Ramachandran 2016; Abid *et al.* 2019; Cochrane *et al.* 2020). Thereby, the local farmers' perception of climate change has to be collected and verified against the rainfall and temperature trends before planning for an agriculture adaptation for any region.

Climate-smart agriculture practices such as changing crop varieties, planting short duration crops, multiple cropping, water harvesting technologies use of greywater, and conjunctive use of surface and groundwater, and wastewater aquifer recharge are the widely used adaptations (Al-Jayyousi 2003; Getahun *et al.* 2021; Nyang'au *et al.* 2021; Raji & Packialakshmi 2022). Besides these, soil and water conservation methods are also practiced to increase water productivity and to combat the impacts of climate change (Khan & Hanjra 2009; Kahsay *et al.* 2019; Animashaun *et al.* 2020).

The study presented in this paper aimed to (i) analyze the perception of the farmers of Sivakasi taluk, Tamil Nadu state, India on climate change, analyze the actual rainfall and temperature trends, and compare the farmer's perception with the actual climate change; (ii) suggest an alternate sustainable agriculture adaptation to combat the climate crisis; and (iii) develop an index to quantify the fraction of supplement or replacement for freshwater irrigation.

The research hypotheses are (i) the study area is vulnerable to climate change but the farmers are unaware of it and thus they are not practicing alternate adaptations; (ii) Land Use Land Cover (LULC) changes of an area influences or is being influenced by the climate change and thus it can be considered as a cross validation tool for actual conditions of water availability and agricultural practices; (iii) annual heterogeneity – variation in magnitude within a year and over the years – in rainfall exists in the study area and it influences the agricultural practices; (iv) assessment of drought severity index can give an insight on water scarcity; (v) adopting an alternate adaptation that can supplement the freshwater irrigation even during dry weather conditions will be useful; (vi) water reuse, use of treated wastewater (TWW), is a potential sustainable adaptation which could provide multiple benefits; and (vii) availability of mathematical model to quantify the TWW that can supplement the freshwater irrigation is important.

Though water reuse is an age-old context, its implementation is in a nascent stage. The research gaps which are to be addressed to overcome the hurdles of water reuse projects are (i) complexities in collection of wastewater for treatment and redistribution of TWW from a large-scale Centralized Sewage Treatment Plant (C-STP); (ii) unavailability of mathematical models to quantify the water reuse potential as supplement or replacement for freshwater irrigation; and (iii) lack of policies and regulatory frameworks are yet a problem for effective implementation. The research objective of the study presented in the paper is to overcome these problems in order to foster water reuse in agriculture.

The study area, Sivakasi taluk, is an important revenue zone and at present it is steering toward water scarcity. The demand for water is steadily increasing and the agricultural practices are reduced. The region is progressively transitioning into a drought-prone zone, because of climate change. To curb the vulnerability of the agriculture sector to the climate crisis, a detailed study is vital to implement a potential sustainable adaptation so as to revitalize agriculture and to nurture the livelihoods of farmers.

In the study, the local farmers' perception of climate change is obtained by conducting a questionnaire survey and subsequent descriptive analysis. The farmers' perception of climate change is compared against the actual trend obtained by performing trend analysis of rainfall and temperature data using Mann–Kendall and Sen's slope estimator tests. Further, the trend in groundwater level change is analyzed. The influence of rainfall on groundwater is analyzed using Spearman's rho (ρ) correlation method. The annual heterogeneity in rainfall – average distribution in rainfall within a year and degree of annual rainfall variability over the years are analyzed using Precipitation Concentration Index (PCI) and Coefficient of Variation (C_v), respectively. The drought severity is analyzed using Standard Precipitation Index (SPI). LULC changes of Sivakasi taluk are analyzed using Quantum Geographic Information System (QGIS).

The outcomes of all these analyses confirm that there is a need for a potential sustainable adaptation to cope up with the climate crisis. Therefore, this paper recommends water reuse, use of TWW, from a Decentralized Sewage Treatment Plant (D-STP) as an alternate adaptation to supplement or replace fresh water irrigation. By this method, wastewater generated in an area can be treated and used locally. This can reduce the pressure on existing water bodies and restore the agricultural practices and its sustenance. The study develops a novel index and suggests the use of credible alternative agriculture adaptation to improve the livelihoods of local farmers and to achieve sustainable agricultural development.

To estimate the possible extent of fraction of TWW supplement to fresh water irrigation, an index named Water Reuse Index (WRI) is proposed and applied for the study area. This work is a small-scale representation of a larger area, the findings of the study can be used as baseline data for the development and implementation of alternate climate change adaptation. Water reuse can be used for any area of any size.

2. MATERIALS AND METHODS

2.1. Study area

Sivakasi is a taluk located in the Virudhunagar district of Tamil Nadu state, which is in the southern part of India (Figure 1). The taluk is located at 9.45° N latitude and 77.81° E longitude and has an average elevation of 101.0 m. It has a geographical

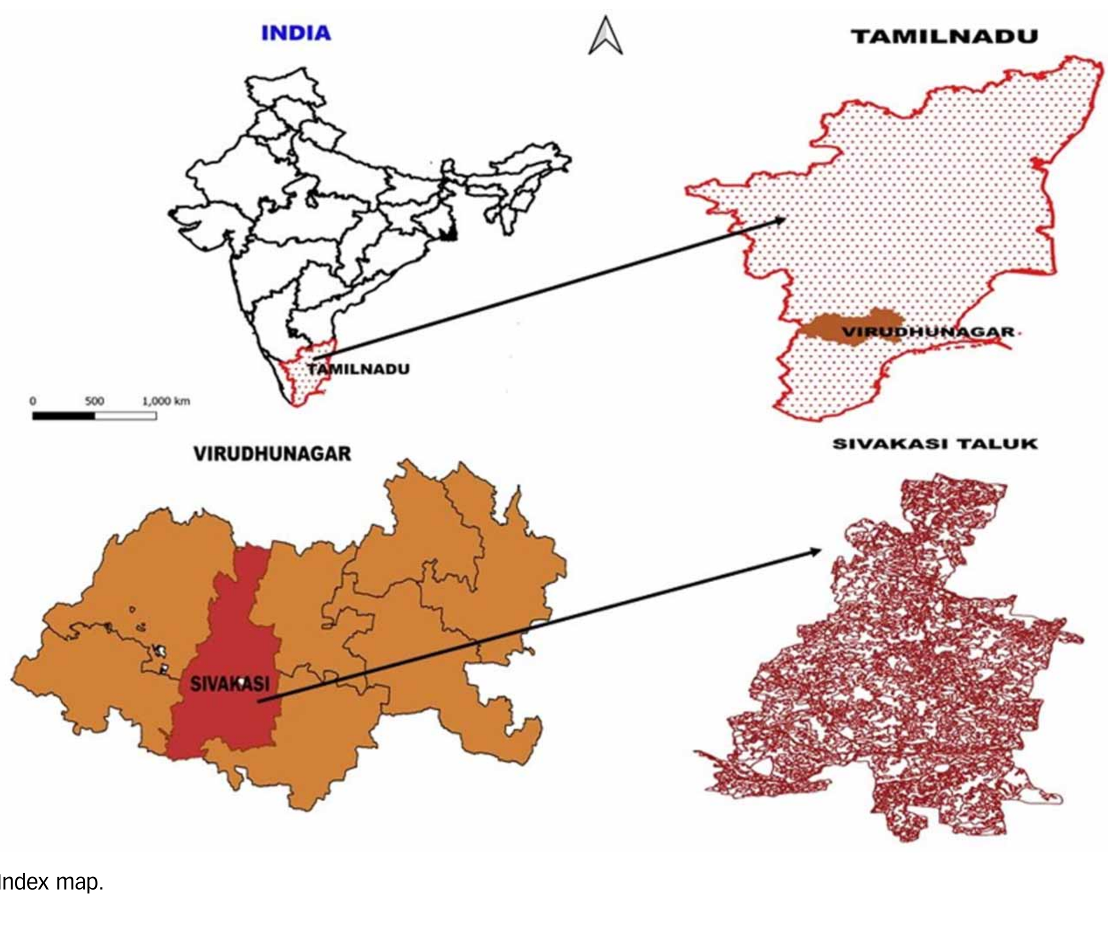

Figure 1 | Index map.

area of 579.25 km^2 with 52 villages and 63,832 households. According to 2011 census data, the population of the taluk is 230,505 with about 50:50 male-to-female ratio. It is one of the 10 taluks in the district and is an important revenue division.

Arjuna is the major river flowing in the taluk, which is an important tributary of Vaippar river basin. The topography is almost plain with black and red soil. Archaean Charnockite and Unclassified Genesis type geological formations exist in the sub-surface. The average annual rainfall is between 778 and 812 mm, which is lower than the state average value of 950 mm (Baanu *et al.* 2022). North-East monsoon is the predominant rainy season, which usually onsets from late September and continues up to December. The area experiences hot and dry weather throughout the year. The temperature varies from the maximum of 39 °C to the minimum of 22 °C. The humidity ranges between 79.2 and 65.6%.

Rabi is the primary agricultural cropping season, in which crops are grown from the late August and harvested in mid-January. The cultivation of dry crops is the major agricultural practice in the area. The predominant crops cultivated are maize, cotton, red gram, black gram, Bengal gram, cow pea, millets, chillies, and onion. In addition to the dry crops, horticultural crops like banana, guava and mango are also cultivated. The chief irrigation source is groundwater and as per the district groundwater profile records, the wells are in critical zone due to overexploitation.

2.2. Methodology

The study consists of the following eight steps (Figure 2): (i) Conduct of a questionnaire survey and analysis of farmers' perception of climate change and its impacts – water scarcity – in Sivakasi taluk; (ii) analysis of actual climate change, rainfall and temperature trends, including effect of rainfall on groundwater; (iii) analysis of annual rainfall heterogeneity; (iv) analysis for water scarcity in the area; (v) development of LULC map to analyze the land use and water body area changes over time; (vi) comparison of the farmers' perception of climate change and its impacts with the actual climate crisis; (vii) suggestion for a potential sustainable adaptation to revitalize agriculture; and (viii) development of a mathematical mode to estimate the fraction of TWW that can replace freshwater irrigation.

2.3. Dataset

The dataset includes primary data obtained by a questionnaire survey and a secondary data set: daily rainfall; daily minimum and maximum temperature; monthly groundwater levels; and LULC maps.

The questionnaire survey is conducted on the farmers of the study area in order to get their perception of local climate change and its impacts. The questionnaire is designed as a mixture of open and close ended questions, but predominantly of closed end questions. The mode of questionnaire administration is mainly a personal approach or face to face evaluation. The random sampling method is adopted for the survey; six to seven well-informed farmers from each village are surveyed to address all the variables in the questionnaire. In this manner, a total of 397 farmers are interviewed across the study area. Full consent is obtained from the farmers prior to the questionnaire survey. The privacy is ensured by not disclosing the identity of the farmers in public.

The survey focuses on the following three components: (i) profile of the farmer; (ii) agricultural factors; and (iii) climatic factors and adaptation followed to combat the impacts of climate change (Table 1). Among the 397 farmers surveyed, most of them responded well to the questionnaire. The response rate obtained is greater than 85%. The consistency and quality of the responses obtained through the questionnaire are evaluated using the test–retest reliability method. For this, the farmers are re-questioned through the taluk's agriculture office about their perception of climate change.

Rainfall and temperature data are necessary to get the actual climate trend. Daily rainfall data for the period 1991–2021, and daily minimum and maximum temperature data for the period 2006–2021 are collected from the Public Works Department (PWD) of Tamil Nadu state. Twenty observation wells are available in the taluk; monthly groundwater level data which are available for the period 2011–2021 are also collected from the PWD to analyze the influence of rainfall on groundwater.

Identification of LULC changes can provide a baseline for assessing the consequences of climate change on natural resources. It can also help in the effective restoration, planning and management of resources for socio-economic development (Yin *et al.* 2011; Liping *et al.* 2018). The LULC maps of the study area for the years 2006, 2015, and 2021 are taken from the National Remote Sensing Centre (NRSC) Bhuvan portal.

2.4. Data analysis

The Mann–Kendall test and the Sen's slope estimator test are the two most popular non-parametric tests used for trend analysis. The actual trends in rainfall, temperature and groundwater level are analyzed using Mann–Kendall and Sen's slope estimator tests, which are available in the XLSTAT program (Isabella *et al.* 2020). Mann–Kendall test is a two-tailed

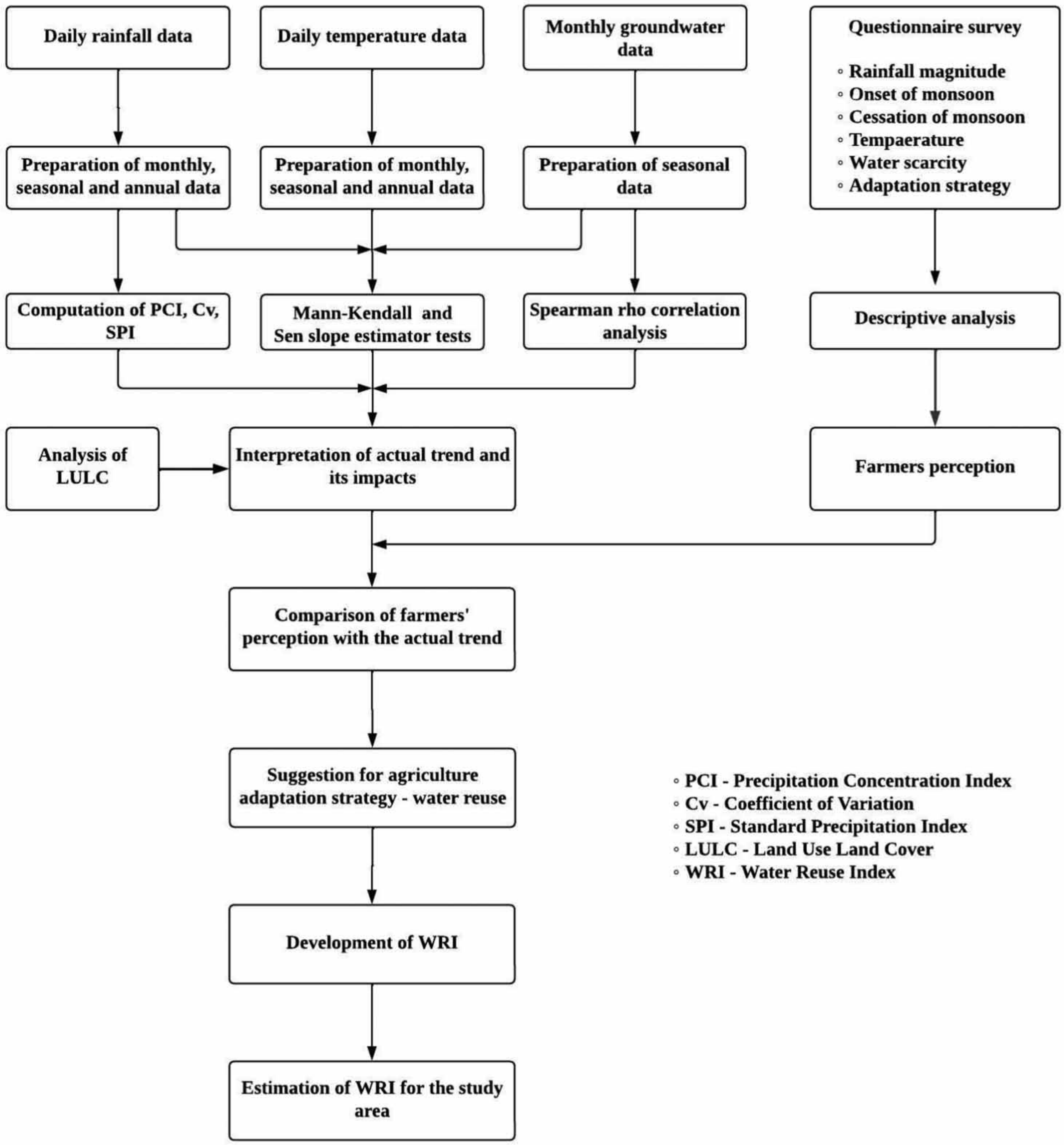

Figure 2 | Study flow chart.

non-parametric test; the test statistic (S) was formulated by Mann in the year 1945 (Equations (1) and (2)) and the Z test statistic (Z) was later added by Kendall in the year 1975 (Equations (3) and (4)) (Isabella *et al.* 2020). The test hypothesis includes a null hypothesis – no trend exists (H_0); and an alternate hypothesis – trend exists (H_1). The analysis is performed at 95% confidence level. The probability value (p) conveys the existence of the trend and its significance: no trend if $p = 0$; significant trend if $p < 0.05$; and insignificant trend if $p > 0.05$. In a like manner, Z conveys the nature of the trend: increasing trend if $Z > 0$; and decreasing trend if $Z < 0$.

Table 1 | Description of parameters considered for the questionnaire survey

Group	Variables	Description
Profile	Name	Name of the farmer
	Village	Name of the village
Agricultural factors	Possession of land	Own/Lease/Own + Lease
	Type of land	Rainfed/Wetland
	Source of irrigation	Rainfall/Rainfall + Well water/Rainfall + Bore water/Rainfall + Well water + Bore water
	Cropping seasons	January – July/August – December/ Throughout the year
	Crops cultivated	Rainfed/All crops/Pulses/Vegetables/Flowers/Vegetables + Fruits/Fodder crops/ Millets
Climatic factors	Rainfall	No significant change/Increase/Decrease
	Onset of monsoon	No significant change/Early/Late/On-time
	Cessation of monsoon	No significant change/Early/Late/On-time
	Temperature	No significant change/Increase/Decrease
	Water scarcity	Yes/No
	Alternate adaptation practiced	Yes/No

$$S = \sum_{i=1}^{nd-1} \sum_{j=i+1}^{nd} \operatorname{sgn}(X_j - X_i) \tag{1}$$

$$\operatorname{sgn}(X_j - X_i)\begin{cases} 1, & \text{if } (X_j - X_i) > 0 \\ 0, & \text{if } (X_j - X_i) = 0 \\ -1, & \text{if } (X_j - X_i) < 0 \end{cases} \tag{2}$$

where X_j and X_i are the time series observations; and nd is the number of data points.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}}, & \text{if } S > 0 \\ 0, & \text{f } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}}, & \text{if } S < 0 \end{cases} \tag{3}$$

$$Var(S) = \frac{1}{18}\left[nd(nd-1)(2nd+5) - \sum_{k=1}^{ntg} ndtg_k(ndtg_k - 1)(2ndtg_k + 5)\right] \tag{4}$$

where $Var(S)$ is the variance; ntg is the number of tied groups; and $ndtg_k$ is the number of data points in the kth tied group. A tied group is a set of data having the same value.

The nature of trend (Q_i) (Equations (5) and (6)) and magnitude of change in trend (β) (Equation (7)) are also obtained using Sen's slope estimator test (Sen 1968). The trend is increasing if Q_i is positive and decreasing if it is negative.

$$Q_i = \begin{cases} T\left(\dfrac{ny+1}{2}\right), & \text{if } ny \text{ is odd} \\ \dfrac{T\left(\dfrac{ny}{2}\right) + T\left(\dfrac{ny+1}{2}\right)}{2}, & \text{if } ny \text{ is even} \end{cases} \tag{5}$$

$$T_i = \frac{X_j - X_k}{j-k} \text{ for } i = 1, 2, 3 \ldots ny \tag{6}$$

$$\beta = \operatorname{median}\frac{X_j - X_k}{j-k} \;\forall\; k < j \tag{7}$$

where X_j and X_k are the consecutive data values of series in years j and k, respectively; and ny is the number of years.

In groundwater trend analysis, as the water table level is measured from the ground surface, a decreasing trend denotes a rise in groundwater level (water positive) and an increasing trend denotes a fall in groundwater level. The correlation between groundwater and rainfall is identified using Spearman rho correlation analysis (Ahmad *et al.* 2015). ρ finds the correlation between the dependent (groundwater) and independent (rainfall) variables based on ranking. Positive correlation represents a fall in groundwater level due to rainfall deficiency while negative correlation expresses an increase in rainfall and subsequent rise in groundwater level.

Typically, the statistical tests assume that successive data in a time series are independent to detect a trend. Thus, the presence of autocorrelation in the data has to be tested and accounted for to get the correct results. The Durbin-Watson statistic (D) (Equation (8)) is used to verify the presence of autocorrelation in the dataset (Hewer & Gough 2020).

$$D = \frac{\sum_{n=2}^{N} (\epsilon_n - \epsilon_{n-1})^2}{\sum_{n=1}^{N} \epsilon_n^2} \tag{8}$$

where ϵ_n is the residual from the ordinary least-squares regression; and N is the number of observations.

The test hypothesis for the Durbin Watson test includes a null hypothesis – first order autocorrelation does not exist (H_0); and an alternate hypothesis – first order autocorrelation exists (H_1). Positive autocorrelation exists in the data – rainfall, temperature and groundwater level, so the Hamed and Rao method at 5% significance level is taken into account for the trend analysis (Hu *et al.* 2020).

The annual heterogeneity of rainfall is evaluated using PCI (Oliver 1980) (Equations (9) and (10)) and the distribution of rainfall is analyzed (Equation (11)) (Zhang *et al.* 2020; Bharat & Venkatesh 2022).

$$\mathrm{PCI} = \frac{\sum_{j=1}^{ny} \mathrm{PCI}_j}{ny} \tag{9}$$

$$\mathrm{PCI}_j = \frac{\sum_{i=1}^{12} P_\mathrm{i}^2}{\left(\sum_{i=1}^{12} P_\mathrm{i}\right)^2} \times 100, \quad j = 1, 2, 3 \ldots ny \tag{10}$$

where PCI_j is the PCI of the year j; P_i is the total precipitation in the month i; and ny is the number of years.

$$\text{Distribution of rainfall} = \begin{cases} \text{uniform,} & \textit{if } \mathrm{PCI} \leq 10 \\ \text{moderate,} & \textit{if } 11 \leq \mathrm{PCI} \leq 15 \\ \text{irregular,} & \textit{if } 16 \leq \mathrm{PCI} \leq 20 \\ \text{strongly irregular,} & \textit{if } \mathrm{PCI} \geq 21 \end{cases} \tag{11}$$

The degree of annual rainfall variability is quantified using C_v (Equations (12) and (13)) (Asfaw *et al.* 2018).

$$C_v = \frac{\sigma}{\mu} \times 100 \tag{12}$$

$$\text{Degree of annual rainfall variability} = \begin{cases} \textit{Less}, & \textit{if } Cv < 20 \\ \textit{moderate}, & \textit{if } 20 < Cv < 30 \\ \textit{High}, & \textit{if } Cv > 30 \end{cases} \tag{13}$$

where μ and σ are the mean and standard deviation of annual rainfall, respectively.

The drought severity is assessed using SPI (Equations (14) and (15)) (Shah *et al.* 2015).

$$SPI = \frac{P_i - \mu}{\sigma} \tag{14}$$

$$\text{SPI} = \begin{cases} \textit{extremely wet}, & \textit{if}\ \text{SPI} \geq\ 2.0 \\ \textit{very wet}, & \textit{if}\ \ 1.5 \leq\ \text{SPI} \leq\ 1.99 \\ \textit{moderately wet}, & \textit{if}\ \ \ 1.0\ \leq\ \text{SPI} \leq\ 1.49 \\ \textit{near normal}, & \textit{if}\ -0.99 \leq \text{SPI} \leq\ 0.99 \\ \textit{moderately dry}, & \textit{if}\ -1.49\ \leq\ \text{SPI} \leq -1.0 \\ \textit{severely dry}\ , & \textit{if}\ -1.99 \leq\ \text{SPI}\ \leq -1.5 \\ \textit{extremely dry}, & \textit{if SPI}\ \leq -2.0 \end{cases} \tag{15}$$

where P_i is the precipitation of the year i, and μ and σ are the mean and standard deviation of annual rainfall, respectively.

The LULC maps are processed using QGIS to identify the LULC changes. The process involves (i) pre-processing to correct the geometric distortions in the data; (ii) classification of the maps into different classes and assigning labels to them – four different classes, namely agriculture land, built-up land, wasteland and waterbodies with a three-level classification scheme are used; (iii) post processing to assess the accuracy of the results obtained – Semi-Automatic Classification plugin (SCP) option available in QGIS and the accuracy is used and the accuracy value is found to be within the range of 80–87% for all the four classes; and (iv) map generation and documentation for LULC spatial and temporal changes.

Descriptive analysis that yields frequencies and percentages is performed to study the farmers' perceptions of climate change. For this analysis, Statistical Package for Social Science (SPSS) version 26 is used (Hamdan *et al.* 2022).

3. RESULTS AND DISCUSSION

3.1. Analysis of actual climate change and its impacts

3.1.1. Rainfall

North-East monsoon, which occurs in the months of October, November and December, is the predominant rainy season of the area. The minimum, maximum, mean and median annual rainfall are 360; 1,163; 784; and 767 mm, respectively.

The monthly, seasonal and annual time series data, which are prepared from the daily rainfall data, are analyzed separately (Table 2). Significant decreasing trend and significant increasing trend are noticed for April and May, respectively. However, more rainfall is required during April but not in May. This particularly affects the crop growth, crop yield and harvesting of the Zaid crops, grown during March to May (Sreenath *et al.* 2022). An insignificant decreasing trend is noticed for September and October, but these are the predominant rainy months of the area. Rainfall in these months is vital for the flowering and ripening of Kharif crops grown between June to September, and for the seedling of Rabi crops, grown between August and January. The results are in agreement with the findings of Praveen *et al.* (2020), Mathew *et al.* (2021).

The annual PCI value is found to be 20.52. This is an indication of a higher concentration of rainfall in certain months. The C_v value is found to be 21.69% and it represents moderate variations in rainfall occurrence over the year. The results are in agreement with the findings of Kumar *et al.* (2023a, 2023b) which explains that there is a significant variation in rainfall distributions over the years. Only 654 rainy days over the span of 31 years. The SPI value is found to be −1.41 and this conveys that the area is moderately drought prone with a greater number of dry years than the wet years.

The major issues in rainfall occurrences are not only the quantity as well as the spatial and temporal variability but also shift in onset and cessation time. The onset of rain is late by 15 days in both the monsoon seasons, North-East and South-West, and also ceases earlier than usual. The results are in agreement with the findings of Dong *et al.* (2016), which explains the effect of global warming is the reason for delayed onset of monsoon.

The decreased rainfall magnitude, annual heterogeneity in rainfall and delayed onset and early cessation of monsoon has a significant impact on agricultural practices in the study area.

3.1.2. Temperature

The trends in monthly, seasonal and annual minimum and maximum temperature time series data, which are prepared from the daily data, are analyzed independently (Table 2). For both maximum and minimum temperature, a significant increasing trend is noticed for most of the months, and insignificant trend for the rest. For the minimum temperature, an insignificant increasing trend is noticed only during the winter, December and January, and in the predominant rainy season, October and November. For the maximum temperature, in addition to these months, for the hottest month May also, an insignificant increasing trend is noticed. The MK trend test and Sen's slope estimator reveal that monthly, seasonal and annual minimum temperatures describe a statistically significant increasing trend which is in accordance with Khan *et al.* (2022). The

Table 2 | Mann–Kendall and Sen's slope estimator test statistics for rainfall and temperature data

	Rainfall (mm)			Minimum temperature, T_{min} (°C)			Maximum temperature, T_{max} (°C)		
Months	Mann–Kendall test (*p* value)	Sen's slope value	Inference	Mann–Kendall test (*p* value)	Sen's slope Value	Inference	Mann–Kendall test (*p* value)	Sen's slope value	Inference
January	0.262	0	NT	0.620	0.118	IIT	0.065	0.253	IIT
February	0.816	0	NT	0.005	0.178	SIT	0.008	0.230	SIT
March	0.642	0	NT	0.005	0.242	SIT	0.000	0.265	SIT
April	0.011	−2.077	SDT	0.001	0.326	SIT	0.001	0.304	SIT
May	0.040	2.067	SIT	0.005	0.385	SIT	0.096	0.096	IIT
June	0.264	0.131	IIT	0.001	0.353	SIT	0.003	0.192	SIT
July	0.203	0.244	IIT	0.003	0.270	SIT	0.003	0.188	SIT
August	0.423	0.456	IIT	0.000	0.340	SIT	0.002	0.151	SIT
September	0.696	−0.340	IDT	0.005	0.227	SIT	0.095	0.142	IIT
October	0.646	−0.996	IDT	0.009	0.330	SIT	0.300	0.051	IIT
November	0.529	1.710	IIT	0.020	0.243	SIT	0.620	0.050	IIT
December	0.324	0.900	IIT	0.620	0.023	IIT	0.417	0.107	IIT
South-West Monsoon (SWM)	0.300	1.720	IIT	0.001	0.289	SIT	0.006	0.145	SIT
North-East Monsoon (NEM)	0.440	2.913	IIT	0.053	0.107	IIT	0.344	0.112	IIT
Annual rainfall	0.333	5.450	IIT						
Annual temperature				0.001	2.773	SIT	0.001	2.677	SIT

NT, No Trend; IIT, Insignificant Increasing Trend; IDT, Insignificant Decreasing Trend; SIT, Significant Increasing Trend; SDT, Significant Decreasing Trend.

maximum temperature shows a significantly increasing trend for most of the months except for the rainy months (September-December). The South-West monsoon season portrays a significant increasing maximum temperature while the North-East monsoon season depicts an insignificant increasing trend which is in agreement with Birthal *et al.* (2014).

3.1.3. Influence of rainfall on groundwater

The observation wells in the taluk include three bore wells (BWs) and 17 dug wells (DWs). It is noted from the groundwater level data that 7 out of 17 dug wells are dry and closed. The monthly groundwater level data are processed to pre-monsoon (June to September) and the post-monsoon (January to May) datasets and analyzed (Table 3).

In the pre-monsoon period, an insignificant increasing trend is noticed in 9 out of the 13 observation wells. Similarly, in the post-monsoon period, an insignificant increasing trend is noticed in 11 out of 13 wells. The results are in alignment with the findings of Bera *et al.* 2022 which explains that there is steady decline in groundwater table in recent years which is mainly due to over exploitation and poor recharging conditions of the aquifer.

Analysis on the dependency of groundwater level on rainfall over the pre-monsoon and post-monsoon seasons of the study area yields a positive correlation between them. The values of ρ during the pre-monsoon season and the post-monsoon season are 0.31 and 0.12, respectively. The findings are in agreement with the study of Mohanavelu *et al.* 2020. The positive correlation manifests the declining groundwater level because of scanty/poor rainfall. Decrease in rainfall and increase in temperature accelerates evapotranspiration. The scanty rainfall and increase in evapotranspiration lead to groundwater over-exploitation. In addition, increase in built-up lands and reduction in waterbody area bring down the recharge of the aquifers and ultimately reduces the agriculture area. The findings are also in alignment with Hao *et al.* 2019, where human influence also leads to declining groundwater table.

Table 3 | Mann–Kendall and Sen's slope estimator test statistics for groundwater data

Well type & no.	Pre-monsoon groundwater level		Inference	Post-monsoon groundwater level		Inference
	Mann Kendall test (*p* value)	Sen's slope Value		Mann–Kendall test (*p* value)	Sen's slope Value	
BW1	0.368	0.640	IIT	0.230	0.433	IIT
BW2	0.133	−1.390	IDT	0.548	−0.850	IDT
BW3	0.592	0.609	IIT	0.152	0.593	IIT
DW1	0.283	0.992	IIT	0.210	0.759	IIT
DW2	0.004	2.350	SIT	0.214	1.843	IIT
DW3	0.858	1.180	IIT	0.220	1.906	IIT
DW4	0.915	0.135	IIT	0.858	0.656	IIT
DW5	0.283	0.694	IIT	0.283	0.600	IIT
DW6	0.857	−0.418	IDT	0.474	1.470	IIT
DW7	0.271	−0.443	IDT	1.000	−0.028	IDT
DW8	0.474	0.655	IIT	0.371	1.450	IIT
DW9	0.283	2.178	IIT	0.152	2.126	IIT
DW10	0.436	8.168	IIT	0.241	15.35	IIT

IIT, Insignificant Increasing Trend; IDT, Insignificant Decreasing Trend; SIT, Significant Increasing Trend.

3.1.4. LULC changes

Analysis of the LULC area (Figure 3) reveals that the areas occupied by built-up lands and wasteland have increased to 21.6% from 2.7% and 7.7% from 3.5%, respectively. Conversely, there is a significant decrease in agricultural lands, which decreased from 89.1 to 69.7% from 2006 to 2021. This portrays the reduction in agricultural practices in the region. The area covered by water bodies decreased from 4.7 to 1% from 2006 to 2021, which proves the prevailing water scarcity in the region. The decrease in waterbodies and increase in wasteland areas indicates the parchedness of the region. Overall, the LULC changes of the study area shows a declining trend of agricultural practices in the area.

3.2. Farmers' perception of climate change and comparison

Descriptive analysis is performed to obtain the farmers' perception of climate change and the results are compared with the actual trend (Figure 4). The results imply that most of the farmers are aware of the decreasing rainfall. Also, most of them responded with the late onset and early cessation of monsoon seasons.

Only a few farmers in the study area are cognizant of temperature change and most of them are ignorant of the increasing temperature. This brings into the light that the actual climatic conditions should be disseminated to the farming community while planning for adaptation, so as to make the adaptation successful. A large number of farmers in the region are conversant with the water scarcity. However, a very few of them have adopted alternate adaptation such as practicing micro-irrigation, mixed irrigation and planting crops in rotation to manage the water scarcity.

3.3. Sustainable agriculture adaptation

The climate change and its impacts affect the hydrological cycle and produce extreme events. Decreasing rainfall results in water shortage and increasing temperature escalates the water demand. These factors force different sectors to go for excessive pumping of groundwater.

The alternate adaptations have to be identified to achieve agricultural sustainability with the consideration to food security and environmental protection. Water reuse is one of the potential sustainable adaptations due to its multiple benefits. It can be considered as a dependable source of irrigation even during the dry weather conditions. It reduces the groundwater pumping, thereby conserving the freshwater for other purposes. Proper treatment of wastewater and use of TWW for irrigation will lower discharges of pollutants and nutrients into freshwater bodies. In this way, it can protect the environment also, because untreated sewage disposal into water bodies will cause severe damage to the aquatic ecosystem.

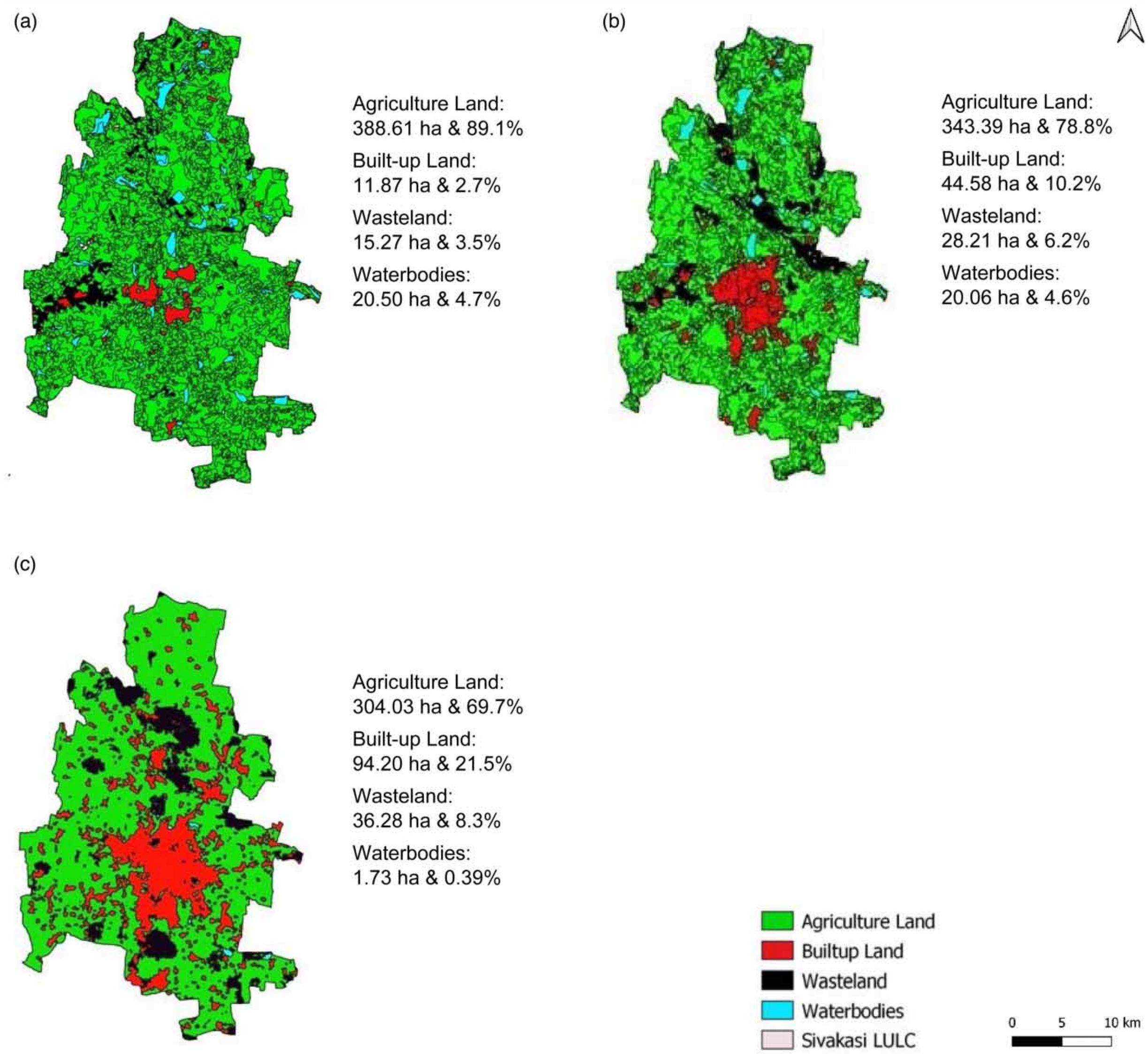

Figure 3 | LULC area comparison for the years 2006, 2015, and 2021: (a) year 2006, (b) year 2015, and (c) year 2021.

Water reuse is an Integrated Water Resources management (IWRM) approach that couples water and wastewater management simultaneously, and can play a vital role in achieving the sustainable development goals (SDGs).

Water reuse conserves the limited available freshwater and prevents the pollutant discharges into water bodies. This contributes toward the SDG 6, clean water and sanitation for all. TWW has a higher concentration of macro and micro nutrients, so it can increase the soil fertility and crop productivity. Water reuse can reduce the fertilizer application and thereby greenhouse gas emissions which evolved during the production of fertilizers. Thus, it contributes toward SDG 13, combating climate change. Water reuse also contributes toward the SDG 2, zero hunger, by reinstituting agricultural practices even during dry weather conditions.

For the implementation of water reuse projects, a Sewage Treatment Plant (STP) is essential to treat the wastewater to the desired level for reuse. A C-STP has its own drawbacks mainly incurring huge capital cost, high operation and maintenance costs, and complexity in collecting the raw sewage and redistribution of TWW for agriculture. A D-STP can be seen as a potential alternative option to maximize water reuse as it deals with the wastewater from the local community. This is a sustainable option because it conserves the freshwater and at the same time protects the environment with relatively less energy consumption. Water reuse also requires energy for wastewater treatment but the cost requirement is considerably lower than

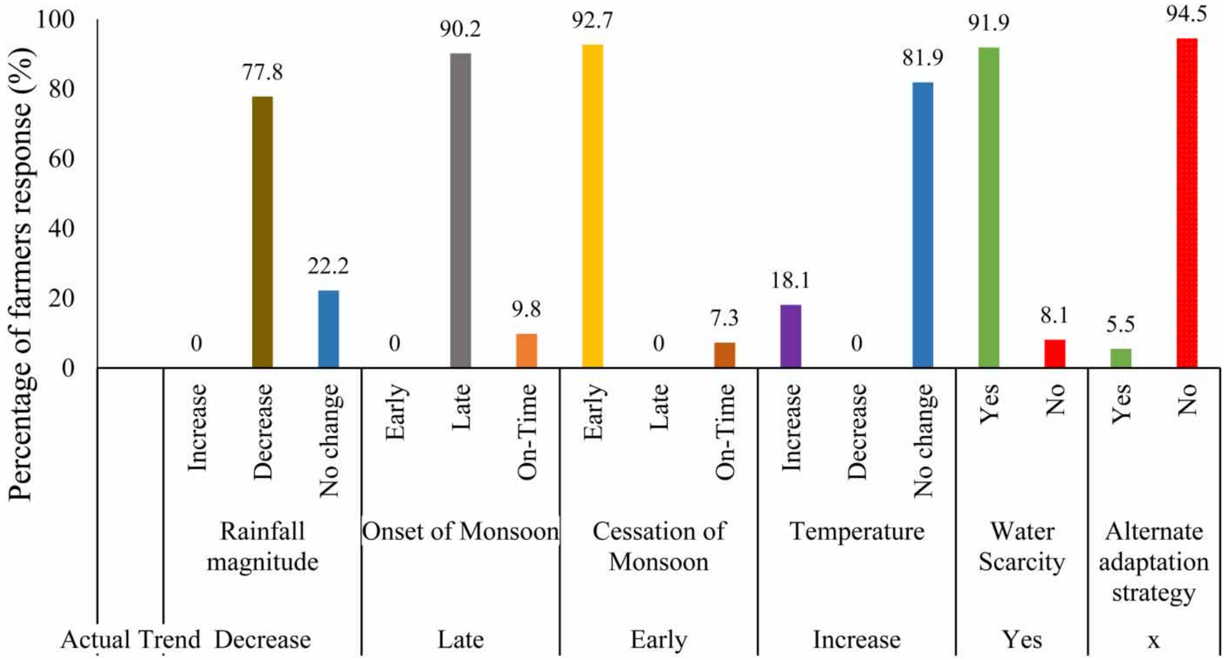

Figure 4 | Comparison of farmers' perception and actual trend.

the groundwater pumping unless otherwise the groundwater is available at a shallow depth. However, water reuse is not all required if plenty of groundwater is available in an area. In addition, a D-STP-based water reuse project can include participation of the local stakeholders and their support for proper operation and maintenance. Thereby this system can facilitate the decision-making at local community level and establishes a link between users and water and wastewater management sectors. This inclusive approach, water reuse with D-STP, can increase the reliability of the project among the farmers and will lead to successful adaptation.

To verify the suitability of TWW from a D-STP for irrigation, the TWW is collected from the Moving Bed Bio-Reactor (MBBR) type of D-STP of the institutional campus that produces an effluent volume of 1.5–2 lakh liters per day approximately. The raw sewage for the D-STP is collected from the amenities including cafeterias, residential quarters and hostel zones. This wastewater is of similar quality to the domestic wastewater produced by a community or cluster of households.

The physical, chemical and microbial characteristics of the TWW are analyzed and compared with the well water available in the taluk as well as with the FAO standards (FAO 1985) (Table 4). It is found that the characteristics of TWW are comparable with the local well water and meet the FAO standards. Thus, the TWW from a properly functioning D-STP is suitable for irrigation. However, the possible impacts of long-term water reuse for irrigation over the area and development of preventive or remedial measures are yet challenging tasks.

3.4. Water reuse index

To date, no indicator is available to quantify the possible extent of fraction of TWW supplement to irrigation, and to overcome this, WRI is developed. The proposed WRI is the ratio between the volume of TWW available in an area and the total volume of crop water required for irrigation in the area (Equation (16)). Its value will vary between 0 and 1.

$$\mathrm{WRI} = \frac{\text{Volume of TWW available}}{\sum_{n=1}^{\textit{No. of crops}} \mathrm{CWR}_n \times \text{Crop Area}_n} \tag{16}$$

The volume of wastewater generated is estimated based on Daily Water Consumption (DWC) and population size of the area (Schilling & Tränckner 2020). The DWC for the urban and rural population as per the Tamil Nadu Water Supply and Drainage Board (TWAD) guidelines are 110 and 40 liters per capita per day, respectively. Typically, 80%

Table 4 | Physicochemical and microbial properties of the TWW

				FAO standards		
Parameter	**Unit**	**TWW concentration**	**Farmer's well water**	**None**	**Slight to moderate**	**Severe**
TDS	mg/l	1,200.000	1,000.000	<450	450–2,000	>2,000
EC	ds/m	1.042	0.790	<0.7	0.7–3.0	>3.0
Calcium	mg/l	44.100	80.200	–	–	–
Magnesium	mg/l	1.200	4.600	–	–	–
Sodium	mg/l	16.747	0.913	<3	3–9	>9
Chloride	mg/l	6.603	3.934	<4	4–10	>10
Sulphate	mg/l	189.000	112.000	–		
Nitrate	mg/l	8.500	8.900	–		
Ammonia	mg/l	1.200	0.300	–		
Phosphate	mg/l	0.500	0.100	–		
Potassium	mg/l	3.000	2.000	–		
pH	mg/l	8.000	7.200	6.5–8.4		
BOD	mg/l	27.000	–	–		
COD	mg/l	34.000	–	–		
Total Nitrogen	mg/l	37.500	30.000	–		
Zinc	mg/l	0.160	–	2.0		
Manganese	mg/l	0.000	–	0.2		
Iron	mg/l	0.240	0.05	5.0		
Borates	mg/l	0.120	–	–		
Copper	mg/l	0.050	–	0.2		
E. coli	CFU/ml	100.000	Absent	–		
Coliform	CFU/ml	500.000	Absent	–		
Salmonella	CFU/ml	Absent	Absent	–		

of DWC is converted as wastewater (Goyal & Kumar 2020; Omole *et al.* 2021). The study area has an urban population of 138,715 and a rural population of 91,790. Thereby, it generates about 15,140 m^3 of wastewater in a day (0.8 * [urban population*urban DWC + rural population*rural DWC]). Assuming an average loss during treatment and conveyance of 20% (Khater *et al.* 2016; Goyal & Kumar 2020), the TWW generated from the study area is 12,112 m^3 per day or 4.421 Mm^3 per year.

It is assumed that (i) water supply to an area is as per the TWAD guidelines; (ii) 80% of the supplied water becomes wastewater; and (iii) 80% of wastewater reclaimed is available for TWW irrigation.

The major and minor crops grown in the study area and area of cultivation are obtained from the Taluk's agriculture office. The Crop Water Requirement (CWR) for each of the crops is computed using CROPWAT software (FAO). CWR is estimated by incorporating rainfall, temperature and the other climate factors such as relative humidity, wind speed and sunshine hours. The taluk has a total cultivated area of 5,408 ha; rainfed and horticultural crops occupy 83 and 17%, respectively. The net CWR of the area after accounting the effective rainfall is 6,890.1 mm. The volume of crop water required is 15.459 Mm^3; rainfed and horticultural crops require 79.3 and 20.7%, respectively (Table 5).

The WRI for the present cultivated area of the taluk is estimated and is found to be 0.29. This indicates 29% of freshwater irrigation can be replaced with TWW irrigation. WRI value will vary primarily with the type of crop and the corresponding crop area. The value will be low when the crops demanding higher CWR for their growth are cultivated in larger areas, and vice versa.

The WRI is sensitive to rainfall and temperature because these two parameters will significantly influence the CWR. Decrease in rainfall and increase in temperature will increase CWR. Increase in CWR will increase volume of crop water

Table 5 | Volume of crop water required for cultivation in the taluk

Crop	CWR (mm)	Area (ha)	Volume of crop water required (m^3)
Rainfed crops			
Maize	228.3	3,062.95	6.993
Cotton	244.8	513.00	1.256
Paddy	645.8	469.27	3.031
Sorghum	180.9	329.44	0.596
Blackgram	239.9	54.51	0.131
Kambu	194.3	21.14	0.041
Groundnut	228.1	20.90	0.048
Sunflower	208.8	17.30	0.036
Sesame	95.00	14.50	0.014
Sugarcane	921.5	10.20	0.094
Redgram	239.9	7.12	0.017
Ragi	194.3	4.24	0.008
Sub-Total	3,621.6	4,524.57	12.264
Horticultural crops			
Banana	508.9	289.40	1.473
Guava	240.0	206.40	0.495
Chillies	170.5	83.90	0.143
Sapota	240.0	80.50	0.193
Mango	737.8	66.20	0.488
Lime	374.8	36.50	0.137
Drumstick	199.3	31.40	0.063
Bhendi	199.3	29.20	0.058
Brinjal	199.3	24.50	0.049
Green leaves	199.3	24.10	0.048
Onion	199.3	23.90	0.048
Sub-total	3,268.5	896.00	3.195
Total	6,890.1	5,408.00	15.459

required (CWR of a crop * area of the crop). Finally, an increase in volume of crop water will decrease the WRI. On the other hand, increase in rainfall and decrease in temperature will increase the WRI.

The proposed index can also be used as an objective function of an optimization model for the reuse of TWW for irrigation (Equation (17)).

$$\text{Maximize} \frac{\text{Volume of TWW available}}{\sum_{n=1}^{\text{No. of crops}} \text{CWR}_n \times \text{Crop Area}_n} \tag{17}$$

The crop area is the decision variable to be optimized. The objective function is subjected to a boundary constraint (Equation (18))

$$\text{Crop area}_n^{min} < \text{Crop area}_n < \text{Crop area}_n^{max} \tag{18}$$

where Crop area_n^{min} and Crop area_n^{max} are the minimum and maximum area of cultivation of Crop_n, respectively.

If the net income of the farmers has to be maximized, then the cost–benefit factor (B_n/C_n) shall be included in the objective function (Equation (19)), while keeping the same boundary constraint (Equation (17)).

$$\text{Maximize}\ \frac{\text{Volume of TWW available} \times \sum_{n=1}^{\text{No. of crops}} \frac{B_n}{C_n}}{\sum_{n=1}^{\text{No. of crops}} \text{CWR}_n \times \text{Crop Area}_n} \tag{19}$$

The objective function and the constraint of the optimization models using WRI are introduced in this paper. However, the exploration of optimal solutions is beyond the scope of this paper.

4. CONCLUSION

The study area, Sivakasi taluk, is experiencing climate change which in turn affects the agricultural practices. Thus, practicing sustainable adaptation is vital to combat the climate crisis.

Water reuse is one potential adaptation which can have multiple roles in achieving the Sustainable Development Goals: SDG2, zero hunger; SDG6, clean water and sanitation for all; and SDG13, combat climate change. It can supplement the crop water requirements significantly even during the dry weather conditions and thereby can ensure food security. It conserves freshwater for other sectors, especially domestic needs. It prevents the pollution by reducing the untreated wastewater discharges into water bodies. TWW is enriched with macro and micro nutrients and thus water reuse can boost soil fertility, thereby minimizing the greenhouse gas emissions by reducing the production and the application of inorganic fertilizers.

Main findings and contributions*:*

- This study aims to investigate the perception of farmers in Sivakasi taluk, of Tamil Nadu state India, toward climate change and its impact on their livelihoods and adaptation.
- The comparison between the farmers' perception and the actual trend of climate change revealed that 77% of the farmers perceived the decreasing rainfall but only 19% of them perceived the increasing temperature.
- The LULC changes showed that the waterbody area and agricultural lands were reduced from 4.7 to 0.39% and from 89.1 to 69.7%, respectively, during the period 2006–2021.
- The study area (i) receives uneven annual rainfall distribution within a year (PCI = 20.52); (ii) experiences moderate annual rainfall variations over the years (C_v = 21.69%); and (iii) is prone to drought (SPI = −1.41). These impacts illustrate the need of an alternate adaptation which could supplement fresh water irrigation even during dry weather conditions to ensure the food security and nurture the livelihoods of farmers.
- This paper recommends water reuse, use of TWW, from a D-STP for agriculture.
- A novel index named WRI is developed and applied for the study area. This index is handy to estimate the fraction of freshwater that can be replaced with TWW for irrigation. The WRI for the ongoing cultivation practice of the taluk is found to be 0.29, i.e., 29% of TWW irrigation replacement is possible in the area. The value of this index depends on volume of TWW available; and type of crop and the corresponding crop area. If the crop that demands more crop water requirements is cultivated over a large area, then the index is low and vice versa. This index is sensitive to rainfall and temperature decrease in rainfall and increase in temperature will decrease its value and vice versa.

Implications:

- In recent years, agriculture is practiced only on 21% of the cultivable crop land area because of the climate change impacts.
- The development of more Decentralized Sewage Treatment Plants and the implementation of water reuse projects are recommended. As the local farmers are the primary stakeholders, if they are involved in decision-making, operation and maintenance of the project, this adaptation mechanism will generate a sense of ownership and responsibility.
- The authorities responsible for planning mitigation measures to combat the climate crisis in any area shall take initiatives to address this issue. The farmers have to be educated about the actual climate change, especially increasing temperature and its consequences and understand the need for sustainable adaptations for the successful climate plans, policies and actions.

- The outcomes of this study will be useful for policymakers who are involved in planning and development of climate plans, actions, policies and regulatory frameworks. Also, the findings will be valuable for the researchers who are working on the improvement of socio-economic status of the farmers.

Limitations/assumptions of the study:

- It is assumed that (i) water supply to an area is as per the guidelines, (ii) 80% of the supplied water becomes wastewater, and (iii) 80% of wastewater is available for irrigation as TWW.

Scope for further studies:

- Address the challenges associated with the water reuse projects like operation and maintenance, meeting the energy requirements, formulation of policies and regulatory frameworks, soil health, nutrient and microbial quality of the agricultural produce, and health of the consumers; and (ii) the WRI proposed in this paper can be used to optimize the irrigation water allocation framework and socio-economic benefits of the farmers. Case studies using the optimization models proposed in this paper can be done using appropriate algorithms.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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