Quantitative exploration of the innovative trend method for evapotranspiration and its sensitivity to climatic parameters: The case study in Southeast Vietnam

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Abstract

Understanding the characteristics and correlations between evapotranspiration and climate variables plays a crucial role in determining the probable impact of critical factors on crop water requirements, water resource management, and future planning. This work aims to evaluate the temporal trends of evapotranspiration and its sensitivity to climate variables from 1980 to 2019 in Southeast, Vietnam. The improved Innovative Şen Trend Analysis method was used to identify trends, and the Sobol technique, based on variance-based analysis, allowed for a rapid calculation of sensitivity indices. By estimating the changes in evapotranspiration, the study confirmed different quantitative trends, including a significant increase of 72–135 mm in annual and 12–84 mm in seasonal evapotranspiration. Results also conducted a sensitivity analysis of the historical meteorological quantiles obtained for three climate stations to analyze the sensitivity indices. The sensitivity analysis showed that evapotranspiration is more sensitive to solar radiation, relative humidity, and minimum temperature. The study presents pragmatic approaches for considering the possible interactions between evapotranspiration and climate variables, which may serve as a baseline for sustainable water management in areas with similar climate conditions and adaptation to climate change.

Introduction

The impact of climate change on water resources is recognized as one of the most serious and current challenges in hydrological studies (Sci et al. 2014). Indeed, the assessment of evapotranspiration (ET) is vital in recognizing the possible implications of anthropogenic climate change on the catchment water balance. ET plays a critical role in estimating crop water requirements (Sawan 2018; Biazar et al. 2019), which is essential in predicting and scheduling irrigation. Additionally, it is an important parameter that establishes a relationship between the earth's energy and the surface water balances (Patle et al. 2020). ET is also one of the climatic variables that control the transfer of water and energy between the earth and the atmosphere, making it a key hydrological indicator of climate change (Wen et al. 2020).

Evapotranspiration is influenced by multiple components, including temperature, wind speed, relative humidity, solar radiation, and land-use change (Van Der Velde et al. 2013; Guo et al. 2017; Dong et al. 2020). Changes in any of these variables can affect the spatiotemporal distribution of evapotranspiration (Irmak et al. 2012; Wang et al. 2017). Analyzing the characteristics of meteorological parameters, such as temperature, wind speed, relative humidity, and solar radiation, is crucial for exploring the sensitivity of evapotranspiration to climate variables and understanding the potential effects of climate change on evapotranspiration (Li et al. 2018). Many researchers have investigated changes in evapotranspiration in the context of climate variability to demonstrate its importance (Paulino et al. 2019). Evapotranspiration has decreased in different climatic regions around the world. This includes the dry climate region of the United States (Harper et al. 2014), the humid climate region of Eastern Uttar Pradesh (Tyagi et al. 2019), the tropical and subtropical climate zone of China and Korea (Zhao et al. 2015; Jeon et al. 2018), and the arid and semi-arid climate of Iran (Biazar et al. 2019). This decrease in evapotranspiration in the face of rising temperatures is known as the "evaporation paradox" (Brutsaert and Parlange 1998). The paradox can be explained by a combination of factors, including the increase in relative humidity (Dong et al. 2020), the decrease in wind speed (Zhao et al. 2015; Liu et al. 2021), the decrease in solar radiation (Guo et al. 2017; Ndiaye et al. 2021).

Over the last few decades, evapotranspiration has been measured using different methods, including the Blaney-Criddle method (Cotta et al. 1986), Thornthwaite method (Steenhuis et al. 1986), Priestley Taylor method (Priestley and Taylor 1972), Hargreaves-Samani method (Hargreaves and Samani 1985), and FAO Penman-Monteith method (Howell and Evett 2017). Each of these approaches employs a standard equation for ET estimation on certain climate parameters. The choice of a specific method for the estimation of evapotranspiration depends on the available data and the desired accuracy of the computation (Goyal 2004). Simplified reference evapotranspiration (ET0) estimation equations may also be preferable under some conditions, as they require a smaller number of input climate values. These situations may arise when data for some meteorological variables are missing (Ali 2004). However, in cases of limited availability of weather data, ET calculation based on temperature and radiation have demonstrated better results (Droogers and Allen 2002; Pasupa and Thamwiwatthana 2013; Cunha et al. 2017). Therefore, in assessing the impact of climate change, researchers should consider the relative importance of each variable in the estimation of evapotranspiration (Guo et al., 2016), projections of changes in each meteorological factor (Mosadegh et al. 2021), and their correlation with extreme climate events (Dimitriadou and Nikolakopoulos 2021; Schirmer et al. 2021).

It is noteworthy that numerous researchers and organizations have conducted research on changes in meteorological, hydrological, and climatological variables. The scholars have used various non-parametric or parametric methods to investigate the trends of climate variables in general, and evapotranspiration in particular, such as the Mann-Kendall test (Obada et al. 2017; Kim and Jehanzaib 2020), Sen's slope (De Lima et al. 2010; Vu et al. 2018), Spearman's rho test (Yue et al. 2002), cumulative sum, linear regression (Cui et al. 2017) and an Innovative trend analysis (Öztopal and Zekâi 2016; Sezen and Partal 2020). In addition, there have been a large number of different test cases based on the same time series data (Güçlü 2020; Phuong et al. 2020). Compared to other classical approaches, the ITA test not only showed that the results match the overall trends detected by other tests (Güçlü 2018; Huang and Liu 2019), but also performed significant advantages (Girma et al. 2020). Especially, ITA has a flexible graphical visualization with the common application and irrespective of distribution assumptions, including a serial correlation, and the size of a time series (Şen 2015). However, almost all the previous studies have only determined tendencies qualitatively that demand an algorithm to measure the uncertainty quantification of trend results and comparison with others.

Furthermore, one of the main aims of recent evapotranspiration studies has been to emphasize sensitivity analysis. This is of great importance, both in theory and practice for a thorough comprehension of evapotranspiration impaction on the other climate variable. The arid region of India is a good case in point, identified that PET was most sensitive to perturbations in temperature (Goyal 2004). Likewise, Zhao derived the effects of climate change from evapotranspiration in the Heihe River Basin, China. The results showed that relative humidity (RH) was the most critical factor for evapotranspiration change, followed by wind speed, air temperature, and solar radiation were less sensitive factors (Zhao et al. 2015). Tiwari and Debnath (2020) investigated the spatial and temporal characteristics of the sensitivity coefficients (SCs) between potential evapotranspiration and key climatic factors from 1981 to 2015. The results showed that the model output was significantly sensitive to relative humidity and net solar radiation (Tiwari and Debnath 2020). In 2020, the relationship between the variations in evapotranspiration and each meteorological factors in India was analyzed (Patle et al. 2020). The sensitivity coefficient derived from the observed data during the period from 1985 to 2013 may be used to estimate evapotranspiration for the study area. These results revealed that sensitivity analysis was required to gain a better understanding of the meteorological systems, particularly to indicate the physical meaning of different parameters used in the estimation of evapotranspiration. At the same time, Emeka quantified the correlations of climate parameters and noticed that the evapotranspiration estimation was most sensitive to the relative humidity (Emeka et al. 2021). Also, this study used the sensitivity coefficient to recognize the relative change of evapotranspiration according to meteorological factors. They identified a positive sensitivity coefficient of evapotranspiration to short wave solar radiation (Rs), maximum temperature (Tmax), wind speed (U_2), minimum temperature (Tmin), and negative sensitivity coefficient for relative humidity (RH). Besides, the results showed the wide variations of evapotranspiration sensitivities across different agro-ecological zones and seasons. Recently, in the Mono river basin of West Africa, Batablinlè et al. (2021) projected the sensitivity coefficient to analyze the degree of impact of each meteorological factor on the flow. The results of the sensitivity of flow to evapotranspiration and rainfall showed the influence on water availability from climate change (Batablinlè et al. 2021). With reference to the Piazza Armerina area in Italy, Aschale et al. (2023) also introduced research that combines explaining evapotranspiration trends and analyzing sensitivity, which yields more quantitative changes in the contribution rate of specific humidity for reference evapotranspiration (Aschale et al. 2023). These studies have shown that sensitivity analysis is a valuable tool for better understanding the complex interactions between evapotranspiration and climate variables.

In Vietnam, despite numerous studies on climatic and hydrologic trends (Phuong et al. 2020) such as rainfall (Dao Nguyen Khoi and Hoang Thi Trang 2016; Ngo-Thanh et al. 2018; Phuong et al. 2019; Şan et al. 2021), temperature, and stream flow discharge during the last few decades, their relationship with the evapotranspiration trend has not been investigated in the region of climate projections. In view of above preamble, the objectives of the study are to (i) detect the long-term trends of annual and seasonal evapotranspiration at the scale of Southeast region and (ii) analyze the sensitivity of evapotranspiration to climatic variables namely maximum temperature, minimum temperature, relative humidity, and solar radiation.

Study area

The Southeast Vietnam administration includes the southern economic hub of Ho Chi Minh City, and 5 provinces including Tay Ninh, Binh Phuoc, Binh Duong, Ba Ria–Vung Tau, and Dong Nai (Fig. 1). It covers 23.605 square kilometers, which accounts for 7.1% of the total area of Vietnam. The Southeast region is characterized by numerous large rivers, including the Dong Nai and Saigon rivers, and primarily flat topography with only a few minor hills. There is a region with an important position and role in the country's socioeconomic development, national defense, security, and foreign affairs.

The weather in Southeast is hot and rainy with high humidity. Due to topographic factors, Southeast has a tropical monsoon climate with two contrasting seasons: dry and rainy seasons. The dry season usually starts from December to April next year, the rainy season lasts from May to November. The average temperature in the region ranges from 26℃-27℃. The temperature reaches its highest point at about 39℃, the lowest point at about 16°C at night, and 18℃ in the early morning. In the dry season, the average humidity is about 76% – 80%, mounting the highest point of 86% in September and the lowest one of 66% in February. The amount of annual rainfall oscillates around 1800-2000mm. These climatic parameters are recorded from meteorological monitoring stations. Dong Xoai, Tan Son Hoa, and Vung Tau are three of the outstanding hydro-meteorological stations that contribute to collecting data in the Southeast region. Therefore, based on the preliminary analysis of climatic variables, it is becoming increasingly necessary for the local decision-makers to take these factors into consideration.

Methods

Methodological framework

A schematic of the approach followed in this study is shown in Fig. 2. To begin, a large number of climate variables were obtained from each station, which were used as inputs for the model. Before conducting trend analysis and computing Sobol' indices, the model output was mapped onto the input space to visualize model output uncertainty and identify sensitivity patterns. The methodology proposed in this study consists of three key parts:

i. The first part of the framework involves identifying the properties of the hydroclimate variable that affect system performance, which is referred to as the "experimental setup". This step involves selecting which input factor will be subject to testing; setting the values of other input factors that will be kept constant throughout the trend test and sensitivity analysis; and defining the model output.
ii. The quantity of evapotranspiration is then visualized and evaluated using an appropriate time series generation, which involves comparing the modified illustration of the Innovative Şen Trend Analysis with the classical ITA test at each station.
iii. The sensitivity analysis uses a variance-based estimator to assess the relative importance of each climate variable. The sensitivity of evapotranspiration to all climate variables is first compared to the conditional sensitivity when holding each variable constant, which allows for an assessment of the relative impact of each variable on total evapotranspiration sensitivity. The difference between the first-order and total-order indices shows that evapotranspiration has a noteworthy interaction with other input variables.

The improved illustration type of Şen’s method

According to Şen (2012) ITA is a graphical tool and formal hypothesis testing method based on a specific template and application. The author developed the ITA's fundamental basis by dividing a given data set into two equal parts and plotting them on a Cartesian coordinate system (Şen 2015, 2017a, b; Almazroui and Şen 2020). The upper/lower triangular areas are determined by combining the 1:1 straight line and ± 10% error lines, which correspond to increasing/decreasing tendencies. The 45^0 straight line represents trend-free cases (Şen 2012, 2015). One of the significant advantages of this technique is that it does not make restrictive assumptions and is not affected by sample size, serial correlation, or type of distribution.

The internal structures of ITA and Improved Innovative Şen’s Trend Analysis (IITA) are similar. However, IITA proposed by Güçlü (2020) is the modification and more comprehensive version of ITA, with a deep-quantitative dimension. Unlike classical ITA, which only shows overall and partial trends, the improved Şen’s method uses Pettit's change point test to objectively define sub-categories in the data (Güçlü 2020). The Pettit test considers a sequence of random variables X_1, X_2, …, X_T. The test statistical T may follow a few probability distribution functions (PDFs) with the same position parameter, against the alternative one, where a change point exists (Kropp and Schellnhuber 2011).

The equation of Pettit test statistic can be describe as Eq. (1):

$$K_T = max|U_{t,T}| \quad (1)$$

Where the statistic $U_{t,T}$ is then considered parameters of T with $1 \leq t < T$. The formula is suggested in Eq. (2):

$$\mathrm{Ut, T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} sgn(X_i - X_j)\,(2)$$

And K_T is the change point location in case of significance level probability (p), which is approximately less than or equal to 5%, see Eq. (3).

$$\mathrm{p} \approx 2\exp\left(\frac{-6K_T^2}{T^3+T^2}\right)(3)$$

In the modified illustration of ITA, the Pettit change point test can be applied to difference series using the suggested method, and the change point can be identified. Then, the left (right) side of the change point can be classified into "low" ("high") values objectively (see Fig. 3).

Sensitivity analysis method

The Sobol method is a well-established variance decomposition technique and considered one of the standard global sensitivity analysis methods. Unlike any other sensitivity analysis approach, it does not reply on any previous assumptions concerning the structure of the model (Saltelli et al. 2011). Theoretically, the fundamental basis of this method is to consider each input as varying randomly over its entire range. It covers a parameter's direct influence and interaction with others by means of the covariance.

If the model Y = f(X) = f(X_1,X_2, …, X_k) that depends on k input variables, S_i(Y) defines the first-order and S_{Ti}(Y) shows the total-effect for the function Y. The Sobol's indices are calculated by Equations 4 and 5, respectively:

$$S_i = \frac{V_{X_i}\left(E_{X_{\sim i}}(Y|X_i)\right)}{V(Y)} \quad (4)$$

$$S_{T_i} = \frac{E_{X_{\sim i}}\left(V_{X_i}(Y|X_{\sim i})\right)}{V(Y)} = 1 - \frac{V_{X_{\sim i}}\left(E_{X_i}(Y|X_{\sim i})\right)}{V(Y)} \quad (5)$$

Where $X_{\sim i} = \{X_1, X_2, \ldots X_{i-1}, X_k\}$; $E_{X_{\sim i}}(Y|X_i)$ is the value of Y obtained by averaging over all factors but X_i; $V_{X_i}\left(E_{X_{\sim i}}(Y|X_i)\right)$ is the variance of this function over X_i itself.

Recent studies have demonstrated the effectiveness of the Sobol method in analyzing the impact of climate variables on reference evapotranspiration by calculating their sensitivity (Tabari and Hosseinzadeh Talaee 2014; Guo et al. 2017; Ndiaye et al. 2020; Emeka et al. 2021; Poddar et al. 2021). The Sobol method is considered a commonly used standard of global sensitivity analysis as it does not rely on any previous assumptions regarding the model structure, and it covers a parameter's direct influence and interaction with others through covariance. To implement this work, we used multiple estimators of the Sobol indices calculated by calling the Sobol-indices function in the sensobol R package (Puy et al. 2021).

Results and discussions

Trends analysis results in evapotranspiration

An average series of evapotranspiration anomalies was evaluated for annual and seasonal time-scales at three meteorological stations in Southeast, as shown in Fig. 1. The ITA and IITA methods were then applied to determine trends in the given data.

Trends in annual evapotranspiration

Based on the ITA test results for the studied periods of the three meteorological stations, it appears that there is generally a significant increasing trend for Tan Son Hoa station with all of three verbal clusters (low, medium and high). In addition, there are no significant overall trends for Dong Xoai and Vung Tau. However, the analysis of partial tendency shows significant decreasing trends in high values at Dong

Xoai. On the contrary, there are slight increasing trends at low and high groups in Dong Xoai and Vung Tau, respectively. These trends were identified using the proposed graphical approach, which demonstrates the importance of this method.

In terms of annual evapotranspiration, the IITA method has clearly identified quantitative trends for almost all stations. The IITA graphics for Dong Xoai, Tan Son Hoa, and Vung Tau stations are shown in Fig. 4. The IITA results for the three locations are examined and discussed separately below:

In Dong Xoai station, Fig. 4a shows that evapotranspiration in the low values category is in the increasing trend zone at 7.98%, while the evapotranspiration in the high values is decreasing by 12%. In addition, the Pettit change point test in the improved type of ITA provides information on the number, value change, and range of data, whereas the classical method only shows the range. Figure 4a indicates the specific values of trend lengths, which are 72.1 mm and 160.7 mm for the low and high groups, respectively. Furthermore, a different change point is reflected in this method, with the change point value located at number 8 (in 1998), and the numbers belonging to the positive and negative tendency zones are also defined separately as 16 and 20 years.

In the Tan Son Hoa evapotranspiration time series, there is increasing trend in all groups. The change values are calculated as 122.4 mm and 135.6 mm for low and high values, respectively. According to the visual interpretation, the low group has a longer trend period than the high group, but the high group seems to have a stronger positive trend rate than the low group. The visual results of the percentages and numbers of change of groups are presented in Fig. 4b.

Figure 4c shows the daily data from the Vung Tau meteorological station, which indicates that Vung Tau tends to have higher evapotranspiration compared to Dong Xoai for low and high value groups. Specifically, the low group shows a negative tendency of -1.68%, while the high group shows a positive tendency of approximately 2.79%. The different evapotranspiration values of the two half series are 20.7 mm and 36.7 mm, respectively. Moreover, with the change point at number 11, the IITA method clearly demonstrates one of its advantages in determining the timeline (during the year 2004) of fluctuations. These detection points are possibly related to climatic factors.

Trend in seasonal evapotranspiration

Regarding the seasonal evapotranspiration in Dong Xoai, the time series is partitioned into two sub-series comprising 38 years in terms of "the first haft" duration covering the 1982–2000 periods, while "the second haft" runs through 2001–2019 periods. The ITA and IITA methods are applied to analyze the same time scale. The ITA and IITA results of this station are examined and displayed separately in Fig. 5A(i) and Fig. 5A(ii). Based on Fig. 5A(i), the clearest results was the overall positive trend shown by the rainy season, with some data outside the 0.1 bound. A particular behavior has been detected for this season that performed a significant positive trend for the low values and a no trend for the medium and high data. However, the overall and partial trend in dry season appeared to be in stark contrast to the rainy season. The results presented a negative tendencies for the medium-high groups, while the low group was not clear evidence of trend, with almost all the points near the no-trend line. For the IITA results, Fig. 5A(ii) reveals the specific in quantitative analysis in Dong Xoai station in each separately seasonal. Although, a qualitative assessment of this analysis results is similar to the ITA classical method with a growing change in the rainy season and falling down in the dry season. However, the outstanding analytical results of this approach lies in the exploration of quantitative value and the precise determination of the change point in the trend. In particular, the positive difference values of rainy data are 84.7 mm and 12.76 mm for the low and high categories, respectively. Meanwhile, the downtrend value for both groups reached 22.56 mm and 166.2 mm. From the above analysis, it can be seen that IITA has the ability to accurately represent the quantitative trend value, which has not been evaluated in the classic ITA method.

In the mean graph of the Tan Son Hoa station depicted in Fig. 5B, the only sharp transition observed were increases in the both overall and partial identification. According to the ITA results, although all groups shown the most obvious uptrend, with scatter points appear quite far from the 1:1 line. However, this result only describes a qualitative information. Therefore, the comparison between the ITA and the IITA methods performed in this work was particularly important to provide a quantitative assessment. In fact, in addition to describing the uptrend for the groups, Fig. 5B calculated different values and change points for the seasonal anomalies. As shown in the rainy season, the low and high values categories showed increases of 46.7 mm and 77.1 mm, respectively. At the change point in 2004, the increasing transition changed from 9.1% up to 14%. Similarly, in the dry season, the mean evapotranspiration values were 51.49 mm and 68.7 mm for the low and high groups, respectively.

Regarding seasonal evapotranspiration, the results of Vung Tau showed contrasting tendencies (Fig. 5C). The positive and negative tendencies detected in the rainy and dry data through the ITA classic method were confirmed by the IITA test with more statistical evidence. Specifically, the increasing trend value in the rainy season fluctuated from 5–8% from the low to high areas. Additionally, this analysis showed a decrease of 4.7% in the dry season.

Sensitivity Analysis Results

Annual Scale

The results presented qualitative and quantitative findings for three stations in Fig. 6. Before computing Sobol's indices, the study explored how the model output is mapped onto the model input space through scatter and multi-scatter plots. These plots provided visual inspections of climate variables for approximately 36 years and allowed for the rapid estimation of global sensitivity indices. The first scatterplot displayed evapotranspiration against climate variables while showing the mean evapotranspiration values. Then, the study identified patterns denoting the sensitivity of the quantitative amount of variance that each input contributes to the total variance value of evapotranspiration.

The scatterplots in Figs. 6(i) for all stations indicated that RH and SH had more influence on ET than temperatures because they had more "shape". However, the scatter plots did not always permit detecting which parameters had a contributing effect on the model output. To gain a first insight into these interactions, multi-scatterplots were created to show double climate parameters against each other and map the resulting coordinates to their respective model output value. Interactions were visible through the emergence of colored patterns (Fig. 6ii). The results suggested that RH might interact with SH given the colored pattern of the (RH, SH) facet: the highest values of evapotranspiration are concentrated in the corners of the inputs space (RH, SH), resulting from a combination of high/low RH values with high/low SH values. To assess the exact weight of this higher-order interaction, the computation of second-order indices would be required. To avoid this drawback, the study computed Sobol's indices for climate variables in this case study.

Figure 6(iii) quantified the amount of variance that each input parameter contributed to the total variance values of evapotranspiration. As shown in these figure, it can split the variance values of a given contribution into two parts: that caused by variations of individual inputs, which represent the main effect, and that caused by mutual interactions of several inputs. The sum of the total index reaches 1, which proves the independence of the different parameters and good convergence of the algorithm. These figures present the magnitude of each climate variable for evapotranspiration, as well as their interaction.

In term of the Sobol's indices for the Dong Xoai site, Fig. 6(iii) shows that the red-colored bars denoted the first-order sensitivity index, and the blue-colored bars stood for the total sensitivity index. The Sobol's indices in the figure suggested that SH was generally the most crucial variable for ET, with approximate index values of 0.63. The relative humidity affecting the sensitivity values had also clearly evident, with humidity being the second-most important variable (with Sobol's indices up to 0.21), followed by temperatures.

The Sobol's results for Tan Son Hoa station were used to illustrate the observed changes in meteorological variables, and in particular, these panel outcomes had quite close to the Dong Xoai site. The input factors determining solar radiation (SH) and relative humidity (RH) were by far the most important, explaining 64.7% and 24.6% of output variance, respectively. In contrast, other input factors were minor (with Sobol's indices below 10%).

A similar analysis of parameters for the Vung Tau location, the outcomes presented somewhat identical results compared to those obtained for Dong Xoai and Tan Son Hoa sites. Consistent with Fig. 6C, solar radiation also represented the greatest impact, contributing up to 70% of the first-order sensitivity in evapotranspiration responses (Fig. 6C(iii)). The lower influence of RH (13.6%) and T (11%) on ET was also apparent. Moreover, the temperature at mean and minimum values showed light interaction effects on evapotranspiration.

The above findings illustrate several typical characteristics related to sensitivity analysis. The first-order effect indicates the share by which output variance can be reduced if the considered input factor is fixed individually. None of the first-order sensitivity indices is equal to 1, which implies that no input factor uniquely determines the index ranking. In addition, this approach inspects Ti, which adds to an input factor's Si all interaction effects that involve said input factor. The total effect sensitivity index is close to zero for the input factor determining Tmin, Tmean, Tmax. Hence, by assessing the concept behind Sobol's notation, the influence of these meteorological choices is relatively negligible, and these input factors can be declared non-influential. Accounting for interaction effects, the most influential input factors are those that trigger the imputation of RH and SH. A notable difference between Si and Ti indicates interaction effects with one or several other inputs.

Monthly scale

To examine the sensitivity of evapotranspiration at a monthly scale, RH, SH, Tmax, Tmean, and Tmin were used as independent variables and ET as the dependent variable for the Sobol method. The monthly ranges of these meteorological parameters were based on historical data from 1982 to 2019 in Southeast region. Figure 7 present the first-order and total sensitivity indices at different months.

In this case, the monthly analysis of the sensitivity of evapotranspiration to changes in the climate variables can provide insights that may not be apparent from annual analyses. The interaction of relative humidity, solar radiation, and temperatures on evapotranspiration varied significantly across the months at most stations.

Figure 7A shows that there was a strong correlation between SH and T in different months over the past 40 years at Dong Xoai station. Specifically, SH was the main sensitivity parameter for January and February, with first-order sensitivity coefficients of 92% and 94%, respectively. Similarly, the main sensitivity parameters for other months were SH (59.2%), Tmin (40%) in March, SH (55%), Tmin (44.9%) in May, SH (84.9%) and Tmin (15.1%) in December. However, the remaining months had the largest sensitivity value of the entire parameter displayed as Tmin, which had a contribution in the magnitude of 65–87%. Besides, SH was characterized either by the slighter sensitivity values than the Tmin, oscillating from 15–30%, meaning that SH in this situation was the secondary climate factor influencing the affection of monthly evapotranspiration.

For Tan Son Hoa and Vung Tau stations, observed datasets in the monthly sensitivity results were relatively identical to the annual scale. Figures 7B,C also showed that evapotranspiration was most sensitive to solar radiation (60%), followed by relative humidity (which varies from 15–30%), and minimum temperature.

Conclusions

Any change in evapotranspiration is likely to have a profound effect on agriculture and water resource planning. This study attempts to provide a preliminary idea about the performance of a trend analysis of long-term time series of ET and its sensitivity to major climatic parameters, including relative humidity, solar radiation, maximum temperature, minimum temperature and mean temperature values. Two main types of analysis were conducted for reference evapotranspiration at three stations: (i) An extension to the established method of Improved Innovative Trend Analysis (IITA) originally proposed by Şen (2012);

and (ii) Based on the variance algorithm, the global sensitivity analysis supports the 'golden standard' tool known as Sobol's method to expose sensitivity indices.

The first aspect results of this study showed a highlighted variability that the evapotranspiration trends obtained by the analyses in the ITA classical method. Besides, the results show not only a trend consistent with the records analyzed by the traditional Şen's method but also quantify the percentage of the fluctuations. The study applied the proposed methods, including the classical ITA method, and the Improved Visual Trend Şen's Analysis (IITA) in the same test case, comparing both results and finding IITA to be as efficient, reliable, and consistent an estimator as the ITA test. Furthermore, IITA can present the data in quantitative graphical format for a better understanding of the results by detecting the amount of a percent of sub-trend values.

For another purpose, the calculation of sensitivity indices by using the Sobol method performed sensitivity analysis. The outcomes observed that change in humidity and solar radiation had large indices, representing highly significant results. The study thoroughly assessed the effects of input data dimension on the model predictions. Given the changing above and the crucial role of evapotranspiration in hydrology and agriculture, this case study enables a better understanding and interpretation of the complex relationship between input drivers and sectorial output indicators under the different climate models.

Such information is essential for further refinement and application of the IITA and Sobol methods for use in climate change adaptation planning and impact assessment of meteorological variability on crop water requirements in different climate regions across Vietnam.

Declarations

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Availability of data and material: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

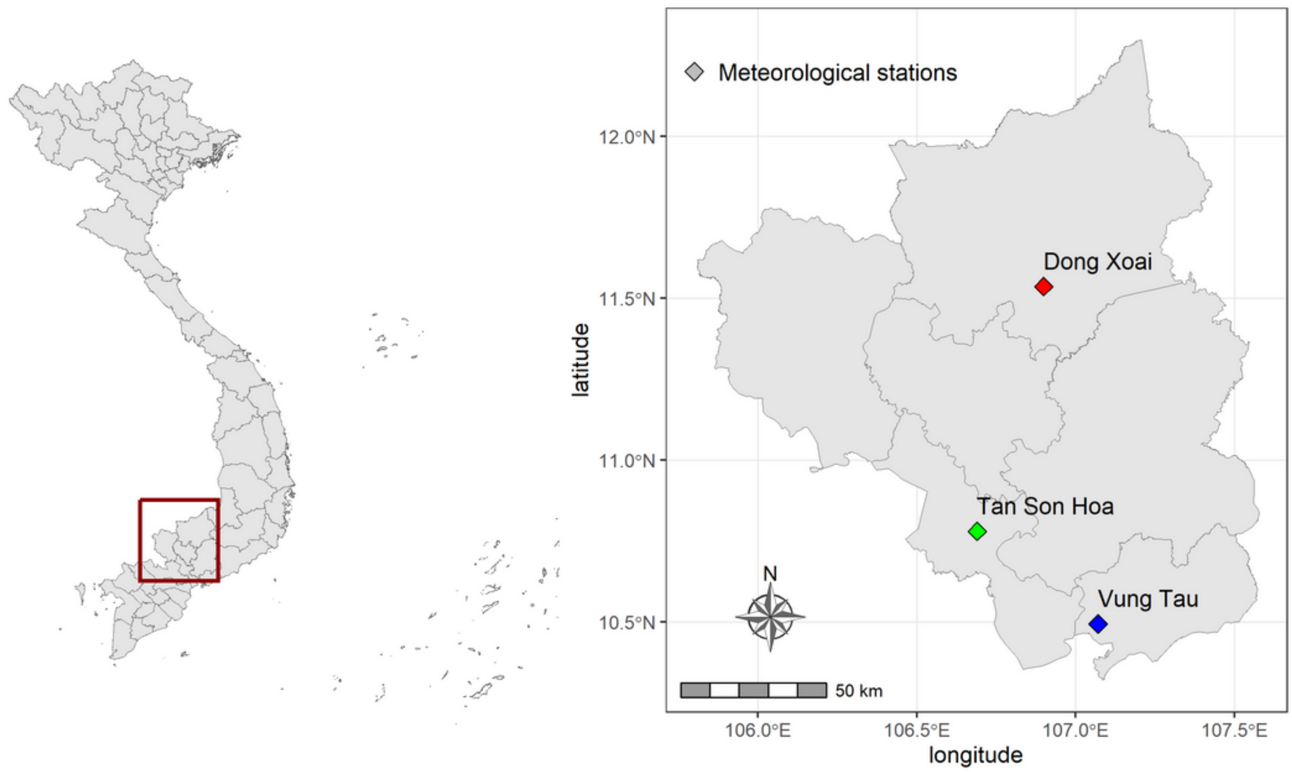

Figure 1

Geographical map of Southeast Vietnam

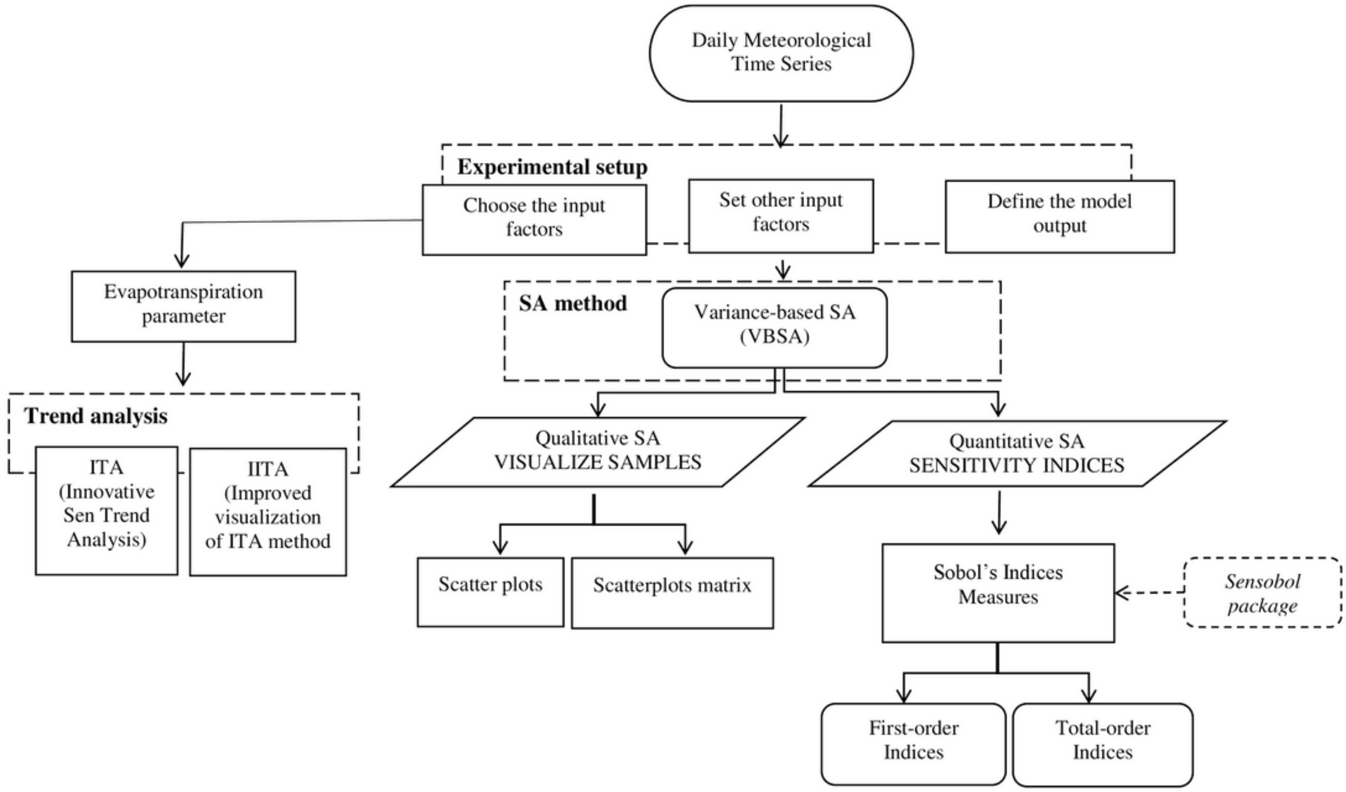

Figure 2

Brief flowchart of research methodology

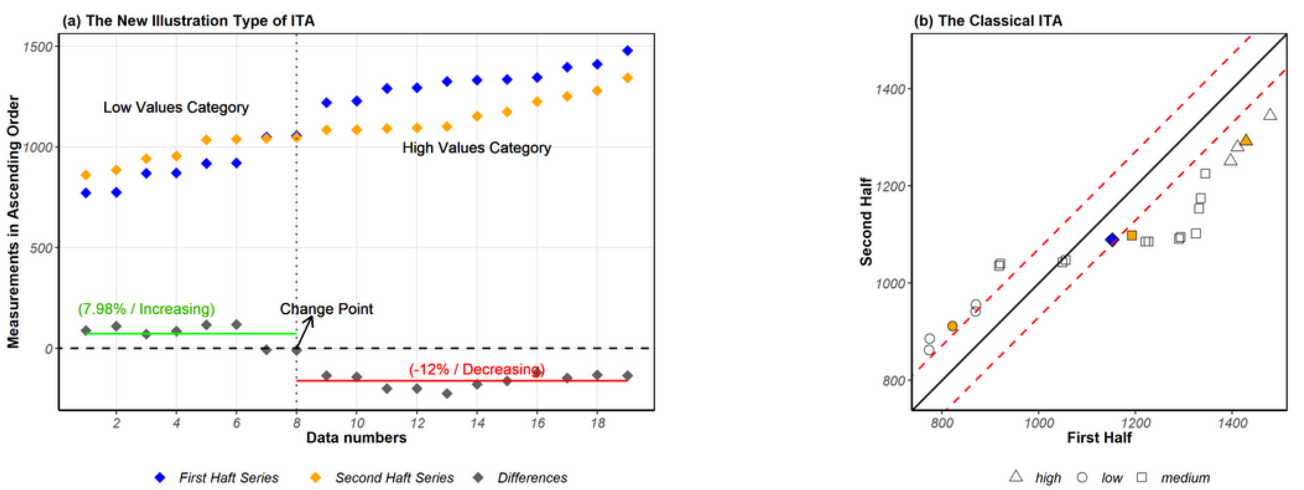

Figure 3

Sketch map of the improvement (a) and classical (b) ITA methods

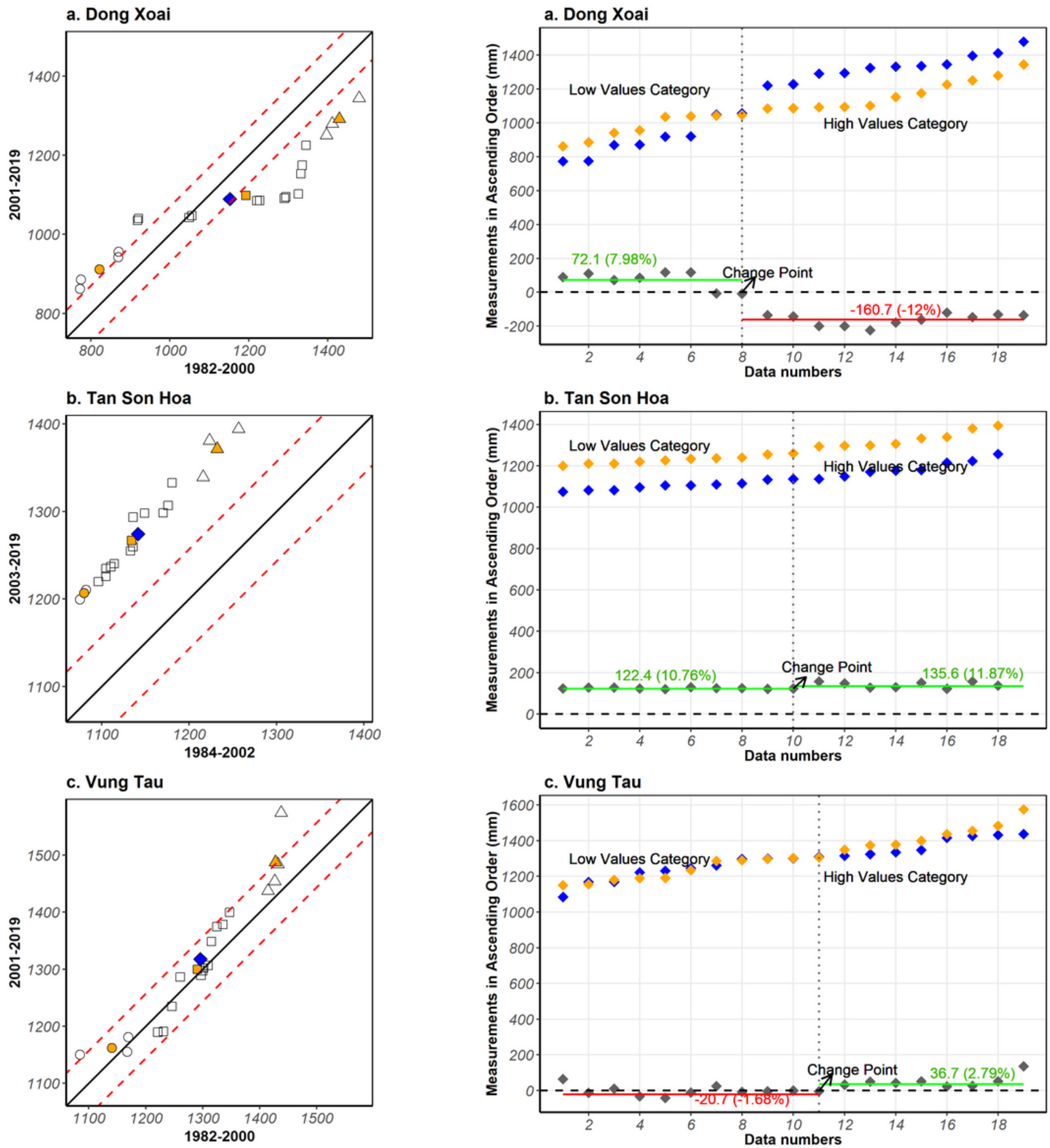

Figure 4

Annual trends analysis of Dong Xoai, Tan Son Hoa, Vung Tau stations using classical and improved types of ITA

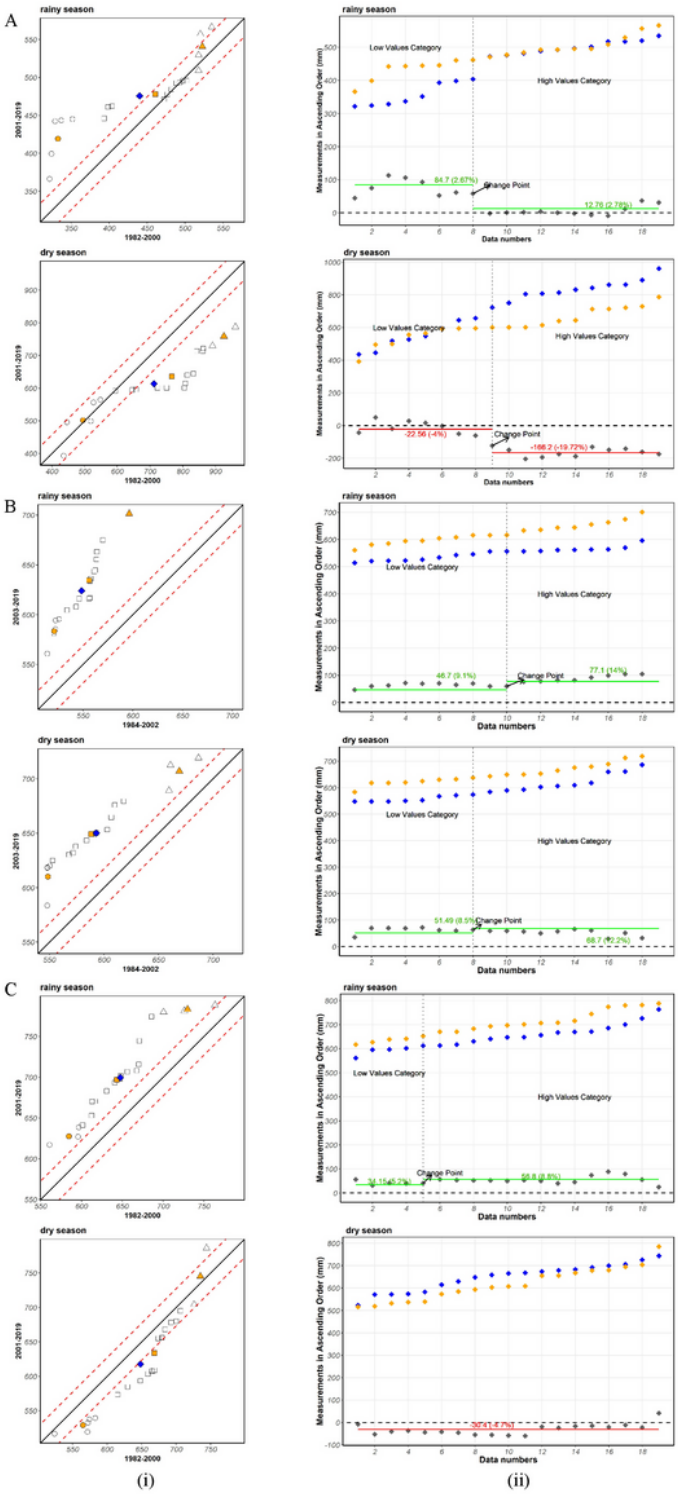

Figure 5

The seasonal evapotranspiration trends in Dong Xoai (A), Tan Son Hoa (B), Vung Tau (C) stations

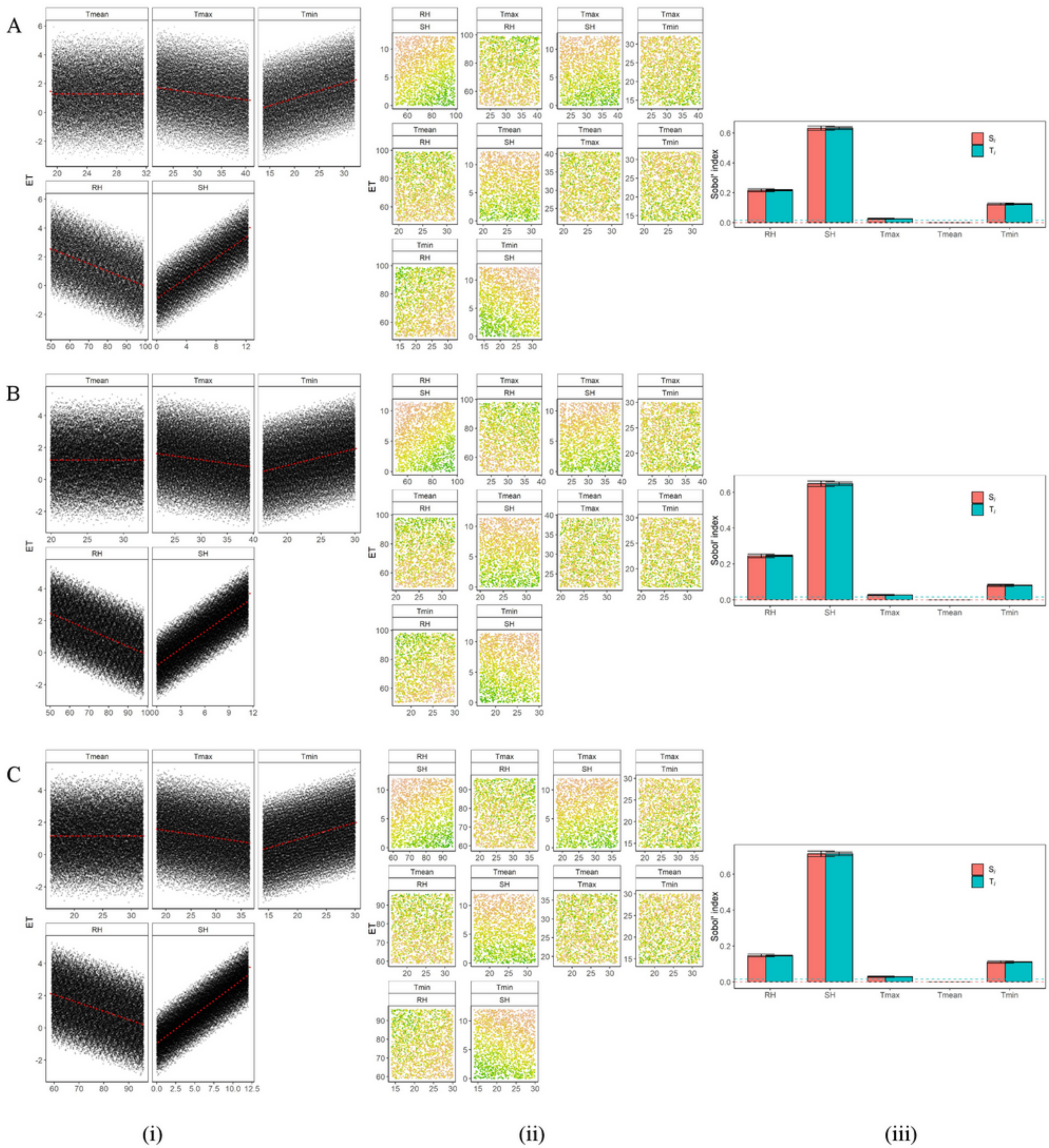

Figure 6

Dong Xoai (A), Tan Son Hoa (B), Vung Tau (C) stations sensitivity analysis results

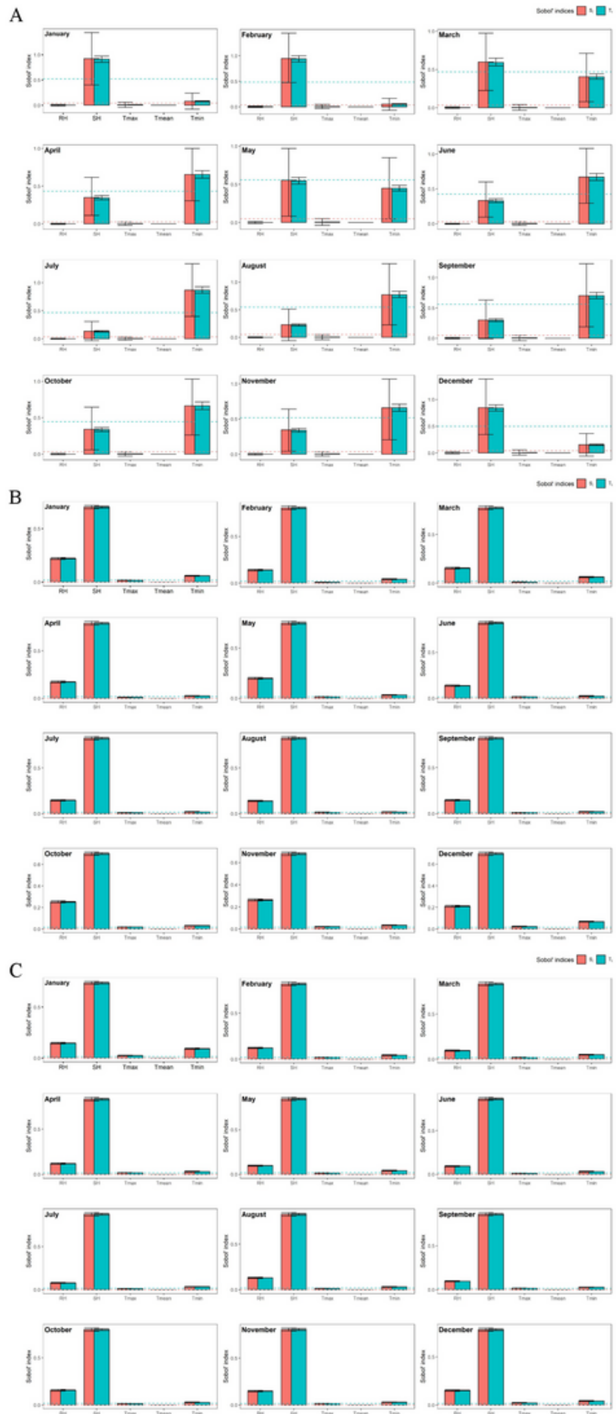

Figure 7

Monthly scale sensitivity analysis results in Dong Xoai (A), Tan Son Hoa (B), Vung Tau (C) stations (S_i: First-order sensitivity index; T_i: total sensitivity index)