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Influence of Surface Water Bodies on the Land Surface Temperature of Bangladesh

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Received: 9 October 2019; Accepted: 22 November 2019; Published: 28 November 2019

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Abstract: Recent climate change has resulted in the reduction of several surface water bodies (SWBs) all around the globe. These SWBs, such as streams, rivers, lakes, wetlands, reservoirs, and creeks have a positive impact on the cooling of the surrounding climate and, therefore, reduction in SWBs can contribute to the rise of land surface temperature (LST). This study presents the impact of SWBs on the LST across Bangladesh to quantify their roles in the rapid temperature rise of Bangladesh. The moderate resolution imaging spectroradiometer (MODIS) LST and water mask data of Bangladesh for the period 2000–2015 are used for this purpose. Influences of topography and geography on LST were first removed, and then regression analysis was conducted to quantify the impact of SWBs on the LST. The non-parametric Mann–Kendall (MK) test was used to assess the changes in LST and SWBs. The results revealed that SWBs were reduced from 11,379 km^2 in 2000 to 9657 km^2 in 2015. The trend analysis showed that changes in SWBs have reduced significantly at a 90% level of confidence, which contributed to the acceleration of LST rise in the country due to global warming. The spatial analysis during the specific years showed that an increase in LST can be seen with the reduction of SWBs. Furthermore, the reduction of 100 m^2 of SWBs can reduce the LST of the surrounding regions from −1.2 to −2.2 °C.

Keywords: land surface temperature; surface water bodies; MODIS; Bangladesh

1. Introduction

Rises in temperature have been noticed all over the world due to the emission of greenhouse gasses [1–4]. The increase in temperature over the globe is not uniform as many local factors affect the land surface temperature [5,6]. South Asia is one of the most vulnerable regions due to climate change where the temperature has been rising more than the global average [3,7–9]. The impact of the rising temperature is more prevalent in the South Asian country of Bangladesh due to the poor adaptation capacity.

Surface water bodies (SWBs) play an important role in buffering the effects of global warming induced temperature rise and help in climate adaptation and resiliency (Millennium Ecosystem Assessment 2005). Due to high heat capacity, water needs a high amount of heat energy to change its temperature. This makes water bodies capable of limiting the rise of air temperature. If the air temperature is rising, the water absorbs heat and can slow down the air temperature rise, without much change in water temperature. The positive influence of SWBs on the cooling of the microclimate of the surrounding regions indicates that more SWBs can help in better adaptation to climate change.

Though SWBs plays a key role in the reduction of air temperature and can be an effective way of reducing temperature rise due to global warming or the urban heat island effect, studies related to the quantification of the effect of SWBs on the micro-climate around the SWB are very limited. Murakawa et al. [10] assessed the effect of SWBs on air temperature in Japan and reported a difference of about 3–5 °C in air temperature between the river and the city area. Wong et al. [11] also reported the cooling benefits of SWBs on the tropical climate of Singapore. Carroll and Loboda [12] reported that SWBs, especially ponds and lakes, have decreased substantially in global scale, which has caused an alteration of micro-climate around the SWBs, including an increase in temperature. The authors further reported that surface water bodies play a major contributing role in the cooling of the environment. Wong, Tan, Nindyani, Jusuf, and Tan [11], also reported that the air temperature reduced by only 0.1 °C at every 30 m interval from SWBs in Singapore due to the high humidity in the region. This indicates the assessment of the effect of SWBs on the cooling of surface temperature at a regional scale.

It is evident from the above studies that SWBs can limit the increase in temperature rise. However, there is a decline of SWBs globally due to unsustainable human activities, changes in sedimentation, prolonged drought, changes in precipitation patterns, balance in evapotranspiration, and glacier retreating [13]. The authors further asserted that these changes are outcomes from different anthropogenic activities [14]. Pekel et al. [15] reported that more than 90,000 km^2 of the permanent surface water has been disappeared globally from 1984 to 2015. This change is observed more in Asia than in another continent of the world, which in turn has caused a further increase in the temperature of the region.

Due to the location of several rivers, Bangladesh is abundant with SWBs [16]. However, the rapid growth of population, urbanization, and other sustainable human activities have caused the gradual decline of SWBs in Bangladesh. It is evident that SWBs can be a good buffer to limit the rise of temperature due to global warming. The decline of SWBs has reduced the cooling effect and excoriated the condition of rising temperature [17]. It has been observed that the number of SWBs is continuously declining in Bangladesh [18]. This decline in the SWBs has caused an increase in the land surface temperature (LST). However, the influence of SWBs on local and regional LST has not been documented in Bangladesh.

Most of the water bodies in Bangladesh are relatively small in size and, due to limited resources and unavailable remote sensed data, these water bodies have not been mapped. Therefore, despite a large significance, the effect of SWBs on LST has not been assessed in Bangladesh. The recent advances in satellite and radar observations have made tracking and record keeping of land water bodies much easier [12]. These multi-sensor data fusion methodologies led to the development of a comprehensive global map of surface water from the Shuttle Radar Topography Mission (SRTM) combined with the daily 250 m moderate resolution imaging spectroradiometer (MODIS) observations [19]. The advantage of the MODIS SWB product is that water bodies as small as 2–3 hectares can be detected. Furthermore, it offers a good temporal frequency of observations allowing for dynamic observations of interannual and seasonal variability of the extent of SWBs [20]. When compared to Landsat data, the new global 250 m water map MODIS was found capable of mapping 80% of the total lakes and over 90% of the surface area of water correctly [19].

The objective of this study is to assess the trend of SWBs over Bangladesh and evaluate the relation between the changes in SWBs and LST. The SWB and LST data obtained using MODIS (MOD44W and MOD11A1) were used for this purpose. The study quantified the impact of changes in the water mask on the changes in the LST of Bangladesh. The study will help in recognizing the ecological changes on the LST of Bangladesh.

2. Study Area and Data

Bangladesh, located in South Asia, lies between 20°34′ N–26°38′ N latitude and 88°01′ E–92°41′ E longitude (Figure 1) and has a total landmass of 147,570 km^2. The climate of the country is characterized as tropical humid, where seasonal rainfalls vary widely, temperatures are moderately warm, and humidity is high for most of a year [21–23]. Rainfall is about 1500 mm in the west while it can be more than 4400 mm in the east. Due to the location of Bangladesh in the northern hemisphere, the country experiences four distinct seasons; the summer monsoon season (June–September), the autumn post-monsoon season (October–November), the winter season (December–February), and the spring season, also termed as the pre-monsoon season (March–May). In Bangladesh, more than 75% of the rainfall occurs during the monsoon.

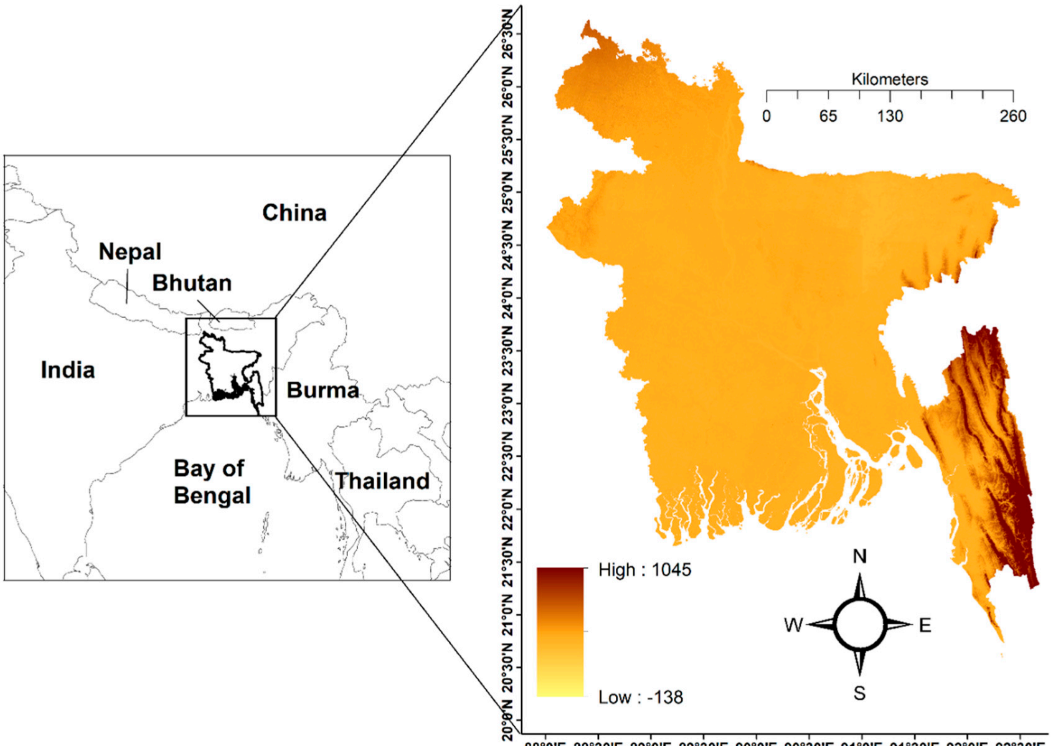

Figure 1. Geographical location of Bangladesh in South Asia and topography.

To create the complete representation of the SWBs, the MODIS satellite utilizes the 250 m water mask from the SRTM water body data and the 250 m MODIS (MOD44W). For the estimation of the daily LST data (MOD11A1), the MODIS instrument uses the daily surface reflectance. Figure 2a,b shows the spatial variability of the LST and the SWBs over Bangladesh from 2000–2015 respectively. MODIS provides daily global coverage of LST, which is particularly useful for continental to global scale assessments. There have been two MODIS datasets of MODIS-Aqua and MODIS-Terra. The temporal extent of the dataset for the terra has been available since February 2000, while that for the aqua has been usable since July 2002 [24]. In this study, the LST of MODIS terra was used in order to have a longer temporal coverage. MODIS LST data are widely used for different applications, ranging from drought analysis to climate change estimation [11,25–29].

The measurement from the MODIS satellite always has uncertainty in its pixel reliability. The reliability of the LST data was checked based on the quality control (QC) layer. The average error in these data is smaller than 1 °C for the LST data [30]. If this designated error in the data is not achieved, then the error in each pixel is defined based on 4 to 7 bits of the QC data [31]. Pixels having an error smaller than or equal to 2 °C were extracted for further calculation [29].

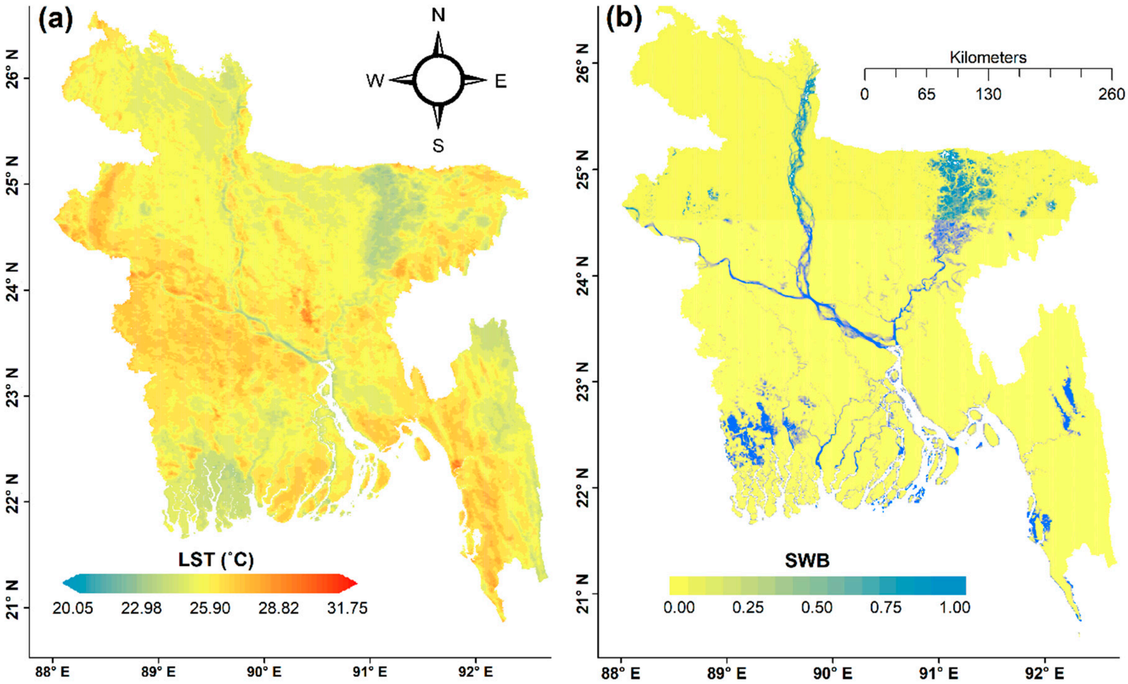

Figure 2. (**a**) Spatial variability of land surface temperature (LST) over Bangladesh estimated using moderate resolution imaging spectroradiometer MODIS data for the period 2000–2015; (**b**) Spatial distribution of surface water bodies (SWBs) from 2000–2015 extracted from MODIS data.

3. Methodology

In this study, the MODIS SWBs and LST were aggregated to 10 km^2 spatial resolution to assess the relation of LST to the ratio of land having SWBs in order to assess the effect. The trends in SWBs and LST were assessed using the Mann–Kendall (MK) test [32–34] at a significance level of 0.1. The Sen's slope estimator was used to assess the magnitude of change [35]. The linear regression approach was used to quantify the impact of SWBs on LST. Furthermore, the effect of SWBs on regional temperature was analyzed to understand the impact of SWBs on regional climate.

The Sen's slope estimator (Q_{med}) uses the median of two consecutive points of the series for the calculation of the change in the time series. The Sen slope is calculated by:

$$Q_{med} = \begin{cases} Q_{\left|\frac{N+1}{2}\right|} \; if\ N\ is\ odd \\ \dfrac{Q_{\left|\frac{N}{2}\right|} + Q_{\left|\frac{N+2}{2}\right|}}{2} \; if\ N\ is\ even \end{cases} . \quad (1)$$

The significance of the trend calculated from the Sen's slope estimator was assessed using the Mann–Kendall (MK) test. The classical Mann–Kendall test statistic (S) for a time series, x, with n number of data points is calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} sign\ (x_i - x_k) \quad (2)$$

where

$$sign\ (x_i - x_k) = \begin{cases} +1 & when\ (x_i - x_k) > 0 \\ 0 & when\ (x_i - x_k) \\ -1 & when\ (x_i - x_k) < 0 \end{cases} . \quad (3)$$

The significance of the trend is calculated using Z statistics as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\ (S)}} & when\ S > 0 \\ 0 & when\ S = 0 \\ \frac{S-1}{\sqrt{Var\ (S)}} & when\ S < 0 \end{cases} \quad (4)$$

where, $Var\ (S)$ is the variance of S. The trend is considered significant at a 0.1 confidence level when absolute value of Z is higher than 1.64.

4. Results

4.1. Changes in MODIS Water Bodies and Surface Temperature

The areal coverage of SWBs and the average of LST over the period 2000–2015 estimated using MODIS data are presented in Figure 3a,b. Figure 3a shows that the areal coverage of the SWBs of Bangladesh has decreased from 11,379 km^2 in 2000 to 9657 km^2 in 2015. The fluctuations in the SWBs of Bangladesh happens mainly due to flooded land and highly flooded irrigation land. The figure shows a decreasing trend in SWBs while there is an increasing trend in LST. The decline was much higher after 2007, while a high fluctuation in trend is noticed between 2002 and 2011. The trend line seems to have decreased very rapidly in recent years. The trend in SWBs is observed to be significant at a 90% level of confidence.

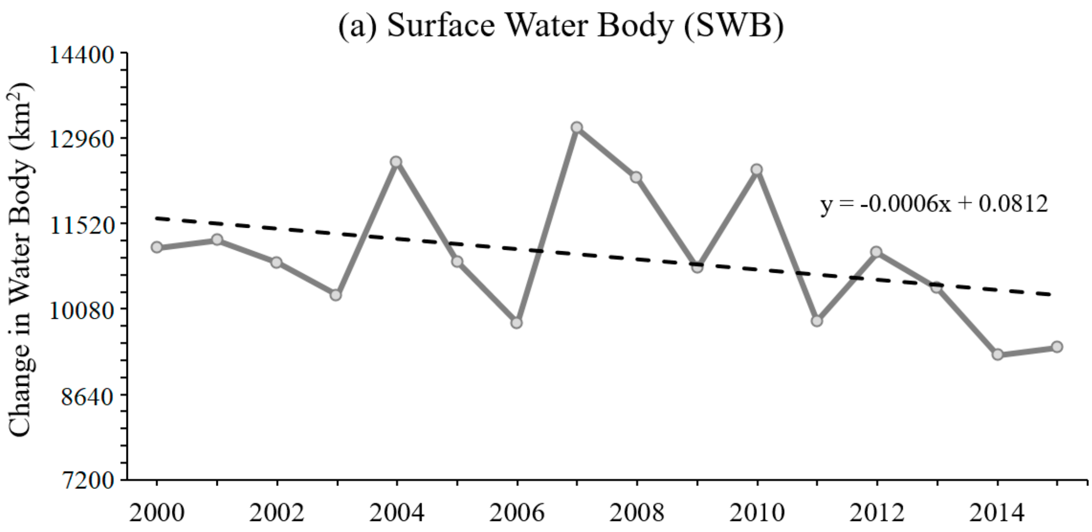

Figure 3. *Cont.*

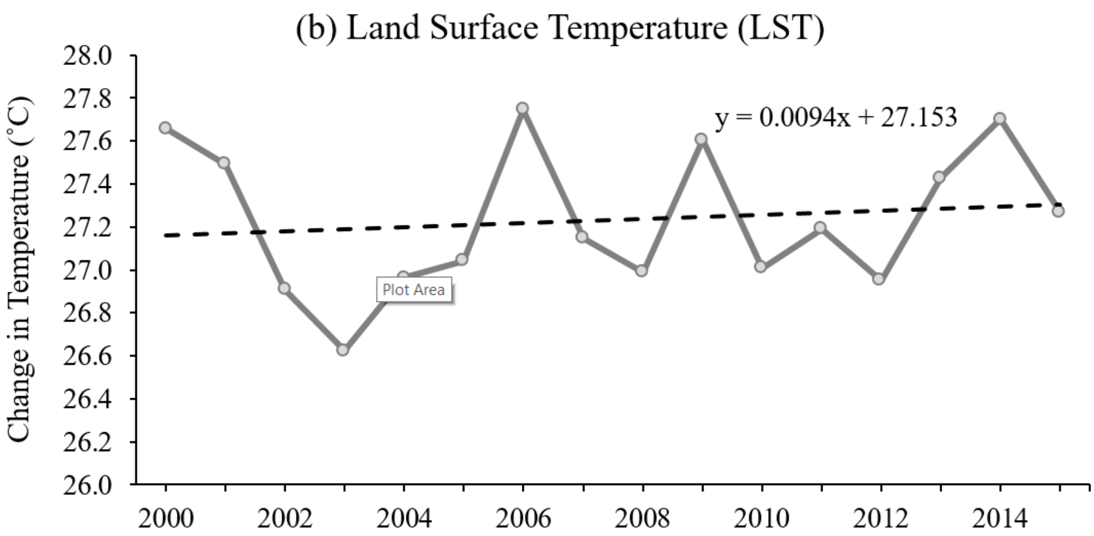

Figure 3. The time series of the areal coverage of SWBs and the average of LST for the period 2000–2015 estimated using MODIS data.

Figure 3b shows an increase in LST over Bangladesh from 2000 to 2015. The trend analysis revealed that the change was 0.01 °C/year during this period, but the change was not significant. This may be due to the short period of data used for analysis. The long-term temperature of the country was found to significantly increase [36,37].

4.2. Relationship between Surface Water Bodies and Temperature

The relationship between the yearly LST and the SWBs is shown in Figure 4 using box plots. The *y*-axis on the left represents the SWBs, and the *y*-axis on the right represents LST. The box plots are prepared using LST or SWBs values of all pixels in a year. The figure shows that the medians of the SWBs lie between 0.0 and 0.1. The high values of SWBs indicate a presence of larger water bodies such as rivers, lakes, or ponds, the presence of a rice paddy or other highly flooded agricultural practices. The LST in different years was found to fluctuate between 26 and 28 °C. The figure shows a negative correlation between LST and SWBs. Lower LST is observed in the year with more SWBs. For example, the increase of SWBs in 2010 caused a decrease of LST in the year 2010.

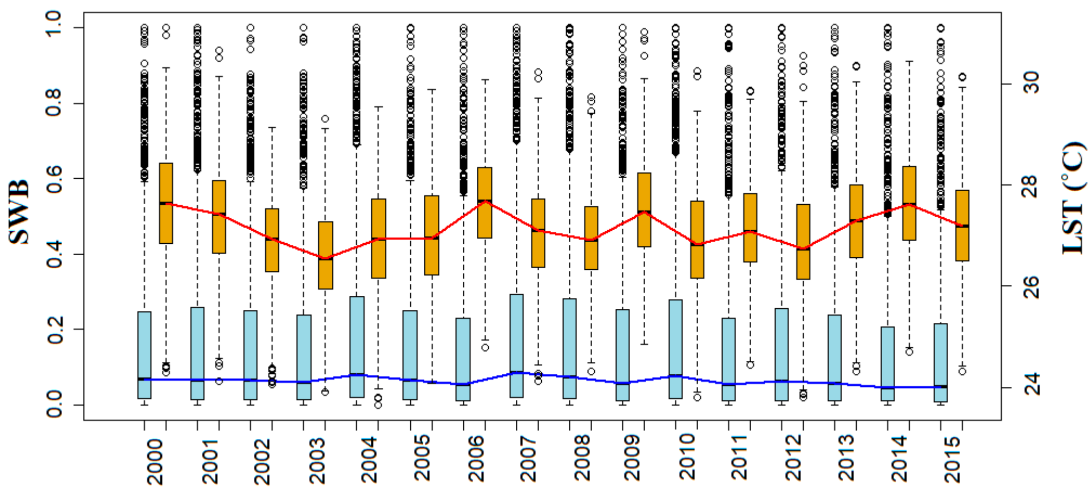

Figure 4. The variation of SWBs and LST in different years during 2000–2015. The brown color box plot represents the time series of LST and the light blue color box plot shows the time series of SWBs.

The relationship between the LST and the SWBs for the years 2000, 2005, 2010, and 2015 are shown in Figure 5. A decrease in the LST is noticed with the increase in the SWBs due to the cooling effect of SWBs. The temperature difference between the region with no SWBs and the area completely covered by SWBs was found to vary between 1.5–2.0 °C for different years. The relationship between the LST and SWBs was found to vary for different years. The slope of the regression line was found steeper in 2000 and 2010 compared to 2005 and 2015. The effect of water bodies on micro-climate depends on many other factors like humidity, wind and turbulence, and dew. The year to year variation of those factors may be the cause of the variation of the relationship between LST and SWBs.

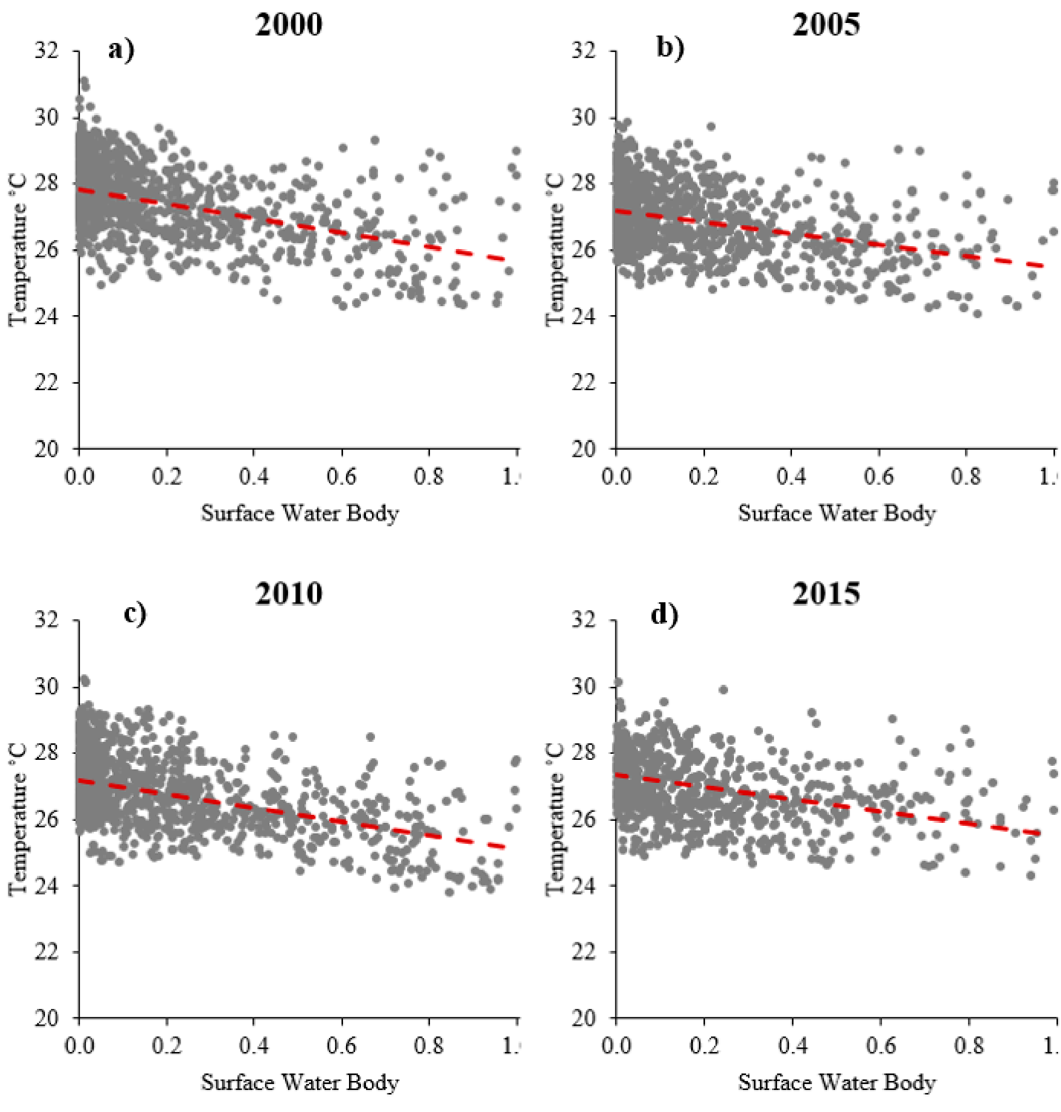

Figure 5. Relationship between the LST and SWBs in the year (**a**) 2000, (**b**) 2005, (**c**) 2010, and (**d**) 2015.

4.3. Quantitative Impact Assessment

The impact of SWBs on LST is quantitatively estimated for all the years between 2000 and 2015. Obtained results are presented using the box plot in Figure 6. The temperature variation over the study years is presented in Figure 6a, while the temperature reduction due to SWBs in different years is presented in Figure 6b. The horizontal line in the middle of the box represents the mean, and the height of the box represents the inter-quartile range temperature. Figure 5a shows that the mean LST of Bangladesh varies between 26.6 °C to 28 °C, with an aerial average mean of 27.34 °C. The reduction of LST due to SWBs was found to vary between −2.2 and −1.4 °C.

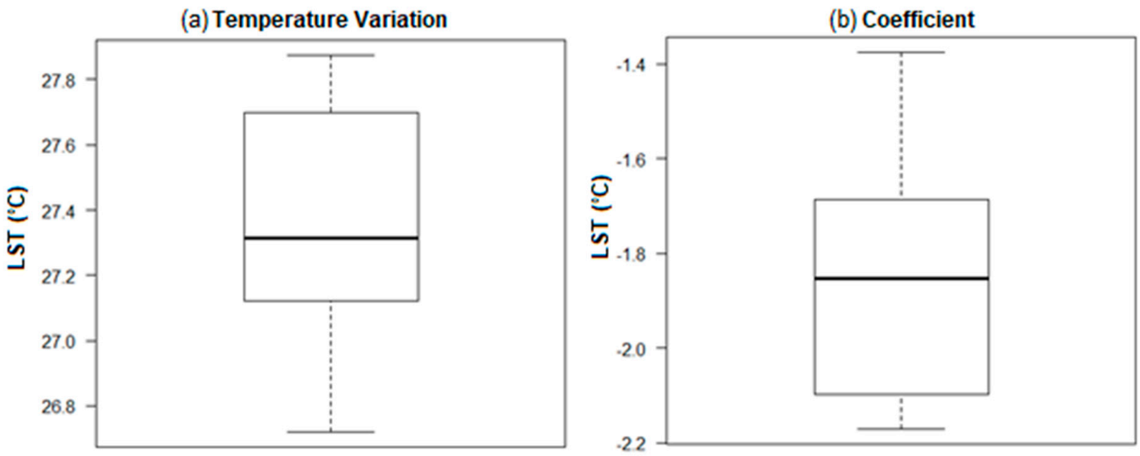

Figure 6. (**a**) Variation of land surface temperature; (**b**) reduction of LST due to SWBs in different years during 2000–2015.

4.4. Change in Regional Temperature Due to SWBs

To assess the impact of SWBs on regional climate, the spatial variability of SWBs and LST in northeast Bangladesh for different years is assessed. The locations of the region in the map of Bangladesh and the area covered by SWBs in the region are shown in Figure 7. Many large water bodies and agricultural lands are located in the region. A gradual reduction of SWBs in the region has been reported. Therefore, this assessment was conducted in order to understand the changes in both SWBs and in the regional temperatures of the area.

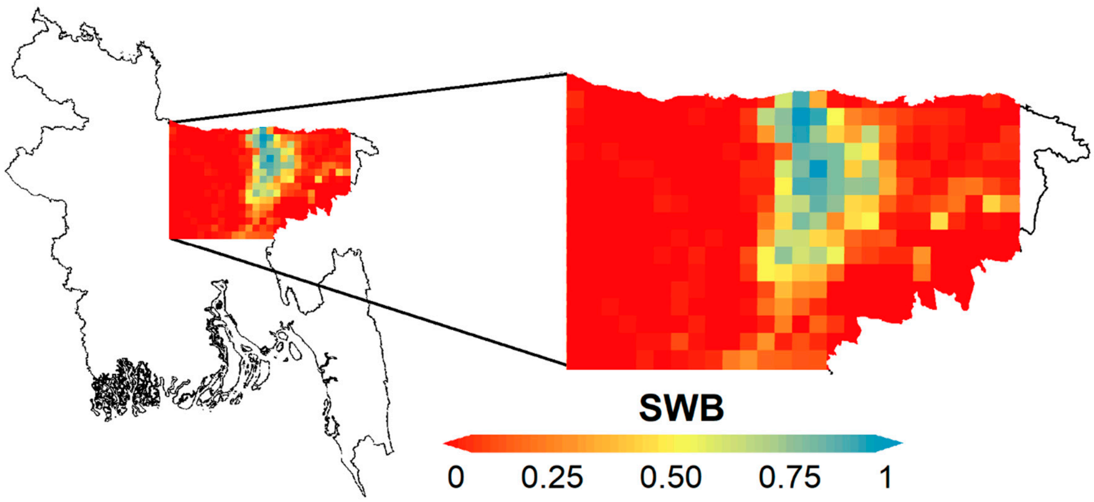

Figure 7. The sample area selected in this study to show the influence of SWBs on regional LST. A pixel area completely covered by water bodies is presented using 1 while complete absence of water bodies is presented using 0.

The spatial distribution and anomaly of SWBs for different years in the region are presented in Figure 8. The difference in LST from the average LST of the region is presented to remove the effect of any other external factors on LST rise. The relationships are shown in Figure 8 for the years 2000, 2005, 2010, and 2015. With the decrease of SWBs, the increase in LST is observed. However, the change in the LST is less, compared to the changes in SWBs.

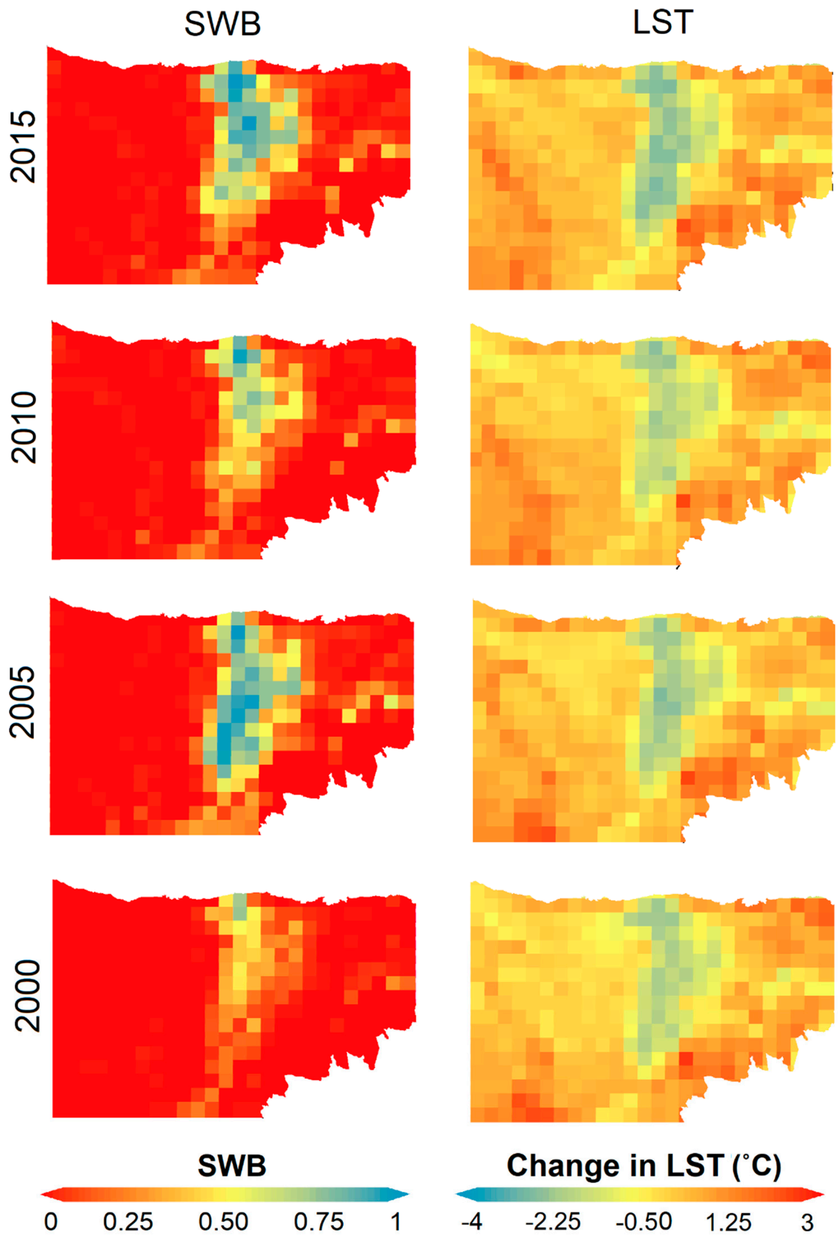

Figure 8. Comparison of SWBs and LST over the northeast region of Bangladesh.

5. Discussion

The study presents the relation and the impact of SWBs on the LST of Bangladesh, where depletion of SWBs has been observed due to climate change and other unsustainable anthropogenic activities [24]. While the SWBs are highly dynamic due to the changing pattern of rainfall, a decrease in SWBs has been noticed in most parts of the globe [38]. The changes in SWBs in Bangladesh were found in the line of global trend of SWBs. The number of SWBs in Bangladesh was found to decrease significantly at a 90% level of confidence. An increase in LST was also noticed in Bangladesh. However, the increase was not found statistically significant, which might be due to the lower temporal extent of the dataset [39].

Banerjee and Kumar [25] reported that the surface water over neighboring India increased during 2002–2015. An increase is also reported by Donchyts et al. [40]; both contradict the current study. However, studies have also reported that the waters of the Meghna, which is one of the important rivers of Bangladesh, have diminished significantly and have reduced to nearly 9580 km^2 at present. One of the reasons for the decrease in SWBs across Bangladesh may be due to over-pumping of groundwater in recent years [41]. This has caused a rapid decline of the groundwater table and disappearance of water bodies in many regions, particularly in northwest Bangladesh. Over pumping of groundwater also causes more surface water to percolate into the ground and leads to the reduction of SWBs [42]. In some cases, water bodies have been dried up or have shrunk significantly over the years due to the rise in evaporation under higher temperatures [43]. Among other factors, drought also plays a major role in the reduction of the SWBs [44,45]. The localized droughts in Bangladesh have increased in the last few decades [46–48], which in turn may cause a reduction in SWBs [49].

Overall, it can be remarked that increased anthropogenic pressure is the main cause of the reduction of surface water bodies. However, climate change has accelerated the negative impacts. The impact is further compounded by the changes in micro-climate, particularly the rise in local temperature due to the reduction of water bodies. It is very important to take necessary adaptation measures for the protection of water bodies in order to mitigate the impacts of climate change. Different adaptation measures can be taken for maintaining or enhancing water bodies in the context of climate change, which include increasing aquatic biodiversity, sustainable catchment management, improving riparian buffers, control of water extraction, and improving connectivity. Shifting of rain-fed agriculture to irrigated agriculture has caused an increase in the surface and groundwater abstraction for irrigation and reduction of water bodies. It is very important to regulate the abstraction of surface and groundwater resources for controlling the gradual reduction of surface water bodies. The construction of dams, barriers, and roads in recent years has interrupted connectivity among the water bodies and the recharging ability of water bodies. Land management practices should ensure the maintenance or improvement of connectivity between water bodies. Furthermore, it is very important to adopt sustainable catchment management practices, such as the afforestation, for the mitigation of negative impacts of climate change on water bodies.

6. Conclusions

The relationship between LST and SWBs was evaluated in this study to understand the impact of reducing SWBs on the rapid temperature rise of Bangladesh. MODIS LST and water mask data for the period 2000–2015 were used for this purpose. This study revealed that the presence of SWBs over the land area greatly reduces the LST in the region. A temperature reduction of 1.2 to 2.0 °C in a region with SWBs compared to a region without SWBs was observed for Bangladesh. The spatial analysis in specific years showed that the reduction of SWBs causes an increase in LST on the regional scale. The results indicated that a decline of SWBs in Bangladesh due to unsustainable human activities also played a role in rises of temperature. Sustainable management of water bodies can help in the reduction of climate change impacts in Bangladesh. In future, a similar study could be conducted with high-resolution data of SWBs and LST from different sources such as Landsat derived high resolution LST and SWB data. The relationship between SWBs, LST, and other meteorological variables like potential evapotranspiration could be explored to understand the interlinkage between SWBs and climate change.

Author Contributions: N.K., S.S., and S.K. conceived and designed this study; N.K. and S.S. analyzed the data; N.K., S.K., E.-S.C., and R.A. wrote the paper.

Funding: This research was funded by the SeoulTech (Seoul National University of Science and Technology).

Conflicts of Interest: The authors declare no conflict of interest.

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