water

MDPI

Article

Monitoring Shoreline and Land Use/Land Cover Changes in Sandbanks Provincial Park Using Remote Sensing and Climate Data

Esmaeil Kouhgardi [1], Mohammadali Hemati [2], Elaheh Shakerdargah [3], Hodjat Shiri [1] and Masoud Mahdianpari [2,4,*]

[1] Civil Engineering Department, Faculty of Engineering and Applied Sciences, Memorial University of Newfoundland, St. John's, NL A1C 5S7, Canada
[2] Department of Electrical and Computer Engineering, Memorial University of Newfoundland, St. John's, NL A1C 5S7, Canada
[3] Department of Environmental Sciences, Faculty of Science, Memorial University of Newfoundland, St. John's, NL A1B 3X7, Canada
[4] C-Core, St. John's, NL A1B 3X5, Canada
* Correspondence: m.mahdianpari@mun.ca

Abstract: Climate change-driven forces and anthropogenic interventions have led to considerable changes in coastal zones and shoreline positions, resulting in coastal erosion or sedimentation. Shoreline change detection through cost-effective methods and easy-access data plays a key role in coastal management, where other effective parameters such as land-use/land-cover (LULC) change should be considered. This paper presents a remotely sensed shoreline monitoring in Sandbanks Provincial Park, Ontario, Canada, from 1984 to 2021. The CoastSat toolkit for Python and a multilayer perceptron (MLP) neural network classifier were used for shoreline detection, and an unsupervised change detection framework followed by a postclassification change detection method was implemented for LULC classification and change detection. The study assessed the recent coastal erosion and accretion trends in the region in association with spatiotemporal changes in the total area of the West and East Lakes, the transition between LULC classes, extreme climate events, population growth, and future climate projection scenarios. The results of the study illustrate that the accretion trend apparently can be seen in most parts of the study area since 1984 and is affected by several factors, including lake water-level changes, total annual precipitations, sand movements, and other hydrologic/climatic parameters. Furthermore, the observed LULC changes could be in line with climate change-driven forces and population growth to accelerate the detected accretion trend in the East and West Lakes. In total, the synergistic interaction of the investigated parameters would result in a greater accretion trend along with a lower groundwater table amid even a low carbon scenario. The discussed findings could be beneficial to regional/provincial authorities, policymakers, and environmental advocates for the sustainable development of coastal communities.

Keywords: coastal erosion; land use; climate change; Sandbanks Provincial Park; shoreline; GIS; carbon scenario

Citation: Kouhgardi, E.; Hemati, M.; Shakerdargah, E.; Shiri, H.; Mahdianpari, M. Monitoring Shoreline and Land Use/Land Cover Changes in Sandbanks Provincial Park Using Remote Sensing and Climate Data. *Water* **2022**, *14*, 3593. https://doi.org/10.3390/w14223593

Academic Editors: Fei Zhang, Xiaoping Wang, Chenfeng Wang and Mou Leong Tan

Received: 7 October 2022
Accepted: 3 November 2022
Published: 8 November 2022

1. Introduction

Coastal areas are among the most important parts of the earth's environment [1]. Coastlines are subject to change due to the interaction of social, political, economic, climatic, and environmental drivers at the local scale [2]. Global warming and climate change-induced forces such as storm surges and sea-level rise are introduced as an additional layer to the complexity of coastal vulnerability [3]. These climatic forces are related to many codependent parameters and covariant forces impacting the generation, flow, and distribution of sediments across the coastal systems of lakes [4]. Moreover, anthropogenic interventions affect the natural dynamic processes of coastal ecosystems, causing the coastline to be more vulnerable to any stressors [5]. Human activities toward coastal development have led to more coastal erosion and flooding hazards worldwide [6]. These hazards and climate-driven long-term coastal erosion and flooding risks will affect marine ecosystems, infrastructures, freshwater quality, and other associated sectors.

Moreover, population density (both residents and visitors) is one of the key parameters affecting the carrying capacity of coastal systems through land-use/land-cover (LULC) changes. Consequently, it increases the vulnerability of these economically valuable zones to coastal erosion, flooding, and arable land loss [7]. Therefore, loss, damage, and limitation in adaptation opportunities in coastal zones will follow an increasing trend [3].

Extreme climatic events (e.g., tsunamis, storms, and cyclones) are the most forcible morphological evolution accelerators. LULC also acts as an effective parameter while being affected by climate change. The human presence is another effective accelerator of the coastal environment deterioration through both planned utilization of coastal resources and the side effect of their activities. Furthermore, increased exposure of low-lying and flat areas to other drivers of coastal morphodynamics is happening through relative sea-level rise [8].

LULC change pattern is correlated with numerous interconnected parameters including legislation, land development, environmental, socio-economic, and demographic conditions [9]. Monitoring spatiotemporal patterns of the LULC change could potentially reveal the role of socio-economic drivers of change in sustainable landscape management [10]. Moreover, the format of the relationship between anthropogenic interventions and the natural environment characterized the spatial pattern of LULC change [11]. From another perspective, core drivers of change in LULC are expressed as population growth, increasing demand for farmlands, biophysical parameters, and policy change [12]. In this viewpoint, water scarcity, climate change, biodiversity loss, and habitat degradation are logical results of LULC change [12]. For instance, rapid urbanization in natural resources would result in land and vegetation degradation, more water consumption, and urban heat islands [13]. Furthermore, population pressure and agricultural development are the major driving forces of LULC change, mainly in favor of farmlands [14], in regions with agricultural dominance economies.

Both climatic forces and human interventions result in changes in shoreline positions leading to erosion or accretion in coastal zones. Over time, detecting this change provides coastal managers and engineers with practical information to adjust their management plans. Remotely sensed data has shown its potential to detect shoreline changes over a large span of time through major earth observation instruments, including MSS, TM, ETM+, Sentinel, etc. Change detection of remotely sensed data covers an expanded type of detection from visual comparison to complex image processing schemes. More specifically, satellite data can provide a comprehensive view, including a wide geographic coverage, intermittent scanning of the same region, and multispectral data [15]. These satellite images are very effective and reasonably accurate in mapping LULC allocations and transitions [16,17].

A variety of methods and techniques have been used to detect coastal changes, including field investigation and monitoring via laser and aerial photography. The main characteristics of these tools of high-resolution data at local and regional scales made them suitable for comparative analyses. However, researchers found these techniques were not cost-effective in large-scale monitoring projects. With satellite technologies and their free-access data advancement, remote sensing has become an attractive and efficient option for monitoring coastal morphodynamics [8]. Shoreline extraction and configuration through remote sensing (RS) and geographic information system (GIS) data have been performed using various techniques, such as Laplacian filter [1], Digital Shoreline Analysis System (DSAS) [5,18,19], Postclassification Change Detection [15], Normalized Difference Water Index (NDWI) [20], Integrated Land and Water Information System (ILWIS) [21], Histogram band thresholding method [22], SHOREX System [23], and other automated tools [24]. For instance, the CoastSat toolkit for Python is an efficient automated tool for shoreline detection [25].

Monitoring shoreline changes over time and its trends along with introducing the most influential driving forces of the change in the water bodies' levels of eastern Lake Ontario is a vital step in assessing current shoreline vulnerability and future trends. This assessment should involve well-updated global warming and climate change data and scenarios to provide a set of noteworthy data valuable for coastal communities and shoreline managers to take the necessary actions and adjust their plans toward the sustainable management of the coastal area. In other words, detecting and monitoring the spatiotemporal shoreline changes is a promising pathway to finding how coastal systems behave to regulate the human pressure and natural processes [7]. The aim of this study was to assess the recent coastal erosion/accretion trend in the study area and spatiotemporal changes in the total area of the East and West Lakes in association with LULC changes, extreme climate events, population growth, and future climate projection scenarios.

The shoreline positions of Lake Ontario have been affected by a set of drivers, including the level of wave energy, sediment volume and transfer, water body fluctuations, geotechnical characteristics of the coastal zone, anthropogenic activities, precipitation, rainfall intensity, and changes in winter ice cover due to increase in temperature [26,27].

2. Materials and Method

2.1. Study Area

2.1.1. Study Area Location and Description

The study area is located on Lake Ontario in Prince Edward County, Ontario, Canada, in Ecodistrict 6E–15 (Picton) [28]. The site includes Sandbanks Provincial Park (in an area of 1600 ha), West Lake, East Lake, and surrounding areas (Figure 1). Both West and East Lakes have waterway connections to Lake Ontario. Sandbanks Provincial Park was introduced as "one of the most popular and highly used parks in the Ontario provincial park system" [29]. The park is famous for its coastal dune communities and associated pannes [28], "the largest freshwater baymouth barrier dune system in the world" [30]. These beach ecosites have experienced and been exposed to active shoreline processes such as storms, high waves, seasonal high-water levels, coastal erosion/accretion, ice scour, extreme moisture and temperature events, and low nutrient availability [28]. Although this region has a long history of human activities, recreational development was initially started in 1962 [28]. The dune system was naturally forested until the 1850s, and sand mining operations were in place between 1915 and 1970. Then, recreational activities were considered in 1972 when the government decided to have a particular focus on preserving and interpreting the natural and cultural values of the park [29]. Coastal erosion has been affecting the park's natural and cultural values and could be more common due to climate change and global warming.

The East and West Lakes were initially created around 12,000 years ago after the retreat of the last glaciers. The hydrology of the lakes is related to the underlying geology (limestone bedrock) and the on-top shallow soil [31,32], plus climate conditions and the nearby Lake Ontario. Natural and climatic conditions of the early Lake Ontario shoreline resulted in sand accumulation in the region in the past. This long-term process generated baymouth sandbars which segregated the West and East Lakes from Lake Ontario [32]. West Lake is connected to Lake Ontario through a dredged channel [33], while East Lake is connected via the Outlet River. The two lakes and the surrounding areas support some important aquatic and terrestrial species at risk [32].

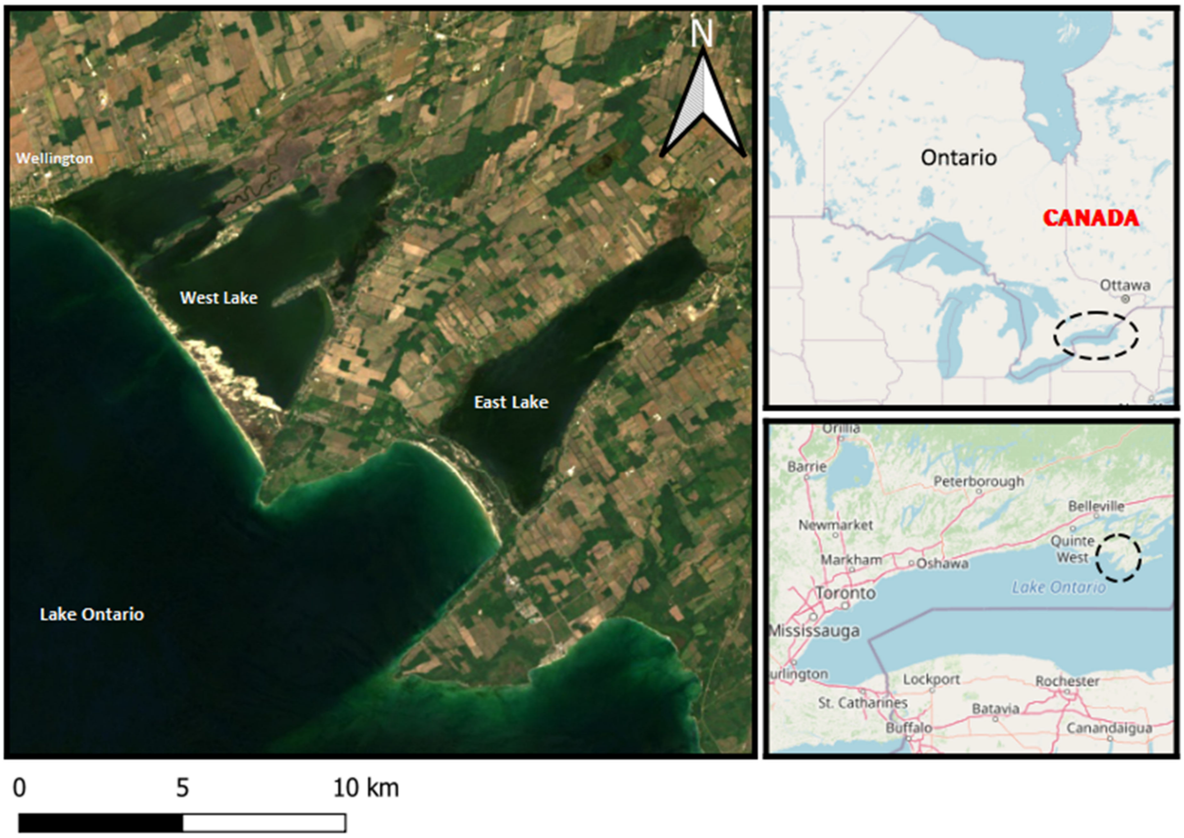

Figure 1. Location of the study area in Prince Edward County, Northeast Lake Ontario, Ontario, Canada. Provided map of the study area includes two regional maps adopted from OpenStreetMap (by "© OpenStreetMap contributors"—the data is available under the Open Database License at https://www.openstreetmap.org/copyright, accessed on 15 July 2022) and a true-color image from Landsat-8.

The selected parts of the county were chosen because of their unique natural and socio-economic values and their conservation importance due to climate change, sea-level rise, and human interventions. The county's main economic drivers are farming, tourism, and manufacturing [34]. Therefore, monitoring regional changes in LULC and shoreline positions in the long term plays an essential role in the sustainable management of the region.

2.1.2. Study Area Climate Conditions

The region experiences a warm-summer humid continental climate, including humid summers and very cold winters. The average annual temperature is 7.8 °C, average annual precipitation of 943.1 mm (138.9 days with precipitation), and relative humidity of 78% with an average of 540 mm evapotranspiration. The month with the most rain is October and with the most snow is February. The warm season starts from early June and lasts until late September, and the cold season from early December to mid-March. The hottest month is July (with an average of 17 to 24 °C), and the coldest is January (with an average of −9 to −2 °C). The shortest length of the day is 8 h and 53 min in December, and the longest with 15 h and 29 min in June. Moreover, the growing season is around 180 days, from late April to mid-October [35]. The length and the weather conditions in the growing season are crucial to the sustainability of the food and agriculture sectors in the region.

The region is mainly flat, and the common elevation from sea level being less than 100 m. The ecosites between the East and West Lakes and Lake Ontario were introduced as a coastal zone with active shoreline processes. These processes include erosion, accretion, ice scour, periodic high water levels and storm events, extremes in moisture and temperature, and wave action. Drought and temperature extremes are more likely to happen in the dune section of the area [28]. In addition to this, the wave actions and the strong winds in the Lake Ontario basin can significantly move sediments in the coastal parts of the area [36].

2.2. Remote Sensing Data and Preprocessing Stage

As the longest operating earth observation mission, Landsat provides unbroken time-series of satellite images with spatial and temporal resolution suitable for monitoring environmental changes. Landsat data are freely available with state-of-the-art specified algorithms for calibration between satellites, from sensor to sensor and bands to bands, which provides the basis for mapping land covers and detecting changes from time to time and across the large geographic area [37]. We accessed Landsat data from Google Earth Engine (GEE), a cloud computing platform with the accessibility of petabytes of earth observation data and massive computational power [38]. A total of 1599 Collection 2 Tier 1 TOA (Top-of-Atmosphere) images were used in this study. Details are shown in Table 1. For efficient usage of computational resources, such as use memory and storage, the RGB bands, in addition to near-infrared (NIR) and short-wave infrared (SWIR1) bands, were extracted from images and cropped to the area of interest, and then, all the images were downloaded from GEE.

Table 1. Remote sensing data used in this study.

Source of Data	Time Period	Spatial Resolution (m)	Quantity of Images
Landsat-5	1984–2020	30	675
Landsat-7			375
Landsat-8			549
Total			1599

For Landsat-7 and Landsat-8, the panchromatic band with 15 m spatial resolution was also downloaded separately. Each Landsat image is provided with a metadata file that includes a calculated percentage of cloud and cloud shadow coverage. A user-defined threshold was used to filter cloudy images. The next stage of preprocessing was dedicated to enhancing the geometric accuracy of optical shoreline detection. For Landsat-7 and Landsat-8, the high-resolution panchromatic band was used for pan-sharpening the other multispectral bands. For pan-sharpening, the principal component analysis [39] was used in this study. Additionally, Landsat-5 images were down-sampled to 15 m by bilinear interpolation for consistency through time-series and shoreline detection at higher spatial resolution.

2.3. Time-Series Analysis and Shoreline Extraction/Detection

For shoreline detection, we used the CoastSat toolkit for Python, which takes advantage of the capabilities of the GEE for efficient earth observation data retrieval [25]. This toolkit consists of a robust algorithm for shoreline detection at subpixel resolution. Shoreline detection is applied to preprocessed data in two main steps: classifying the images into four classes and the segmentation of borders in subpixel resolution. A multilayer perceptron (MLP) neural network classifier was used for the first step with two hidden layers with 100 and 50 neurons, the rectified linear unit function as the activation function, and a stochastic gradient-based optimizer as the solver for weight optimization. This pre-trained model was well-trained with 5000 samples from 50 images from 5 different sites for each class with a 70/30 test-to-train ratio. Features of this classification were multispectral band pixel values from Landsat data, in addition to five common spectral indices. These spectral features are normalized difference indices between NIR and green, SWIR and green, NIR and red, SWIR and NIR, and blue and red bands. Additionally, the variance of spectral bands and indices were calculated using a 3×3 window and were included in the classification features. This classifier was evaluated using 10-fold cross-validation and reached an overall accuracy of 99%.

The Modified Normalized Difference Water Index (MNDWI) was computed using normalized differences between the SWIR1 and green bands for the second step and shoreline detection. The resulting values of this water-sensitive index were between −1 (water) to +1 (sand). Then, the histogram of pixels within a defined distance (150 m for default) from the classified sand pixels was computed. The resulting histogram's probability density function (PDF) of classified pixels was computed. In the end, a threshold was defined by the Otsu method [40] to separate water and nonwater pixels in the MNDWI image, and the marching squares algorithm [41] was used to produce individual shorelines from the iso-valued contour on the MNDWI image that presents the interface of water and sands.

2.4. Land-Use/Land-Cover (LULC) Classification and Change Detection

Change detection of different LULC classes requires a suitable amount of reference data in different years. To overcome this problem, we used an unsupervised change detection framework. We created a summer median composite image from Landsat-5 and Landsat-8 images in the GEE platform. The surface reflectance data from Landsat Collection 2 Tier 1 data were acquired from June to August 2010 and 2021. A median filter was used to create composite images after filtering the images with more than 20% of cloud coverage. Then, an unsupervised K-Means classifier was performed on both images to classify images into four classes. Due to a lack of reference data and spectral variation of different existing classes, we only classified four main classes (water, forest, bare land, and cropland). These classes were assigned to classified images using visual interpretation of each class. To evaluate the results, a set of test data was created based on the interpretation of true-color RGB Landsat images, and the accuracy of the classified maps was calculated. In the end, a postclassification change detection method was used to compare the classified images and identify changes.

3. Results

3.1. Overall Coastal Accretion/Erosion

The coastal erosion and accretion detected in different parts of the study area are shown in Figures 2–4. The figures demonstrate coastal changes from water to land as accretion and land to water as erosion from 1984 to 2020. Two parts are shown with more details from the adjacent Lake Ontario coasts (D and E), one part at the very end of the East Lake (C), one part at the eastern side of West Lake (B), and another zone at the narrow section of the baymouth dune between Lake Ontario and West Lake (A). The coastal change study revealed a considerable predominance of water-to-land transition in the region during the past four decades. However, there are some erosion points at East Lake and the adjacent Lake Ontario shores to West Lake. These coastal margin areas are introduced as the joint points between socio-economic, environmental, and development activities. Therefore, it is vital to monitor how potential climate changes affect the sustainability of these coastal margin areas in and around Lake Ontario and connected water bodies [27].

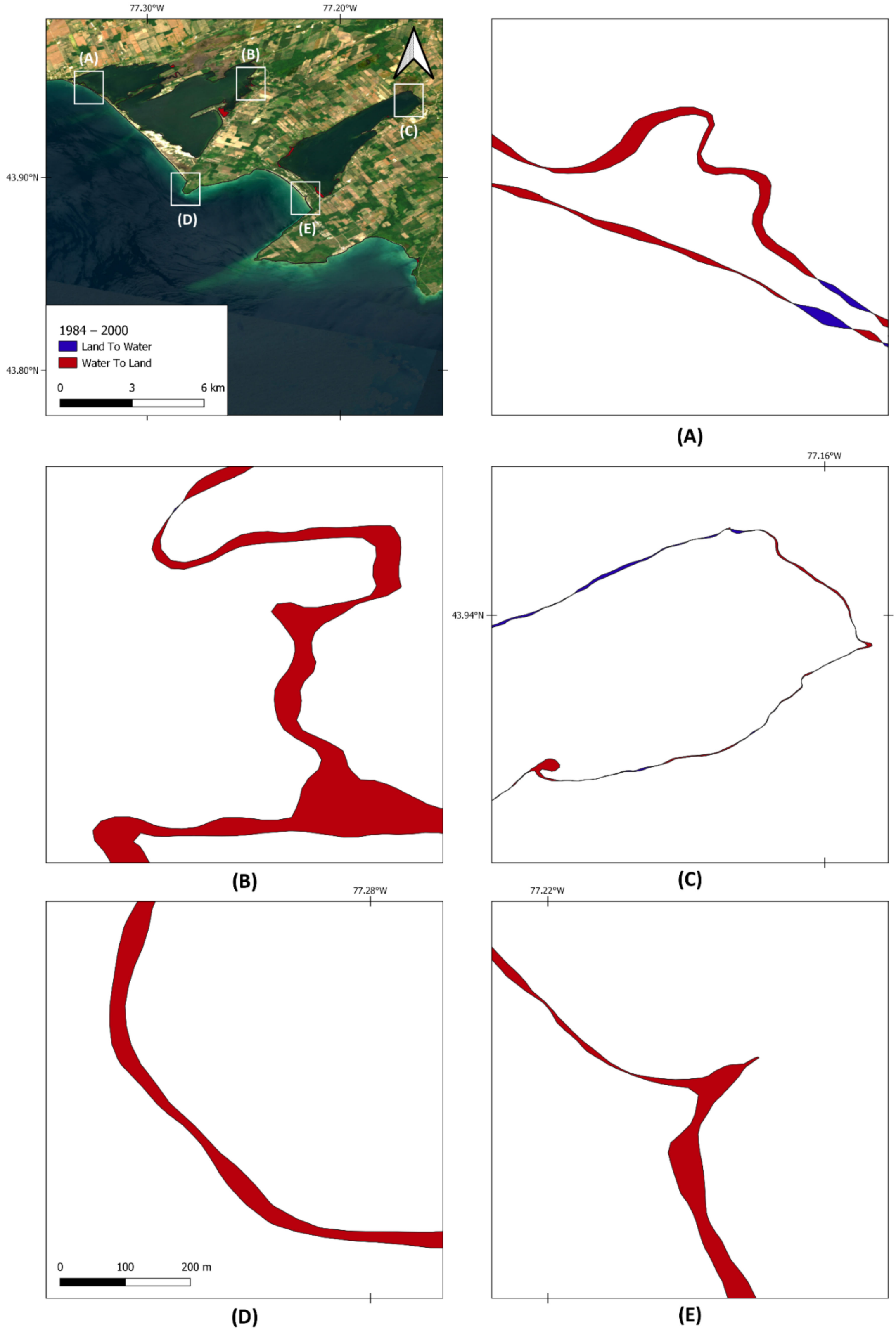

Figure 2. Coastal erosion and accretion from 1984 to 2000. Two parts are shown with more details from the adjacent Lake Ontario coasts (**D**,**E**), one part at the very end of the East Lake (**C**), one part at the eastern side of West Lake (**B**), and another zone at the narrow section of the baymouth dune between Lake Ontario and West Lake (**A**).

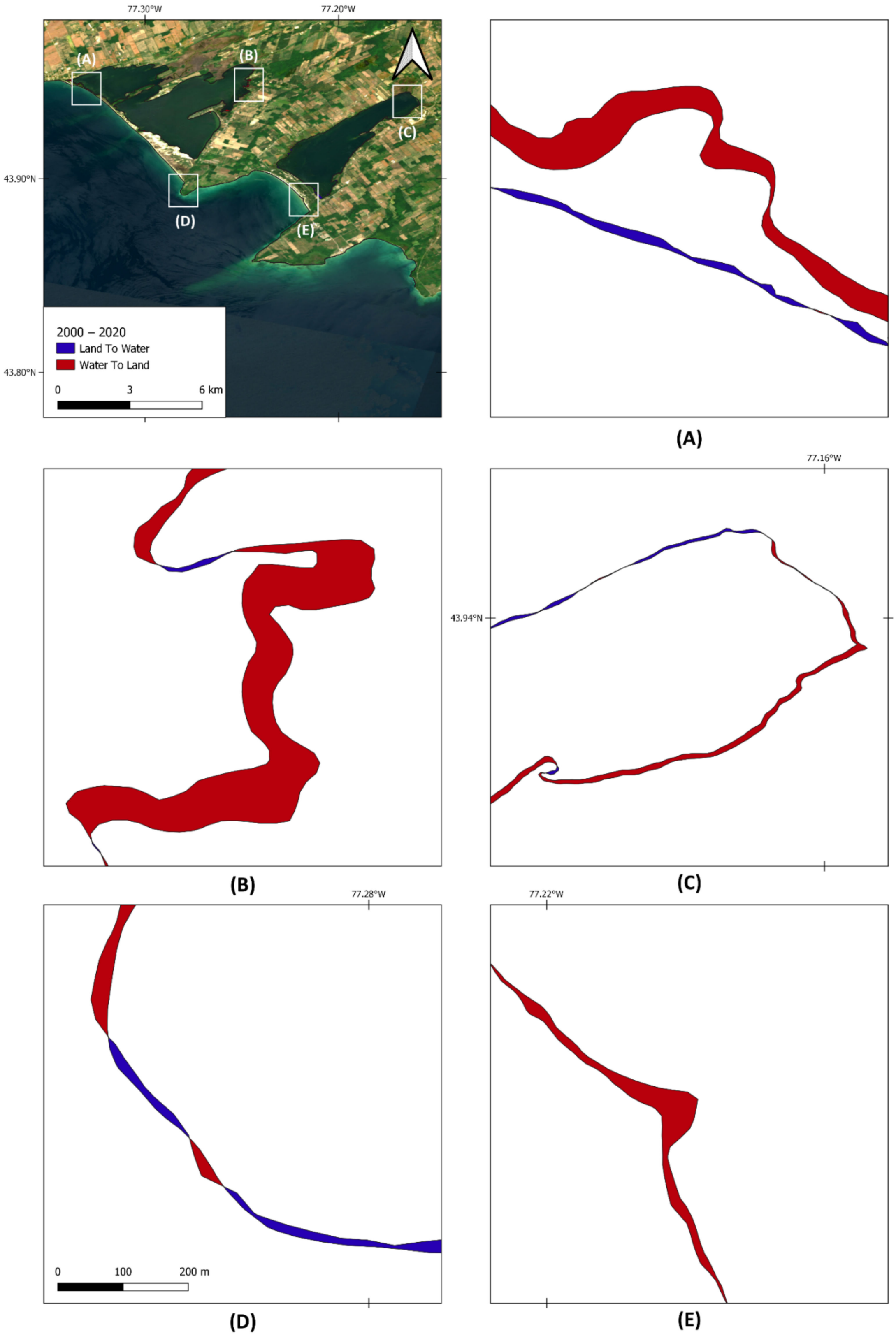

Figure 3. Coastal erosion and accretion from 2000 to 2020. Two parts are shown with more details from the adjacent Lake Ontario coasts (**D**,**E**), one part at the very end of the East Lake (**C**), one part at the eastern side of West Lake (**B**), and another zone at the narrow section of the baymouth dune between Lake Ontario and West Lake (**A**).

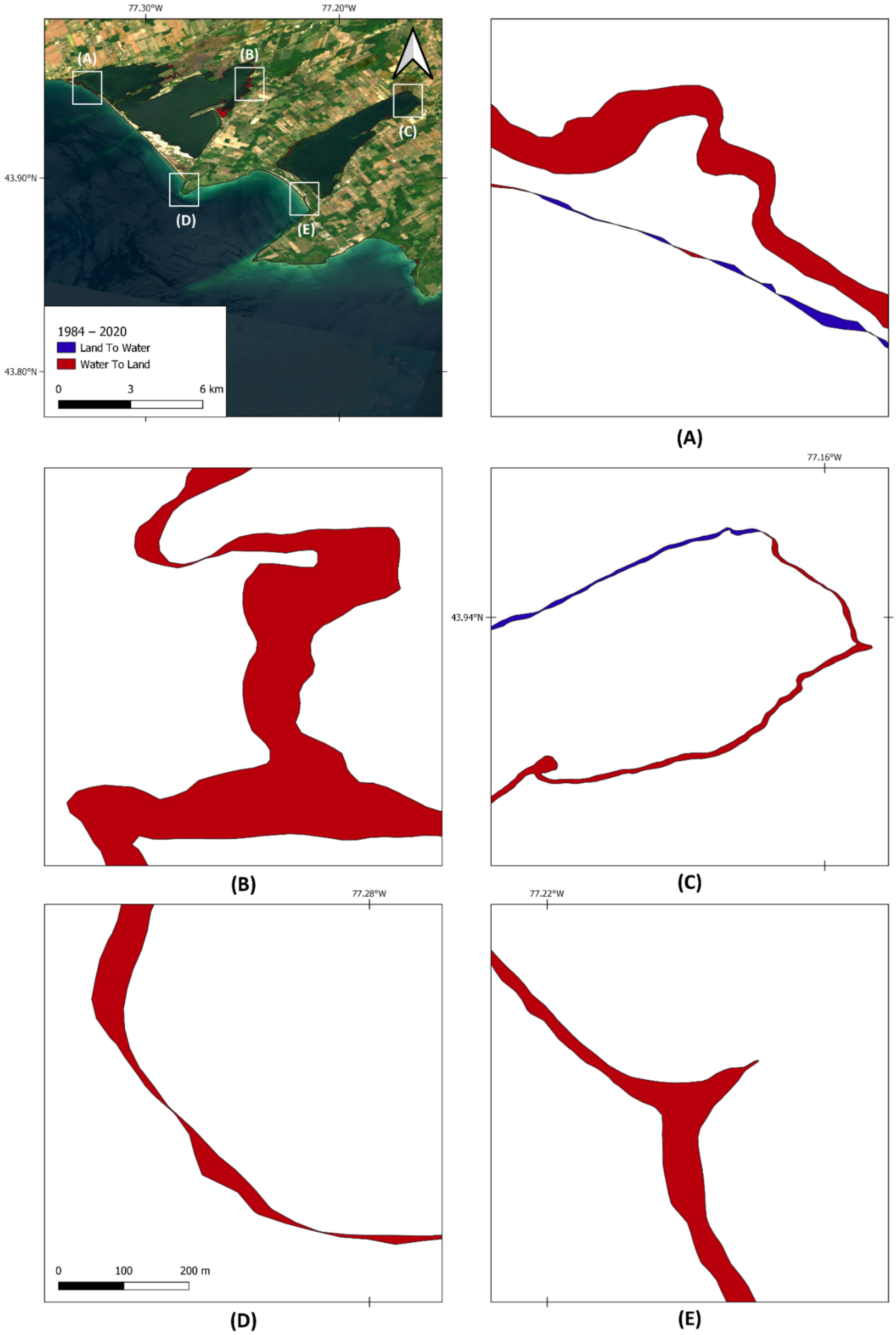

Figure 4. Total coastal erosion and accretion from 1984 to 2020. Two parts are shown with more details from the adjacent Lake Ontario coasts (**D**,**E**), one part at the very end of the East Lake (**C**), one part at the eastern side of West Lake (**B**), and another zone at the narrow section of the baymouth dune between Lake Ontario and West Lake (**A**).

3.2. Zonewise Erosion and Accretion from 1984 to 2021

Trends of coastal erosion/accretion in the region have been studied in two different periods, from 1984 to 2000 and 2000 to 2020. Figure 2 shows these coastal changes in the last two decades of the last century, starting from 1984, and Figure 3 shows coastal changes in the first two decades of the 21st century. A detailed description of the changes in each zone is expressed in Table 2.

Table 2. Coastal erosion/accretion trends in the study area.

Zone Name	**Time Period**	
	1984–2000	**2000–2020**
A	- Accretion in both West Lake and Lake Ontario's coasts. - Erosion in the narrowest part of the West Lake dunes from both sides of the adjacent lakes.	- Continued accretion trend in the coastal zone of West Lake. - Erosion in the adjacent Lake Ontario shoreline. This erosion was the opposite of the previous trend.
B	- Considerable accretion in the shallow waters and coastal marshes.	- Continued the accretion trend at the whole coastline except for two small patches at the northern and southern parts of the zone.
C	- Expanded coastal stretch (accretion) on the eastern side. - Erosion on the northwest side, and pieces of erosion and accretion on the southeast side.	- Accretion at the very end of East Lake. This accretion was the opposite of the previous trend. Accretion at the southeastern side of the zone. - Erosion at the northwestern side of the zone.
D	- A uniform accretion in the coastal zone of Lake Ontario.	- A combination of erosion and accretion with the dominance of erosion. - Accretion at the northwestern part of the zone and a small patch at the headland of the site.
E	- Accretion around the river's delta, resulting in the expansion of the beach even around the shallow water of the river's mouth.	- Continued the same accretion pattern as the previous period, resulting in an extra expansion in the Outlet beach, especially around the Outlet River's embouchure.

The total erosion/accretion trend in the study area is expressed in Figure 4. Monitoring coastal changes in the region revealed that West Lake experienced water-to-land transition trend in some parts, while there was no detected erosion trend in the lake since 1984. This trend correlates with the changes in the lake's total area (for more details, please see the spatiotemporal monitoring of the lakes). The accretion trend was slightly milder in East Lake, where eastern and southwestern parts of the lake faced water-to-land transition, especially in the last two decades of the previous century. However, a small stretch of land-to-water transition happened in the northwestern part of the very end of the lake. This trend is also correlated with the lake's total area changes since 1984. In addition to this, and based on the detected changes, the lakeshores experienced a narrow strip of accretion in the southwestern parts of East Lake. The same has happened to the shallow water located at the eastern side of Sheba's island in West Lake and some small patches in the Wellington harbor and Bloomfield Creek.

The coastal part of Lake Ontario alongside the dune pannes (between Lake Ontario and West Lake) showed a slight land-to-water transition, while the opposite trends were detected in zone D and the Outlet beach.

3.3. Shoreline Changes in the Study Area from 1985 to 2020

Shoreline detection using RS and GIS resources and tools is an opportunity to monitor shorelines' recession/accretion due to water level fluctuations over time. Thanks to the availability of satellite images, researchers are able to analyze spatiotemporal changes in shoreline positions in a large span of time.

Like most parts of our planet, Sandbanks Provincial Park and the surrounding lakes have been under pressure from climate change forces. This study introduced an up-to-date spatiotemporal evolution in shoreline positions in the region since 1985 at five-year intervals (Figure 5).

Results expressed that zone A faced both shoreline recession and accretion from 1985 to 2020. In the adjacent Lake Ontario, shoreline position fluctuations from 1985 to 2005 were bilateral. However, a slight shoreline recession has been observed since 2010. In the West Lake part of the zone, an accretion happened from 1985 to 1995, then it partially compensated in the next 10 years, and, thereafter, experienced a significant accretion to date. Zone B at the eastern side of West Lake showed a persistent accretion trend since 1985, except for a recession that happened in 1990.

Shoreline position fluctuations in East Lake around Flakes Cove (zone C) were not considerable between 1985 and 2010, while a notable accretion trend was found since 2010. The Outlet beach (zone E), which is connected to East Lake (via Outlet River), had no specific pattern in shoreline position changes. It showed sharp changes in shoreline positions in the first decade of the present century, with a final accretion trend since 2015 (Figure 6). The same shoreline changes happened to zone D, where it had sharp landward changes (recession) in 2010 and 2015 with no certain pattern in the rest of the study period.

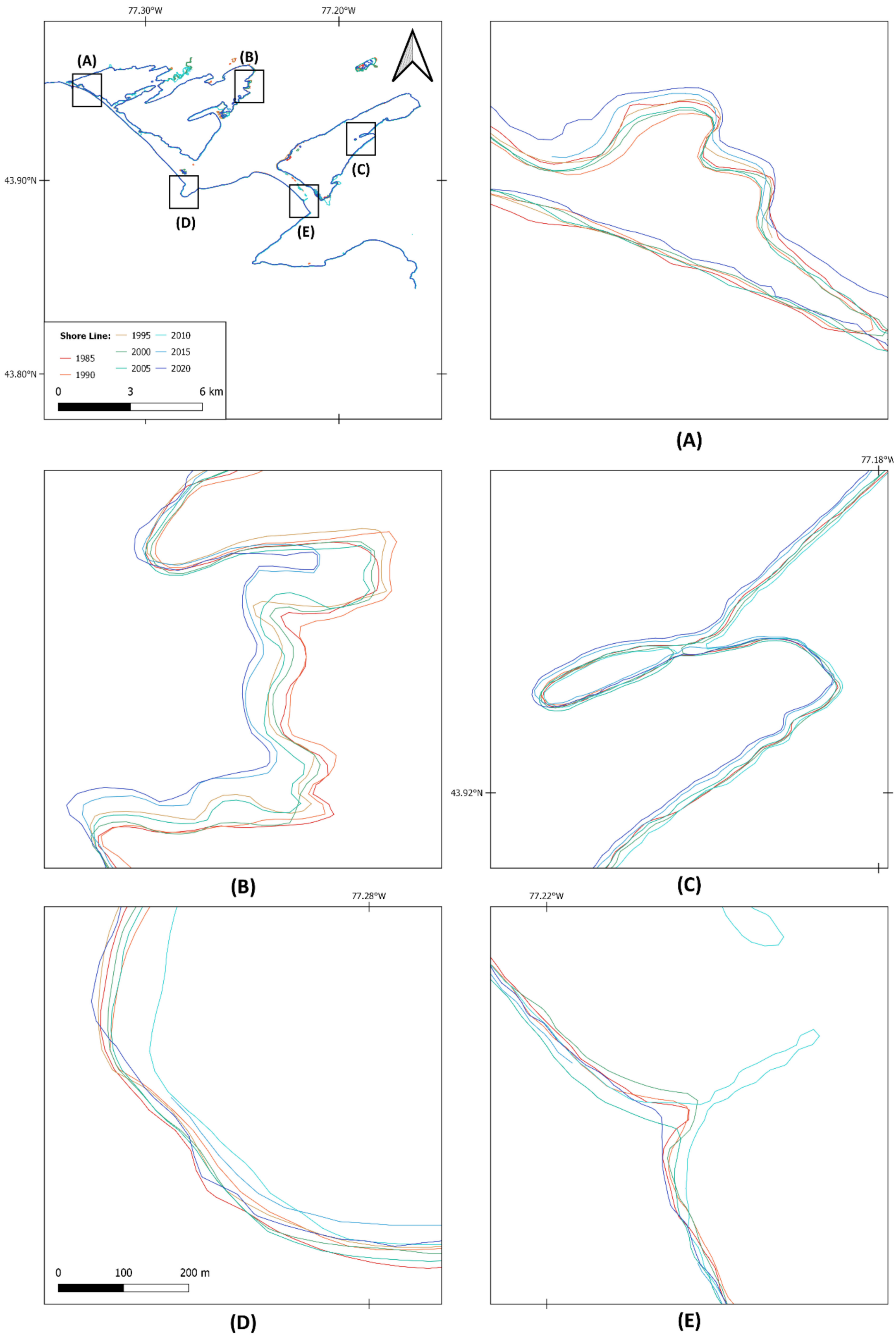

Figure 5. Shoreline position changes from 1985 to 2020. Two parts are shown with more details from the adjacent Lake Ontario coasts (**D**,**E**), one part at the very end of the East Lake (**C**), one part at the eastern side of West Lake (**B**), and another zone at the narrow section of the baymouth dune between Lake Ontario and West Lake (**A**).

Figure 6. Accretion at Outlet Beach and Outlet River mouth (Aerial image by: John A. Brebner, 2018 © 2012–2018, Friends of Sandbanks Park).

3.4. Monitoring the Total Area of West and East Lakes

Climate change-driven forces, global warming, Great Lakes water-level fluctuations, and other regional factors (e.g., LULC change) are the most influential parameters in determining West and East Lakes' water level (and, consequently, the total area).

In a bigger frame, although sea levels are rising due to global warming, Lake Ontario water levels are projected to be 25–40 cm lower than the current long-term mean by 2080 [27]. This trend, along with increasing drought events and evapotranspiration (according to the future climate change scenarios), affects the total area of the two lakes in the region. Hence, monitoring the changes in the water body of these two lakes (Sections 3.4.1 and 3.4.2) provides valuable information for management and environmental protection purposes.

3.4.1. Spatiotemporal Changes in the Total Area of West Lake since 1984

Spatiotemporal monitoring of West Lake using 1599 satellite images detected the exact area of the water body from 1984 to 2021 (Figure 7).

The lake's total area was 19.8 km^2 in 1984. The lake experienced a period of descending trend in the water level from then to 1989. The highest water level in West Lake was recorded in 2006 when the lake's total area was almost 2100 hectares. Some other remarkable high water levels were observed in 1991, 2002, and 2015. However, the lake level fluctuations in these periods were not relatively considerable, where the lake's total area was between 19.2–19.6 km^2. West Lake has started a descending trend in the total area since 2008, with just three expansive records in 2011, 2015, and 2019 (Figures 8 and 9). The most recent area of the lake was observed as 1880 hectares, which is the lowest record since 1984 (Figure 10). The lake basin's sharpest difference between the wettest and driest years (2006 and 2021, respectively) was detected as 220 hectares. This decrease in the total area of the lake has a direct effect on the volume of stored water, which impacts aquifers' recharge, water supply, and natural habitats.

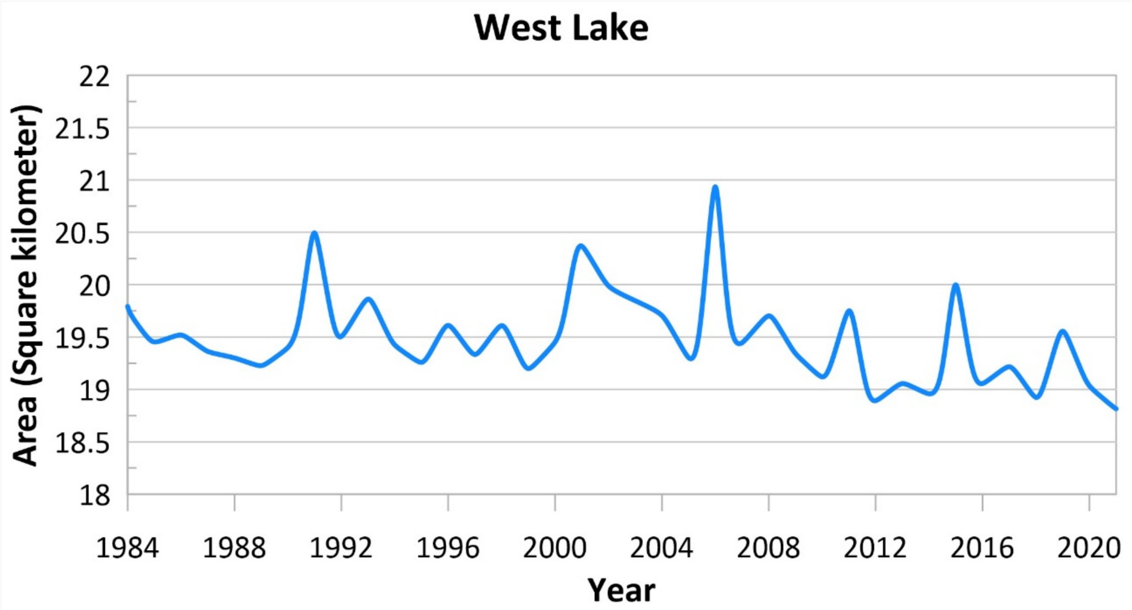

Figure 7. Spatiotemporal monitoring of West Lake from 1984 to 2021.

Figure 8. The high water level in West Lake (Aerial image by: John A. Brebner, 2015 © 2016 Friends of Sandbanks Park).

Figure 9. The high water level in West Lake (Aerial image by: John A. Brebner, 2019 © 2019 Friends of Sandbanks Park).

Figure 10. Low water level in West Lake (Photo by: John A. Brebner, 2021 @friendsofsandbanks on Facebook).

3.4.2. Spatiotemporal Changes in the Total Area of East Lake since 1984

As a large lagoon (historically named Spence Lake), East Lake covers almost 20% of the East Lake watershed. Published resources expressed that the watershed is around 68 km^2, and the lake area itself is approximately 12 km^2 [32]. Spatiotemporal monitoring of the lake using 1599 satellite images detected the exact area of the water body from 1984 to 2021 (Figure 11).

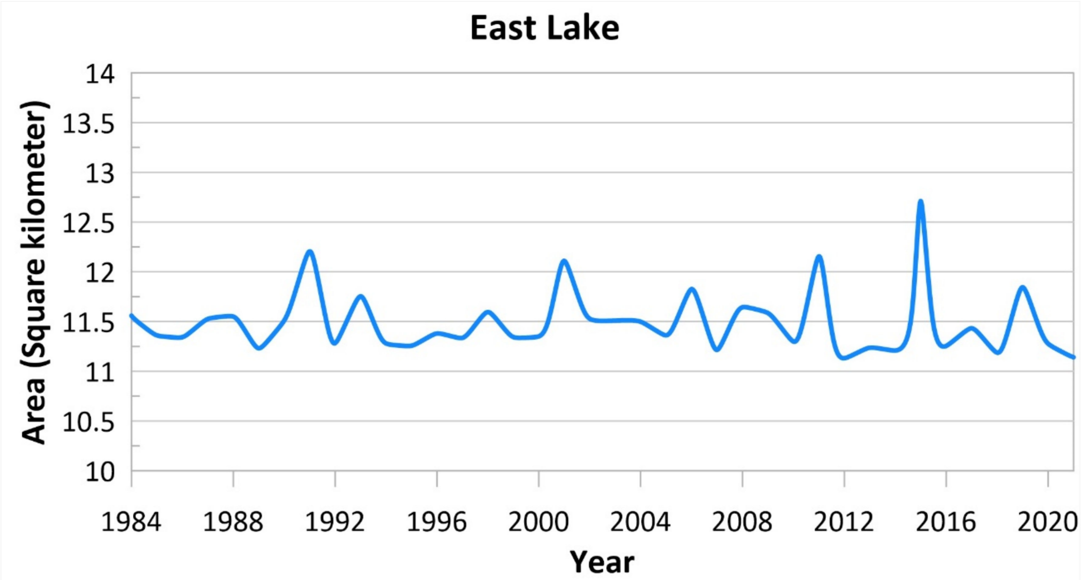

Figure 11. Spatiotemporal monitoring of East Lake from 1984 to 2021.

The total area was subject to change every year, with some sharp changes in certain years, where peak water levels were observed in 1991, 2001, 2011, 2015, and 2019 (Figures 12 and 13). The highest peak happened in 2015 when the lake's total area reached a new record of 12.75 km^2 (1275 hectares). The low water levels at the lake were observed in 1989, 1992, 2007, 2012, 2018, and 2021. The lake was faced with relatively prolonged low water levels from 1993 to 2000 and even lower water levels from 2012 to 2014. Except for two peak levels in 2015 and 2019, the lake water levels have been considerably below the mean long-term level, approaching 11,000 hectares in 2021 (Figure 14).

Figure 12. The high water level in East Lake, Outlet River, and Lake Ontario (Aerial image by: John A. Brebner, 2019 © 2019 Friends of Sandbanks Park).

Figure 13. The high water level at Salmon Point—East Lake (Aerial image by: John A. Brebner, 2019 © 2019 Friends of Sandbanks Park).

Figure 14. The low water level at Outlet River and Beach (Photo by: John A. Brebner, 2021 @friendsofsandbanks on Facebook).

3.5. Land-Use and Land-Cover (LULC) Changes

The LULC map of the study area in 2010 and 2021 is shown in Figure 15. An overall accuracy and Kappa coefficient of 92.01% and 0.89 for the year 2010 and 91.31% and 0.88 for the year 2021 were achieved, respectively. Changes in different classes of the LULC from 2010 to 2021 are also shown in Figure 16. More specifically, the data of these transitions between different LULC categories are analyzed in Table 3.

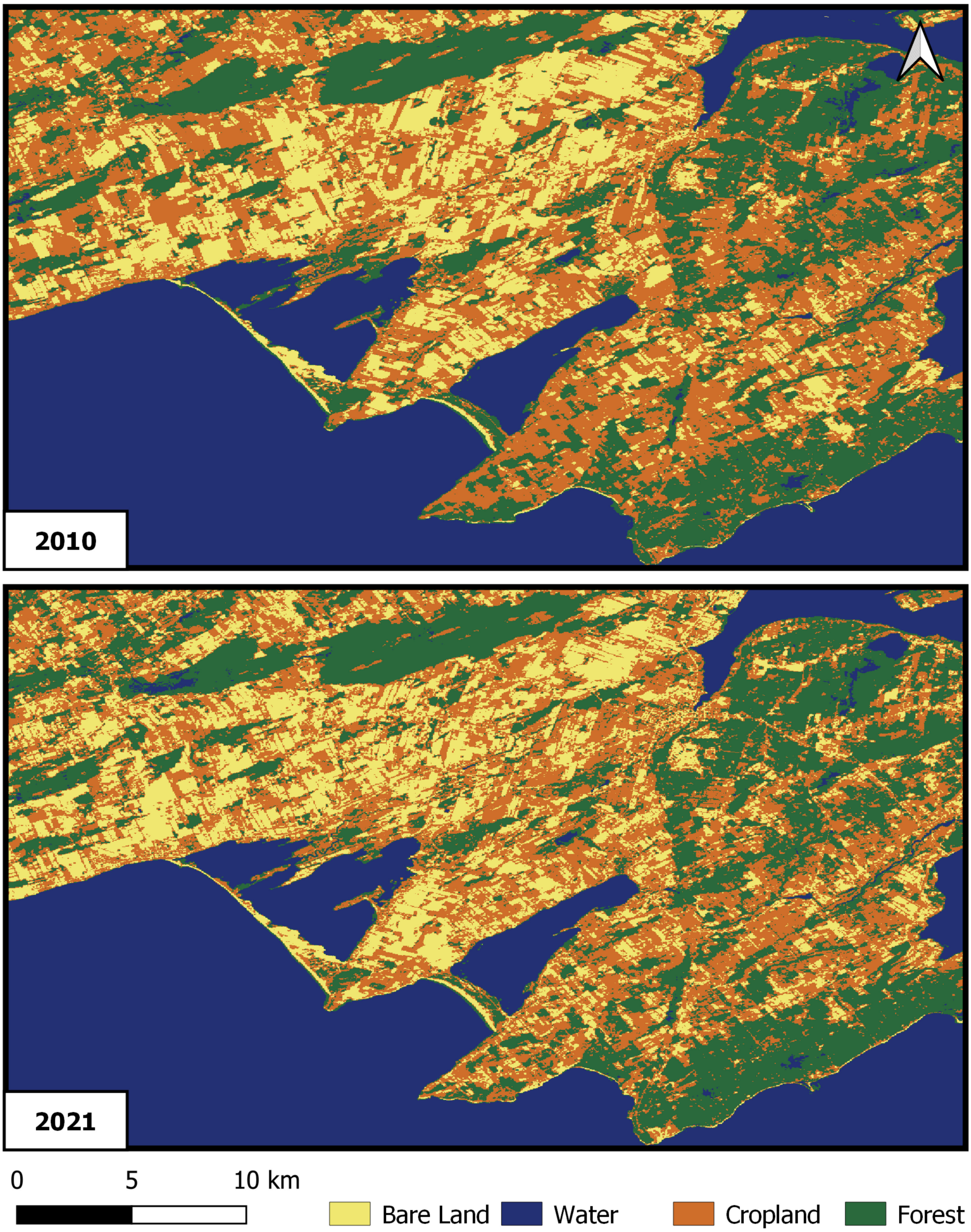

Figure 15. The study area's LULC map in 2010 and 2021.

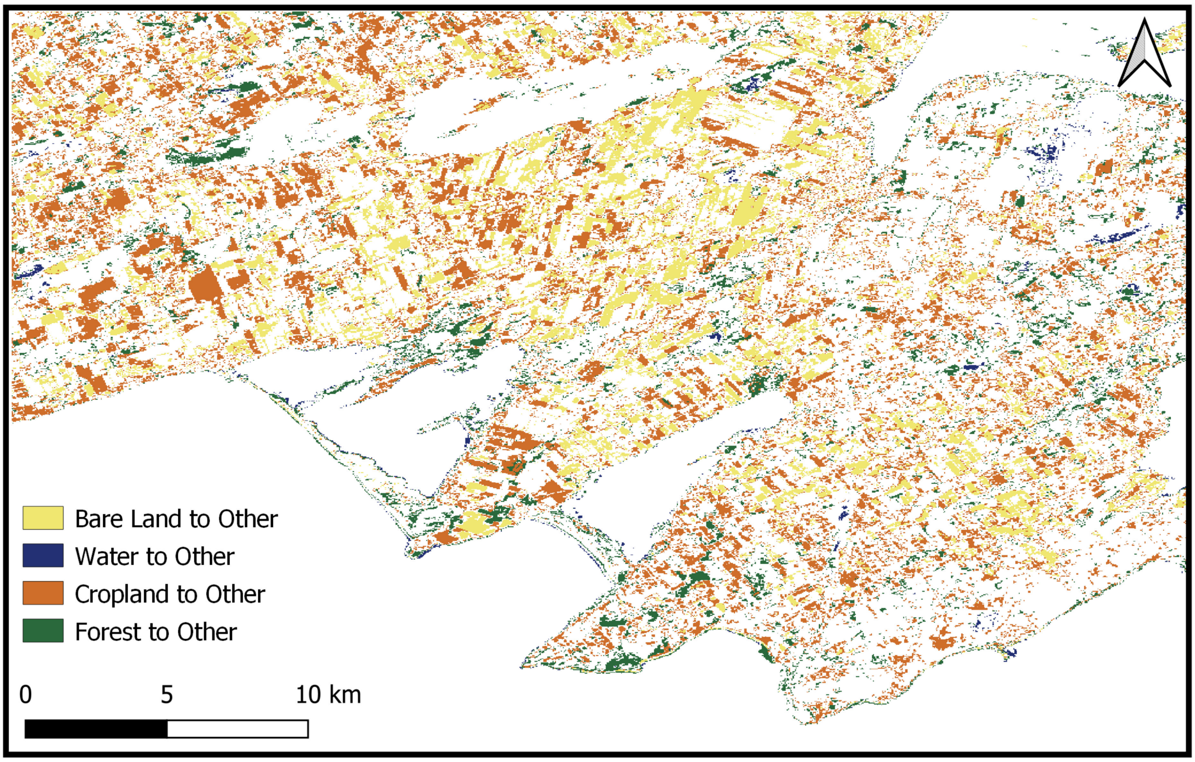

Figure 16. Map of changes in LULC from 2010 to 2021.

Table 3. The transition between LULC classes in the study area from 2010 to 2021. Reference classes referred to LULC in 2010, and new classes were current LULC in 2021. Measurements are presented in hectares.

Reference Class	New Class Bare Land	Water	Cropland	Forest	Total
Bare land	9427	6	6481	372	16,286
Water	3	34,525	10	316	34,854
Cropland	8204	5	20,411	3506	32,126
Forest	177	295	3038	20,849	24,359
Total	17,811	34,831	29,940	25,043	107,625

Data in Table 3 expressed a considerable decrease in the total areas of bare land (8.6%) and forests (2.7%), mainly in favor of croplands. Croplands' expansion in the region was calculated at just over 7.3% since 2010. At the same time, areas with water coverage remained at the same level with an inappreciable increase of 0.07%.

3.6. Historical Climate Data and Future Projections for the Region

Many global climate models (GCMs) with a wide range of climate conditions have been developed to predict climate change in the future [42]. Temperature and precipitation data are among the most important parameters for these climate models. The Climate Atlas of Canada has developed 24 different GCMs to project the future climate. The future climate conditions are highly correlated with the concentration of greenhouse gases (GHGs) in the atmosphere. These future GHG projections are referred to as Representative Concentration Pathways (RCPs). The high carbon scenario (RCP8.5) will be the case if GHG concentration continues to increase at current rates, while the low carbon scenario (RCP4.5) is projected based on a sharp reduction in GHG emissions [42]. The Climate Atlas of Canada utilized advanced statistical techniques to create high-resolution (daily, 10 km) future projections for all of Canada. Climate conditions based on these two high and low emission scenarios for

Prince Edward County (Trenton station) are shown in Tables 4 and 5. Moreover, historical annual precipitation data for the county during the last four decades are shown in Figure 17.

Table 4. Historical data and future climate projection (RCP8.5: high carbon climate scenario) for Prince Edward County. Adopted from Ref. [42].

Variable	Period	Historical Data	Projection (Mean)	
		1976–2005 (Mean)	2021–2050	2051–2080
Precipitation (mm)	Annual	877	937	969
Precipitation (mm)	Spring	222	244	259
Precipitation (mm)	Summer	197	201	197
Precipitation (mm)	Fall	245	257	260
Precipitation (mm)	Winter	213	235	253
Mean Temperature (°C)	Annual	7.5	9.6	11.8
Mean Temperature (°C)	Spring	6.2	8	10
Mean Temperature (°C)	Summer	19.6	21.7	24
Mean Temperature (°C)	Fall	9.4	11.6	13.6
Mean Temperature (°C)	Winter	−5.5	−3.1	−0.6
Tropical Nights *	Annual	5	17	37
Very Hot Days (+30 °C)	Annual	8	24	50

* A tropical night occurs when the lowest temperature of the day does not go below 20 °C [43].

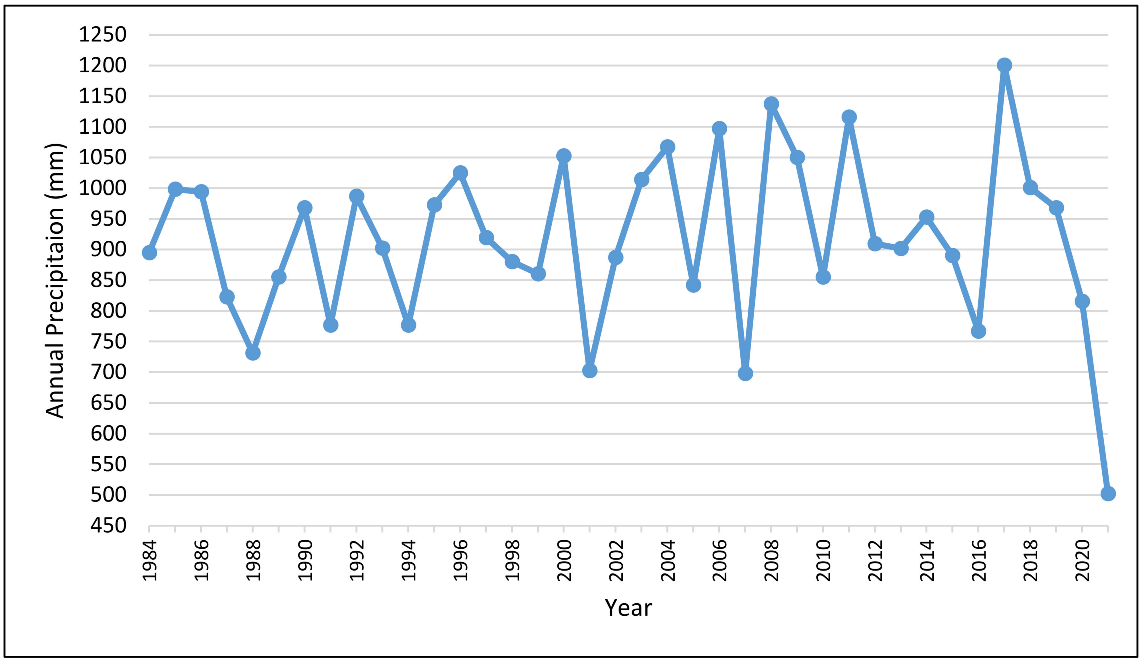

Figure 17. Total annual precipitation data for Prince Edward County (Trenton station) since 1984. Adopted from [44,45].

Historical annual precipitation data expressed that the highest and the lowest precipitation amounts in the last four decades were recorded over the previous five years, where 2017 had 1200 mm, and 2021 represented an extremely dry year with only 502 mm of precipitation [44,45].

Table 4 shows that annual precipitation in the study area will increase by 6.8 and 10.5% by 2050 and 2080. This increase will be 28 and 57.3% in mean annual temperature, 240 and 640% increase in the number of tropical nights, and 200 and 525% increase in extremely hot days by 2050 and 2080, respectively, if climate changes based on the high carbon scenario (RCP8.5). These changes will be slightly milder (but still high) if the low carbon scenario happens in the region (Table 5). Based on the current assumption (RCP4.5), annual precipitation will increase by 5.1 and 8.4%, the annual mean temperature will increase by 25.3 and 38.6%, tropical nights will increase by 180 and 340%, and there will be a 162.5–300% increase in extremely hot days in the region by 2050 and 2080, respectively.

Table 5. Historical data and future climate projection (RCP4.5: low carbon climate scenario) for Prince Edward County. Adopted from Ref. [42].

Variable	Period	Historical Data	Projection (Mean)	
		1976–2005 (Mean)	2021–2050	2051–2080
Precipitation (mm)	Annual	877	922	951
Precipitation (mm)	Spring	222	236	244
Precipitation (mm)	Summer	197	200	203
Precipitation (mm)	Fall	245	254	265
Precipitation (mm)	Winter	213	232	240
Mean Temperature (°C)	Annual	7.5	9.4	10.4
Mean Temperature (°C)	Spring	6.2	7.9	8.8
Mean Temperature (°C)	Summer	19.6	21.4	22.4
Mean Temperature (°C)	Fall	9.4	11.3	12.2
Mean Temperature (°C)	Winter	−5.5	−3.3	−2.1
Tropical Nights *	Annual	5	14	22
Very Hot Days (+30 °C)	Annual	8	21	32

* A tropical night occurs when the lowest temperature of the day does not go below 20 °C [43].

Higher temperatures, more tropical nights, and more extremely hot days will lead to more evapotranspiration. This trend could result in coastal accretion and more severe droughts in the region.

3.7. Extremes and Climate Events in the Region

Extreme climate events such as heat waves, severe rainstorms, ice storms, windstorms, coastal retreats, and droughts were increasingly happening and predicted to become more intense and frequent in the future [46]. For instance, some studies expressed that the region is the most drought-susceptible area in southern Ontario [47,48], with a high risk of drought impact [49]. Figure 18 shows the low water events based on levels of precipitation and streamflow in the Quinte region, including Prince Edward County (level 1 is the least and level 3 is the most severe low water condition).

The region's annual low water data recorded by MNRF revealed that 11 years in the 2000s and 2010s faced drought conditions, mainly in late summer and early fall. Six of these years experienced level 2, and one severe drought period happened in 2016 with 30 weeks total duration [49]. Based on Figure 14, 2018 and 2019 had drought periods of 16 weeks, while annual precipitations in these two years were considerably above the long-term mean.

From an annual precipitation viewpoint, extreme wet periods were observed in 2000, 2004, 2006, 2008, and 2017, where the latest was the highest record over the previous two decades.

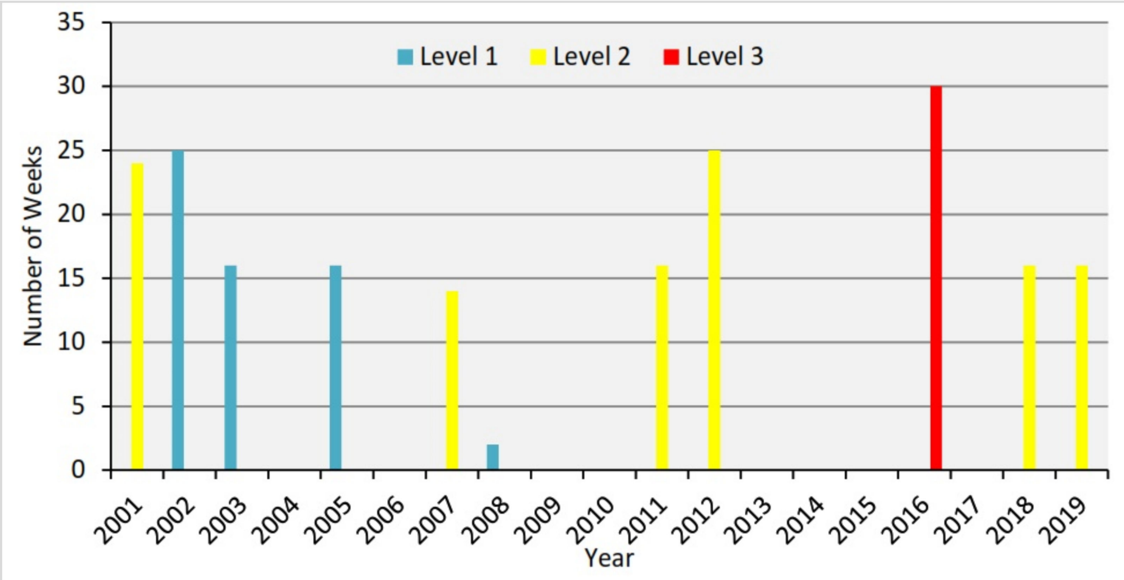

Figure 18. Low water events in the study area from 2001 to 2019 (based on the records of the Ontario Ministry of Natural Resources and Forestry (MNRF)). Adopted from Ref. [49].

3.8. Population Growth in the County

Full-time residents of Prince Edward County were 25,841 (based on the Canadian Census records) in 2020, reaching just over 32,000 with seasonal residents [50]. The county's population has shown a 14.5% growth from 1976 (22,559 people) to 2020. In addition to this, the county is the host for Sandbanks Provincial Park visitors every year. Based on the park's records, the visitors' population was 328,898 in 1990, reaching 822,389 in 2020, showing a 150% growth in the visitors' population in the last three decades. These vast population numbers could impact the natural environment and resources such as coastal areas and freshwater bodies. Climate change can also worsen this trend and the pressure on the resources as additional stress [51].

4. Discussion

4.1. Zonewise Erosion and Accretion Monitoring

Based on the shoreline changes detection and erosion/accretion trends in the region since 1984, water-to-land transition (accretion) apparently can be seen in most parts of the study area. This transition has been found to be affected by several factors, including lake water-level changes, total annual precipitations, sand movements, and other hydrologic/climatic parameters. Spatiotemporal monitoring of the West and East Lakes was paralleled with annual precipitation data of the region, and other climatic extremes such as drought periods were added to the discussion. According to this, the present study explains the observed changes and trends for every zone.

Zone A showed considerable water-to-land transition in the West Lake portion of the zone. This constant change is mainly due to the decrease in the West Lake water level, especially in recent years. In the case of low water levels, shallow parts of the lake are faced with more accretion, impacting the local ecosystem and the related creatures in the long term. Furthermore, total annual precipitation has followed a descending trend since 2012 (except for a sharp peak in 2017), while the severity of the drought periods has grown to upper levels (levels 2 and 3). In addition, the highest sand dunes in this part (up to 18 m in height) are next to West Lake and migrate in a northeasterly direction, progressively depositing into West Lake [36,52]. This sand migration trend is primarily due to the wind force and direction.

On the other side of the zone located in Wellington Bay (Lake Ontario), coastal erosion has been observed mainly since 2000. This trend is primarily followed by Lake Ontario's water level fluctuations and is projected to remain at the same level in the near future [53].

Zone B, which includes shallow waters and coastal marshes, has faced considerable accretion since 1984. Based on the spatiotemporal monitoring of West Lake, the lake water level has started a descending trend (except a few wet years) since 2009. This trend resulted in an average lake area of about 19 km^2, more than 4% smaller than the water body in 1984. This loss in the water body (around 80 hectares) has become chiefly visible in the shallow parts of the lake. Coastal marshes of Zone B are in the proximity of croplands. This water-to-land transition could potentially change the ecosystem and the microclimate of the zone, especially in drought periods and heatwaves. Moreover, this accretion trend will impact the sustainability of aquatic and terrestrial species in the zone in the long term.

Zone C at the very end of East Lake has continuously experienced coastal erosion on the northwest side of the zone since 1984 (in a narrow strip), while the lake's total area has decreased by 2.6% in the last four decades. This decrease in the water body has been partially detected in the eastern and southeastern parts of the zone and southwest of East Lake (the Outlet River's estuary). Climate change and global warming caused prolonged dry seasons/years in many parts of the world, with the consequence of less annual precipitation and less watershed flow budget to inland lakes. This trend has led to a narrow accretion ring on the eastern side of East Lake.

Zone D at the West Point, which includes an outcrop (exposed) of bedrock, has faced more exposure during the study period and showed a slight water-to-land transition. According to the texture of the coast, the main driver of the observed accretion at West Point is the lower water level of Lake Ontario in this region. Furthermore, this accretion trend at the point is going to continue as the future water level of the Great Lakes (including Lake Ontario) is projected to stand below the mean long-term level [53].

Although Outlet beach and the Outlet River's baymouth (Zone E) experienced some peak water levels, an accretion trend has been detected in the zone since 1984. This zone has been affected by the water level of both adjacent lakes (Lake Ontario and East Lake). The shoreline recession and low river flow rate have led to the expansion of Outlet Beach and the river's baymouth. This expansion would be the most likely scenario for this zone due to the beach's gentle slope. The gentle slope could accelerate the expansion of the beach in severe drought seasons, which are projected to occur with greater frequency and severity levels [42]. Additionally, hydrologic droughts are predicted to be more severe in Canada throughout the next 50 to 100 years leading to droughts with durations of 35 to 55 weeks in a row [54]. Hence, Outlet River would be at low water levels or drought conditions for longer durations in the future. This trend, alongside the other climate-driven forces, could result in more accretion and beach expansion in Outlet Beach and the river's baymouth.

As a result, exposed rivers, beaches, and lake sediments (during low water conditions and rewetting) could enhance CO_2 and CH_4 emissions [55].

4.2. Effects of LULC Changes on Coastal Ecosystems

LULC changes in the study area between 2010 and 2021 showed a tendency to use bare lands for other types of land use. At the same time, forests have lost 2.7% of their total area since 2010. On the other hand, croplands have replaced other land uses. This increase in farming demand has expanded the croplands' area at a rate of 7.3% in the monitored period. These land-use changes could potentially affect the natural hydrological cycle of the region in both water bodies and groundwater. Forests, for instance, stabilize the quality and quantity of water, slow down erosion, and recharge and maintain the quality of groundwater [56]. Forests also act as a host for some small streams and creeks in the region, helping them to survive in the changing climate. This opportunity contributed to preventing a decrease in the total coverage of water bodies in the study area since 2010 despite the observed accretion trend in the East and West Lakes.

In contrast, croplands are closely dependent on precipitation in the growing season. Then, in the low water conditions, which is projected to be the common trend in the region, croplands would add to more water consumption and contribute to the accretion trend in water bodies and a lower water table in groundwater resources. The mentioned lack of water availability would affect the region's ecosystems and might change the structure of some aquatic and terrestrial habitats. Furthermore, wetlands and their crucial functions (especially in coastal protection) are more sensitive to these low water conditions, while their biodiversity and species richness could be more at risk [57,58].

Therefore, the observed LULC changes could be in line with climate change-driven forces to accelerate the detected accretion trend in the East and West Lakes.

4.3. Effects of Population Growth and LULC Changes on Coastal Sustainability

From community sustainability goals, proper land use is vital in providing necessary materials and ecosystem services to all active sectors in a region. These goods and services include food, biomass, biodiversity, natural areas, clean air and water, and human well-being [59,60]. The sustainability would be at risk when demands for specific land use conflict with the existing balance between different categories of LULC. This possible improper LULC could affect the sustainability of essential ecological services, aesthetics, and healthful living conditions [61]. The detriment to ecological functions could be seen as more endangered species, decreased carbon storage [62,63], ecosystem vulnerability [61], and more disruptions in the nutrient cycle [64].

On the other hand, population growth would contribute to more LULC changes in the study area. The growing seasonal population would also add more pressure on freshwater resources as they visit the region primarily in relatively warm seasons. Hence, the county's land-use planning was adopted to achieve sustainable development and avoid severe environmental disturbances [65]. However, climate change and its consequences are increasingly visible in the prolonged low water conditions in the county. This trend, along with the growing population, could potentially cause more freshwater scarcity, especially in coastal areas of the region with high recreational activities.

This water demand would be added to the increasing water demand in the agricultural section, especially in low water conditions and drought periods. Finding sustainable supply resources for the cumulative water demand plays a crucial role in the sustainable management of the region amid the changing climate.

4.4. Climate Change-Driven Forces and Coastal Erosion/Accretion

Recreational and other unique values of the county have made the region a well-known tourism destination at the provincial and national scales. Data from Census Canada, along with the county's visitors' information, revealed that there was a growth rate of 140.5% in the county's population (residents plus visitors) from 1990 to 2020.

Moderate and severe low water conditions, on the other hand, showed a 250% increase in the first two decades of the present century related to the available data of the last century. This increase has recognized Quinte watersheds among regions with the highest risk of water supply shortage in Ontario [49].

As mentioned in Section 3.4, the two main inland water bodies of Prince Edward County showed a descending trend in their total areas. Recent remote sensing data for West Lake in 2021 showed a 5% decrease in the total area related to 1984, while this rate is a 3.4% decrease for East Lake. These data are shown in Figures 19 and 20 in blue bars. The two figures show changes in climate factors with potential impacts on coastal erosion and accretion by 2080 based on the mean data of 1976–2005. However, among all climate parameters, precipitation and temperature are structural climate factors that directly interact with human and natural systems [66]. Figure 19 shows the projection for the low carbon emission scenario (RCP4.5) in light orange bars where the most considerable changes are expected in mean temperature and heatwaves. The mean annual temperature will also increase up to more than 25%. Moreover, this warming-up trend will add extremely hot days and nights by 162.5 and 180%, respectively. These hot days and nights could cover up to a length of one month, mainly in late spring and the entire summer period. On the other hand, the total amount of precipitation in summer would remain around the current mean level, while the total annual precipitation trend is to increase up to 8.4% by 2080 [42].

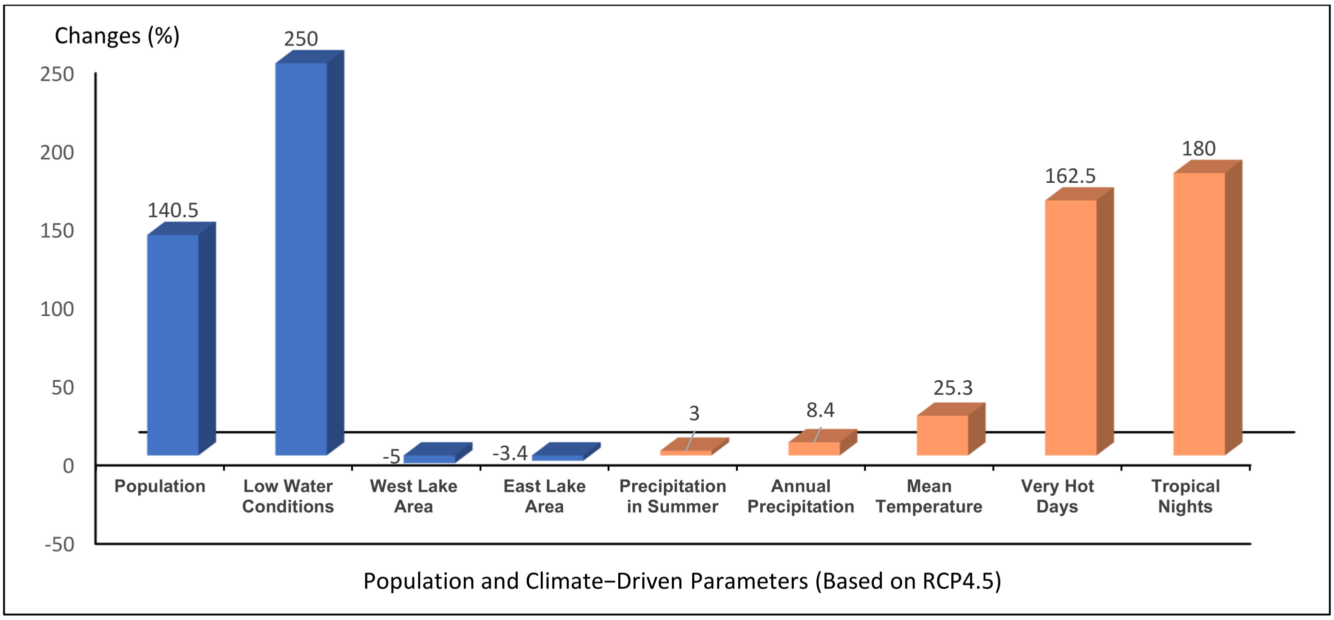

Figure 19. Changes in population and climate-driven parameters in the study area (blue represents observed data and light orange refers to future projections for 2080).

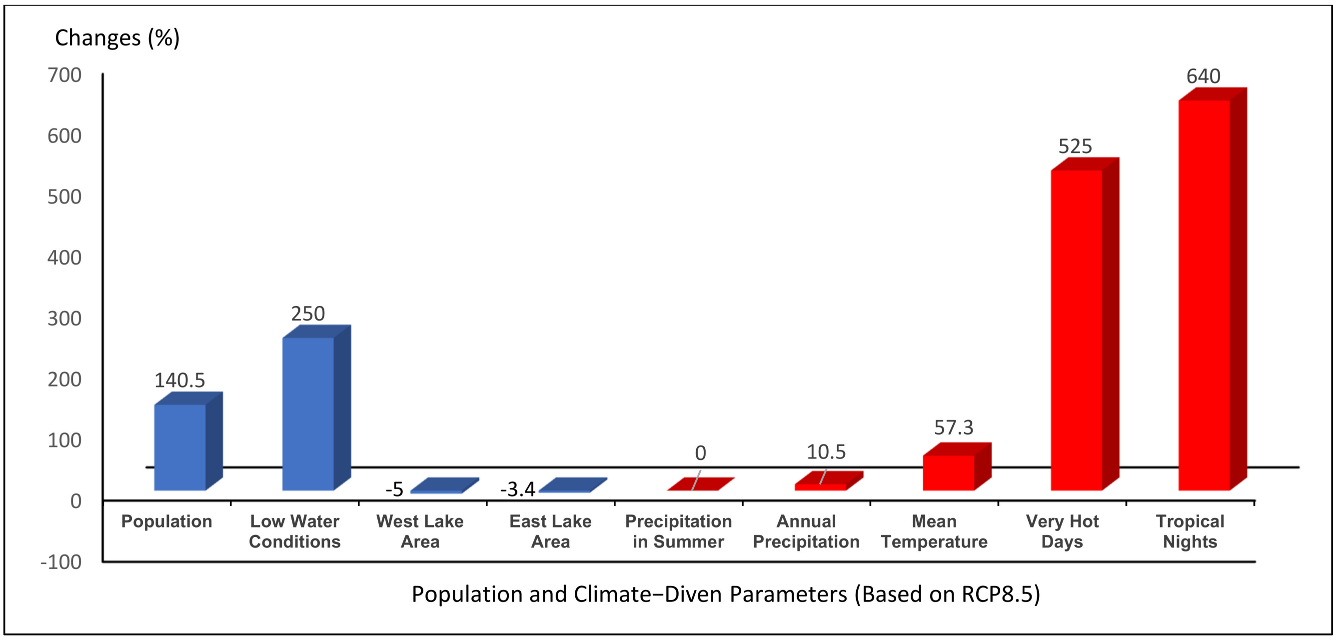

Figure 20. Changes in population and climate-driven parameters in the study area (blue represents observed data and red refers to future projections for 2080).

Figure 20 shows the future projection based on the high emission scenario (RCP8.5) in red bars. This scenario will be the case if our planet continues with the current level of GHG emissions. More specifically, global warming will be more visible in Canada, where the observed and projected increase in mean temperature is two times greater than the global mean temperature [66].

In the high emission scenario (Figure 20), the quantities of mean temperature and extremely hot days and nights would significantly be more than the low emission scenario degrees. As a fundamental climate quantity, the mean temperature will increase up to more than 57% by 2080. This enormous warming quantity and a sharp increase in the occurrence of extremely hot days and nights (525 and 640%, respectively) [42] would seriously impact water bodies and coastal ecosystems in the study area. In recent years, reported increases in surface water temperature have mostly been forced by higher temperatures in summer and spring. The United States Environmental Protection Agency (EPA) expressed that the warmer waters in spring and summer could be partially characterized by an earlier thawing of winter ice [67].

These extremely hot periods could reach up to 50 days a year, impacting the water supply in the county. Total annual precipitation is also projected to increase by 10.5%, whereas summer precipitation is expected to remain at the current level [42]. This increase in annual precipitation (in both high and low emission scenarios) would be more visible in winter than in any other season [42,66]. At the same time, extreme precipitation is expected to be more frequent in the region as well as the whole country [66].

Observations and future projections of extreme temperature events in Canada align with the overall global warming trend. More specifically, extremely warm periods have become hotter and are projected to be elevated in the rest of the present century. On the other hand, extremely cold temperatures have become milder and are projected to be less cold in the future. The magnitude of these trends in both the hot and cold sides depends on the magnitude of changes in the mean temperature, which is mainly correlated with the emission scenarios [68].

The projected increase in mean temperature would change the normal balance between photosynthesis and respiration in freshwater ecosystems such as the inland lakes in the study area. This balance changes with increasing temperature in favor of respiration, causing more GHG emissions from the freshwater bodies of the region [69]. This extra emission from exposed freshwater lakes is estimated at about 320 mmol/m^2/year [55,70]. However, nearby terrestrial vegetation (if any) is a reasonable means to capture some extent of the emitted CO_2 from shallow wetlands during low water conditions [70]. The imbalance could potentially contribute to accelerating climate change trends in the area.

5. Conclusions

The present study utilized Landsat images to detect coastal erosion/accretion trends and LULC changes in the southern part of Prince Edward County. Historical climate data and the most likely future climate scenarios were also used to detect and reveal the region's present and future climate conditions.

The discussed warming trend (according to present data and future climate scenarios) would continuously result in a more extended growth period in the region. Hence, this enhancement in farming time (and other encouraging factors) could potentially increase the present demand for agricultural lands and consequently affect the LULC patterns of the study area. Furthermore, the observed and more potential changes in agrarian land demand would influence the hydrology and water consumption of the region, acting as additional stress on the water levels of the inland lakes and groundwater of the region. For instance, the volume of water consumption in Ontario's agricultural section in 2016 was five times greater than the recorded amount in the Agriculture Water Survey of 2014 [71]. This massive increase in agricultural water demand was highly correlated to low water conditions in the area (discussed with more details in Section 3.7) from August to November, as expressed in the Ontario Low Flow Maps [72]. Farmlands in

Ontario mostly rely on direct precipitation and smaller inland water sources such as rivers, small lakes, and groundwater [73]. Other sectors also use these local resources, including rural municipalities, rural commercial and industrial consumers, and golf courses [74,75]. Therefore, droughts, severe low water conditions, and lack of precipitation in the growing season would extensively affect farmlands and the other rural water users in the county. The growing population (mainly visitors) and projected expansion in agriculture activities could elevate this competition for freshwater. It will put extra pressure on the water reservoirs, resulting in more accretion in the region's inland lakes through the changing climate. Therefore, shrinking would be the common trend in the East and West Lakes, where the climate change mitigating plans would moderate this accretion.

In total, the synergistic interaction of the discussed parameters would result in more water-to-land change (accretion trend) along with a lower groundwater table amid even a low carbon scenario. From another point of view, groundwater is a safe source of drinking water in climate change-driven disasters [76], and overexploitation of this vital resource could result in lower agriculture production rates [77,78], a decline in water quality [79], and more vulnerability among coastal communities [80].

However, most adaptation programs for projected water-related issues are achievable at lower emission scenarios. This dependence reveals the role of climate change mitigation efforts in the success of future adaptation plans. For instance, the coastal wetlands accretion trend will affect 20–90% of their total area depending on climate change severity. This loss will seriously impact the wetlands' roles in coastal protection, ecological balance, and carbon sequestration [69].

Our study tried to fill some knowledge gaps in the consequences of population growth and climate and LULC changes on coastal erosion/accretion trends through utilizing GIS, remote sensing, and other local and nation-wide accessible data. Collaboration of regional authorities and provincial departments has been an added value to this research. Nevertheless, as the context of climate change is going to be more discussed and monitored in every part of the world, the results of this research could be beneficial to regional/provincial authorities, policymakers, and environmental advocates for the sustainable development of coastal communities, especially in the Quinte region. However, there are remaining critical knowledge gaps in the attribution of the climate-induced changes to freshwater quality and quantity (both surface and groundwater) in coastal areas and their societal impacts [69], especially in Prince Edward County.

Author Contributions: Conceptualization, E.K., H.S. and M.M; formal analysis, E.K. and M.H.; writing—original draft preparation, E.K. and M.H.; writing—review and editing, E.S. Project administration. all authors.; visualization, E.K. and M.H.; supervision, H.S. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: The Authors acknowledge the Memorial University of Newfoundland and the research funding provided by Mitacs through the entrepreneurship accelerate program.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available upon reasonable request.

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

Nomenclature

The following abbreviations are used in this paper:

CH_4	Methane
CO_2	Carbon Dioxide
DSAS	Digital Shoreline Analysis System
EPA	United States Environmental Protection Agency
GCMs	Global Climate Models
GEE	Google Earth Engine
GHGs	Greenhouse Gases
GIS	Geographic Information System
ILWIS	Integrated Land and Water Information System
LULC	Land Use/Land Cover
MLP	Multilayer Perceptron
MNDWI	Modified Normalized Difference Water Index
MNRF	Ontario Ministry of Natural Resources and Forestry
NDWI	Normalized Difference Water Index
NIR	Near-Infrared
°C	Degrees Celsius
PDF	Probability Density Function
RCP4.5	Low Carbon climate scenario
RCP8.5	High Carbon climate scenario
RCPs	Representative Concentration Pathways
RGB	Red, Green, and Blue
RS	Remote Sensing
SWIR1	Short-Wave Infrared

References

1. Neshaei, S.A.; Safaval, P.A.; Zarkesh, M.M.K.; Karimi, P. Study of morphological changes and sustainable development on the southern coasts of the Caspian Sea using remote sensing and GIS. *WIT Trans. Ecol. Environ.* **2018**, *217*, 771–779. [CrossRef]
2. Bennett, N.J.; Blythe, J.; Tyler, S.; Ban, N.C. Communities and change in the anthropocene: Understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Reg. Environ. Chang.* **2016**, *16*, 907–926. [CrossRef]
3. Hoegh-Guldberg, O.; Jacob, D.; Bindi, M.; Brown, S.; Camilloni, I.; Diedhiou, A.; Djalante, R.; Ebi, K.; Engelbrecht, F.; Guiot, J.; et al. *Special Report on Global Warming of 1.5 °C-Chapter 3: Impacts of 1.5 °C Global Warming on Natural and Human Systems*; World Meteorological Organization Technical Document; University of Helsinki: Helsinki, Finland, 2018; pp. 175–311.
4. Mattheus, C.R. Climate-induced changes in rates of headland-beach progradation along the southern coast of lake erie. *J. Coast. Res.* **2014**, *30*, 743–755. [CrossRef]
5. Caspell, M.; Vasseur, L. Evaluating and visualizing drivers of coastline change: A lake ontario case study. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 375. [CrossRef]
6. Fernández-Montblanc, T.; Duo, E.; Ciavola, P. Dune reconstruction and revegetation as a potential measure to decrease coastal erosion and flooding under extreme storm conditions. *Ocean. Coast. Manag.* **2020**, *188*, 105075. [CrossRef]
7. Peponi, A.; Morgado, P.; Trindade, J. Combining Artificial Neural Networks and GIS Fundamentals for Coastal Erosion Prediction Modeling. *Sustainability* **2019**, *11*, 975. [CrossRef]
8. Mentaschi, L.; Vousdoukas, M.I.; Pekel, J.F.; Voukouvalas, E.; Feyen, L. Global long-term observations of coastal erosion and accretion. *Sci. Rep.* **2018**, *8*, 12876. [CrossRef]
9. Allan, A.; Soltani, A.; Abdi, M.H.; Zarei, M. Driving Forces behind Land Use and Land Cover Change: A Systematic and Bibliometric Review. *Land* **2022**, *11*, 1222. [CrossRef]
10. Dimobe, K.; Ouédraogo, A.; Soma, S.; Goetze, D.; Porembski, S.; Thiombiano, A. Identification of driving factors of land degradation and deforestation in the Wildlife Reserve of Bontioli (Burkina Faso, West Africa). *Glob. Ecol. Conserv.* **2015**, *4*, 559–571. [CrossRef]
11. Liu, J.; Zhang, Z.; Xu, X.; Kuang, W.; Zhou, W.; Zhang, S.; Li, R.; Yan, C.; Yu, D.; Wu, S.; et al. Spatial patterns and driving forces of land use change in China during the early 21st century. *J. Geogr. Sci.* **2010**, *20*, 483–494. [CrossRef]
12. Bufebo, B.; Elias, E. Land Use/Land Cover Change and Its Driving Forces in Shenkolla Watershed, South Central Ethiopia. *Sci. World J.* **2021**, *2021*, 9470918. [CrossRef]
13. Wu, H.; Lin, A.; Xing, X.; Song, D.; Li, Y. Identifying core driving factors of urban land use change from global land cover products and POI data using the random forest method. *Int. J. Appl. Earth Obs. Geoinf.* **2021**, *103*, 102475. [CrossRef]
14. Ketema, H.; Wei, W.; Legesse, A.; Wolde, Z.; Temesgen, H.; Yimer, F.; Mamo, A. Quantifying smallholder farmers' managed land use/land cover dynamics and its drivers in contrasting agro-ecological zones of the East African Rift. *Glob. Ecol. Conserv.* **2020**, *21*, e00898. [CrossRef]

15. Hereher, M.E. Mapping coastal erosion at the Nile Delta western promontory using Landsat imagery. *Environ. Earth Sci.* **2011**, *64*, 1117–1125. [CrossRef]
16. Tarawally, M.; Xu, W.; Hou, W.; Mushore, T.D. Comparative analysis of responses of land surface temperature to long-term land use/cover changes between a coastal and Inland City: A case of Freetown and Bo Town in Sierra Leone. *Remote Sens.* **2018**, *10*, 112. [CrossRef]
17. Mushore, T.D.; Mutanga, O.; Odindi, J.; Dube, T. Assessing the potential of integrated Landsat 8 thermal bands, with the traditional reflective bands and derived vegetation indices in classifying urban landscapes. *Geocarto Int.* **2017**, *32*, 886–899. [CrossRef]
18. Mujabar, P.S.; Chandrasekar, N. Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS. *Nat. Hazards* **2013**, *69*, 1295–1314. [CrossRef]
19. Wen, S.; Zhang, F.; Wang, Z.; Li, F.; Jing, X.; Zhao, J. Coastal Erosion Monitoring and Hazard Degree Assessment at Penglai Sandy Coast Based on Remote Sensing. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *234*, 12014. [CrossRef]
20. Calkoen, F.; Luijendijk, A.; Rivero, C.R.; Kras, E.; Baart, F. Traditional vs. Machine-learning methods for forecasting sandy shoreline evolution using historic satellite-derived shorelines. *Remote Sens.* **2021**, *13*, 934. [CrossRef]
21. Vaz, E.; Bowman, L. An application for regional coastal erosion processes in urban areas: A Case Study of The Golden Horseshoe in Canada. *Land* **2013**, *2*, 595–608. [CrossRef]
22. Elkafrawy, S.B.; Basheer, M.A.; Mohamed, H.M.; Naguib, D.M. Applications of remote sensing and GIS techniques to evaluate the effectiveness of coastal structures along Burullus headland-Eastern Nile Delta, Egypt. *Egypt. J. Remote Sens. Space Sci.* **2021**, *24*, 247–254. [CrossRef]
23. Cabezas-Rabadán, C.; Pardo-Pascual, J.E.; Palomar-Vázquez, J.; Fernández-Sarría, A. Characterizing beach changes using high-frequency Sentinel-2 derived shorelines on the Valencian coast (Spanish Mediterranean). *Sci. Total Environ.* **2019**, *691*, 216–231. [CrossRef] [PubMed]
24. Rogers, M.S.J. Exploiting satellite technology and machine learning to describe and predict hazardous shoreline change. In Proceedings of the 22nd EGU General Assembly, Online, 4–8 May 2020; p. 276.
25. Vos, K.; Splinter, K.D.; Harley, M.D.; Simmons, J.A.; Turner, I.L. CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. *Environ. Model. Softw.* **2019**, *122*, 104528. [CrossRef]
26. Amin, S.M.N.; Davidson-Arnott, R.G.D. A statistical analysis of the controls on shoreline erosion rates, Lake Ontario. *J. Coast. Res.* **1997**, *13*, 1093–1101.
27. Mackey, S.D. *Great Lakes Nearshore and Coastal Systems*; U.S. National Climate Assessment Midwest Technical Input Report; National Laboratory for Agriculture and the Environment: Ames, IA, USA; GLISA: Ann Arbor, MI, USA, 2012; p. 14.
28. Department of Primary Industries Water and Environment. *Vegetation Management Plan (VMP)*; Department of Primary Industries Water and Environment: Tasmania, Australia, 2021.
29. Johnstone, D. Sandbanks Provincial Park Management Plan (Amended 2021). 1993. Available online: https://files.ontario.ca/environment-and-energy/parks-and-protected-areas/mnr_bpp0304.pdf (accessed on 1 November 2022).
30. Ontario Parks. Saving Sand by Planting Grass. The Web Log of Ontario Parks. Available online: https://www.ontarioparks.com/parksblog/saving-sand-planting-grass/ (accessed on 15 November 2021).
31. Holland, T.; Smit, B. Recent climate change in the Prince Edward County winegrowing region, Ontario, Canada: Implications for adaptation in a fledgling wine industry. *Reg. Environ. Chang.* **2014**, *14*, 1109–1121. [CrossRef]
32. Quinte Conservation, French Planning Services, Friends of East Lake, County of Prince Edward. "State of the Lake, East Lake watershed report. Quinte Conservation Publication. 2013. Available online: https://www.quinteconservation.ca/en/watershed-management/resources/Documents/Reports%20and%20Studies/East%20Lake%20Stewardship%20Plan/East%20Lake%20Stewardship%20Report%202013.pdf (accessed on 4 July 2022).
33. Rotary Club of Wellington. *Wellington Beach Park Improvement Project Plan*; Rotary Club of Wellington: Wellington, ON, Canada, 2007.
34. County of Prince Edward Planning Department. *Our Local Economy*; County of Prince Edward Planning Department: Prince Edwar County, ON, Canada, 2012.
35. WeatherSpark. Climate in Prince Edward County. Available online: https://weatherspark.com/y/21252/Average-Weather-in-Prince-Edward-Canada-Year-Round (accessed on 27 January 2022).
36. Childs, J.A. *An Investigation into the Spatial and Temporal Movement of the Sand Dunes in the West Lake Ecosystem of Sandbanks Provincial Park and the Implications for Management (Ontario)*; Wilfrid Laurier University: Waterloo, ON, Canada, 2006.
37. Hemati, M.; Hasanlou, M.; Mahdianpari, M.; Mohammadimanesh, F. A systematic review of landsat data for change detection applications: 50 years of monitoring the earth. *Remote Sens.* **2021**, *13*, 2869. [CrossRef]
38. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ.* **2017**, *202*, 18–27. [CrossRef]
39. Tu, T.; Su, S.; Shyu, H.; Huang, P.S. A New Look at Ihs-Like Image Fusion Methods. *Inf. Fusion* **2001**, *2*, 177–186. [CrossRef]
40. Otsu, N.; Smith, P.; Reid, D.B.; Palo, L.; Alto, P. Otsu_1979_otsu_method. *IEEE Trans. Syst. Man Cybern.* **1979**, *1*, 62–66. [CrossRef]
41. Cipolletti, M.P.; Delrieux, C.A.; Perillo, G.M.E.; Piccolo, M.C. Superresolution border segmentation and measurement in remote sensing images. *Comput. Geosci.* **2012**, *40*, 87–96. [CrossRef]

42. Prairie Climate Centre. *Climate Atlas of Canada, Version 2 (Municipality: Trenton)*; University of Winnipeg: Winnipeg, MB, Canada, 2019.
43. Tentative Climate Atlas of Canada. Climate Variables. 2021. Available online: https://climateatlas.ca/map/canada/tropicalnights_2060_85# (accessed on 8 February 2022).
44. Government of Canada. Monthly Data Report. 2022. Available online: https://climate.weather.gc.ca/climate_data/monthly_data_e.html?hlyRange=1953-01-01%7C2022-01-23&dlyRange=1935-01-01%7C2022-01-23&mlyRange=1935-01-01%7C2017-12-01&StationID=5126&Prov=ON&urlExtension=_e.html&searchType=stnProx&optLimit=specDate&StartYear=20 (accessed on 22 February 2022).
45. Trenton Weather Report. 2022. Available online: https://trenton.weatherstats.ca/ (accessed on 22 February 2022).
46. Gough, W.; Anderson, V.; Herod, K. Ontario Climate Change and Health Modeling Study Report. Toronto. 2016. Available online: https://www.health.gov.on.ca/en/common/ministry/publications/reports/climate_change_toolkit/climate_change_health_modelling_study.pdf (accessed on 4 June 2022).
47. Levesque, H. *Management Plan: Prince Edwar Point National Wildlife Area*; Canadian Wildlife Service: Ottawa, ON, Canada, 1985.
48. County of Prince Edward Planning Department. *Prince Edward County Natural Environment Plan*; County of Prince Edward Planning Department: The County of Prince Edward, ON, Canada, 2012.
49. Quinte Conservation. *Quinte Region Drought Plan*; Quinte Conservation: Belleville, ON, Canada, 2021.
50. County of Prince Edward Planning Department. *Prince Edward County Community Investment Profile Contents*; County of Prince Edward Planning Department: The County of Prince Edward, ON, Canada, 2016.
51. Olivares, E.A.O.; Torres, S.S.; Jiménez, S.I.B.; Enríquez, J.O.C.; Zignol, F.; Reygadas, Y.; Tiefenbacher, J.P. Climate change, land use/land cover change, and population growth as drivers of groundwater depletion in the Central Valleys, Oaxaca, Mexico. *Remote Sens.* **2019**, *11*, 1290. [CrossRef]
52. Ontario Parks. *Sandbanks Provincial Park Management Plan (Amended 2021)*; Government of Ontario: Toronto, Canada, 2021. Available online: https://www.ontario.ca/page/sandbanks-provincial-park-management-plan#section-5 (accessed on 12 July 2022).
53. NOAA. Great Lakes Water Levels. 2022. Available online: https://www.glerl.noaa.gov/data/dashboard/data/ (accessed on 16 June 2022).
54. Sharma, T.C.; Panu, U.S. Modeling of hydrological drought durations and magnitudes: Experiences on Canadian streamflows. *J. Hydrol. Reg. Stud.* **2014**, *1*, 92–106. [CrossRef]
55. Keller, P.S.; Catalán, N.; von Schiller, D.; Grossart, H.-P.; Koschorreck, M.; Obrador, B.; Frassl, M.A.; Karakaya, N.; Barros, N.; Howitt, J.A.; et al. Global CO_2 emissions from dry inland waters share common drivers across ecosystems. *Nat. Commun.* **2020**, *11*, 2126. [CrossRef]
56. Government of Canada. Conservation and Protection of Canada's Forests. Available online: https://www.nrcan.gc.ca/our-natural-resources/forests/sustainable-forest-management/conservation-and-protection-canadas-forests/water/13207 (accessed on 6 April 2022).
57. Verones, F.; Saner, D.; Pfister, S.; Baisero, D.; Rondinini, C.; Hellweg, S. Effects of consumptive water use on biodiversity in wetlands of international importance. *Environ. Sci. Technol.* **2013**, *47*, 12248–12257. [CrossRef]
58. Zhai, Y.; Hao, L.; Zhang, Y.; Li, Y.; Liu, Z. Wetland biodiversity disturbance evaluation induced by a water conservancy project in the flooded plain of the huolin river lower reaches. *Sustainability* **2021**, *13*, 4476. [CrossRef]
59. Francis, C.A.; Hansen, T.E.; Fox, A.A.; Hesje, P.J.; Nelson, H.E.; Lawseth, A.E.; English, A. Farmland conversion to non-agricultural uses in the US and Canada: Current impacts and concerns for the future. *Int. J. Agric. Sustain.* **2012**, *10*, 8–24. [CrossRef]
60. Goldstein, J.H.; Caldarone, G.; Duarte, T.K.; Ennaanay, D.; Hannahs, N.; Mendoza, G.; Polasky, S.; Wolny, S.; Daily, G.C. Integrating ecosystem-service tradeoffs into land-use decisions. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7565–7570. [CrossRef]
61. Cox, L.; Hansen, V.; Andrews, J.; Thomas, J.; Heilke, I.; Flanders, N.; Walton, B.T. *Land Use: A Powerful Determinant of Sustainable & Healthy Communities*; U.S. Environmental Protection Agency: Washington, DC, USA, 2013.
62. Mcdonald, R.I.; Kareiva, P.; Forman, R.T.T. The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biol. Conserv.* **2008**, *141*, 1695–1703. [CrossRef]
63. Usepa. *Alternative Futures Analysis of Farmington Bay Wetlands in the Great Salt Lake Ecosystem*; U.S. Environmental Protection Agency: Cincinnati, OH, USA, 2010; pp. 1–94.
64. Nagy, R.C.; Lockaby, B.G. Urbanization in the Southeastern United States: Socioeconomic forces and ecological responses along an urban-rural gradient. *Urban Ecosyst.* **2011**, *14*, 71–86. [CrossRef]
65. Planning Department, Community Sustainability Report. County of Prince Edward, ON, Canada, 2012. Available online: https://www.thecounty.ca/wp-content/uploads/2020/09/Community-Sustainability.pdf (accessed on 17 June 2022).
66. Zhang, X.; Flato, G.; Kirchmeier-Young, M.; Vincent, L.; Wan, H.; Wang, X.; Rong, R.; Fyfe, J.; Li, G.; Kharin, V.V. Changes in Temperature and Precipitation Across Canada. In *Canada's Changing Climate Report*; Chapter 4; Bush, E., Lemmen, D.S., Eds.; Government of Canada: Ottawa, ON, Canada, 2019.
67. EPA. *Climate Change Indicators: Great Lakes Water Levels and Temperatures*; EPA: Washington, DC, USA, 2021.
68. Bush, E.; Lemmen, D.S. (Eds.) *Canada's Changing Climate*; Government of Canada: Ottawa, ON, Canada, 2019.
69. IPCC. *Climate Change 2022: Imapct, Adaptaion, and Vulnerability*; IPCC: Geneva, Switzerland, 2022.

70. Marcé, R.; Obrador, B.; Gómez-Gener, L.; Catalán, N.; Koschorreck, M.; Singer, G.; von Schiller, D. Emissions from dry inland waters are a blind spot in the global carbon cycle. *Earth-Sci. Rev.* **2019**, *188*, 240–248. [CrossRef]
71. Statistics Canada. *Agricultural Water Survey*; Statistics Canada: Ottawa, ON, Canada, 2016.
72. Ontario Ministry of Natural Resources and Forestry, "Ontario Low Water Program". 2016. Available online: https://www.lioapplications.lrc.gov.on.ca/webapps/swmc/low-water-response/, (accessed on 28 June 2022).
73. Watters, A. *Freshwater Scarcity: The Current Situation in Southern Ontario*; York University: Toronto, ON, Canada, 2019.
74. Shortt, R.; Caldwell, W.J.; Ball, J.; Agnew, P. A Participatory Approach to Water Management: Irrigation Advisory Committees in Southern Ontario. *Can. Water Resour. J.* **2006**, *31*, 13–24. [CrossRef]
75. Kreutzwiser, R.D.; de Loë, R.C.; Durley, J.; Priddle, C. Water Allocation and the Permit to Take Water Program in Ontario: Challenges and Opportunities. *Can. Water Resour. J.* **2004**, *29*, 135–146. [CrossRef]
76. Richts, A.; Vrba, J. Groundwater resources and hydroclimatic extremes: Mapping global groundwater vulnerability to floods and droughts. *Environ. Earth Sci.* **2016**, *75*, 926. [CrossRef]
77. Asoka, A.; Mishra, V. A strong linkage between seasonal crop growth and groundwater storage variability in India. *J. Hydrometeorol.* **2020**, *22*, 125–138. [CrossRef]
78. Jain, M.; Fishman, R.; Mondal, P.; Galford, G.L.; Bhattarai, N.; Naeem, S.; Lall, U.; Singh, B.; DeFries, R.S. Groundwater depletion will reduce cropping intensity in India. *Sci. Adv.* **2021**, *7*, eabd2849. [CrossRef]
79. Mas-Pla, J.; Menció, A. Groundwater nitrate pollution and climate change: Learnings from a water balance-based analysis of several aquifers in a western Mediterranean region (Catalonia). *Environ. Sci. Pollut. Res.* **2019**, *26*, 2184–2202. [CrossRef]
80. Blakeslee, D.; Fishman, R.; Srinivasan, V. Way down in the hole: Adaptation to long-term water loss in rural India. *Am. Econ. Rev.* **2020**, *110*, 200–224. [CrossRef]