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RESEARCH ARTICLE

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Exploring long-term datasets of land use, economy, and demography variations in karst wetland areas to detect possible microclimate changes

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Abstract

This study explores the possibility of deciphering changes in the total area of a karst wetland due to shifts inland use, economy and population over a long-term period (35 years) and microclimate changes (1958–2019). To achieve this goal, we focused on Huangcaozhou Karst Wetland, a national karst wetland park located in China. Based on remote sensing interpretation, long-term climate data, and statistical yearbook datasets, our results showed that from 1984 to 2019, owing to the rapid rates of urbanization and economic development, swamplands in our study area decreased by 16.4%, while urban lands increased up to 16.7%. The inflection point on the land use and land cover (LUCC) curve we constructed appeared in 2006, after which the areas of swampland, rocky desertification land, and wasteland sharply decreased and those of urban land and farmland increased. This is consistent with the increase in gross domestic production (GDP) and the totalnumber of inhabitants. From 1958, when Luxi registered an annual average temperature of 14.8°C, to 2019, the air temperature increased with a gradient of 0.157°C per decade, until it reached an average of 15.3°C. We did not find a clear trend for the number of annual rainy days (average of 140.6 rainy days per year) but the mean torrentiality (average annual volume divided by the annual number of rainy days) shows a slight trend of increase (0.72 mm per day per decade). Precipitation we found has gradually declined. We concluded that economic and demographic changes are interacting with microclimate changes, which are affected by the regional eco-environment over a long-time scale in the Huangcaozhou Karst Wetland, causing the wetland quality significantly varied in recent decades. This would help to develop more efficient land management plans to better correctly handle new human activities allowing policymakers to regulate the wetland ecosystem in Southwestern China.

KEYWORDS
economy, karst wetland, land management, microclimate change, population

1 | INTRODUCTION

Land use and land cover change (LUCC) can be clear indicators of the advance of human economic and social activities and moreover non human factors that modify the Earth's landscapes (Aburas et al., 2019; Akter et al., 2018; Bajocco et al., 2016; Li, Jiang, Chen, et al., 2020). That disturbance of the Earth's surface by anthropogenic activities can lead to changes in the ecosystem services such as biodiversity, climate, land quality, and water-soil configuration (Rao et al., 2020; Baveye et al., 2016; de Groot et al., 2010). The consequences of rapid and non-planned changes in LUCC can manifest as land degradation, biodiversity loss, climate change, species invasion, and decreased ecosystem service functioning in a given region (Shi et al., 2022; Foley et al., 2005; Hesslerova et al., 2012; Jarvie et al., 2008; Jiang, 2013; Piao et al., 2007; Pielke, 2005). Land transformation from original ecosystem status to agricultural, industrial or urbanized uses can have critical consequences (Ceccarelli et al., 2014; Cerdà et al., 2021; Rodrigo-Comino et al., 2021). Recent investigations suggest that karst ecosystems are extremely fragile, once degradation happens, they are unlikely to recover in the short term (Chen et al., 2020). With the intensification of human activities, ecosystems in the karst region of China showed lower maintenance capacity than in non-karsregions. (Zhang et al., 2021).

An increase in population size commonly corresponds to increased land consumption and more demand for natural resources and ecological services (Bimonte & Stabile, 2017; Guo et al., 2010). Excessive population growth induces new pressure on the economy, society, environment, and natural resources, and in some cases leads to overdevelopment that destroyis the ecosystem balance (Norman, 2020; Novara et al., 2017). In rapidly developing countries, the occupation of natural lands is increasing, resulting in reduced soil fertility, widespread soil erosion, and the release of nutrients and sediments to aquatic ecosystems (Rabalais et al., 2009; de Sousa et al., 2022; Yu et al., 2022). Recently, some authors have hypothesized that, at the regional scale, climate change is a key indicator that could reflect changes in land use/land cover which drive the land-atmosphere and eco-environmental dynamics (Anderson et al., 2011). For example, from 1961 to 2010, some estimates revealed that the annual mean temperature in Southwest China increased by 0.12°C per decade, while the annual precipitation slightly decreased (Ma et al., 2013). Such changes could modify the vulnerable aspects of Southwest China, such as agriculture and biodiversity (Ma et al., 2013). In India, the land surface temperature showed seasonal asymmetry and there were changes in atmospheric circulation. These changes were about 1°C in winter and post-monsoon months, with differences of about 0.8°C between summer monsoon and post-monsoon months (Dash et al., 2007). Considering these data, some authors suggest that this global warming could significantly impact regional ecological and socioeconomic systems (Li et al., 2010), and vulnerable territories such as wetlands could be reduced (Huang et al., 2017). However, to date, understanding of the interactions between both driving factors behind LUCC and climate change in karst wetland ecosystem is inadequate (Chazal & Rounsevell, 2009).

LUCC is a reflection of human activities and can be a driving force behind changes in environment and climate (Bu et al., 2014; De Vries et al., 2013; Park et al., 2014). Agricultural expansion and/or intensification, urban sprawl, and losses of natural resources and biodiversity have been explored by researchers (Lambin et al., 2001; Lawrence et al., 2012). Non-sustainable management can cause anthropogenic disturbances, which are often the main driving factors causing environmental degradation (Dunn et al., 2012). Important changes in land use are likely to occur as a consequence of other externalities factors and above climate change (Stonestrom et al., 2009). Climate plays an important role in determining land use (Brown et al., 2008). Human activities are related to climate change and vice versa - reciprocal causation (Dunn et al., 2012; Huang et al., 2015). Therefore, the relationship between land-use changes, human activities, and climate change is highly complex and requires in-depth research and novel techniques.

The study of wetlands in Yunnan Province in Southwest China began in the 1990s when some authors observed that air temperature had been increasing since the beginning of the century (Bian, 2006; Hong et al., 2006). This generated a division of the wetlands of Yunnan into six categories in 2001: permanent river wetlands, permanent and seasonal freshwater lake wetlands, and grassy marsh wetlands. The wetlands are situated across a unique hydrogeological structure on karst parent materials. It is well known that karst wetlands exhibit clear differences from other wetland types and have unique qualities (Cerkvenik et al., 2018; Beltram, 2016; Moran et al., 2008). Karst wetlands in Yunnan Province, occupy areas such as Dianchi, Pana, Datun, Changqiao, and Puzhehei (Bian, 2006). So far, ecological and environmental studies on wetlands have mainly focused on sediments, pollution treatment, biodiversity, and environmental change (Ma et al., 2009; Tong & Hou, 2004; Zhang et al., 2010); however, studies assessing wetland connections (or none) with changes in land use/land cover and climate have not yet really been undertaken (Bai et al., 2020; Huang et al., 2014; Tian et al., 2004). For example, remote sensing could be a useful tool to achieve this goal, as it is convenient for observation across larger areas and at higher frequencies than ground-based observations (Cardille & Foley, 2003; Olofsson et al., 2013; Xian & Homer, 2009). Detection, ground observation, and obtaining LUCC data from remote sensing images to relate the data with climate have the advantages of speed and efficiency of the analysis (Chen, 2002; Ruelland et al., 2011).

In Southwest China, the earliest satellite imaging data to assess land uses and cover were obtained in 1972 (LANDSAT). Therefore, it is now possible to conduct studies spanning over 40 years. The Huangcaozhou Karst Wetland in the Luxi County is the main source of karst groundwater recharge for features such as the Pijiazhai Spring, the ancient Alu Caves Underground River, and Baxin Spring. Furthermore, it is also an important economic potential source for tourism and research. However, owing to the rapid increase in the human population and social development, most of the Huangcaozhou Karst Wetland has been occupied and exploited (Hong et al., 2006). Coinciding with the rapid social and economic development of Luxi County, human activities are negatively impacting the Huangcaozhou Karst Wetland national park more and more. Humans are occupying the swampland, polluting the water and destroying the ecosystems, etc. We hypothesized that possible microclimate changes and recent socioeconomic dynamics, led to the LUCC in the Huangcaozhou Karst Wetland from 1984 to 2019. Our study used LANDSAT, and Google Earth image data to explore key drivers of this degradation. Our main research aim was to find out if there wast a correlation between land uses, climate changes, and the exploitation and degradation of the Huangcaozhou Karst Wetland over the past decades. This would help to develop more efficient land management plans to better handle new human activities allowing policymakers to regulate them.

2 | MATERIALS AND METHODS

2.1 | Study area

The Huangcaozhou Karst Wetland is located close to the Zhongshu Town, in Luxi County, Honghe Hani and Yi Autonomous Prefecture, Yunnan Province, China (Figure 1). The wetland lies on the left bank of the Nanpanjiang River (a first-grade tributary of the Zhujiang River) at an elevation of approximately 1700 m and covers an area of approximately 6 km^2 in the southwestern Yungui Plateau. The wetland is located in the middle of the Luxi Fault basin and was formed by the fault activity and erosion that caused the Yungui Plateau uplift during the Cenozoic Era (Li, Jiang, Yu, et al., 2020; Wang et al., 2017). The area is characterized by karst groundwater resources with the exposed stratum dating mainly from the Triassic and consisting of dolomite and limestone, covered by a Quaternary soil layer. According to our survey, fieldwork, and collected statistics, about 74,800 m^3 of water flows into the Huangcaozhou Karst Wetland daily (Zhang et al., 2021), 82% of this (about 61,336 m^3) originates from underground rivers and springs such as the Basin Spring, Pijiazhai Spring, and the Alu Cave Underground River. This portion of the inflow is the main source of water within the national wetland park. Urban residents use 4488 m^3 of high-quality groundwater which is then dischargedas waste to the wetland every day. This accounts for 6% of the total water reaching the Wetland. Furthermore, there are 8976 m^3 (12% of total) of surface water and agricultural runoff flowing to the Huangcaozhou Karst Wetland daily.

The Huanfcaozhou Karst Wetland is bordered by the Baxin Spring in the north, the Alu Cave in the northwest, Huangcaozhou Pond in

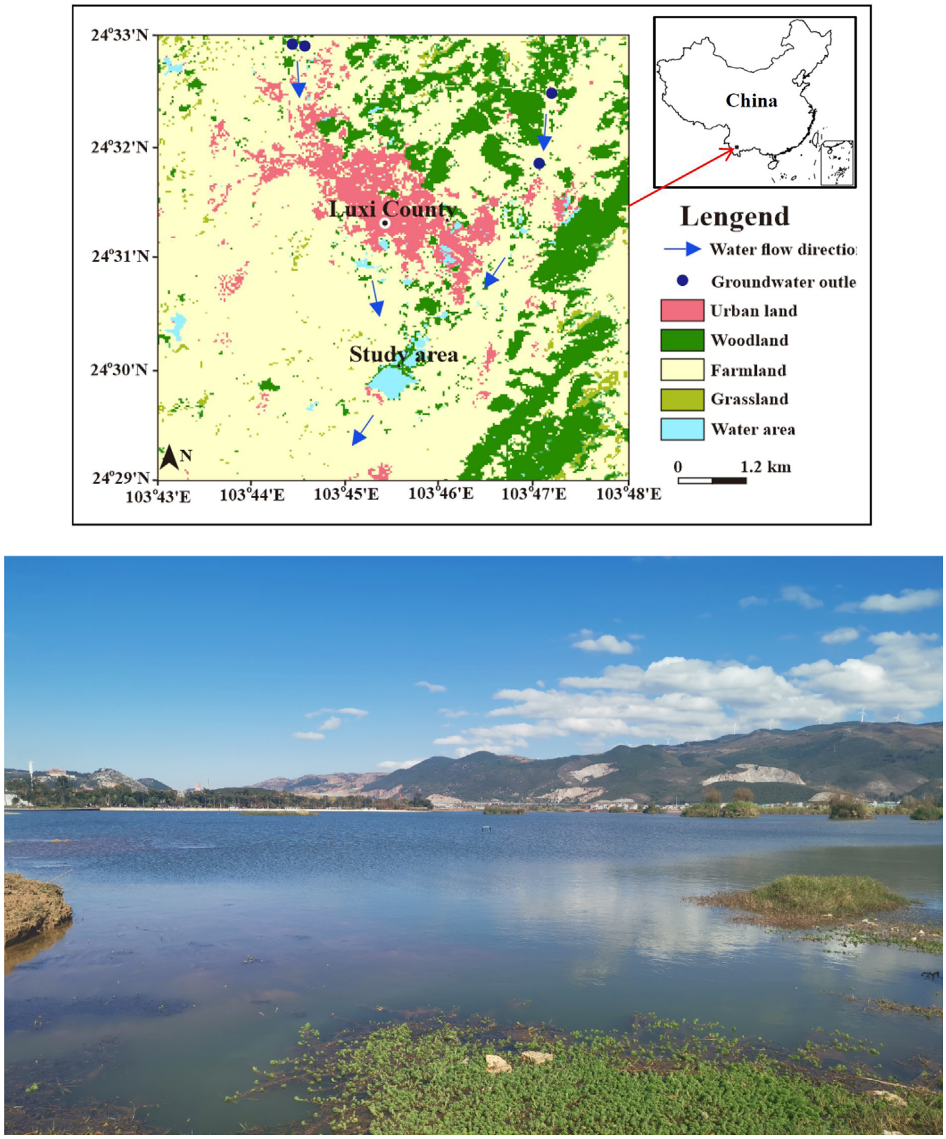

FIGURE 1 Map of the study area and photograph showing general overview of the Huangcaozhou Karst Wetland. Wiley acknowledges that the borders within the figure are subject to multiple territorial claims [Colour figure can be viewed at wileyonlinelibrary.com]

the south, Wenbi Mountain in the west, and Buyi Mountain in the east (103°44′20″–103°47′30″E and 24°29′30″–24°33′20″N). Groundwater outflow from Baxin Spring, Pijiazhai Spring, and Alu Cave Underground River is in the northeast and northwest, and then directly flows into the northern marsh of Huangcaozhou Wetland, where it can remain for a long time before it is discharged to enter the Zhongda River in the south. Overall, karst marshes and lakes occupy most of the Huangcaozhou Karst Wetland region. There is shallow groundwater in the area at a depth of less than 10 m. There are a few residual karst hills distributed throughout the wetland. The study area has a subtropical plateau monsoon climate and mild temperatures (Zhang et al., 2021). The mean annual precipitation is less than 1200 mm, while the water surface evaporation is high, reaching 1690.8–2154.1 mm (recorded since 1980). The average annual temperature is 15.2°C, while the monthly average temperatures range from 7.4°C to 20.5°C. The mean frost period is 92.3 days, and the main soil types in the study area are calcareous Cambisols (IUSS-WRB, 2015) on limestones.

2.2 | Data sources and treatment

2.2.1 | Remote sensing data

To better understand and intuitively show the LUCC and possible changes in the climate conditions, we considered it necessary to expand the study area to 100 km^2, which represents a fourtimes larger territory than the Huangcaozhou Karst Wetland, occupying the area between 103°43′03″–103°48′50″E and 24°28′32″–24°33′47″N. It is emphasized that to enhance our research accuracy, we only calculated LUCC in a five kilometres radius around the core area of the Huangcaozhou Karst Wetland. The remote sensing images were acquired at a resolution of 30 × 30 m from the LANDSAT-5 database of the US Geological Survey (landsat.usgs.gov). We selected cloud-free satellite images captured during the dry season from November to January (mostly December) in 1984, 1986, 1991, 1996, 2001, 2006, 2011, 2016, and 2019 (Figure 2). ArcGIS 10.2 and ERDAS 2011 (ESRI) were used to perform digitalization and image processing. Then,

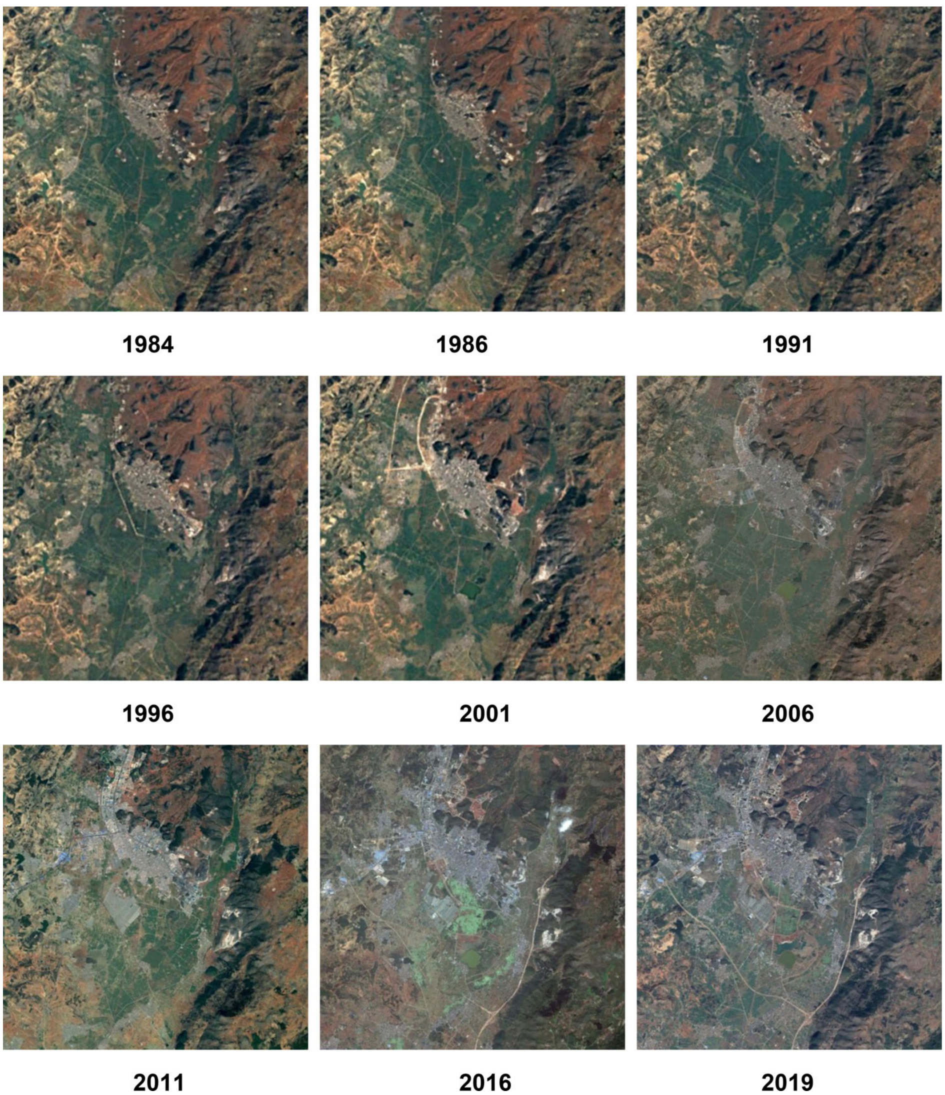

FIGURE 2 Remote sensing images of the study area were obtained every December from 1984 to 2019. [Colour figure can be viewed at wileyonlinelibrary.com]

we calibrated, matched, and enhanced the LANDSAT-5 images (TM) (Li et al., 2017).

We divided the LUCC into seven categories according to the Class-One Classification system under normal conditions (Zhang et al., 2011): swampland, urban land, woodland, grassland, rocky areas, farmlands, and wastelands. The historical images of each period were interpreted using a human–computer interactive interpretation pattern (Huang et al., 2015). Finally, based on the GPS field investigation, the visual interpretations captured in 2019 were confirmed and we discerned different land-use types in various periods to calculate the area.

2.2.2 | Demographic changes

Data relating to the population, gross domestic product (GDP) (a core economic indicator used to measure a region's social-economic status), and urban development data were obtained from the *Luxi County Statistical Yearbook*.

2.2.3 | Climate conditions

The climate data for the study area were obtained from the complete series at the Luxi County Station located near the Huangcaozhou Karst Wetland (103°45′30″E and 24°31′24″N), which was established in 1958 and thereafter monitored rainfall, humidity, and temperature. We collected and analyzed monthly data from 1958 to 2019.

2.3 | Statistical analysis

Data on climate and economic factors, and land use variations were analyzed to provide annual averages for each year. A Pearson correlation and principal component analysis (PCA) were carried out to first determine the correlations among the explanatory variables, and to reduce the number of studied factors involved in the interaction among climate, economy, and land-use variables. The raw datasets were standardized before conducting the analysis. All statistical analyses were conducted using the R version 4.00 software and the vegan package.

3 | RESULTS AND DISCUSSION

3.1 | Spatial and temporal variations of land use and land cover changes

The coverage area and distribution of the seven LUCC classes significantly changed during the study period (Figures 3 and 4). This is key to start to the design of a land management plan and the collecting of accurate data on the distribution, extent, and condition of wetlands at different scales (Rebelo et al., 2007). Most types of land uses and cover in the Huangcaozhou Karst Wetland steadily changed from 1984 to 2006. In our study, areas surrounding the swamplands (area of land that is always wet and mainly grows with aquatic plants) were mainly urban lands, grasslands, farmlands, rocky areas, and wastelands. The most drastic change was registered for 2006 to 2019 (excluding woodlands and grasslands, which only slightly changed). Swamplands were mainly converted into urban lands, rocky areas into woodlands and grasslands, and wastelands into farms and urban lands. This indicates that human activities and the prosperous economy close to wetland areas greatly changed from 2006 to 2019 in the Huangcaozhou Karst Wetland. However, as Zhao et al. (2004) revealed in Dongtan (China), the reduction of wetland areas could also be linked in future to a reduction of the final value of ecosystem services, which in this area declined by 62% from 316.77 to 120.40 million $US per year between 1990 and 2000.

Urban land was mainly distributed in the mid-north and northwestern areas of the study area and has expanded toward the south, occupying many of the swampland areas, increasing from 5.3% in 1984 to 22% in 2019. Overall, swampland has been also changed by agricultural activities and has become increasingly fragmented by farmlands, which expanded from 9% in 1984 to 19.6% in 2019. These marked increases received full attention in our study since some authors confirmed that urban expansion across swampland areas can affect species richness and species composition (Eppink et al., 2004), and promote landscape fragmentation, ecosystem degradation, and variations in wetland water levels (Liu et al., 2004). In addition, soil sealing and disruptions of the dynamic river floodplain and a decrease in floodplain area can have clear implications for flooding peak flows and runoff generation (Bhullar et al., 2013; Pascual-Aguilar et al., 2015).

Swampland was mainly distributed in the middle, while most northern areas were occupied by urban areas. Rocky areas use to coincide with the most degraded territories and wastelands are primarily distributed throughout the karstic mountains that surround the swampland. The percentages varied from 47% to 34.7% during the last 35 years. Woodlands and grasslands were mainly distributed at the edges of the foothills of the Luxi Fault basin and the small hills scattered among the Huangcaozhou Karst Wetland, varying in area from 4.2 and 3 km^2 in 1984 to 6.8 and 6.2 km^2 in 2019, with a increase of about 0.65% and 0.8%, respectively.

3.2 | Demographic and economic changes

In Figure 5, demographic and economic changes are depicted. The total population of Luxi County was 263,969 in 1978 and increased to 448,654 by 2019. Meanwhile, the gross domestic product (GDP, 10,000 Yuan: tty)(tty is ten thousand yuan ,1 yuan = 0.15 $US)) and urban land area in Luxi County increased with similar growth trends, while the wetland area followed an opposite trend during the whole study period (1984–2019). From the GDP data that was published by local government, we can see that the GDP of Luxi County was very

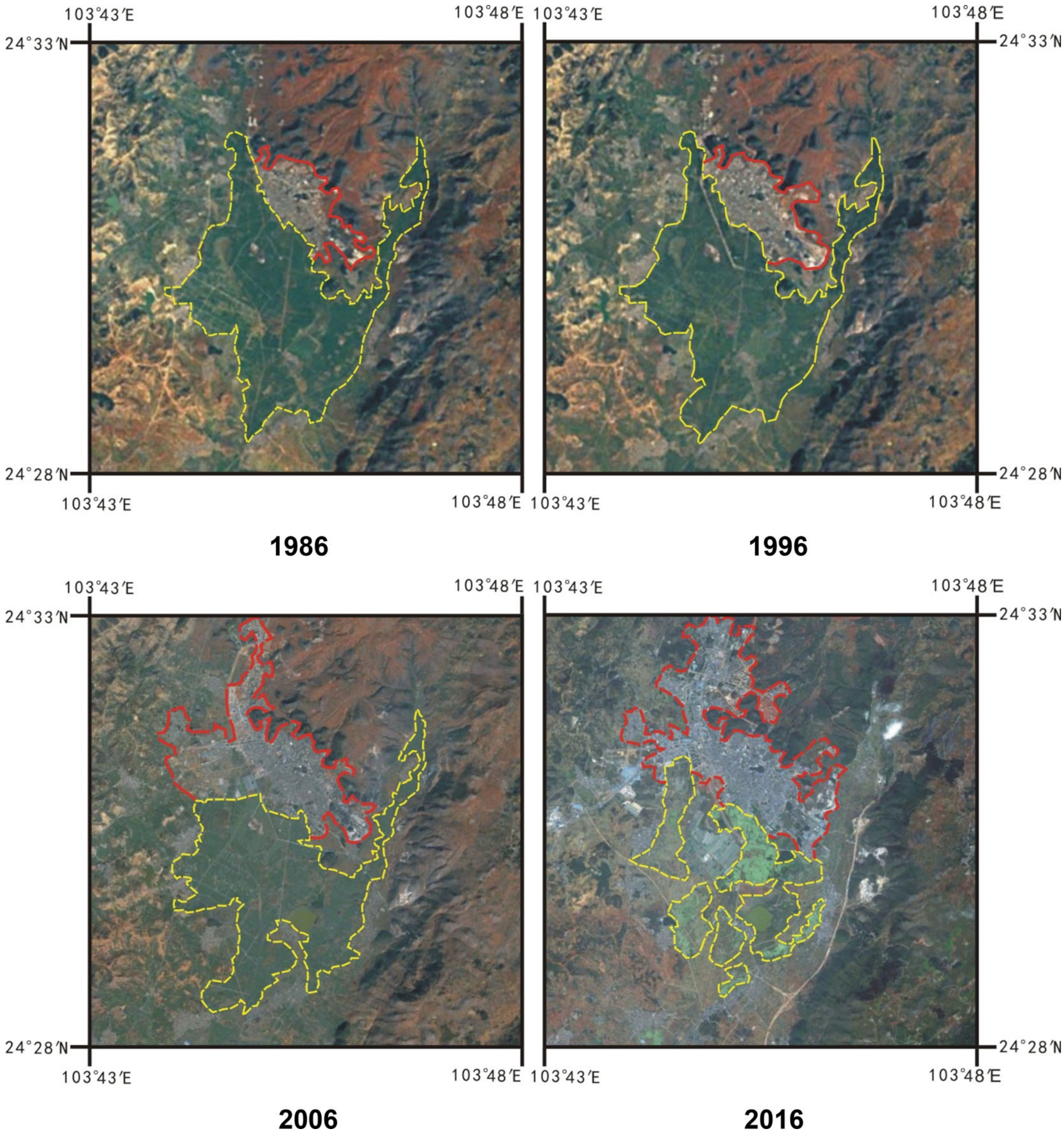

FIGURE 3 Changes in the two main types of land use in the Huangcaozhou study area (wetland—yellow colour; and town—red colour) in 1986, 1996, 2006, and 2016 [Colour figure can be viewed at wileyonlinelibrary.com]

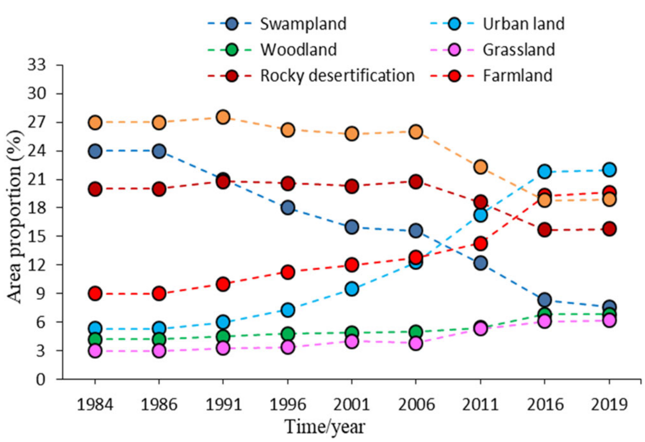

FIGURE 4 Land use and cover changes in the study area from 1984 to 2019 [Colour figure can be viewed at wileyonlinelibrary.com]

low from 1978 to 1991, gradually increased from 1992 to 2005, and then began to sharply increase from 2006 to 2019. In contrast, the area of the Luxi Karst Wetland slowly decreased from 1984 to 2006 and was sharply reduced thereafter. This indicates that the Luxi Karst Wetland is affected by population growth and economic and social development. Previous studies on the influences of socio-economic activities and population growth on wetlands also coincide with our results. For example, Song et al. (2020) found that in Northeast China, agricultural reclamation and socio-economic development have changed the land use of wetland ecosystems from 1980 to 2015. This coincides with our results too. Moreover, Sousa et al. (2020) tracking 130 years of coastal wetland reclamation in Ria Formosa (Portugal) showed that since the end of the 19th century nearly 2000 ha of wetlands were converted into human-influenced environments and has suffered a 20% natural area reduction

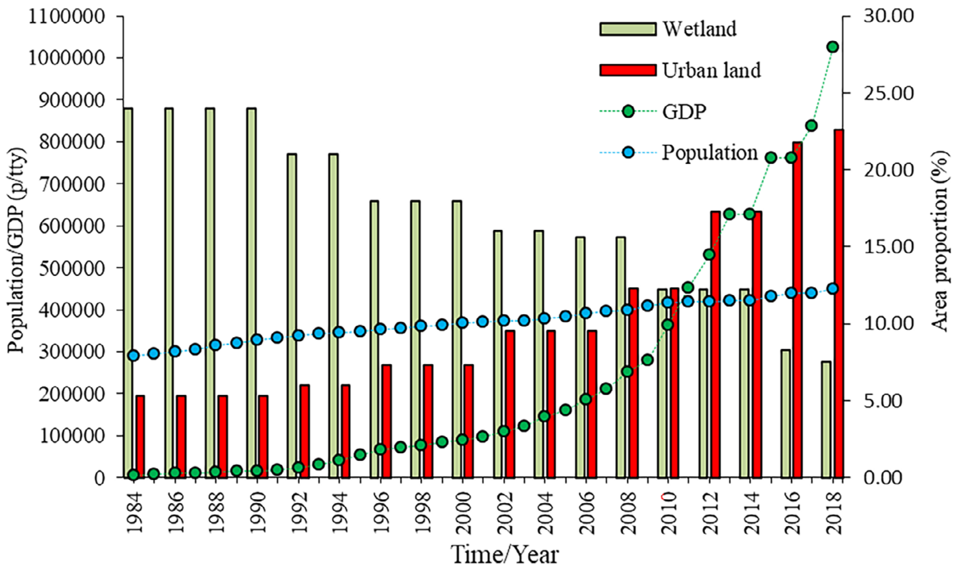

FIGURE 5 Changes in the population size, gross domestic product, wetland area, and urban land area from 1984 to 2019 [p is per person, tty is ten thousand yuan (1 yuan = 0.15 $US)] [Colour figure can be viewed at wileyonlinelibrary.com]

From the aforementioned results, it can be seen that societal and economic development activities in Luxi have influenced Huangcaozhou Karst Wetland significantly over the past 35 years. Similar research findings by Song et al. (2020) and Sousa et al. (2020) also held for other areas of China. As urban expansion and population increased, the Huangcaozhou Karst Wetland has faced increased pollution from industrial, agricultural, and domestic waste discharged from nearby Luxi County. Also, air quality could be impacting the Wetland as other authors found in territories linked to aquatic ecosystems (Cusack et al., 2020). Our data indicates that the water quality in the Huangcaozhou Karst Wetland could deteriorate due to human activities. Using the relevant criteria of the National Wetland Park Assessment Standard (LY/T1754-2008) and the five National Groundwater Environmental Quality Standards an investigation revealed that, after flowing through the urban area, groundwater quality decreased greatly and many indicators became substandard at the point of entry to Huangcaozhou Karst Wetland. For example: permanganate (IV, 0.02 times than the standard), ammonia nitrate (V, 0.54 times than the standard), TN (V, 5.81 times than the standard), and so forth (Zhang et al., 2021). This means that the water in the upstream entrance of Huangcaozhou Wetland water body is reaching the fourth water quality grade (poor). However, the water flowing out of the upstream underground water source was rated as of first water quality grade (Bo, 2018). Therefore, efforts must be devoted to understanding the importance of environmental protection, rationally controlling the scale of cities, towns, and villages. Improving the utilization of land for green spaces, increasing public awareness of the local inhabitants, and strengthening sewage treatment before discharging to the wetland system could be suitable options as demonstrated in some studies in the Cache River Wetlands in Southern Illinois or the Mississippi Alluvial Valley in the United States (Davenport et al., 2010; Jenkins et al., 2010). Based on the previous measures, the ecosystem's degradation of the Huangcaozhou Karst Wetland could be alleviated. Other research has shown that it is difficult for the ecological capacity to adapt to the current situation of elevated land-use changes; something similar occurred in the Lower Paraná River Delta, Argentina, and along the Western Corn Belt, including North Dakota, South Dakota, Nebraska, Minnesota, and Iowa (Sica et al., 2016; Wright & Wimberly, 2013).

3.3 | Climate variations from 1958 to 2019

In Table 1, the climate indicators calculated from the Luxi Karst Wetland climate station are summarized. The relative humidity did not significantly change, reaching mean values from 62.3% to 82.6% (with a range from 47% to 90%) with the lowest values in April (62.3 ± 6.1) and the highest one in August (84.0 ± 2.5) and July (82.6 ± 2.3). Two different periods of changes in humidity can be detected (Figure 6a): (i) from 1958 to 1988 with an annual average value of around 75.9% and a trend to increase; and (ii) from 1989 to 2019 with an annual average value of around 80.1% but a trend to decrease below 76% since 2016.

The air temperature varies greatly throughout the year, from 7.7°C in January to 20.6°C in June and July. The lowest values are reached in January (7.7°C) and secondarily in December and February (8.3°C and 9.7°C, respectively). On the other hand, the highest air temperatures are reached from May to August with a low difference between the values of these months (19.9°C–20.6°C). From 1958, when Luxi registered an annual average temperature of about 14.8°C, to 2019, the air temperature has increased with a gradient of 0.157°C $10yr^{-1}$, until reaching 15.3°C. Two trends can be observed (Figure 6b): (i) from 1958 to 1978, a period with a decreasing temperature trend (−0.3°C $10yr^{-1}$); and (ii) from 1979 to 2019, which is the longer period with an increasing temperature trend (0.3°C $10yr^{-1}$). This increasing trend is explained especially by an increase in winter temperatures; thus, since 2000, only eight Januaries registered values below the mean temperature of this month (7.72°C), whilst 12 of them were higher. These results are more evident in December, February, and March when only 5 months (in both) are below their mean temperatures since 2000, but especially in October, when only 3 months are below since 2000. Although summer months also show

TABLE 1 Descriptive statistics of the monthly relative humidity, temperature, and precipitation recorded from 1958 to 2019 at the Luxi County climate station

Variables	Humidity (%)		Temperature (°C)		Pp (mm)	
Months	Range	Mean	Range	Mean	Range	Mean
January	65–89	76.1 ± 4.9	4.1–12.3	7.7 ± 1.5	0.6–317.0	24.0 ± 41.8
February	47–90	70.3 ± 7.7	3.7–14.7	9.7 ± 2.1	0.0–85.8	20.5 ± 20.9
March	49–77	63.7 ± 6.6	9.9–16.2	13.8 ± 1.4	0.0–91.0	23.5 ± 20.6
April	48–73	62.3 ± 6.1	14.6–20.6	17.5 ± 1.3	0.3–92.9	35.0 ± 23.1
May	52–79	68.4 ± 6.0	17.7–22.7	19.9 ± 1.2	6.8–280.7	92.7 ± 57.0
June	69–84	78.3 ± 3.4	19.2–23.1	20.6 ± 0.8	24.4–371.6	169.8 ± 69.7
July	77–88	82.6 ± 2.3	19.7–21.8	20.6 ± 0.5	70.1–413.9	182.9 ± 72.9
August	77–89	84.0 ± 2.5	18.4–22.0	19.9 ± 0.6	17.5–365.2	161.8 ± 72.3
September	77–87	82.5 ± 2.5	16.5–20.6	18.4 ± 0.8	17.3–214.5	99.4 ± 45.5
Octorber	75–87	81.6 ± 2.4	13.5–17.6	15.7 ± 1.0	0.6–175.2	69.3 ± 41.6
November	68.5–86	80.0 ± 3.7	9.0–14.4	11.9 ± 1.2	0.3–103.9	34.8 ± 27.2
December	64–86	78.4 ± 4.7	4.5–11.0	8.3 ± 1.3	0.0–93.0	16.8 ± 21.9
Total	70.3–80.2	75.7 ± 2.0	14.3–17.5	15.3 ± 0.6	522.3–1367.3	930.5 ± 157.8

Note: range: minimum and maximum values.

a similar trend, the number of months below the mean temperature is higher and the standard deviation is lower. Annually, average data show the same fact: only 5 years were below the mean temperature since 2000 (2000, 2004, 2007, 2008, and 2011). It is worth emphasizing that J. G. Chen et al. (2009) studied variations of the Yunnan climatic zones in the last 50 years and found that the size of tropical and subtropical zones shows a decreasing trend during the 1960s–1970s, while has a significant increase after the 1970s, and especially marked change since the 1990s. Hence, the changing trend of air temperature in Huangcaozhou karst wetland is highly consistent with tropical and subtropical zone, which is characterized by a varied trend in recent 50 years. Our results indicate that global climate change has impacted the Huangcaozhou Karst Wetland greatly for a long time.

Finally, precipitation values registered reached the lowest values from October to April (69.3–34.0 mm) and the highest ones from June to September (169.8–99.4 mm), reaching the highest values in July (182.9 mm). Monthly data show a high standard deviation during winter, but high regularity in summer despite the summer months being the rainiest. The average rain decreased continuously from 1958, but very fluctuating. It has been identified as a trend to lose 3.3 mm yr^{-1}, which implies a total average loss of 202.2 mm concerning the mean values in 1958. There is no clear trend for the number of annual rainy days, which reaches an average of 140.6 rainy d yr^{-1}. Because of this, the mean torrentiality (average annual volume divided by the annual amount of rainy days) shows a slight trend to increase (0.72 mm d $10yr^{-1}$). These trends can be explained by analyzing monthly data: during the last 20 years, winter months tend to be dryer but very irregular, increasing the mean torrentiality despite the months usually more torrential (summer months).

Some authors highlighted that the fragmentation of wetlands due to urban sprawl is highly likely to reduce their microclimate regulation function, which is significant in summer (Zhang et al., 2016). As we noted a drastic loss of the wetlands areas occurred, and subsequently, the vegetation cover and water surface were also reduced. Plants have a stabilizing effect on temperature, whereas a waterbody has a stabilizing effect on humidity (Devaney et al., 2020; Mao et al., 2002; Zhang et al., 2016). Therefore, we can infer that the decrease in humidity, evaporation, and annual rainfall, and an increase in air temperature could be due to microclimate changes that are related to the drastic increase in human activities and the reduction of wetland areas. To achieve an effective understanding of future impacts and contribute to better design of urban development, climate projections should follow the points we raised above and could then be a useful tool (Almazroui et al., 2020; Nicholls, 2004; Zhu & Zeng, 2018).

3.4 | Potential correlation among wetlands, urban areas, socioeconomic changes, and climate changes

The correlation and PCA were conducted using all the above mentioned variables (Table 2 and Table 3). We found that besides urban land, the only population showed a negative significant correlation (0.32) with wetlands ($p < 0.05$). Whereas urban lands showed significant positive correlations with GDP (0.517) and population (0.392). Figure 7 shows a plot of the eigenvector in the plane of the first two PCs together with their PC scores, PC1 explaining 45.4% of the total variance and PC2 28.8%. The decrease in wetland areas is mainly caused by human activities; however, human changes and climate affect the process of urbanization together.

This analysis has provided convincing evidence of climate change accompanied by increasing variability in the Luxi Karst Wetland and the surrounding area. Global warming is occurring across the world

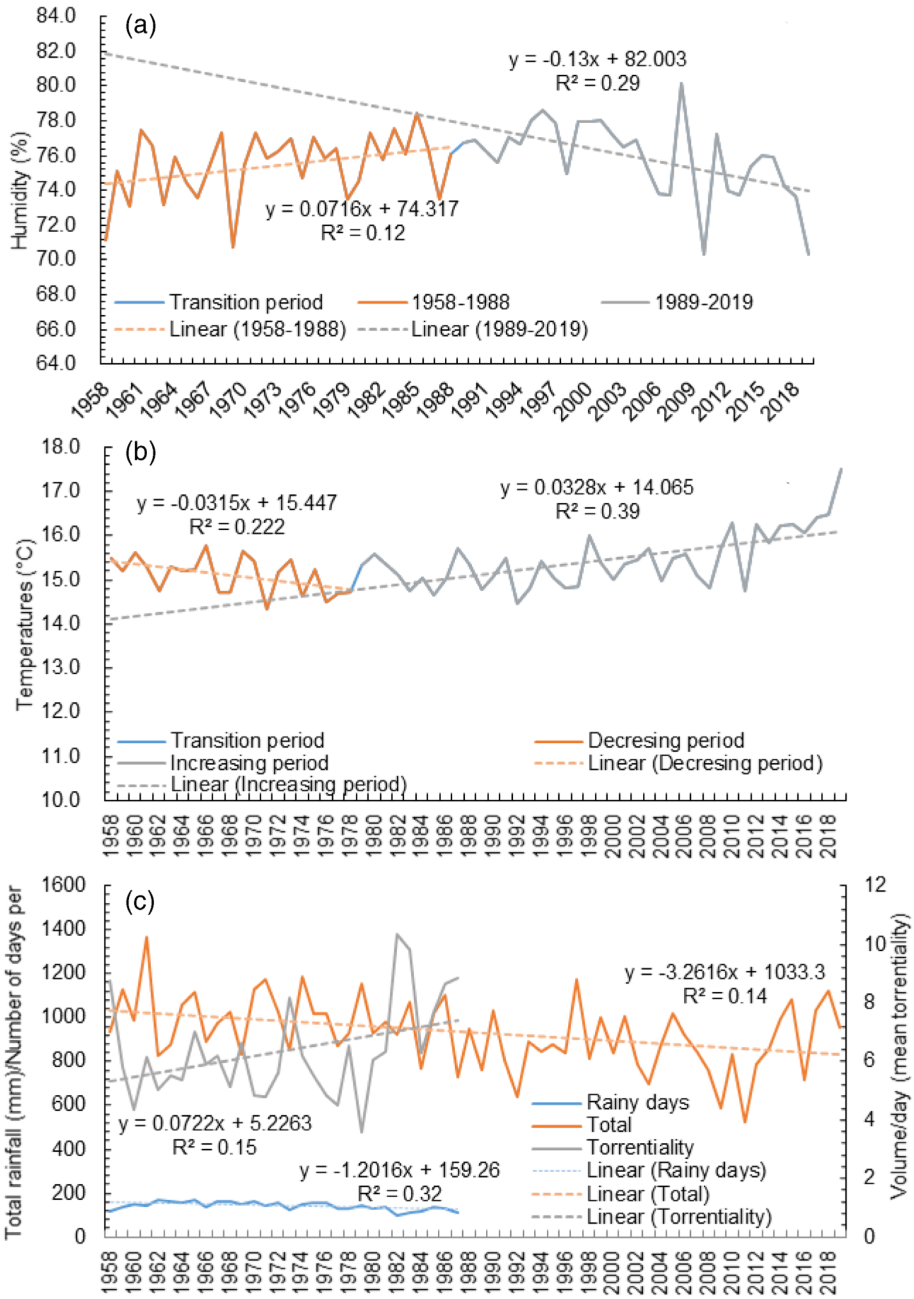

FIGURE 6 Linear graphs represent the main annual results of humidity, air temperature, and precipitation. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Correlation matrix of the potential connection among land uses, climate, and economics

	Precipitation	Temperature	Humidity	GDP	Population	Wetland
Temperature	−0.04					
Humidity	0.15	−0.61				
GDP	−0.14	0.69*	−0.33*			
Population	−0.27	0.61*	−0.21	0.1*		
Wetland	0.15	−0.26	0.14	−0.24	−0.33*	
Urban Land	−0.06	0.25	−0.13	0.52*	0.39*	0.47*

Note: * indicates the significant correlation at the significance level 0.05

(IPCC, 2014; Liu et al., 2020; Qu, 2019; Root et al., 2003) but it seems that changes at the local scale can be also identified. According to Serpa et al. (2015), precipitation and evaporation play a key role to determine the region's ecological environmental conditions. Our research indicates that from 1984 to 2019, precipitation gradually declined, while evaporation slightly increased. As a result, the

TABLE 3 Principal component analysis of the potential connection among land uses, climate, and economics

Principal component	PC 1	PC 2
Eigenvalues	0.29	0.18
Variance (%)	45.4	28.8
Cumulative (%)	45.5	78.2
Precipitation	0.12	−0.02
Temperature	−0.42	−0.25
Humidity	0.16	0.09
GDP	−0.38	−0.29
Population	−0.52	−0.30
Wetland	0.62	−0.63
Urban land	−0.15	−0.59

Note: PC 1 and PC 2 indicate the first principle component and second principal component, respectively.

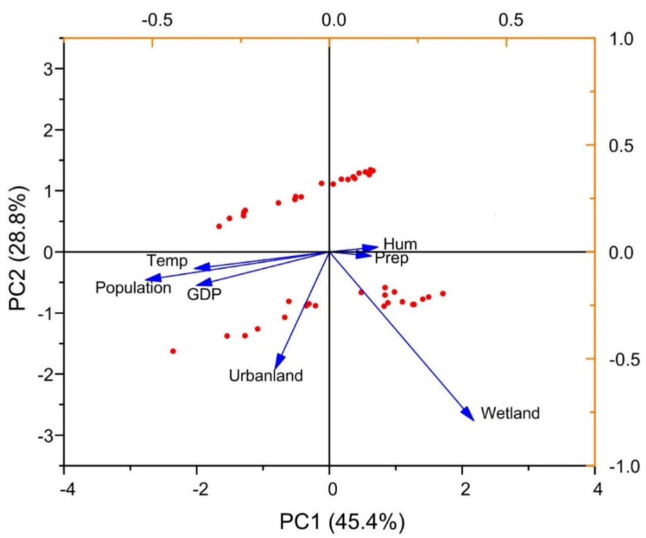

FIGURE 7 Eigenvectors from the principal component analysis (PCA) of the first two components (PC1 and PC2) [Colour figure can be viewed at wileyonlinelibrary.com]

Huangcaozhou Karst Wetland is experiencing more prolonged drought periods and water shortages every year, which could be dangerous for soils, plants, waterbodies, and human-related activities (Kracauer Hartig et al., 1997). On a larger scale, we observed that the Yunnan Province climatic zones have changed markedly in the last 50 years. The north tropical zone experienced an increase of 90.2%, and the size of the tropical and subtropical zones shows a decreasing trend during the 1960s–1970s, while has a significant increase after the 1970s, and especially marked change has happened since the 1990s (Chen et al., 2009). Additionally, a warm and dry climate has become more and more prevalent in Yunnan Province in the last 50 years (Li et al., 2010). The aforementioned analyses show that different scales of climate change have affected the Huangcaozhou Karst Wetland and have varied the ecology and environment of the Wetland in recent decades.

We can also hypothesise that there has been the appearance of an urban heat island formation (Duy et al., 2017), which influences the surrounding eco-environment, which also was observed in Mediterranean cities (Krüger et al., 2018; Senciales-González et al., 2020). According to the correlation analysis, the urban land area, air temperature, and Huangcaozhou Karst Wetland changed from 1984 to 2019. The correlation coefficients between air temperature at Luxi County Weather Station and urban Luxi land area/wetland area in this study were 0.68 correlation coefficient and − 0.67, respectively, which were both significant at the 0.01 level (two tailed). This illustrates that the change in land use and urban development affected the regional air temperature and significantly changed the structure and function of the Huangcaozhou Karst Wetland over the last 35 years. Our results also coincide with Zhang et al. (2016), who demonstrated in Xixi Wetland (Hangzhou, China) that urbanization affected the local microclimate but also decreased human comfort, losing the wetland's potential as a microclimate regulator. Also, in colder environments such as the UK and Ireland, water availability in wetlands may increase in winter and register a small increase during summer, but at the local-scale, significant seasonal stresses have been registered due to microclimate changes and the associated lowering of water levels (Dawson et al., 2003). Therefore, we suggest that it is necessary to develop efficient land management plans to prevent irreparable negative impacts during the medium- and long-term periods (Candela et al., 2009; Johnson et al., 2005; Milzow et al., 2010).

4 | CONCLUSIONS

In this study of a karst wetland ecosystem in China, it was found that climate changes, LUCC, and socio-economic development have significantly affected the wetland mainly from 1984. This dynamic is still increasing and coinciding with other areas around the World, characterized by a decrease in humidity and annual rainfall and an increase in torrentiality and air temperatures. Our correlation and PCA revealed that the decrease in wetland areas is mainly caused by climate change, human activities, and especially, due to urban sprawl. Both long-term climate change in the study area and Yunan Province showed that the Huangcaozhou Karst Wetland has been affected by an increasingly warm and dry climate in recent decades. This dynamic is still increasing and coinciding with other areas around the World, caused by a decrease in humidity and annual rainfall and an increase in torrentiality and air temperatures.

Human activities are negatively impacting the study Wetland, including the occupation of the area, leaving pollutants in the water and destroying the biodiversity, and so forth. From 1984 to 2019, urban land and farmland in the study area increased from 5.3% to 22% and 9% to 19.6%, respectively. While wetland decreased from 24% to 7.6% during the last 35 years. Overall, wetland has also been changed by agricultural activities and has increasingly become fragmented by farmlands, and some wetlands have been occupied by urban areas.

Moreover, it was observed a coincidence between changes in land uses and economic growth (population and GDP) with microclimate change, which allows inferring a cause-effect relationship. As a result, the environmental health status of this karst wetland is being affected in size (a drastic reduction of total area) and biodiversity due to a loss of vegetation, water, and fertile soils. Therefore, we claim that it is necessary to implement urgent control measures to manage the urban expansion and the exploitation of the natural resources coming from this karst wetland area.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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