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Guizhou Karst Carbon Sink and Sustainability—An Overview

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Abstract: Global warming and climate change are becoming the most popular topics among scientists. In this century, the research focusing on the process and mechanism of the carbon cycle, especially the research of reducing the concentration of atmospheric CO_2 (carbon sink and carbon sequestration technology), are the core issues of global change. The karst carbon sink was neglected due to the consideration that it was a geological process with a long timescale. Recently, studies have proven that carbonate rock weathering is a rapid and sensitive process, and the Fifth Climate Change Assessment Report of the United Nations Intergovernmental Panel on Climate Change confirmed this. Guizhou, as the center of karst in China, has the unique advantages of the karst carbon sink, and is the core area of the karst carbon sink. On the basis of summarizing the development and evolution trend of karst carbon sinks, through data collection and field research, the Carbon Neutralization Research Group of Guizhou Institute of Technology has conducted an exploratory investigation on karst carbon sinks in Guizhou Province, and basically identified the mechanism, influencing factors and measurement methods of karst carbon sinks in Guizhou karst areas. The results show that the potential of the karst carbon sink in Guizhou is huge. Vegetation restoration, soil improvement, irrigation with external water and the cultivation of aquatic plants are important ways to increase the karst carbon sink by artificial intervention. A series of achievements have been made in the theory, technology and platform construction of the karst carbon cycle geological survey and carbon sink effect evaluation. It is worth noting that there are still great challenges in karst carbon sink measurement and verification, and in the demonstration of artificial intervention in carbon sequestration and sink enhancement, which need to be continuously tackled and improved in the "14th Five-Year Plan" period and beyond, so as to meet the needs of the carbon neutralization target of geological carbon sink services.

Keywords: karst carbon sink; sustainability; Guizhou; suggestion

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1. Introduction

At the general debate of the 75th Session of the United Nations General Assembly on 22 September 2020, President XI Jinping announced that China would scale up its Nationally Determined Contributions by adopting more vigorous policies and measures, strive to peak CO_2 emissions before 2030, and achieve carbon neutrality before 2060. China is taking pragmatic actions to meet these goals. China's carbon peaking and carbon neutralization strategy is a major demand for the Global Climate Governance, which seeks to protect the Earth and foster a shared future for the global community. China's efforts also address the country's internal demands for high-quality development, an ecologically centered nation, and the comprehensive management of the ecological environment. In 2020, China's carbon dioxide emissions were 9.9 billion tons, accounting for 30.66% of global carbon dioxide emissions. Even though the growth rate of China's CO_2 emissions has slowed down in recent years, achieving the carbon peak target by 2030 is a daunting challenge, especially in the context of rapid industrialization and urbanization. Although China has proposed to control the total amount and intensity of its energy consumption, it the optimization of the energy structure and the reduction of coal consumption is a gradual process. As shown in Figure 1, a variety of policy instruments must be adopted to reduce CO_2 emissions or absorb CO_2. In recent years, the carbon trading market and carbon tax have attracted wide attention. The carbon trading market means that the government departments set the total amount of carbon emissions and allocate the carbon emission quota to each enterprise participating in the carbon market. If the enterprise's CO_2 emissions are lower than the quota, the enterprise sells the remaining quota to obtain income. If the enterprise's CO_2 emissions exceed the quota, it must purchase the quota from other enterprises. Now, however, the market has not been standardized to reflect the construction. It is important to note that in addition to reducing emissions, we can also increase carbon sinks. The carbon neutralization strategy involves the in-depth transformation of social and economic development, with a view to achieve low- or even zero-carbon emissions and increase foreign exchange based on technological change. This is a major opportunity for sustainable development. Carbonate rock is the material basis of karst development. This rock has recorded the environmental changes to the planet, and it is the largest carbon pool on Earth. Carbonate rock is important in the evolution of the Earth's atmosphere and life. The karst area of Earth measures 22 million km^2, accounting for 15% of the land area. In China, a karst area of 3.44 million km^2 accounts for 15.6% of the planet's total karst area. The karst carbon cycle is active due to interactions between water, CO_2, carbonate weathering, and the biological pump. The karst carbon sink constitutes up to 0.824 Pg C/a, accounting for 29.4% of the terrestrial CO_2 sink (Figure 2) [1–6].

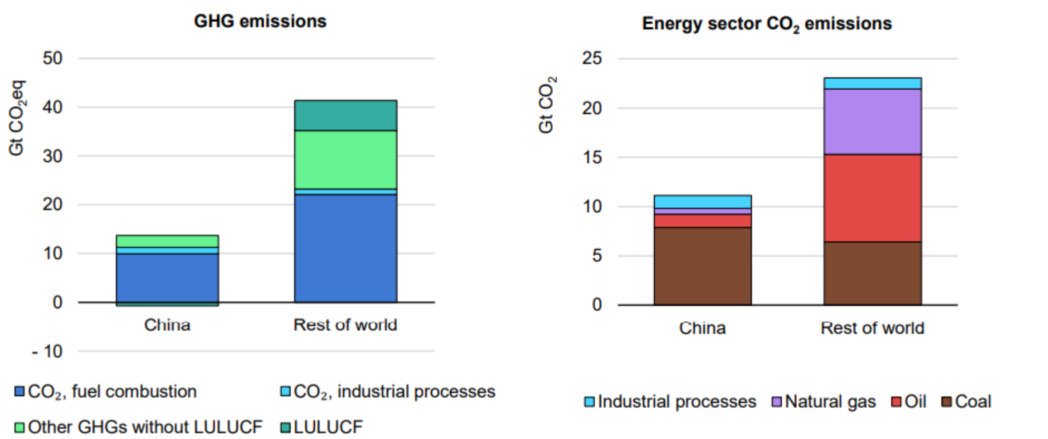

Figure 1. Greenhouse gas emissions in China and the rest of the world, 2020. Note: GHG = greenhouse gases; LULUCF = land use, land-use change and forestry. Sources: IEA data for CO_2 emissions from fuel combustion and industrial processes [7].

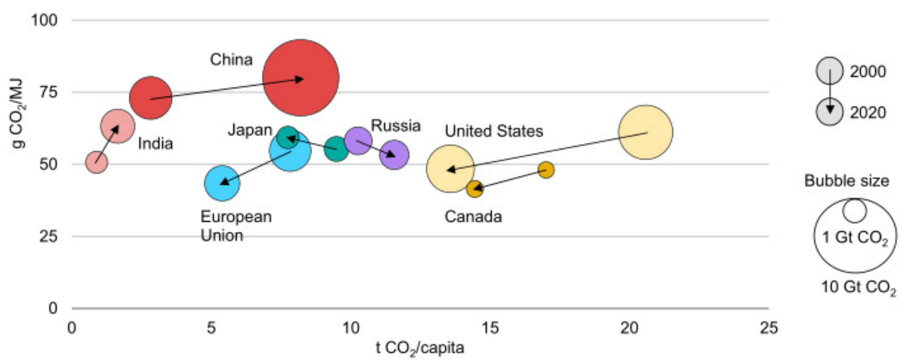

Figure 2. CO_2 emission intensity of the primary energy demand relative to CO_2 emissions per capita by country/region, 2000 and 2020 (IEA 2021) [7].

The karst carbon sink is one of the four technological pathways identified by the United Nations Intergovernmental Panel on Climate Change (IPCC) to remove atmospheric carbon dioxide (CO_2), which is juxtaposed with the terrestrial ecological process carbon sink, the ocean carbon sink, and artificial direct capture, and which has a great carbon sink capacity and contribution. However, limited by the incomplete data of the karst carbon sink monitoring platform, the uncertainty of the calculation method and the inconsistency of the evaluation system, the calculation of the karst carbon sink flux in karst areas has not been widely applied, so it is urgent to build a systematic karst basin carbon sink monitoring system and carry out pilot demonstration studies to promote the standardization of the application process. Guizhou Province, as an important karst area in China, has the natural advantages necessary to carry out the study of karst carbon sinks. Therefore, it is of great significance to build a karst monitoring platform; to study and formulate technical specifications for the monitoring, measurement and evaluation of karst carbon sinks; and to improve the technical methods for increasing the ability of artificial carbon sinks, so as to guide the economic utilization of Guizhou karst carbon sinks and promote China to achieve the goal of "double carbon" [7,8].

In this work, we use the existing research basis to carry out the research and data collection of karst carbon sinks in the Guizhou karst area. This paper analyzes the characteristics of karst carbon sinks in the Guizhou karst area; determines the contribution rate of the karst ecosystem to achieve the goal of carbon neutralization; studies the economic value of local karst carbon sinks, the key technologies of carbon sequestration, and value-added efficiency; and scientifically calculates the carbon sink flux in the Guizhou karst area. At the same time, closely following the requirements of the national "double carbon" strategy, this paper puts forward the general idea, strategic objectives and realization path of "carbon peak, carbon neutralization" in the field of natural resources, in line with the development trend of Guizhou and the characteristics of the karst ecosystem, so as to provide scientific and technological support for Guizhou to formulate carbon sequestration management strategies for the karst ecosystem.

2. Development Process of Karst Carbon Sink Research

Karstification (mainly the chemical weathering of carbonate rocks) can absorb a large amount of CO_2 in the atmosphere/soil. With the continuous process of karstification, CO_2 is continuously absorbed and enters the hydrosphere in the form of dissolved inorganic carbon (DIC), forming a karst carbon sink. The karst area accounts for a third of the total land area in China, and the karst carbon sink has great potential. The response of karst to climate change and human activities has been one of the hot issues of global climate change research. Since the 1990s, the study of karst carbon sinks has undergone three stages [9–13].

2.1. Karstification and the Carbon Cycle: The Embryonic Stage

The early studies of global climate change mainly focused on the interaction between global climate change and the atmosphere, pedosphere, hydrosphere and biosphere, but did not pay enough attention to the carbon cycle driven by various geological processes within the lithosphere. In 1995, the 379-item "Karstification and Carbon Cycle" of the International Geological Correlation Program (IGCP), which was proposed and organized by Chinese scientists, began to carry out research from 1995 to 1999, emphasizing the joint influence of climate, hydrology, geology, and other factors on karstification, and combining it with the carbon cycle process. Finally, this revealed the differences in the behavior of different types of karst dynamic systems and the effects of rainfall, vegetation and the soil environment, and then entered the stage of karst carbon sink research.

2.2. Whether Karst Carbon Sinks Form Stable Carbon Sinks: Doubts and Debates

After the concept of the karst carbon sink was put forward, it caused widespread controversy in the academic community. In particular, it is widely believed in foreign academic circles that the carbon sink formed by the weathering of silicate rocks (CO_2 + $CaSiO_3 \rightarrow CaCO_3 + SiO_2$) controls long-term geological climate change. The weathering of carbonate rocks ($CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$) does not have this function. As all of the CO_2 consumed in the process of carbonate weathering is returned to the atmosphere through the relatively rapid deposition of calcium carbonate in the ocean, the traditional carbon cycle model regards the geological process as a purely inorganic process, and considers that the chemical weathering of carbonate does not produce a net carbon sink on the geological timescale (Figure 3).

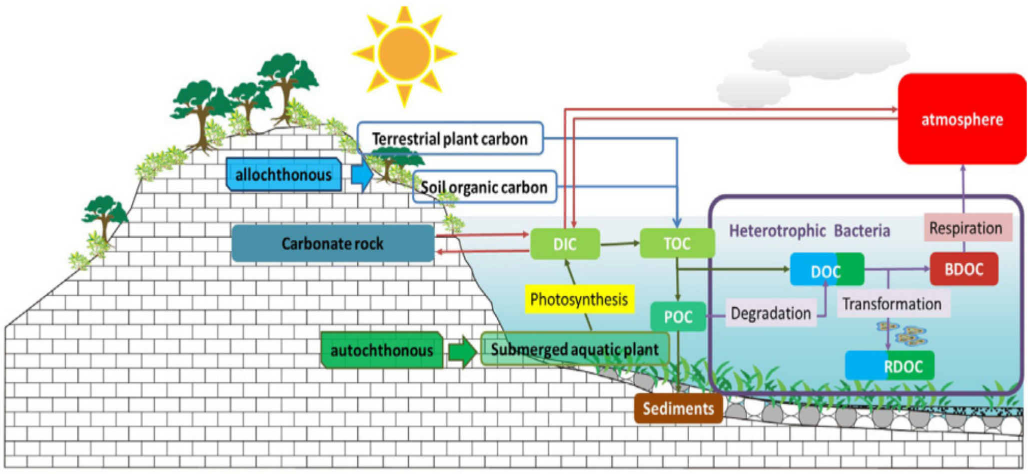

Figure 3. Schematic diagram of the biological carbon pump in karst surface aquatic ecosystems [6].

2.3. *Voice of China: Responding to International Academic Doubts*

Beginning in 2016, based on the project of "Comprehensive Environmental Geological Survey of Carbon Cycle in Karst Watersheds of the Yangtze River, Pearl River and Yellow River" and historical data, Chinese scientists established a conceptual model of the karst carbon cycle at the basin scale, and clarified the process of carbon migration and transformation in karst watersheds (inorganic carbon, organic carbon, and inert organic carbon). The results of long-term dynamic monitoring also showed that 70% to 80% of the total carbon dioxide consumed from the atmosphere and soil by carbonate weathering in an intact watershed is stable. The results of this series of investigations strongly respond to the international doubts about the stability of carbon sinks in the chemical weathering of carbonate rocks, and then draw the conclusion that the karst carbon cycle can produce carbon sinks on a short timescale. This provides a basis for the calculation of carbon sink flux and model research (Figure 4).

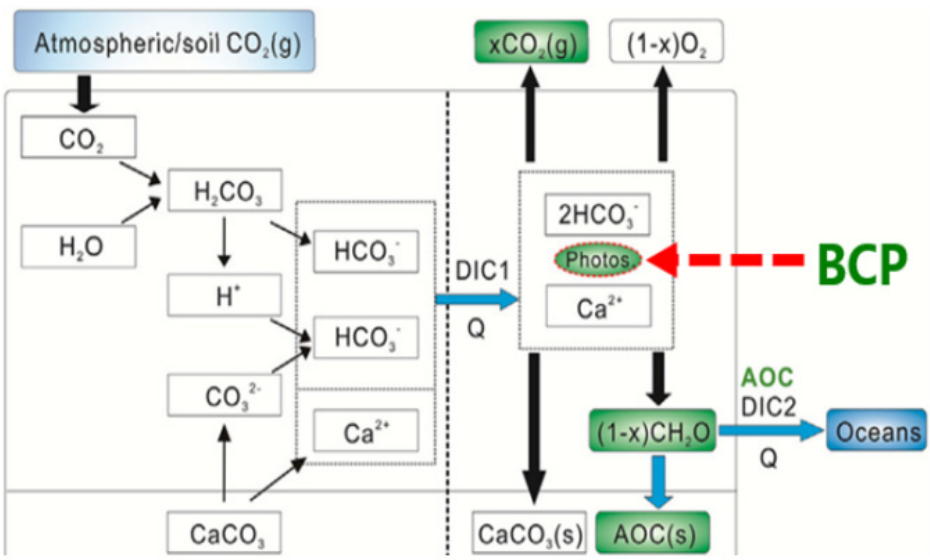

Figure 4. A carbon sequestration model by carbonate mineral weathering coupled with aquatic photosynthesis (Liu [11]).

3. Research Status of the Karst Carbon Sink

In recent years, many promising advancements have been made in the basic and interdisciplinary research related to the carbon cycle of geological processes. It was found that the dissolution rate of CO_2 in water could be increased by one order of magnitude of the catalysis of microorganisms, especially carbonic acid glycosidase. The algae in the water body catalyze the deposition of carbonate through photosynthesis and polypeptide. A series of discoveries has solved two controversial issues in the global carbon cycle of karst geological processes: the rate and stability of karst carbon sinks, and the carbon cycle model of karst carbon sinks (Figure 5) [14–18].

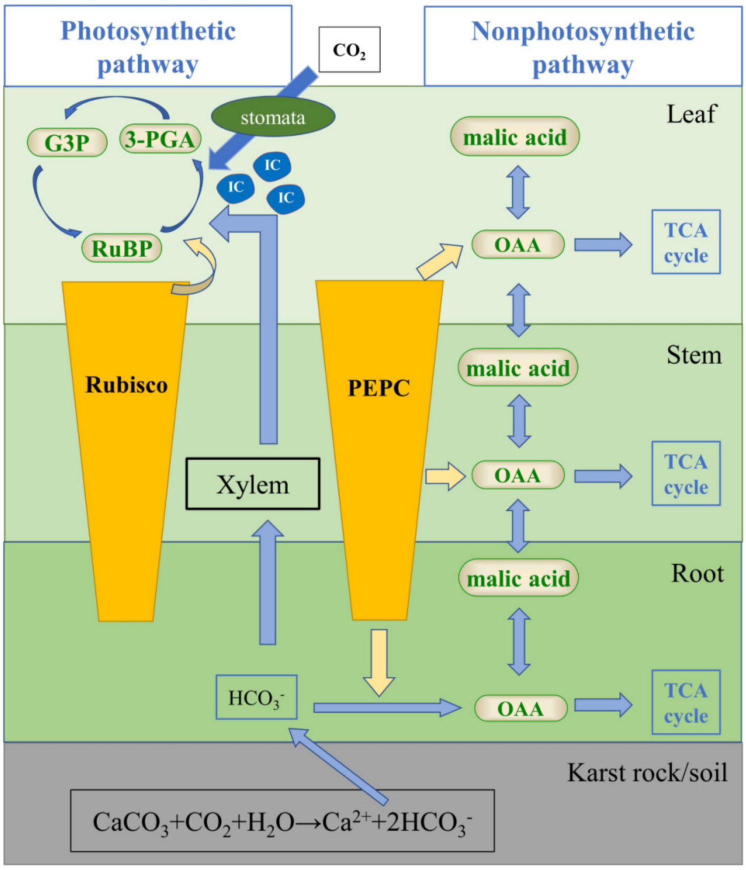

Figure 5. Processes and pathways of the plant use of bicarbonate (metabolic water) [14].

3.1. A Model of an Aquatic, Photosynthetic, Stable Carbon Sink

On the basis of summarizing and sorting the relevant theories, Liu Zaihua—a researcher at the Institute of Geochemistry, Chinese Academy of Sciences—created the theory of carbonate weathering carbon sink (CCW) coupled with aquatic photosynthesis, pointing out that carbonate rocks in karst areas almost control the concentration of dissolved inorganic carbon (DIC) in all river basins, and that the concentration of dissolved inorganic carbon (DIC) in karst areas is higher than that in other areas. These elevated DIC concentrations may also enhance the photosynthetic uptake of DIC by aquatic organisms. If the organic carbon (OC) produced is buried in the sediment, it can act like a carbon pump for marine organisms, and it will no longer be a short-term carbon cycle, which is a process that may be underestimated by a factor of three.

However, there are many defects in the previous methods used to identify the source of OC. With the deepening of the research, it is necessary to analyze the source, composition, spatial, and temporal variation characteristics and influencing factors. The research on the source of OC focuses only on qualitative research, and with the deepening of the research, it needs to be quantitatively analyzed.

3.2. Human Intervention Can Increase Karst Carbon Sink Flux and Stability

According to the process of the karst carbon cycle in the basin, the following four technical methods can be used to improve the karst carbon sink flux and its stability.

3.2.1. Afforestation

In view of the fact that CO_2 + H_2O is the driving force of both plant photosynthesis and carbonate weathering and dissolution, afforestation can not only increase the carbon sink flux of surface organisms but also increase the carbon sink flux of underground karst. From shrub land to secondary forest land and then to virgin forest land, the carbon sink flux produced by karstification can increase by two-to-eight times.

3.2.2. Soil Improvement

The carbon of the karst carbon sink is mainly derived from soil CO_2, and the concentration of soil CO_2 is one-to-two orders of magnitude higher than that of the atmosphere. The effect of the karst carbon sink can be strengthened by improving the soil and increasing the soil CO_2 cycle.

3.2.3. Pay Attention to the Role of Exogenous Water

The external water from the silicate rock area has a strong erosive force. The monitoring results of typical basins show that, in the Maocun underground river basin in Guilin, 32% of the exogenous water from the sandstone recharge area in the upper reaches will increase 34% of the carbon sink flux when it enters the karst area in the lower reaches. The monitoring results of the Lijiang River Basin show that when the distribution area of carbonate rocks in a small watershed is approximately 50%, exogenous water has the greatest impact on the karst carbon sink.

3.2.4. Enhance the Photosynthesis of Aquatic Plants

The high concentration of HCO_3^- in water is very unstable. When the hydrological conditions change, it can easily convert into CO_2 and escape into the atmosphere. If the photosynthesis of aquatic plants consumes part of the HCO_3^-, reduces its concentration, and converts inorganic carbon into organic carbon, the stability of the carbon migration in karst water can be greatly improved.

4. Survey Methods and Data Analysis

In this work, we used the methods of documentation, field measurement, discussion with the government, and a questionnaire survey. This paper is guided by the theory of resource endowment, the theory of "two mountains", the theory of capability, the theory of externality, and the theory of "two commons". Focusing on the core issue of the karst carbon sink in the Guizhou karst area, combined with the actual monitoring data and experience over the years, combining normative research with empirical research, and combining qualitative research with quantitative research, the work was carried out. Some of the scientific investigation methods were as follows.

4.1. Automatic Monitoring of Hydrology and Hydrochemistry with a High Time Resolution

A CTDP300 multi-parameter water quality automatic recorder produced by GreenSpan Company in Australia was installed at the outlet of each karst underground river system in May 2020 (nine instruments in total), and the monitoring time interval was set at 15 min. The rainfall, relative water level, pH value, water temperature (t) and electrical conductivity (EC) were automatically recorded, and the measurement accuracy was 0.5 mm, 0.01 m, 0.01 pH units, 0.01 °C and 0.01 μS/cm (the conductivity was automatically compensated by the temperature, to a value of 25 °C). The discharge (Q) was calculated from the relative water level value automatically recorded by the CTDP300 through the corresponding discharge–water level relationship.

4.2. Water Sample Collection and Testing

Water samples were collected monthly. For the indoor analysis items of the water sample, the objects mainly comprise K^+, Na^+, Mg^{2+} and Cl^- And $SO_4{}^{2-}$ ion concentrations, as measured using the Institute of Geochemistry, Chinese Academy of Sciences National Institute of Environmental Geochemistry Key laboratory test. The anion was determined by an ICS-90 ion chromatograph produced by the Dionex Company in the United States, and the cation was determined by an ICS-90 ion chromatograph produced by the Dionex Company in the United States. The VBTA MPX inductively coupled plasma optical emission spectrometer was produced by the Varian Company. Because the pH value, water temperature, electrical conductivity, [Ca^{2+}], and [$HCO_3{}^-$] change rapidly with the environment, these parameters must be in the field determination. The specific method comprises the following steps: downloading high-time-resolution data monitored by a CTDP300 multi-parameter water quality automatic recorder, the titration of $HCO_3{}^-$ and Ca^{2+} in karst water by a test box in field concentrations with an accuracy of 0.1 mmol/L (or 6.1 mg/L and 4 mg/L), and the selection of the physical and chemical indexes such as the pH value, T and EC corresponding to the collection time of water samples from the data recorded by CTDP300.

4.3. Calculation of the CO_2 Partial Pressure and Calcite Saturation Index in Water

The partial pressure of CO_2 and the saturation index of calcite in karst water mainly depend on the concentrations of Ca^{2+}, Mg^{2+}, and $HCO_3{}^-$, the pH value and the water temperature. In practical calculations, the average value of low-concentration ions such as K^+, Na^+, Mg^{2+} and Cl^-, etc., was often taken as the calculation parameter. The pH value and water temperature can be directly measured by the automatic recorder, while the concentrations of Ca^{2+}, Mg^{2+} and $HCO_3{}^-$ must be estimated by indirect methods. Ca^{2+} and Mg^{2+} as the main cations in karst water, and $HCO_3{}^-$ as the major anion were the main factors determining the conductivity element, which can be based on conductivity and the $Ca^{2+}/Mg^{2+}/HCO_3{}^-$ plasma concentration. We then calculated the concentration of the relevant ions based on the linear correlation between them. As a result, the CTDP300 multi-parameter water quality automatic recorder was used to monitor the water quality. We measured the water temperature and pH, combined with K^+, Na^+, Cl^-, and $SO_4{}^{2-}$ plasma (Table 1), as well as the continuous concentration obtained by the autorecorder. The conductivity data were calculated using a linear correlation (Table 2) of the Ca^{2+}, Mg^{2+}, $HCO_3{}^-$ plasma concentration; continuous water can be obtained from the medium CO_2 partial pressure (pCO_2) and calcite saturation index (SIC).

Table 1. 3-year mean values and CVs of the hydrochemical data measured in situ at the Guizhou catchments (1 May 2020 through 1 May 2022).

Index	Units	Mean Value of Eastern Guizhou	*n* = 44 C.v.	Mean Value of Western Guizhou	*n* = 44 C.v.	Mean Value of Northern Guizhou	*n* = 45 C.v.	Mean Value of Southern Guizhou	*n* = 45 C.v.
T	°C	18.89	0.04	18.10	0.03	18.64	0.08	18.24	0.37
Ph	—	7.43	0.03	7.71	0.02	8.11	0.02	8.39	0.07
K^+	mg/L	0.46	0.38	0.32	0.39	2.71	0.33	3.31	0.39
Na^+	mg/L	0.79	0.28	0.45	0.66	6.74	0.75	3.56	0.62
Ca^{2+}	mg/L	68.74	0.17	73.55	0.08	96.66	0.18	81.02	0.24
Mg^{2+}	mg/L	2.42	0.17	16.79	0.27	20.58	0.32	17.59	0.32
Cl^-	mg/L	1.77	0.45	1.11	0.37	10.46	0.56	8.49	0.33
$SO_4{}^{2-}$	mg/L	15.63	0.23	14.71	0.33	97.46	0.60	53.28	0.33
$HCO_3{}^-$	mg/L	182.59	0.09	228.93	0.07	231.19	0.08	203.95	0.18
Conductivity		322.65	0.05	374.56	0.03	560.83	0.18	447.42	0.14
SI_{Ce}	—	0.51	—	0.38	—	0.42	—	0.53	—
pCO_2	Pa	504.32	0.58	337.24	0.40	527.17	0.32	365.56	0.58

Table 2. Mean minor ion concentrations (mg/L) and concentration–electric conductivity (EC) linear regression equations for the calculations of the major ion concentrations (mg/L) used for continuous pCO_2 and SIC calculation using automatically recorded data.

Index	Mean Value of Eastern Guizhou	Mean Value of Western Guizhou	Mean Value of Northern Guizhou	Mean Value of Southern Guizhou
	0.44	0.61	2.61	2.51
Na^+,	0.57	0.79	6.34	3.26
Ca^{2+}	0.52 × EC − 78.95	0.24 × EC − 21.67	0.119 × EC + 27.97	0.22 × EC − 10.83
Mg^{2+}	0.062 × EC − 0.23	0.04 × EC − 4.68	0.041 × EC − 0.55	0.02 × EC + 9.09
Cl^-	1.37	1.79	1L44	7.99
$SO_4{}^{2-}$	14.02	16.75	0.43 × EC − 154.76	0.18 × EC − 23.55
$HCO_3{}^-$	0.642 × EC − 27.33	0.816 × EC − 72.74	0.196 × EC + 129.20	0.38 × EC + 9.71

4.4. Data Analysis and Communication

The hydrological and hydrochemical dynamics of typical karst watersheds in Guizhou Province have been systematically monitored for many years, and the results show that the average value of karst flux was 36.17 t/CO_2 km^{-2}·A-1. The chemical stability of bicarbonate ions in the outlet water of the karst drainage basin makes the hydrological cycle of the drainage basin the main controlling factor of the karst carbon sink flux. The calculation method is shown in [15]. At the same time, we also actively exchanged with the expert team and government departments. During the exchange and study, Liu Zaihua, a researcher at the Institute of Geochemistry, Chinese Academy of Sciences, and Professor Zeng Sibo, School of Geographic Sciences, Southwest University, proposed that they use high-resolution remote sensing and meteorological data and the carbonate dissolution balance model to study the karst carbon sink flux in the carbonate outcrop areas of China. They found that in the non-karst area, sowing carbonate powder can increase the carbon sink by 38.59 million tons per year, which was a method with great potential to enhance the carbon sink. In the communication with the Department of Natural Resources and the Department of Science and Technology of Guizhou Province, they proposed to carry out key technical research as soon as possible, build different types of karst carbon sink research and development platforms, and establish the karst carbon sink monitoring and measurement database of the province. A scientific and standardized standard system of karst carbon sequestration should be formed as soon as possible.

5. Finding

Guizhou, as the center of karst in China, has the unique advantages of the karst carbon sink, and is the core area of the karst carbon sink. In October 2021, the Central Committee of the Communist Party of China and the State Council issued the "Opinions on Implementing the New Development Concept Completely, Accurately and Comprehensively to Do a Good Job in Carbon Peak and Carbon Neutralization", and the "State Council's Action Plan for Carbon Peak by 2030". The actions of "actively promoting the development and utilization of karst carbon sinks" and "carrying out background investigation of karst carbon sinks" were put forward to consolidate and enhance the carbon sink capacity, and karst carbon sinks, as an important way to achieve "carbon neutrality", were included in the top-level design of the national "double carbon action". In January 2022, the State Council (2022) issued the No.2 document "Opinions of the State Council on Supporting Guizhou to Break a New Path in the Development of the Western Region in the New Era", which pointed out that "pilot projects such as carbon capture and utilization and carbon capture and storage in karst geology should be carried out in an orderly manner", encouraging and urging Guizhou to research and apply karst carbon sinks. However, in view of the research on karst carbon sinks, a unified understanding has not been formed in terms of theory and application, and there are still disputes, which makes it difficult for the existing theory and technology to support the large-scale promotion and application of karst carbon sinks [19–23]. The main problems are as follows.

5.1. Science and Technology Issues

5.1.1. Insufficient Research on the Stability of Karst Aquatic Photosynthetic Carbon Sinks and the Monitoring and Calculation Technology System

According to the connotation of carbonate weathering carbon sink theory (CCW) coupled with aquatic photosynthesis, the key lies in the conversion of unstable DIC into stable OC to achieve stable carbon storage. Therefore, in order to distinguish from the traditional karst carbon sink, it is also called the karst aquatic photosynthetic carbon sink.

5.1.2. The Research on the Feedback Mechanism of the Ecological Environment in Karst Areas Is Insufficient

The ultimate goal of studying karst aquatic carbon sinks is to increase the amount of carbon sink through artificial regulation and control, under the premise of mastering its mechanism and defining the feedback of ecological impact. However, the research on the feedback mechanism of the impact of the karst aquatic carbon sink process on the ecological environment is still lacking, and is not enough to support the application and promotion of sink enhancement. Based on the CCW theory, the karst carbon sink is a form of systematic engineering covering water-rock-soil-air-organism interactions, in which any eco-environmental factor (such as hydrodynamic and hydrochemical characteristics, the sedimentation characteristics of the combination of suspended solids and organic matter in the water body, and the types of aquatic plants in the water body) will affect the aquatic photosynthetic carbon sink. What, however, is the effect of these environmental factors? How big is their impact? How can it be evaluated quantitatively? These are all key issues that have not yet been solved. The mechanism of the artificial regulation of karst aquatic organic carbon sinks under natural conditions is not clear. Studies have been conducted on increasing the reproduction and growth of aquatic algae to achieve the purpose of increasing carbon sinks, but there is still a lack of an accurate qualitative and quantitative evaluation index system in this process, and in most studies the analyses are conducted indoors, the conditions are too singular, and the experiments are not carried out in complex natural environments, so they do not have engineering applications [24–27].

5.2. Popular Science Propaganda and Policy Issues

5.2.1. Low Awareness and Weak Publicity

According to the different karst geological backgrounds of the whole province, the research team selected Yuqing County, Jiangkou County, Jinsha County, Xiuwen County, Panxian County, Puding County, Zhenfeng County, Guiding County and Huangping County to conduct field investigation and research, and conducted popular science lectures and questionnaires in several county-level governments. The results showed that only 57% of the respondents had heard of or understood the relevant knowledge of carbon sequestration. Only 17.6% of the respondents knew about karst carbon sinks, and most of them were young people under 30 years old with bachelor's degrees. Compared with traditional natural resources such as water sources, growing forests, and suitable climates, the respondents generally responded that karst carbon sinks were "vague", an "invisible entity", and a "speculation concept". The inevitability and foresight of the development of carbon sinks are not clear and understood. The awareness of the karst carbon sink is low and the propaganda is weak (Figure 6).

Figure 6. Popularization of science in Huangping, Guizhou.

5.2.2. The Trading Policy Is Not Clear, and Many Parties Hold a Wait-and-See Attitude

Field visits by this work found that many counties have social capital in the field of carbon sequestration, and some companies have initialed cooperation agreements with the government, but due to the lack of clear policy document support, many counties hold a wait-and-see attitude and dare not carry out specific work. Although the national level has established some ecosystem carbon sequestration standards, certification and identification systems, the acceptance rate is low; for the karst carbon sequestration, many county-level governments have shown strong interest, with the feedback being “this is a renewable natural resource”, “can increase revenue for finance, ease the financial pressure of the government”, “do not change the environment, do not increase the government”. We are excited by the comments such as “once and for all”, but at the same time, some feedback such as “this transaction has not seen the policy document”, “what to do if it can’t be sold”, “are there any successful cases for us to see” makes us realize that the karst carbon sink market does not have the leading role of consumption at this stage, and many grass-roots staff think it is difficult. They do not have a clear understanding of the inevitability and foresight of carbon sinks, adopt risk aversion strategies, pay little attention to them subjectively, and mostly hold a wait-and-see attitude.

In sum, the karst carbon sink process involves multiple ecological processes, such as “three waters” (atmospheric precipitation, surface water and groundwater) transformation, rock weathering, aquatic plant growth and reproduction, and water quality evolution, which have a greater impact on the karst carbon sink; but what are these processes? Will their impact result in an increase or a decrease in carbon sinks? How large will this change be? There are no clear answers to these questions. The crux of the above problems is mainly attributed to two aspects: on the one hand, although many studies on the mechanism, impact and even application of karst carbon sinks have been carried out, they are all laboratory or artificial field tests in different regions, reflecting different geological conditions and backgrounds, such that the research data obtained are not matched, and the research results analyzed are often not widely applicable. There are even completely opposite research conclusions. On the other hand, the karst carbon sink is a systematic project of geological weathering, aquatic photosynthesis, and sedimentation, covering all spheres of water-rock-soil-air-biological interactions. It is necessary for multiple departments (such as natural resources departments, ecological environment departments, water conservancy departments and emergency management departments) to coordinate unified planning, exchange data resources, and form a systematic knowledge theory system to guide engineering applications.

6. Suggestion

The achievement of the goal of "double carbon" is a major national strategy, and karst carbon sequestration, as an important way to achieve "carbon neutrality", has been included in the top-level design of the national "double carbon action". Since the 18th National Congress of the Communist Party of China, China has made unprecedented efforts to promote the construction of an ecological civilization; has implemented a series of strategies, measures and actions to deal with climate change; and has participated in global climate governance. Based on the new development stage and the implementation of the new development concept, Guizhou needs multi-party linkage and collective efforts to promote the pilot development of karst carbon sinks in the Guizhou karst areas. In view of the difficulties and problems in the pilot construction of karst carbon sequestration in our province, we put forward the following suggestions.

6.1. Suggestions for Government Policies

6.1.1. National Level

(1) Strengthen international exchanges and cooperation to highlight the leading role of the "karst carbon sink" in Guizhou

As one of the four major carbon sinks, karst carbon sinks should be connected with international institutions such as the Intergovernmental Committee on Climate Change. Guizhou can rely on the strength of universities and research institutions in Guizhou Province to do independent research on the natural characteristics of karst areas in Guizhou, and can actively organize international counterparts to carry out cooperative research on frontier scientific issues. We should establish a basic database of karst carbon sinks in southern karst areas of China, further highlight the "voice of karst carbon sinks" in Guizhou, gradually consolidate the leading position, do a good job in supporting the basic data of strategic decision-making at the national level, and put forward strategies for China to participate in and lead the construction of an international climate cooperation mechanism.

(2) Scientific and rational utilization of karst, and the construction of a karst carbon sink evaluation system

Based on the natural geological advantages of the Guizhou karst area, excellent talents and technical teams from inside and outside the province were organized to analyze the monitoring data of the karst system; develop a new integrated observation system; establish a karst carbon sink algorithm; quantify the list of karst carbon sinks in southern China; evaluate the rate, stability and potential of karst carbon sinks; and establish a comprehensive evaluation system. We should speed up the construction of the investigation and evaluation system of the karst carbon sink mechanism, inventory and sink potential in Guizhou and even in the southwest region, accurately assess the value of the karst carbon sink in Guizhou, and lay a good foundation for the implementation of the "double carbon" strategy in our province.

(3) Build the basic framework of karst carbon sink trading

We should actively study the value system of the karst carbon sink; exploit its potential value of realizing environmental, social and economic benefits; and draw lessons from the transaction pricing model of forest carbon sinks to form the rudiments of transaction products. We should also clarify the rights and responsibilities of the main trading institutions, explores the development process of karst carbon sink trading, and speed up integration into the national carbon market.

6.1.2. Provincial level

(1) Strengthen the construction of a karst carbon sink observation station

In order to coordinate the geological distribution characteristics and eco-geological conditions of the Guizhou karst region, we must speed up the construction of the karst carbon sink process basic data observation station, and ensure the reasonable layout and smooth operation of the karst carbon sink observation station network; at the same time, we must strengthen the effective connection between the karst carbon sink and eco-environmental system observation, and identify the control factors of the karst carbon sequestration process.

(2) Establish a linkage mechanism for departmental collaboration

The process of karst carbon sequestration involves water-rock-soil-gas-biosphere interaction processes, which correspond to the ecological environment, natural resources, science and technology, education, development and reform commissions, and other departments. It is necessary to formulate a departmental cooperation mechanism, set up a special liaison officer within the departments, and cooperate to complete the work of karst carbon sequestration.

(3) Digital economy and the establishment of carbon sink cloud platform

Digital technology is the key technology for carbon sequestration monitoring and assessment. The carbon sequestration digital platform can provide a basic guarantee for carbon sequestration trading, help to form a social consensus on emission reduction and sink increase, and play a leading and docking role in dual-carbon target planning. Therefore, we should strengthen top-level design and strategic planning, strengthen the basic support research of digital carbon sequestration, expand the application of digital technology and carbon sequestration, improve the construction of a carbon sequestration system and a mechanism system, and carry out platform construction in different fields, steps and stages.

(4) Increase policy and legislative support

In order to formulate regulations on karst carbon sequestration, we must clarify the connotation of karst carbon sequestration, incentivize measures for increasing carbon sequestration and industrial implementation policies, and revise and improve relevant construction norms, supporting policies, laws and regulations, such as the demonstration of ecological civilization construction and pilot projects of the green low-carbon cycle, so as to promote the implementation of karst carbon sequestration tasks in Guizhou Province as soon as possible.

(5) Increase investment in scientific and technological research and development

Karst carbon sink research in Guizhou is in the leading position globally at present, but there are still gaps in some aspects of the mechanism theory research and technology application and promotion; as such, we should increase the establishment of such projects and the corresponding investment in scientific and technological research and development, whilst at the same time strengthening the assistance of industries, universities and research, and attracting more channels of joint investment.

(6) Increase the promotion of the karst carbon sink

Karst carbon sink promotion and publicity programs should be formulated on major government publicity and education platforms, and the concept of the karst carbon sink as an important carbon sink type should be implemented in various fields from the aspects of education and the science popularization of the basic scientific research achievements of the karst carbon sink, the introduction of pilot projects in application fields, and the publicity of its potential industrial value.

(7) Explore artificial sink technology

Combined with the feedback mechanism of ecological impact in the process of karst carbon sequestration, the impact degree was evaluated, the technical scheme of artificial carbon sequestration was formulated, and the typical demonstration area was selected for experimental exploration. At the same time, the potential of increasing carbon sinks was assessed to promote the contribution of karst carbon sinks to the "double carbon" goal.

6.2. Prospect of Scientific Research and Technology

At present, the karst carbon sink survey and monitoring system has not been fully connected with the terrestrial ecosystem carbon flux observation system in the upstream, and there is no groundwater monitoring information system or hydrological and water resources monitoring in the downstream. In order to link up the system, it is necessary to integrate the existing monitoring technology system and enrich the karst carbon sink monitoring technology system. We should strengthen the comprehensive investigation of the karst carbon sink, make full use of monitoring data to improve the accuracy of carbon sink investigation, and establish a unified karst carbon sink investigation method and carbon sink measurement system, in order to explore innovative and scientific methods for the measurement of karst carbon sinks, to account for increasing carbon sinks, and to create methodologies for the karst carbon sinks. Although artificial intervention to increase the karst carbon sink has been verified in some working areas, there is no systematic experimental demonstration area, such that it is impossible to carry out a systematic carbon neutralization evaluation from the perspective of the carbon budget; as such, it is necessary to strengthen the experimental demonstration of artificial intervention in order to increase the carbon sink and natural resource spatial management information through information platform construction.

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References

1. Yuan, D.X. The development of modern karstology in China. *Geol. Rev.* **2006**, *52*, 733–736.
2. Jiang, Z.C.; Yuan, D.X.; Cao, J.H.; Qin, X.Q.; He, S.Y.; Zhang, C. A study of carbon sink capacity of karst processes in China. *Acta Geosci. Sin.* **2012**, *33*, 129–134.
3. Pu, J.B.; Jiang, Z.C.; Yuan, D.X.; Zhang, C. Some opinions on rock-weathering-related carbon sinks from the IPCC fifth assessment report. *Adv. Earth Sci.* **2015**, *30*, 1081–1090.
4. Liu, Z.; Zhao, J. Contribution of carbonate rock weathering to the atmospheric CO_2 sink. *Environ. Geol.* **2000**, *39*, 1053–1058. [CrossRef]
5. Zeng, S.B.; Liu, Z.H.; Kaufmann, G. Sensitivity of the global carbonate weathering carbon-sink flux to climate and land-use changes. *Nat. Commun.* **2019**, *10*, 5749. [CrossRef] [PubMed]
6. He, Q.; Xiao, Q.; Fan, J.; Zhao, H.; Cao, M.; Zhang, C.; Jiang, Y. The impact of heterotrophic bacteria on recalcitrant dissolved organic carbon formation in a typical karstic river. *Sci. Total Environ.* **2022**, *815*, 152576. [CrossRef] [PubMed]
7. IEA (International Energy Agency). Net Zero by 2050: A Roadmap for the Global Energy Sector. 2021. Available online: https://www.iea.org/reports/net-zero-by-2050 (accessed on 5 August 2022).
8. Khadka, M.B.; Martin, J.B.; Jin, J. Transport of dissolved carbon and CO_2 degassing from a river system in a mixed silicate and carbonate catchment. *J. Hydrol.* **2014**, *513*, 391–402. [CrossRef]
9. Yang, R.; Chen, B.; Liu, H.; Liu, Z.; Yan, H. Carbon sequestration and decreased CO_2 emission caused by terrestrial aquatic photosynthesis: Insights from diel hydrochemical variations in an epikarst spring and two spring-fed ponds in different seasons. *Appl. Geochem.* **2015**, *63*, 248–260. [CrossRef]
10. Yan, Z.; Wang, X.Y.; Li, W.; Yu, L. Biological carbon pump effect of microalgae in aquatic ecosystems of karst areas. *Acta Microbiol. Sin.* **2019**, *59*, 1012–1025.

11. Liu, Z.H.; Macpherson, G.L.; Groves, C.; Martin, J.B.; Yuan, D.X.; Zeng, S.B. Large and active CO_2 uptake by coupled carbonate weathering. *Earth-Sci. Rev.* **2018**, *182*, 42–49. [CrossRef]
12. Wang, P.; Hu, Q.; Yang, H.; Cao, J.; Li, L.; Liang, Y.; Wang, K. Preliminary study on the utilization of Ca^{2+} and HCO_3^- in karst water by different sources of Chlorella vulgaris. *Carbon. Evapor.* **2014**, *29*, 203–210. [CrossRef]
13. Wang, P.; Hu, G.; Cao, J.H. Stable carbon isotopic composition of submerged plants living in karst water and its eco-environmental importance. *Aqua. Bot.* **2017**, *140*, 78–83. [CrossRef]
14. Liu, Z.H.; Dreybrodt, W.; Wang, H.J. A possible important CO_2 sink by the global water cycle. *Chin. Sci. Bull.* **2018**, *53*, 402–407. [CrossRef]
15. Liu, Z.H.; Dreybrodt, W. Significance of the carbon sink produced by H_2O-carbonate-CO_2-aquatic phototroph interaction on land. *Sci. Bull.* **2015**, *60*, 182–191. [CrossRef]
16. Yang, M.X.; Liu, Z.H.; Sun, H.L.; Yang, R.; Chen, B. Organic carbon source tracing and DIC fertilization effect in the Pearl river: Insights from lipid biomarker and geochemical analysis. *Appl. Geochem.* **2016**, *73*, 132–141. [CrossRef]
17. Xia, F.; Liu, Z.; Zhao, M.; Li, Q.; Li, D.; Cao, W.; Zeng, C.; Hu, Y.; Chen, B.; Bao, Q.; et al. High stability of autochthonous dissolved organic matter in karst aquatic ecosystems: Evidence from fluorescence. *Water Res.* **2022**, *220*, 118723. [CrossRef]
18. Krklec, K.; Domínguez-Villar, D.; Perica, D. Use of rock tablet method to measure rock weathering and landscape denudation. *Earth-Sci. Rev.* **2021**, *212*, 103449. [CrossRef]
19. Cai, Y.L. Spatial scales integration of land system change: A case study design on Guizhou Karst Plateau. *Adv. Earth Sci.* **2009**, *24*, 1301–1308.
20. Xu, S.Y.; Jiang, Z.C. Preliminary estimation of the relationship between karstification and the sources and sinks of atmospheric greenhouse gas CO_2 in China. *Chin. Sci. Bull.* **1997**, *42*, 953–956.
21. Jiang, Z.C.; Jiang, X.Z.; Lei, M.T. Estimation of atmospheric CO_2 sink of karst areas in China based on GIS and limestone tablet loss data. *Carsol. Sin.* **2000**, *19*, 212–217.
22. Wu, W.H.; Zheng, H.B.; Yang, J.D.; Chao, L.; Bin, Z. Chemical weathering of large river catchments in China and the global carbon cycle. *Quat. Sci.* **2011**, *31*, 397–407.
23. Liu, C.; Jiang, Y.; Tao, F.; Lang, Y.; Li, S. Chemical weathering of carbonate rocks by sulfuric acid and the carbon cycling in Southwest China. *Geochimica* **2008**, *37*, 404–414.
24. Cao, J.H.; Yuan, D.X.; Pan, G.X.; Jiang, G.H. Influence of soil carbon transfer under different vegetations on carbon cycle of karst dynamics system. *Earth Environ.* **2004**, *32*, 90–96.
25. Li, H.; Wang, S.; Bai, X.; Cao, Y.; Wu, L. Spatiotemporal evolution of carbon sequestration of limestone weathering in China. *Sci. China Earth Sci.* **2019**, *62*, 974–991. [CrossRef]
26. Yang, Y.X.; Xiang, P.; Lu, W.Q.; Wang, S.L. The sedimentation rate and burial fluxes of carbon and nitrogen in Wujiangdu reservoir, Guizhou, China. *Earth Environ.* **2017**, *45*, 66–73.
27. IEA. Energy Technology RD&D Budgets: Overview. 2021. Available online: https://www.iea.org/reports/energy-technology-rdd-budgets (accessed on 12 August 2022).