IRCK 2020

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Annual Report

2020

International Research Center on Karst (IRCK) under the Auspices of UNESCO

In 2020, with COVID-19 spreading worldwide, impossibility comes to on-site visits. IRCK has a not- easy beginning; however, under kinds of support, all of us worked jointly to overcome those difficulties, and finally reached the set goals, even some unexpected achievements were also obtained. Then, IRCK has a better ending of 2020. On this occasion, we'd like to extend our sincerest acknowledgements to all the agencies that helped us during our tough time, and promise you a better new year.

—IRCK Secretariat

United Nations
Educational,Scientific and
Cultural Organization

International Research Center on Karst (IRCK) under the Auspices of UNESCO

2020 Annual Report

I would like to express my support for the international scientific cooperation envisaged in this project.

I believe this kind of collaboration is essential to overcome the problems we all face as a global society.

I am sure the project will be a great success and I look forward to hearing about its progress and success.

-------Ms. Irina Bokova
Former Director-General of UNESCO

We are confident that "Global Karst" will be a complete success thanks to the unwavering support from UNESCO.

We are confident that "Global Karst" will be a complete success thanks to the experience that China can share with the world.

We are confident that "Global Karst" will be a complete success thanks to the active participation of scientists around the world.

We are confident that "Global Karst" will be a complete success thanks to the strong backing from the Chinese government.

-----Mr. Jiang Daming
Former Minister of the Ministry of Land and Resources, China

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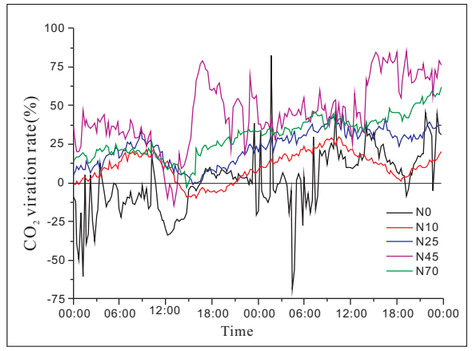
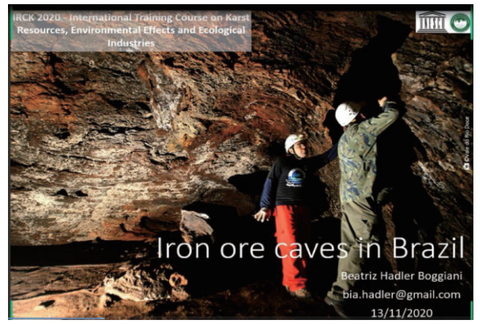




I

Organization and Management

1.1 Closer connection with UNESCO

The International Research Centre on Karst under the auspices of UNESCO (IRCK) maintained closer communication with UNESCO offices, like the Division of Ecological and Earth Sciences, the IGCP Secretariat, and UNESCO Beijing Office through mutual support and help. For example IRCK submitted its annual report regularly, and provided materials about its contributions to the UN 2030 Agenda;meanwhile, UNESCO provided their support and guidance to foster IRCK become better and better.

In March, Ms.Marielza Oliveira, director of UNESCO Beijing Office sent a letter to director Hu Maoyan, expressing her support for IRCK under the epidemic , which encouraged the IRCK staff to overcome difficulties . IRCK once again truly feels a strong sense as a member of UNESCO family.

In April, at the invitation of UNESCO Beijing Office, IRCK selected 12 training courses presented by world-renowned karst scientists meticulously to support its online training and education event, which provided a wonderful platform for relevant practitioners around the world to study and exchange ideas.

In August, IRCK attended “Experts dialogue on SETI Priorities and Implementation Means Asia-Pacific Online Regional Consultation” hosted by UNESCO Jakarta Office, learned innovative experience and methods about how to contribute to the strategic objectives of natural science defined by C/5 and the relevant goals set by the 2030 Agenda from participating institutions.

In December, IRCK provided the IGCP secretariat with relevant materials supporting the SDG 8: Decent Work and Economic Growth. IRCK is making its upmost efforts to support the realization of the UN 2030 Agenda.

Closer connection with UNESCO through effective communication mechanism has promoted the mutual understanding between IRCK and UNESCO, facilitated the mutual support between IRCK and UNESCO, and made IRCK a stronger sense of belonging and mission as a member of UNESCO. Although COVID-19 in 2020, IRCK still completed the set work under the support and guidance of UNESCO.

UNESCO Beijing Office
Office of the Representative to Democratic People's Republic of Korea, Japan, Mongolia, People's Republic of China and Republic of Korea

联合国教科文组织驻华代表处
驻朝鲜民主主义人民共和国、日本国、蒙古国、中华人民共和国、大韩民国代表处

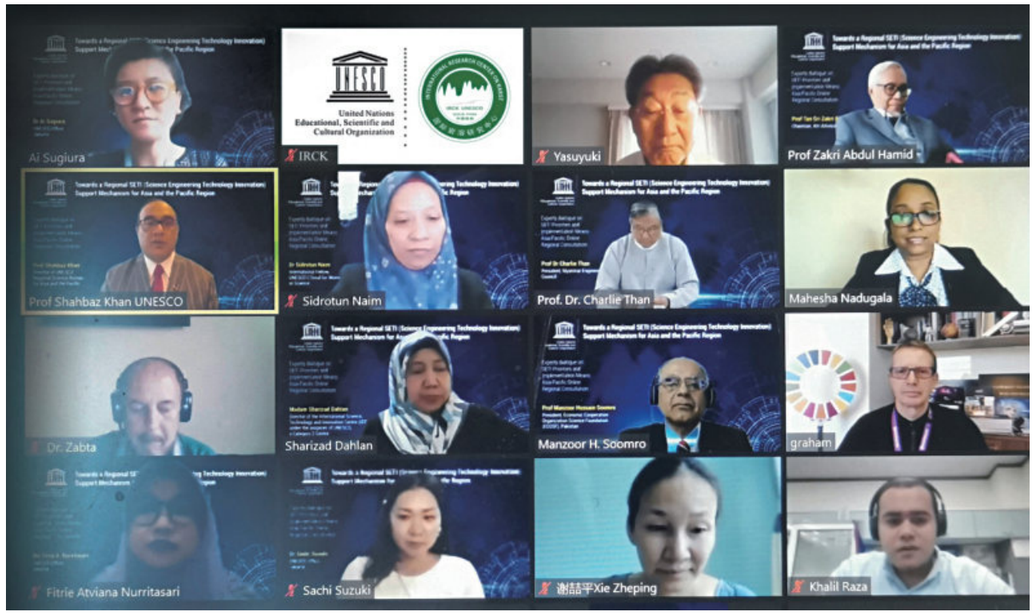
Ref.: BEJ/DIR/2020/029 11 March 2020

Dear Mr. HU Maoyan,

On behalf of UNESCO Beijing Cluster Office, I would like to extend my full solidarity to you and your colleagues in the International Research Centre on Karst (IRCK) following the outbreak of COVID-19. Please know that our thoughts are with you, your families and communities.

This has been a distressing situation, and I sincerely commend all the efforts and measures that are being taken to protect individuals and communities from the impact of the virus. But it is also heartwarming to see the positive, constructive spirit of internal and international collaboration that this shared challenge has brought about.

UNESCO appreciates the long term collaboration with the International Research Centre on Karst (IRCK). We want to reassure you that we fully understand that this exceptional situation affects our normal routines, posing challenges and limitations for us to cope with. You may rest assured that UNESCO stands ready to provide every assistance within its power and fields of competence, to you and your colleagues, and to review work procedures and schedules to both ease burdens and contribute to a return to normalcy at this time.



Left adove:Letter from Ms.Marielza Oliveira, director of UNESCO Beijing Office
Right above:IRCK supports the UNESCO Beijing Office to carry out online teaching and training
Below:Experts dialogue on SETI Priorities and Implementation Means Asia-Pacific Online Regional Consultation

1.2 Closer connection with the National Commission of the People's Republic of China for UNESCO, and closer collaboration with other C2Cs in China

In 2020, IRCK participated in the meetings held by the National Commission of the People's Republic of China for UNESCO (NCC) for twice.The meetings aimed to strengthen exchanges among NCC partners, share anti-epidemic experience, introduce annual work, make joint efforts for fighting COVID-19, and promote the exchange and dissemination of education, science, and culture.

On April 30, NCC organized the "Seminar on Promoting Cooperation with UNESCO to Fight the Epidemic (Online)". Over 100 representatives of Chinese partners took part in this virtual meeting. IRCK shared experiences and exchanged speeches with other C2Cs, creative cities, chairs and partners. Prof. Jiang Zhongcheng, Governing Board Member (GB Member) of IRCK, with Executive Deputy Director Cao Jianhua attended the meeting and made speeches. IRCK expressed its strong willing to make joint efforts to fight the epidemic, which was admired by NCC.

On December 29, a "virtual+on-spot" seminar among NCC partners was held in Beijing. As one of the four annual representatives from 15 C2Cs in China, IRCK made an online speech, introducing its annual outcomes in 2020 and its work plan for 2021.

In the future, with the support of the NCC, IRCK will continue to strengthen exchange and cooperation with other C2Cs, make full use of these interdisciplinary platforms covering education, science and culture, and contribute to 2030 Agenda jointly.

NCC Partners' Seminar

1.3 All-out efforts to build up kinds of platforms

1.3.1 Dynamic ISO/TC 319 Karst

The Karst Technical Committee under the International Organization for Standardization (ISO/TC 319 Karst) was formally established in 2019. It is another important international platform applied by IRCK. Prof. Jiang Zhongcheng, the GB member of IRCK, is the chairman of this committee. In 2020, ISO/TC 319 Karst completed the second round of internal ballot on the *Title, Scope and Strategic Business Plan*, and improved its organizational structure; meanwhile, the proposals for "*Karst Speleology Terminology*" and "*Karst Critical Zone Monitoring Technology*" were sought for advice and planned to be formally submitted in 2021. Two new experts from Saudi Arabia and Iran joined this TC. At present, there are 42 members from 23 countries including Austria, Bulgaria, India, Germany, and Portugal etc working in ISO/TC 319 Karst. Moreover, a new website was established for better management and popularization.

Participating Member and Observer Member

No.	Participating Member	No.	Observer Member	No.	Observer Member
1	Austria	1	Argentina	12	Italy
2	Russia	2	Australia	13	Japan
3	Portugal	3	Bulgaria	14	Latvia
4	Lithuania	4	Czech Republic	15	New Zealand
5	China	5	Finland	16	Norway
6	Saudi Arabia	6	France	17	Poland
7	Canada	7	Germany	18	Serbia
8	Switzerland	8	Hungary	19	Spain
		9	India	20	Tanzania
		10	Indonesia	21	Thailand
		11	Iran	22	United Kingdom

On November 17, IRCK organized the training on karst standardization. The Standardization Administration of the P.R.C.(SAC) and experts in the fields of standardization of natural resources and spatial planning of national land conducted training to the scientists involved. The training focused on the process and rules for generating national or industrial standards, providing instructions to tackle frequent problems by case studies, which is significantly important to guide the compilation of guidelines, norms and standards on karst.

Affected by COVID-19, the second plenary meeting preliminarily scheduled to be held in Canada in August 2020 was postponed to be held on August 24-26 in 2021 in Victoria of Canada.

1.3.2 Active efforts to establish new platforms

In 2020, IRCK applied for various international and domestic platforms actively, with one international platform, two domestic platforms, and one vice ministerial-level platform approved. At the 74th Meeting of IUGS Executive Committee, IRCK was

Above: Website of ISO/TC 319 Karst
Below: Training on karst standardization

officially designated as an affiliated organization of IUGS, making karst geology to be an important member of IUGS, and bringing new impetus to the discipline construction of karst geology. In September, the China-Slovenia Joint Laboratory on Karst Geology was approved by the Ministry of Science and Technology (MOST), providing a bilateral platform for the comparative study of karst between the two countries. In December, the Observation and Research Station on Karst Rocky Desertification in Southwest China was enrolled by the priority national station construction list, providing key studying sites for the observation on rocky desertification in the southwest. Moreover, the Innovative Center on Karst Collapse Prevention Technology was also approved by China Geological Survey (CGS), providing a professional platform to develop prevention technology for geohazards.

These new platforms, targeting on bilateral cooperation with the “Belt and Road” countries, disciplinary construction of karst geology, and innovative development, aim to carry out all-round interdisciplinary research crossing different fields at different levels, and provide more diversified platforms for service and cooperation.

New platforms approved in 2020

No.	Approval Time	Platform Type	Platform	Major Focus
1	Jan.2020	International Platform	IUGS Affiliated Organization	Discipline construction of karst geology
2	Sep.2020	National Bilateral Platform	China-Slovenia Joint Laboratory on Karst Geology	Joint research on monitoring, resources and environmental effects of karst
3	Dec.2020	National Observation and Research Station	Observation and Research Station on Karst Rocky Desertification in Southwest China	“One station with multiple research sites" was adopted to set up a network covering typical karst landforms and environment in southwest China.
4	Sep.2020	CGS S&T Innovative Conter	CGS Innovative Centre on Karst Collapse Prevention Technology	Karst collapse mechanism, early warning and prevention

1.4 Preparation for upcoming Phase-II assessment and Phase-III renewed agreement

On September 8-10, 2020, Director Hu Maoyan, Executive Director Cao Jianhua led a four-member delegation to Beijing to consult how to process the upcoming Phase-II assessment and how to apply for the signing of the renewed Phase III agreement. The delegation met with four organizations, including the Department of International Cooperation under the Ministry of Natural Resources (MNR), NCC under the Ministry of Education, the Department of Science & Technology and International Cooperation under CGS, as well as the International Research and Training Center (IRTCES) on Erosion and Sedimentation, one of the C2Cs in China on natural science. Chief Engineer Zhang Zhanhai of MNR, Secretary-General Qin Changwei of NCC, Deputy Chief Engineer Zhu Lixin, as well as Director Ning Duihu of IRTCES discussed with IRCK delegation with in-depth exchanges.

Through the discussion, IRCK learned about latest requirements for evaluation and renewal of UNESCO and Chinese administrative ministries. Based on the important achievements in promoting the "Global Karst"

International Big Scientific Plan, fostering the regional development along the "Belt and Road", and establishing various platforms, IRCK will complete the self-evaluation in accordance with the settled goals and functions defined by the renewed agreement, summarize and refine the achievements and contributions around the medium and long-term planning of UNESCO and 2030 Agenda systematically. Meantime, IRCK will also summarize the contributions to the concept of “Jointly building a community of shared future for mankind” proposed by President Xi Jinping, and the concept of “Ecological Diplomacy” proposed by the Ministry of Natural Resources. With the support of various ministries and commissions, IRCK will enhance the internationalization of its talents, operations and other aspects.

Since September of 2020, IRCK has officially started its preparation for the second-phase evaluation and the third-phase renewal. It is hoped that through a step-by-step work plan, the second-phase evaluation and the third-phase renewal work will be successfully implemented.

1.5 The Third Session of the Second Governing Board Meeting

On December 21, the Third Session of the Second Governing Board Meeting of IRCK was held in Guilin by “Virtual + On-spot” pattern. A total of 16 domestic and foreign GB members were invited to attend the meeting. They were from 14 agencies including UNESCO Department of Ecology and Earth Sciences, the International Union of Geological Sciences (IUGS), NCC, China Mining Association, CGS, Western Kentucky University, Serbia Chapter of International Association of Hydrogeologists, Chinese Academy of Geological Sciences, Tongji University, China University of Geosciences (Wuhan), Guangxi and Guilin administrations on science and technology, Guangxi General Geological Environmental Monitoring Station under Department of Natural Resources, as well as the Institute of Karst Geology (IKG).

At the host of Mr. Peng Qiming, chairman of the

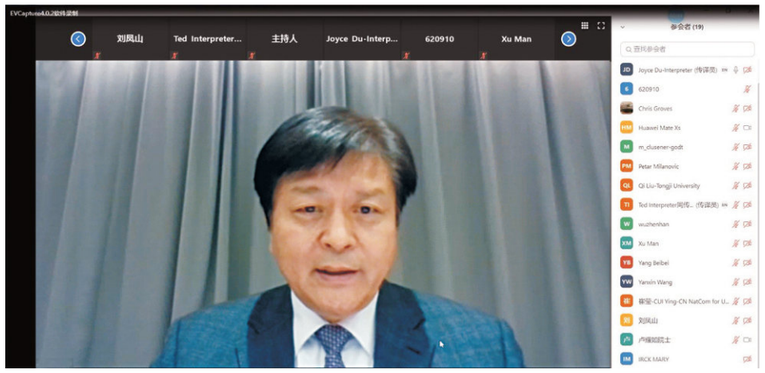
Above: Chief Engineer Zhang Zhanhai（left 3） of the Ministry of Natural Resources gave advice to IRCK
Below: Hu Maoyan, director of IRCK (right 2), with the delegation has a discussion with Qin Changwei, Secretary General of NCC (left 2) and his colleagnes

Governing Board, all members reviewed the biennial work report for 2019-2020 and the biennial work plan for 2021-2022, and listened to IRCK's presentation on organization and management, scientific research, international cooperation and training, as well as science popularization.

All the GB members agreed that the work of IRCK in the past two years was highly effective and fruitful, especially in 4 aspects: 1) closer and effective coordination and communication with UNESCO, IUGS, and MAB; 2) the technology with social significance as landscape resources development and natural heritage sites protection, water resources development and utilization, karst collapse prevention and reduction, as well as ecological industry construction and comprehensive treatment technology of rocky desertification; 3) the stable, continuous and influential annual international training courses; and 4) effective scientific popularization.

Regarding the work plan of IRCK for 2021-2022, the Governing Board put forward the following suggestions: 1) to strengthen the communication with IUGS, and operate better as an IUGS affiliated organization under the leadership of the new president; 2) to prepare for the second phase evaluation and the third phase renewal as soon as possible so as to pass the evaluation and signed the renewed agreement successfully under the guidance by UNESCO, NCC, MNR and other relevant agencies; and 3) to serve for science and technology innovation and development plan, focusing on the contribution to poverty alleviation, the application of new instruments and technology to geohazards prevention and control, as well as the support for major engineering construction. In a word, IRCK should do better to support major development such as high-speed railway construction, hydropower construction, and green urban ecological development.

By showing of hands, all the GB members approved the abovementioned two documents.



Li Pengde, deputy director general of CGS, made a speech

IRCK Work Plan Outline (2021-2022)

Plans	Contents
Management	To organize annual work meetings; to participate in serial events of UNESCO and the Alliance of C2Cs in China ;to prepare the 2nd phase evaluation and the renewed agreement for the 3rd period operation, and to cooperate with Chinese National Committee of MAB
Scientific research and social service	To implement on-going projects to promote Global Karst; to focus on the interaction between lithosphere and biosphere; to expand the cooperation with the countries (regions) along the Belt and Road; to apply for new international cooperative projects, and to serve for the social demand.
International communication, cooperation and training	To promote the exchange of karst technology; to participate in and organize the events for the International Year of Cave and Karst; to improve the influence of international karst research by the cooperation in various fields; and to organize the international training and spread the karst knowledge
Science popularization and consultation	To carry out themed and conventional science popularization activities; to establish the science popularization network of geoparks and natural heritage sites; and to make the products of popular science

Above:GB members voted for the biennial report and work plan Below:Group photo of on-spot attendees

II Scientific Research

2.1 Progress of “Global Karst” Big Scientific Plan

In 2020, the investigation and research carried out by IRCK has promoted the implementation of the International Big Scientific Planon “Resources and Environmental Effects of Global Karst Dynamic Systems” (Global Karst), with progress in many fields achieved.

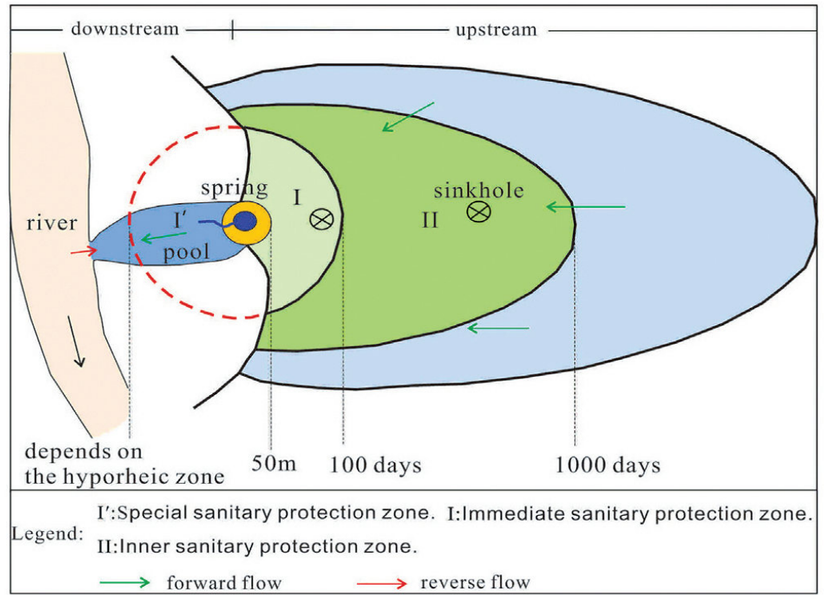
2.1.1 Water cycle, water resources and water environment of karst catchments

Karst area is dominated by the hydrogeological units of underground rivers.The land use has a close relationship with groundwater resources and water environment . By learning from new hydrogeological concepts and technologies, tracking progress in regional and global critical zones, IRCK scientists carried out the research on the hydrological process and their resources and environmental effects, e.g. slope hydrological process and its effects on drought and soil erosion, groundwater-surface water interaction flow and pollution caused by over-exploitation of water resources.

1) Research on karst spring interaction zone reveals the vulnerability of karst groundwater

Karst springs are important water resources, but due to the conduits connecting with the surface, the water environment is easily degraded. This study selected a case of a spring water source affected by a river, and demonstrated the characteristics and consequences of the groundwater-surface water interaction of karst springs through hydrological,hydrochemical and biological indicators.

The study area Wuming County is located in the north of Nanning, Guangxi,China.Controlled by south subtropical monsoon climate, the annual rainfall is 1,100-1,700 mm and the annual average temperature is about 21.9℃.The annual variation of karst water table is generally 0.5-16m. Lingshui is a typical large structural karst spring,also the spring with the largest flow in the Wuming Basin. Lingshui Lake, the outlet of the underground river with a recharge area of 400 km^2, is mainly composed of the Najia syncline water storage structure in the north of Lingshui, with the outlet flow rate as 4,000L/s in dry season.The hydrological and ecological process of the karst spring beside the river is very sensitive to environmental disturbance:there are significant gradients of pH, water temperature and dissolved oxygen along the spring-lake-river in forward flow; whereas, in reverse flow, the water level change of the lake is not synchronized with the chemical change, resulting in obvious chemical



Idealized scheme of groundwater capture areas and transit time perimetersaround an unconfined spring source (Fang Guo, Guanghui Jiang, Journal of Hydrology, 2020)

layering. The back flow of the river caused the spring-lake-river to experience a short but strong groundwater-surface water interaction. Due to the combined effects of land use changes, increased groundwater extraction, and climate change, the discharge of groundwater from karst springs in the interactive zone significantly decreased in the dry season. The hydraulic balance between groundwater and rivers has been broken, and the frequency and duration of river backflow have increased. These changes have weakened the hydrological and hydrochemical functions of the interaction zone.

The aquatic ecological environment of lakes supplemented by spring water is affected by hydrological conditions, local water environment and the intensity of human disturbance.Therefore, the lake's aquatic ecological environment protection should not be limited to the karst groundwater recharge catchment, but also be extended to rivers outside the catchment. The research found that the pollutants, microorganisms and plankton were affected by downstream rivers adversely due to the existence of the interaction zone, influencing the protection effect of current first-grade water source protection zones. Therefore, it is necessary to consider the active groundwater-surface water interaction when divided the first-grade protection zone.

2) Preliminary study on the degradation mechanism of petroleum organic pollutants by karst groundwater

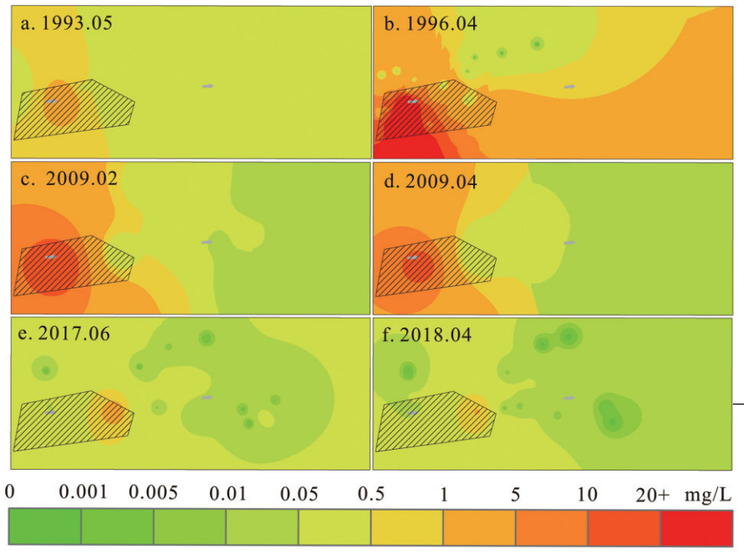
Due to the spatial heterogeneity of karst fractured aquifer in north China, the transportation channels are complicated for petroleum organic pollutants. Because of frequent fluctuation during short time, it is difficult to predict their changing trend for short ,but it is possible to find a long-term changing trend under continuous observation.

The initial pollution source in the study area was neither identified nor blocked, and the concentration of petroleum organic matters in

karst fractured aquifer was increased; with the implementation of effective measures and the natural restoration capacity of the karst fractured aquifer system itself, the concentration of the pollutants has significantly decreased. The NO_3^- in the karst fractured aquifer serves as the electron acceptor that is preferentially used in the biodegradation process. As the concentration of petroleum organic matters decreases, the NO_3^- concentration increases, the $\delta^{15}N_{NO3}$ in the water body decreases, and SO_4^{2-} continues to be lower than the background value, indicating the occurrence of anaerobic biodegradation. The increase of NO_3^- with the decrease of petroleum pollutants indicates that there is a continuous source of NO_3^- in the area. More than 90% of the organic matter in the groundwater in the area is chlorinated hydrocarbons, and the biodegradation of chlorinated hydrocarbons makes the Cl^- concentration in the water body higher than the background value.The CO_2 degraded from the petroleum organic matters dissolved in water will increase HCO_3^- of the water body, thereby reducing the pH value $\delta^{13}C_{DIC}$ decreased with the increase of DIC and CO_2, and $\delta^{13}C_{DOC}$ increased with the increase of DIC and CO_2, indicating that the process of anaerobic biodegradation of petroleum organic matter did not occur in the process of methane production. $\delta^{13}C_{DIC}$ increased with the increase of DO, indicating that the action of microorganisms in the water body significantly changed the isotopes of the water environment.Based on the existing test results, the capacity of the karst fractured aquifer calculated by the electron acceptor model to biodegrade petroleum organic matter is 27.48mg/L, which is far greater than the existing concentration value of 0.36mg/L. The first-order kinetic attenuation coefficient is used to predict that the existing petroleum organic matter can be completely degraded after 6 years.

3) Isotope technology reveals the source of water used for apples in graben basins

Since the National Project on Comprehensive Rocky Desertification Control was implemented in the karst rocky desertification areas in southwest China, apple has been planted on the Dongshan Plateau in the Mengzi Basin in a larger scale, where there was severe rocky desertification, achieving some good experience.



Temporal and spatial variation characteristics of petroleum organic matters in karst fractured aquifer (Yongli Guo, et al., Environmental Science and Pollution Research, 2020)

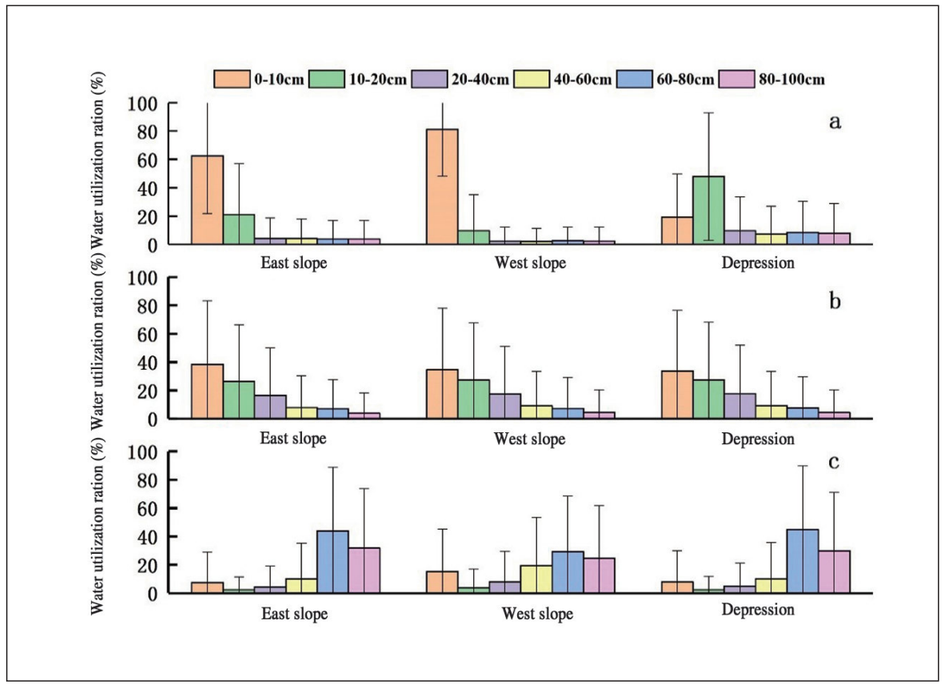
It is currently the southernmost apple plantation in China with better economic and ecological benefits.However, despite the sufficient local light and heat conditions, the rainfall is highly uneven, coupled with the special karst geological background, water limited the growth and ecological restoration in the rocky desertification area of southwest China significantly.

The research has used hydrogen and oxygen stable isotopes to study the soil moisture utilization at different depth during the three major growth periods of apple trees, revealing the moisture utilization strategy. IsoSource model and the MixSIAR model were established based on δD and $\delta^{18}O$ values of soil moisture, apple tree xylem water and atmospheric precipitation. The results are as follows :

(1) Apple trees in the study area mainly use shallow soil moisture during the germination period. The trees on the east slope and west slope mainly use 0-10cm deep soil moisture, with the utilization ratios as 62.6% and 81%, respectively. The apple trees at the depressions mainly use 10-20cm deep soil moisture, with the utilization ratio as 47.9 %.

(2) The apple trees on the east and west slopes, or at the depressions mainly use 0-10cm deep soil moisture during the new-tip vigorous growing period; however, compared with the germination period, the absorption and utilization of soil moisture below 20cm is increased.

(3) The apple trees mainly use the deep soil moisture at 60-80cm and 80-100cm depth during the fruit swelling period.

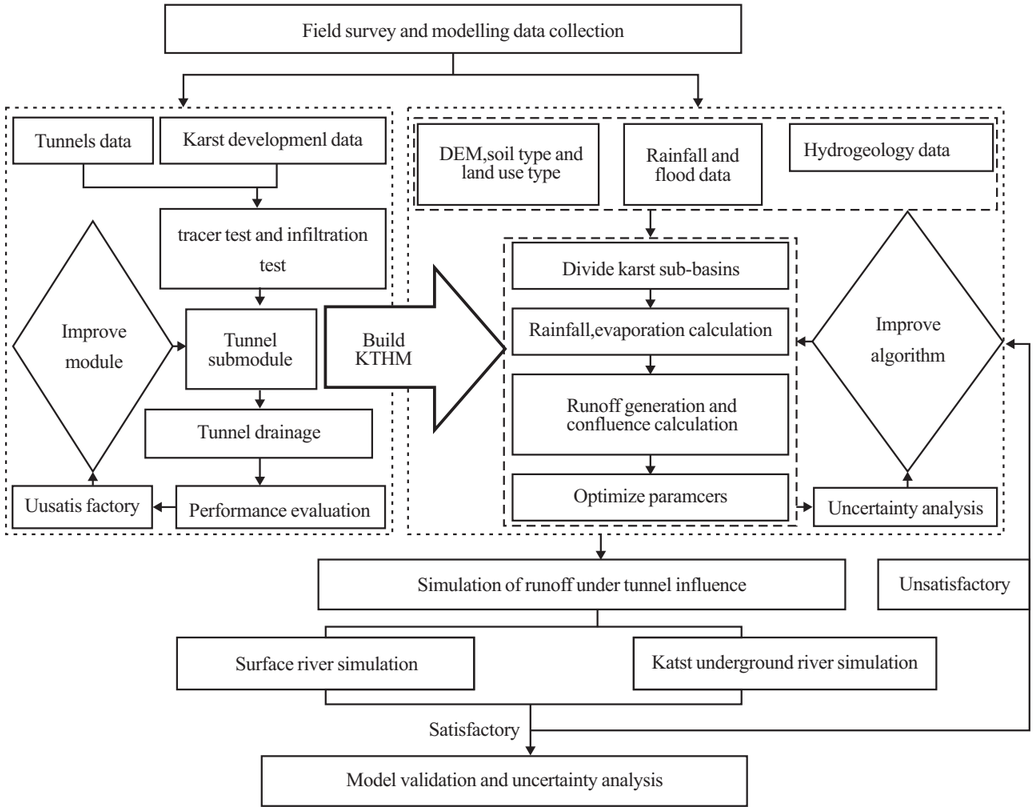


Contribution rate of water sourcestoapple trees on the east slope, west slope and at the depression during different growth periods (average %+ standard deviation) (a: germination period; b: new-tip growth period; c: fruit swelling period) (Hou Weijie, Master Dissertation, China University of Geosciences(Beijing),2020)

4) Influence of expressway tunnel construction on karst aquifers

Tunnel excavation in karst area will affect the local natural karst hydrological process and runoff cycle, leading to surface water leakage, underground river drying up or even cutoff, and other serious ecological and environmental problems such as karst collapse, tunnel water inrush and so on.Taking karst valley in Zhongliangshan Mountain of Chongqing as an example, there are three tunnels in the study area of only 12 km^2, with the average distance about 2 km. The previous catchment survey showed that these tunnels have had a serious impact on the local karst water system and ecological environment, and it is necessary to analyze and evaluate the hydrological effects of tunnel excavation in karst areas.

A fully distributed karst tunnel hydrological model (KTHM) with relatively simple structure and parameters based on physical parameters is proposed.Compared with other commonly used hydrological models, the structure of KTHM is relatively simple. The module for



Modeling and Calculation flow chart of the KTHM（Ji Li et al., Journal of Hydrology, 2020）

groundwater confluence is only divided into two layers-the confluence of epikarst zone and that of the underground river system.This simple model makes it possible to build a distributed hydrological model in karst area with only a small amount of hydrogeological data. The tunnel module is a specially designed submodule to quantify the influence of the hydrological effect of the tunnel on the water quantity at the outlet of the underground river. If the tunnel submodule is closed, the model becomes karst hydrological model (KHM), which can be used to simulate other karst catchment without tunnels.

The simulation of 20 times of runoff process and 2 times of annual runoff process in Zhongliangshan Mountain Karst Valley area of Chongqing, showed that the karst hydrological simulation effect based on KTHM model is better than that of KHM, reflecting that the tunnel submodule designed in the model is effective and necessary. The difference of runoff simulated by the two models (KHM and KTHM), representing the impact of tunnels on the water quantity at the outlet, namely the tunnel hydrological effect, is calculated. The sensitivity sequence of tunnel hydrogeological effect on different runoff in the study area is as follws: dry season runoff > normal runoff > total annual runoff > peak flow > total flood.

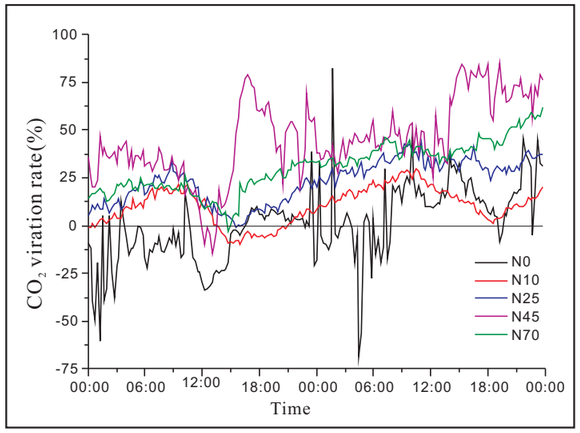
2.1.2 Carbon cycle and carbon sink effect

CO_2 is the most active factor in karst dynamic system and one of the main driving factors of karstification. It shapes and transforms the surface and subsurface karst morphology and results in carbon sink. With the support of different projects, IRCK have carried out various researches on the process of CO_2-driven dissolution, the carbon sink effect of coupling soil and aquatic plant photosynthesis, the stability of carbon sink, and the change of carbon flux at interfaces.

1) Coupling mechanism of soil carbon-nitrogen cycle in karst area

The net atmospheric CO_2 sink formed by land carbonate weathering is 477×10^6 $tC\cdot a^{-1}$, which may increase by 9.8%-17.1% with the change of land use and the increase of rainfall. However, the dissolution of carbonate caused by nitric acid and sulfuric acid generated by human activities should be deducted when calculating the carbon sink. The average nitrogen fertilizer input amount in China is huge, promoting the decomposition or accumulation of soil organic matter, promoting the generation and emission of soil CO_2, and regulating karst carbon cycle indirectly. When the nitrogen fertilizer input is greater than the amount absorbed by the plants, the excessive fertilizer will be nitrified and generate nitric acid, which will participate in the karst carbon cycle directly through the dissolution of carbonates.

Through a series of potted simulation experiments with different nitrogen application concentrations, and the groundwater observation in the Lijiang River Basin, the researches on the lime soil nitrogen effects on the carbon cycle intensity and its source-sink effect, the lime soil-groundwater nitrogen effects on karst carbon cycle, the migration and transformation of nitrogen at the river basin scale and its involvement in the karst carbon cycle have been carried out , with the following conclusions achieved:



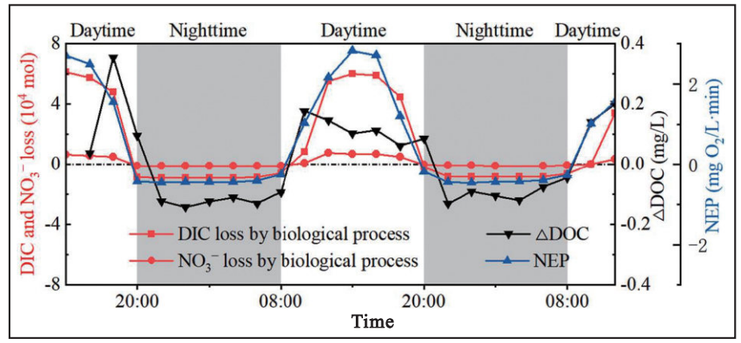
Change rates of soil CO_2 under different N-fertilization

Potted simulation experiments with different nitrogen concentrations found that the effect of nitrogen fertilizer on soil CO_2 increased by 10.5% to 30.6%, and the corrosion rate of the test piece increased by 1.8 to 3.6 times. The soil respiration rate also increased with the increase of fertilization, with an average of 26.97~48.95 $mgC \cdot m^{-2}h^{-1}$, which was 7%~60% higher than that without fertilization. Fertilization leads to an increase in soil carbon source and sink, and with the increase in nitrogen application, the sink/source ratio increases from 0.44% to 0.91%.

Lime soil has three acid buffer mechanisms: carbonic acid-dissolved calcium carbonate, nitric acid-dissolved calcium carbonate and cation exchange. The lower concentration of nitrogen fertilizer ($kgN\ ha^{-1}a^{-1}$) mainly participates in the karst carbon cycle indirectly by increasing the concentration of soil CO_2. The nitrification acid production is all buffered by cation exchange, and the dissolution of soil calcium carbonate comes from soil CO_2. When the fertilizer concentration is 250~700 $kgN\ ha^{-1}a^{-1}$, 45% of H^+ participates in the corrosion of calcium carbonate directly, and 55% of H^+ is buffered by cation exchange. The $\delta^{13}C_{DIC}$ in the leakage is controlled by the partial pressure of soil CO_2 rather than the intensity of nitrification.

2)The carbon-nitrogen coupling cycle in the water environment restricts the conversion of DIC to DOC in the Lijiang River aquatic ecosystem

The carbon and nitrogen cycles in the karst aquatic system are closely related, and the dissolved organic carbon (DOC) is coupled controlled by the metabolism of aquatic organisms. During the C-N coupling cycle, aquatic photosynthesis can consume DIC and NO_3^-, which means that DIC can keep relatively stable by converting DIC to OC; while consuming NO_3^- can improve water quality. In addition, the C-N coupling cycle can lead to the precipitation of calcium carbonate in the karst aquatic system. In this process, DIC and NO_3^- are converted into organic matter with O_2 released, which is different from the traditional concept that CO_2 is released during calcium carbonate precipitation. Taking the typical karst aquatic system-Lijiang River as the research area, the research investigated the daily and seasonal changes of water chemistry and isotopes to understand the C-N coupling cycle. Results showed that about 50% and 72% of the organic carbon in the DOC in summer and winter come from the primary productivity of aquatic organisms. The results of diurnal monitoring showed that the conversion of DIC and NO_3^- in the Lijiang River is mainly controlled by the metabolic processes (photosynthesis and respiration) of aquatic organisms, accompanied by the formation of DOC.The consumption ratio of DIC and NO_3^- by aquatic photosynthesis is 9:1 (mol/mol), and DOC is produced, accompanied by the enrichment of $\delta^{13}C_{DIC}$, $\delta^{15}N$-$NO_3^-$and $\delta^{18}O$-NO_3^-, with the enrichment amounts as 7.9‰ /d, 10.6‰/d, 11.2‰/d respectively. On daily time scale, the proportions of DIC and NO_3^- consumed by the metabolic processes of aquatic organisms are 6.2% and 7.1%, respectively, and these values are consistent with their corresponding values on the interannual time scale. However, the consumption ratio of DIC and NO_3^- in the dry season is higher than in the rainy season. Through aquatic photosynthesis, about 1.18×10^7kg C and 1.64×10^6kg N are converted into organic matter in the Lijiang River every year, of which 80% and 79% of DIC and NO_3^- are consumed in the rainy season. In addition, the DIC and NO_3^- involved in the C-N coupling cycle can promote the production of endogenous DOC and form a relatively long-term carbon and nitrogen sink in the karst aquatic system.



DIC and NO_3^- loss due to metabolism of subaquatic communities and changes in DOC (Haijuan Zhao, et al., Journal of Hydrology)

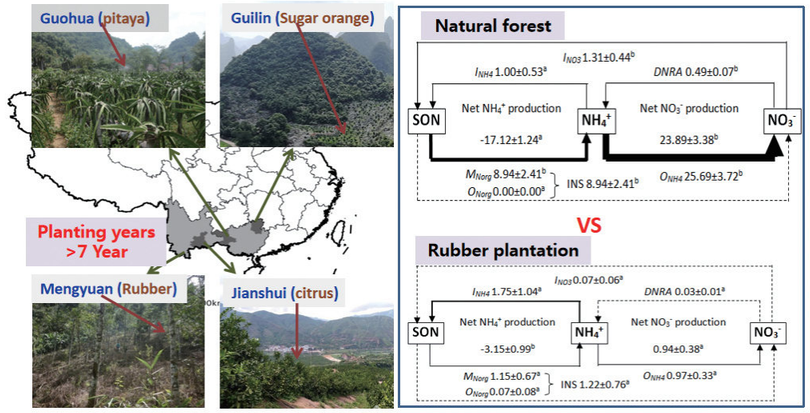
3) Interaction of carbon cycle and calcium migration in karst water and evaluation of carbon stability

Through high-resolution monitoring and high-frequency sampling, the diurnal dynamic changes of water chemistry in Guilin Chaotian River, inorganic carbon removal and its biogeochemical control mechanism were studied. Under the control of aquatic photosynthesis and calcium deposition, the pH, DO, SpC, HCO_3^- and Ca^{2+} of river water produced significant diurnal changes. The diurnal variation of these water chemical indicators is related to the river bed substrate and the types of aquatic plants. In the 1.65 km long process from Niaoling Bridge to Lianghegou monitoring point, the removal or precipitation of calcium and dissolved inorganic carbon were 302 kg/d and 997 kg/d, respectively. Part of the DIC removed from the monitoring reaches is converted into organic carbon, and some is deposited in the form of calcium carbonate. The results implies that:(1) the photosynthesis of aquatic plants in rivers in karst areas with higher content of DIC, can inhibit degassing at the water-air interface, meaning a CO_2 buffering effect; and (2) part of the DIC is fixed in the form of organic carbon and calcium carbonate, which proves that with the participation of ecological processes, the karst carbon cycle is not only atransformation of carbon forms, but also a carbon sequestration process.

2.1.3 Karst ecosystem and comprehensive control of rocky desertification

1) Long-term agricultural plantation in southern China reduces soil inorganic nitrogen supply

In karst areas, cash crops are often planted, but with the prolonging of planting, the crop growth slowed down, and insufficient soil nitrogen supply may become a limiting factor for the growth of cash crops. The ^{15}N isotope labeling method was used to investigate the soil nitrogen transformation rate of typical cash crops in the karst area of southwest China; meanwhile, the soil nitrogen supply was evaluated. The results showed that as the planting years goes on, the soil nitrogen conversion rate decreased, the nitrogen supply was insufficient, and the inorganic nitrogen conversion rate slowed down. The soil inorganic nitrogen supply is significantly positively correlated with the organic matter content, but negatively correlated with the clay content, indicating that the rational application of organic fertilizers can improve the soil environment and enhance the soil nitrogen supply.



Effect of long-term agricultural planting on soil nitrogen transformation process in karst area (Farzaneh Garousi et al., Geoderma)

2) Soil geochemical characteristics in the karst to non-karst junction area of Mashan County, Guangxi Zhuang Autonomous Region

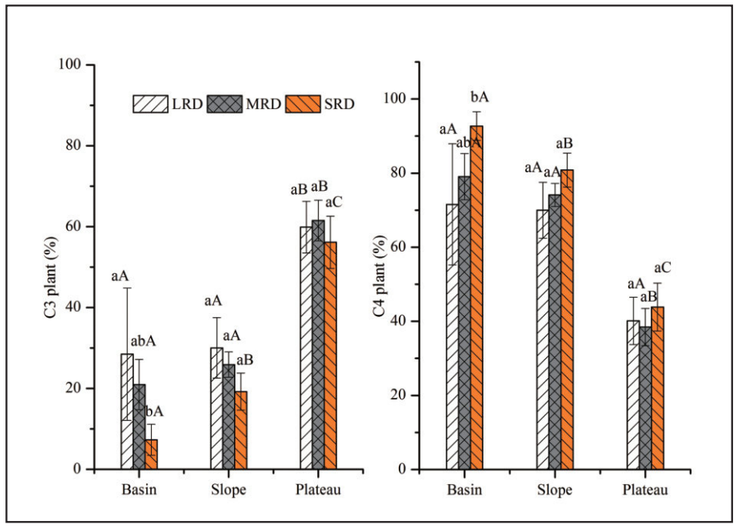
Lime soil is the result of long-term dissolution, weathering and bioconcentration of carbonate rocks. The dissolution residues are the major source of lime soil. It has still high Ca, Mg content after leaching of alkaline material, desilication and aluminum enrichment, so that the soil is neutral or alkaline. The secondary enrichment of heavy metal elements during the carbonate rock weathering and soil formation results in the soil with significant heavy metal elements content. Valley is one of the landform types affected by human activities in karst areas most severely. It has dense population, concentrated villages and towns, and well-developed agricultures and river networks. The soil at the bottom of the valley may have different degree of mixture of carbonate rocks' and non-carbonate rocks' parent materials.

Fingerprint technology is an important method to identify the source of sediment in a river basin. Its theoretical basis is that the potential source of sediment can be distinguished according to the characteristics of soil materials, so that the "fingerprint" with the ability to identify the source can be screened, and then the corresponding relationship between the sedimentation area and the potential source can be established. The geochemical characteristics of lime soil and zonal soil are significantly different. According to the test indicators, the geochemical fingerprint factors such as As, Cd, Cr, Co, Hg, Mo, Ni, P, Zn and K_2O are screened out, and the source contribution ratio is calculated by the hybrid multivariate model. The results showed that:(1) in the junction area from non-carbonate rock to carbonate rock, the contribution ratio of zonal soil to valley soil decreases from slowly to rapidly;(2) the contribution rate of zonal soil transported to karst areas by underground rivers can still reach more than 90% after tens of kilometers' moving, while lower proportion of zonal red soil in dry valley soils that are less affected by allogenic water, meaning that the proportion of allogenic materials in karst areas is controlled by topography and hydrological conditions; and (3) the eroded soil caused by underground rivers in the karst area recharged by allogenic water mainly comes from the zonal soil formed in non-karst area. The study uses geochemical fingerprints and hybrid model methods to determine the sources and soil proportions in karst valleys, providing basic support for the study of soil geochemical elements' migration and ecological environmental effects in karst areas.

Contribution ratio of red soil in karst to non-karstjunctionareato valley soil

3) Soil organic carbon isotopes in the east Yunnan faulted basin reveal the relationship between C3 and C4 vegetation transformation and geo-climate

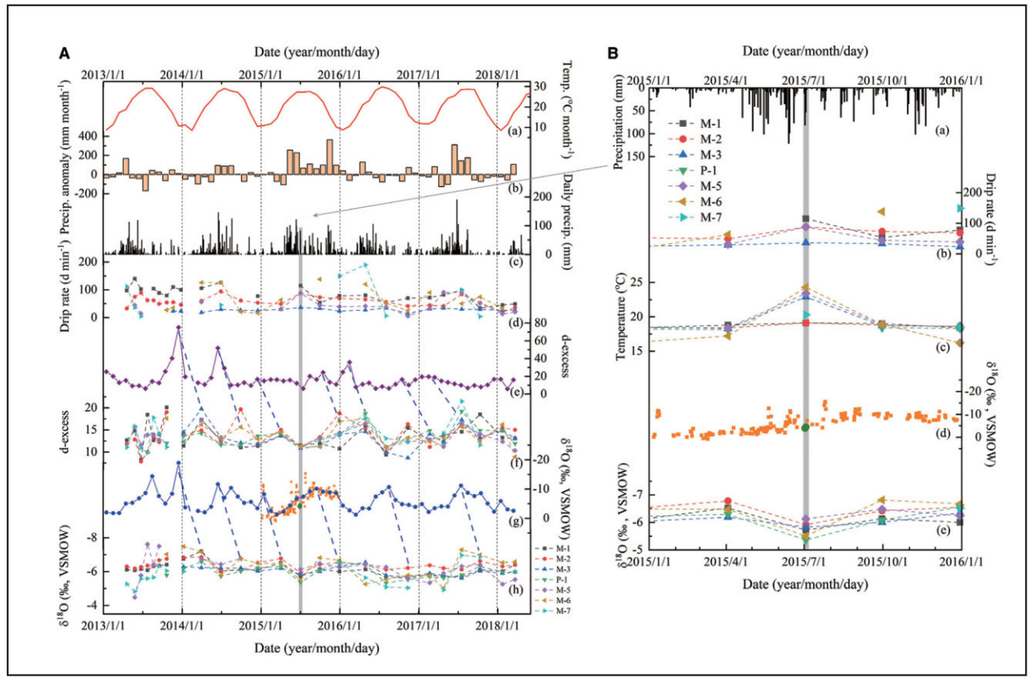
Understanding the controlling factors of soil organic carbon isotopic ($\delta^{13}C_{SOC}$) changes and the process of vegetation succession is of great significance for guiding ecological restoration and agricultural production in karst rocky desertification areas. The relationship between the distribution of C3 and C4 plants and rocky desertification is still unclear. Taking the soils from the areas suffering different degrees of rocky desertification at different geomorphological parts (basins, slopes and plateaus) in the Mengzi Faulted Basin in Yunnan as the major object for the research, the spatial variability of the distribution characteristics of $\delta^{13}C_{SOC}$ was studied. The contribution of C3 and C4 plant species to $\delta^{13}C_{SOC}$ under different rocky desertification degrees in faulted basin was discussed. The $\delta^{13}C_{SOC}$ value has decreased with the altitude changing from basin, slope to plateau gradually. With the same terrain conditions, different rocky desertification degrees don't have significant impact on the $\delta^{13}C_{SOC}$ of slopes and plateaus, while significant different $\delta^{13}C_{SOC}$ values of mild rocky desertification and severe rocky desertification in the basin. C4 plants account for more than 70% basin or slopes, and C3 plants account for more than 70% plateau, probably caused by the long-term plantation of corn in basins and slopes in historical periods. However, the plateau suffered cold climate, which is not suitable for the growth of C4 plants such as corn. On the same terrain, with the intensification of rocky desertification, the proportion of C4 plants to $\delta^{13}C_{SOC}$ increased, and that of C3 plants decreased. With the intensification of rocky desertification, the composition of vegetation species has changed from trees (C3 plants) to small shrubs and herbs (C4 plants). This result has made sense for guiding the ecological restoration and agricultural farming practices in karst rocky desertification areas. For example, when performing rocky desertification ecological restoration in a karst faulted basin, not only the influence of altitude and vertical climate must be considered, but the distribution characteristics of C3 and C4 plants must also be considered. Selecting the suitable tree species according to local conditions is of great significance to promoting the ecological restoration of rocky desertification areas.



The relationship between $\delta^{13}C_{soc}$ and environmental Variables (Hui Yang, et al., Acta Carsologica, 2020)

2.1.4 Karst sedimentary records and global changes

Monitoring of atmospheric precipitation, cave dripping water, and modern sediment system in Guilin area found that the main controlling factors of cave dripping water $\delta^{18}O$ are different at different time scales such as individual event-scale rain, seasonal and inter-annual. On the scale of individual event-scale rain, the $\delta^{18}O$ of dripping water from caves mainly reflects the source of atmospheric precipitation water vapor. The $\delta^{18}O$ of near-source water vapor precipitation is heavier, and the $\delta^{18}O$ of remote-source water vapor precipitation is lighter. On seasonal and inter-annual scales, cave dripping water $\delta^{18}O$ is not only controlled by changes in precipitation $\delta^{18}O$, but also by precipitation changes. Taking 2015 as an example, the whole-year water vapor source was not significantly different from the perennial year. Due to the strong El Niño, the yearly precipitation in Guilin was as high as 3,006 mm, resulting in a lighter annual weighted average $\delta^{18}O$ of rainwater and a lighter $\delta^{18}O$ of cave dripping water. Further analysis found that the precipitation $\delta^{18}O$ in Guilin area is mainly controlled by the intensity of the East Asian monsoon and ENSO model, while the change of precipitation is mainly controlled by the intensity of the subtropical high in the western Pacific.Therefore, more cautions should be paid to the interpretation of cave stalagmites $\delta^{18}O$ at different time scales for tropical and subtropical areas of South China, and even the entire East Asian monsoon area.



Comparison of $\delta^{18}O$ changes of drip water and related environmental parameters in Maomaotou Rock Cave, Guilin (Jianjun Yin et al., Boreas , 2020)

2.1.5 Geohazards and prevention in karst areas

The karst mountainous area in southwest China suffers from fragile geological environment and frequent catastrophic landslide, which threaten the habitat safety and social stability seriously. In order to improve the capacity for geohazard prevention and the control in karst mountainous areas, the research team of Prof. Li Bin with the Institute of Geomechanics under the Chinese Academy of Geological Sciences carried out the project of "Disaster Models and Risk Prevention of Catastrophic Landslide in Karst Mountainous Areas" with high quality in 2020, with the following progress achieved:

1) Disaster model of catastrophic landslide in karst mountain area

Focused on bedded mountain, 9 kinds of large collapses and landslides models in typical karst mountainous areas, according to 3 types of occurrence as oblique, near horizontal and steep dipping, have been initially established, providing geological models for subsequent key blocks division and mechanical analysis. The research has carried out preliminary research on key controlling factors and mechanical models for different hazard-inducing environments and hazard models. Taking oblique slip as an example, the soft sliding interface (bed) as the key blocks for controlling the slide, the mechanical analyzing model was proposed based on the three evolution of weak and soft interlayer of carbonaceous shale, that are, primary soft rocks → interlayer shear zone → slide zone, revealing the evolution of the slide controlling by carbonaceous shale.

2) Water-rock coupling of karst mountains and unstablization mechanism by seepage

The study on the seepage of the matrix pores was carried out. Based on CT test and image processing technology, the geometric structure of the micro-scale rock matrix was constructed by using random statistical mathematical methods, and the fractal characteristics of the microscopic pore structure were analyzed. The expression formula for permeability of matrix pore seepage is proposed.

The QGCS (four-parameter random growth method) is used to construct digital cores and porous media microstructures, with irregular solid matrix distribution and curved solid-liquid boundary, and the boundary angle changes randomly. The fractal parameters were determined according to the porous media geometric model based on fractal theory, the finite element method is used to simulate the seepage of single-phase fluid, and the relationship among permeability, geometric characteristics (porosity, seepage path and pore size) of pore structures, and fractal features is explored as well.

Using the fractal theory, the theoretical expression of the permeability reflecting pore seepage can be obtained as follows:

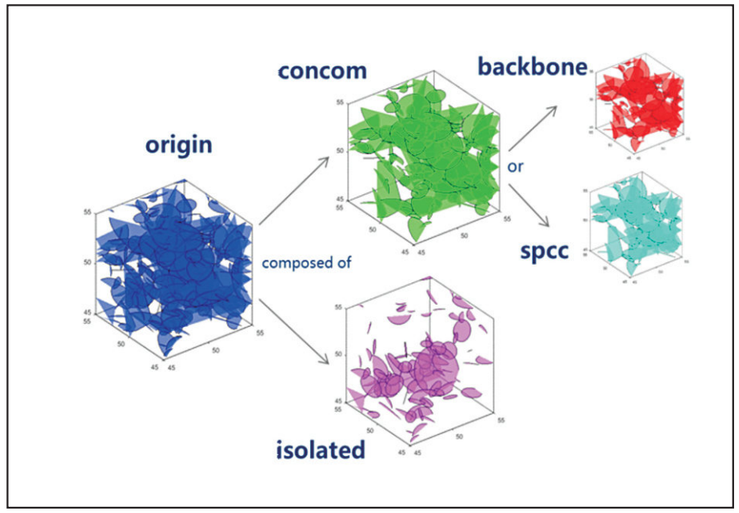
$$k_{\min} = \frac{1}{12}\frac{(D_f - 1)^3}{D_f^3}\frac{\phi_{eff}}{\bar{\tau}^2}\bar{\lambda}^3 \qquad (1)$$

$$k = \frac{1}{12}\frac{(3 + D_f)(D_f - 1)^3}{D_f^4}\frac{\phi_{eff}}{\bar{\tau}^2}\bar{\lambda}^3 \qquad (2)$$

Based on the rock mass scale, focusing on the typical fractured aquifer in karst area, with discontinuous surface surveys of outcrops or boreholes, the random fractured networks was stimulated based on probability theory and statistics; meanwhile, applying depth-first search algorithm and shortest path algorithm to explore fractures connection laws, then quantifying the analysis of the fractures' influence on the seepage direction and velocity, by calculating and analyzing the fractured-medium seepages.

In the three-dimensional fractures network, the fractures are composed of two parts, one is the isolated fractures and the fracture cluster (ISO), and the other is the connected component CONCOM, the intersection of multiple fractures in pairs that penetrate the fractures network. Through the DFS search algorithm, we can determine connected component CONCOM, then using the Djkstra algorithm to determine the backbone of the three-dimensional fracture network. If deleting some dead-end fractures of CONCOM, a simplified connected component SPCC could be obtained.

After the identification and feature extraction of large-scale dissolution structures, the identification and feature extraction of dissolution fractures in the rock mass can be carried out, that is, selecting the local area. If the resolution is insufficient for accurate description of the fine structure, it is better to use waifu2x convolutional neural network model method to enhance the resolution non-destructively, and then the fracture information can be extracted, with multi-scale karst dissolution structural features obtained, based on which a multi-scale model could be set up for further research.



Searching for connected paths in fractured media

3) Damage mechanism of collapse and landslide caused by mining on karst mountains

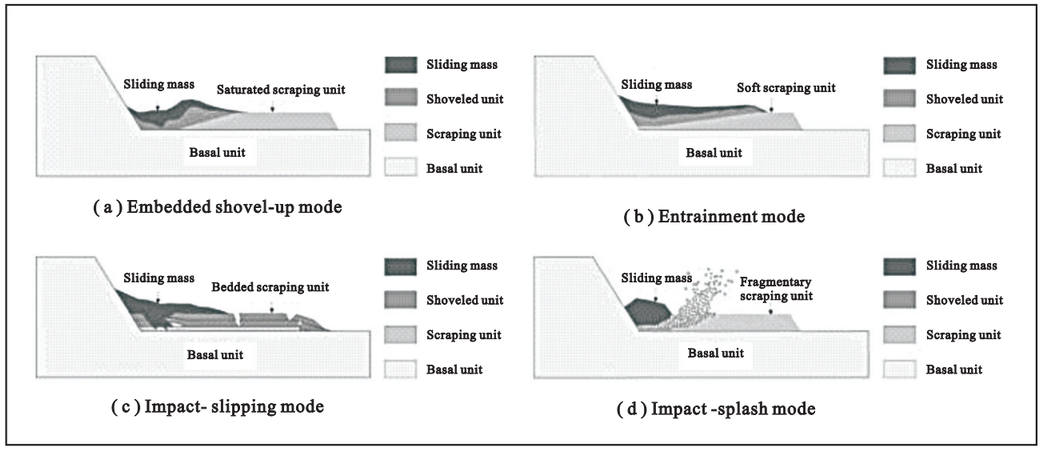
The large-scale physical model experimental results showed that with the continuous mining, the stress and deformation response of the slope body are constantly changing, and the expansion of the structural planes and the destructive characteristics of the slope body under different mining sequences are various. During downward mining, the overlying rocks are deformed like cantilever beam or cantilever plate, the foot of the overlying mountain moves downwards and undergoes sinking deformation first; then the overlying slope loses support and undergoes cantilever tension deformation; the fissures are stretched obliquely downwards, making the rock mass structure loosened, later, the mountain slope continues to sink and be compacted, the slope root is squeezed, and eventually, the slope rock bridge is cut, resulting in shear slip-toppling destructive. During upward mining, the underground mining causes the overlying rock downhill to occur beam-slab type bend and sink, forming a terraced tension fracture, then the slope body moves and deforms downhill; with the continuous expansion of the mining area, the fractures continue to extend to the slope surface, the deep and large structure expands downwards and connects with the mining fractures in terraces. When mining to the slope root, the slope is fully mined, continuing to sink and be compacted, and the slope root is extruded, the slope rock bridge is cut, resulting in shear slip-toppling destructive.

4) Dynamic characteristics of high long-distance landslide in karst mountainous areas

Based on field investigation and disaster-inducing process analysis, the formation patterns of landslide in karst mountainous areas in southwestern China are divided into four categories: collapse-debris flow, landslide-debris flow, collapse-advanced air blast effect chain, and landslide-swell chain. Taking four typical karst mountain landslide, namely Nayong landslide, Shuicheng landslide, Zengziyan landslide, and Fuquan landslide,as cases, the research focuses on the inducement

and dynamics of different types of high-speed and long-distance rocky landslides. Using multi-methods, such as landslide signals, video images, high-density resistivity geophysical prospecting, and numerical simulation, to carry out analysis coordinately, realizing the inversion analysis of the whole process of different types of high-speed and long-distance landslide, and revealing the dynamic inducing mechanism of the whole landslide process.

According to the law of landslide movement and accumulation, focusing on the underlying bed, the research summarizes four impacted shoveling and scraping modes of high landslide in karst mountainous areas:



Conceptual impacted shoveling and scraping modes of high and long-runout landslide

a) Embedded shovel-up mode: the sliding mass is hard-rock clastic blocks, the bed could be shoveled is thick and weak Quaternary residual soil, the sliding mass impact is mainly vertical, the initial contact is that the front edge of sliding body embeds into the underlying bed, the plastic area is mainly developed vertically, the sliding mass mainly accumulated at the impacting site, and the shoveled bed continues to move forwards after being shoveled. Zhaojiagou Landslide is a typical case, the sliding mass is mainly composed of sandstone and hard limestone, after sliding downwards, the mass shoveled the thicker Quaternary residual soil with saturated water at the surface, making its volume increased seriously (Yin et al, 2017). According to the documents (Hungr, et al., 2004), the Frank Slide in Canada is another typical case. **b) Entrainment mode:** the sliding mass is hard-rock clastic blocks, the bed could be shoveled is thin and weak Quaternary residual soil, and the sliding mass movement is mainly horizontal cutting. As the most frequent mode for landslide, the sliding mass possessing greater tangential cutting power, the plastic area is mainly developed tangentially, the sliding mass is easy to cut and entrain the bed that could be shoveled and wrap it into the sliding mass, making the volume of the sliding mass enlarged and moving further. Shuicheng Landslide (Jul 23, 2019) is a typical case (Gao, et al., 2020; Wang L, 2019), the sliding mass impacted, shoveled and scraped residuals on the way. According to the remote sensing images before and after, the sliding mass took away a large quantity of surface Quaternary residuals, with obvious trails of shoveling and scraping. The volume of the sliding mass increased from 70×10^4 m^3 to 116×10^4 m^3, showing that the volume was shoveled and scraped was 46×10^4 m^3. **c) Impact-slipping mode:** the sliding mass is hard-rock clastic blocks, the bed could be shoveled is thin and bedded bedrock, and the sliding mass movement is mainly horizontal pushing and pressing. The underlying bed is usually the thin bedded rock and soil like shale with worse performance, meanwhile, the front part is free or with weak barrier. The sliding mass slides downwards, destroys the stress of the bed that could be shoveled at the impacting point concentratedly at first, then moves the whole mass of the shoveled bed forwards. Jiweishan Landslide is a typical case (Gao Y., et al., 2016), the 500×10^4 m^3 sliding mass was cut at high level, then struck the front-edge bedded mountain, making the shoveled unit moved forward by energy transmission. The volume of the shoveled unit reached 80×10^4 m^3. **d) Impact-splash mode:** the sliding mass is hard-rock blocks, the bed could be shoveled is also harder rock or clastic accumulations, and the sliding mass contact is almost elastic striking, with energy transmission as the main mechanical effect. The sliding mass started to move at high level had greater kinetic energy, generated huge striking power after sliding and striking the impacted unit, which is loosened, disintegrated, and splashed afterwards, moving for long distance. Jiguanling Landslide happened on April 30 of 1994 is a typical case (Wang G., et al., 2014; He K., et al., 2018), the 400×10^4 m^3 limestone sliding mass was cut at high level, then struck the hard rock strata below, and brought away the 60×10^4 m^3 bed that could be shoveled after impacting by the huge energy transmission. Xinmocun Landslide happened on June 24, 2017 is another typical case (Yin et al., 2017; Xu Q., et al., 2017), the nearly 400×10^4 m^3 sliding mass impacted, shoveled and scraped, making the 800×10^4 m^3 accumulation below restart to move, and resulted in debris flow.

2.2 Progress of IGCP 661

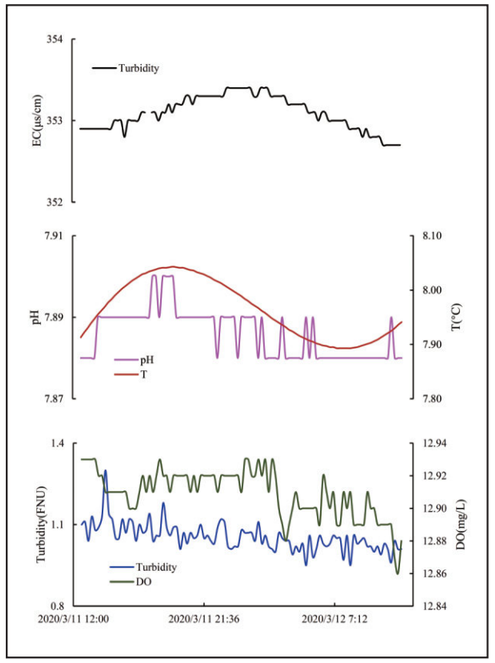
2.2.1 Expansion of the international research team

The critical zone (CZ) of earth is one of the hot issues in the field of geosciences at present. IGCP 661, with its features on karst critical zone, has attracted more and more attention of scholars around the world who are actively applying for taking part in. After scientists from Austria, Russia and Poland joined the project research team, Prof. Jin-Yong Lee and Prof. Heejung Kim from the Department of Geology of Kangwon National University, Republic of Korea took part in the IGCP661 in 2020 successively, expanding the influence of the project and strengthening the international research team further. As of 2020, 52 karst scientists have been involved to promote the effective implementation of IGCP661.

2.2.2 Progress of different karst critical zones

1) Karst critical zone of temperate Mediterranean climate

Due to the epidemic in 2020, under the help of Slovenian side, the Chinese project members installed the monitoring instruments and tested the water quality and water quantity online in March 2020. The monitoring station is located in Planina Cave (the main outlet of the underground river in this catchment) of Postonja karst area. The water level, temperature, conductivity, turbidity, pH and dissolved oxygen index were monitored online. The monitoring system operated well according to the monitoring data in March, which recorded a set of data every 5 minutes.



The monitoring instrument and data of water quality and quantity at the outlet of Planina Cave Underground River

The integrated monitoring system of soil CO_2 was installed and tested on November 15, 2019. It is located in the grassland ecosystem of the Bloska Polica Depression in Postonja karst area of Slovenia. The atmospheric CO_2 concentration (CO_2-air), temperature (T-air) and humidity (RH), as well as soil moisture, temperature, and CO_2 concentration at different depths (20-50 cm) are monitored online. So far, this monitoring system is effective, with one set of data (including 12 indicators) being recorded every 5 minutes. By March 28, 2020, 38,880 sets of data have been recorded. In general, the soil moisture reaches highest at 20 cm depth underground, lower at 50 cm, and lowest at 30 cm, showing a trend that lower at middle part, but higher at shallower and deeper part. Soil moisture is significantly affected by rainfall, increasing rapidly during rainfall. In winter, the soil CO_2 content has gradually decreased generally, and recovered corresponding to the rainfall, also corresponding to obvious declining of atmospheric CO_2. This indicates that the CO_2 increased in soil peak is supplemented by atmospheric CO_2. The atmospheric CO_2 dissolved in rainfall and flew rapidly into the soil system with water flow, causing rapid rise of soil CO_2 that is extremely favorable for the dissolution of the underlying carbonate rocks. It also verified that karst process is beneficial to the atmospheric CO_2 sink.

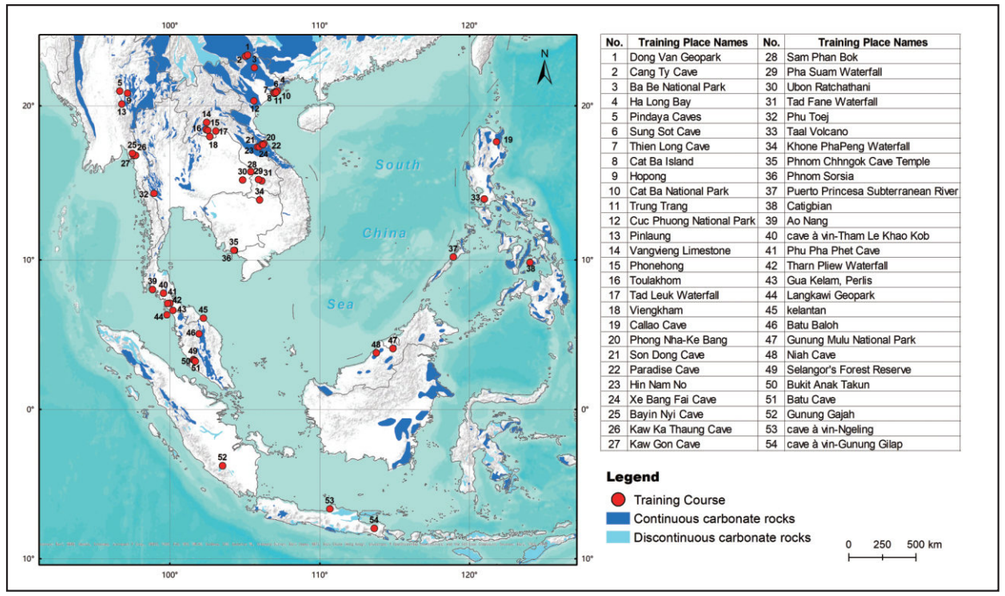
2) Tropical karst critical zone

In cooperation with the Department of Groundwater Resources and Department of Mineral Resources in Thailand, the dynamic monitoring of karst carbon cycle, hydrogeochemistry, soil CO_2 and karst cave environment has been carried out in typical karst areas of Kanchanaburi and Chiang Mai provinces of Thailand, aiming to solve the problems on karst dynamic systems, karst resources and environment jointly in the key areas along the Belt and Road. Hydrogeological survey and continuous high-resolution automatic monitoring of hydrology and hydrochemistry in PhuToej Spring and Badanwang Spring areas have been conducted to study the dynamic hydrological and hydrochemical response process and mechanism in tropical karst areas. The Qingdao Cave monitoring in Chiang Mai has been conducted to compare and study the response process and mechanism of the cave environment to

the external environment in tropical karst areas. The soil profile monitoring station in Chiang Mai has been used to study the response of the important CZ part-soil layer to the rainfall and temperature.

Based on the survey and monitoring data, the karst process is strong in the tropical karst area of Thailand, and the subsoil dissolution rate in the Phu Toej tropical peak cluster-depression area is 1.5-2.5 times than that in the southwest subtropical region of China. Karst springs and underground rivers in the Phu Toej Spring Basin and Badanwang Underground River Basin are generally characterized by high conductivity, high calcium and high bicarbonate content, which mainly caused by the high temperature, good vegetation cover, high soil CO_2 concentration, and strong dissolution. The comparison shows that underground rivers in tropical karst area of Thailand have relatively stable hydrological and hydrochemical features, strong regulating and storage capacity as well, due to uniform rainfall and dolomite-dominating aquifers. Typical soil profiles in Thailand shows more rapid response of soil temperature, moisture and soil CO_2 content at 20 cm and 50 cm depth to the environment. They have obvious seasonal effects and rainfall effects, with the content increasing in rainy season and decreasing gradually in dry season. The soil CO_2 content at 50 cm depth is higher than that at 20 cm depth, because that the soil CO_2 content at 20 cm depth is controlled by both soil temperature and soil moisture, while that at 50 cm depth is mainly controlled by soil moisture.

Carbonate rocks are widely distributed in Southeast Asia, forming well-developed tropical-subtropical karst, and aquifers with large quantity of water. Southeast Asia has become an important and classic karst area in the world. Groundwater flow is dominated by conduit flows in karst areas and causes various environmental problems, including rocky desertification, poverty and other socio-economic problems. According to the topography, karst in Southeast Asia is summarized into four types: plateau karst, mountain karst, plain and island karst, and is used as the reference for classification of the existing karst cases.



No.	Training Place Names	No.	Training Place Names
1	Dong Van Geopark	28	Sam Phan Bok
2	Cang Ty Cave	29	Pha Suam Waterfall
3	Ba Be National Park	30	Ubon Ratchathani
4	Ha Long Bay	31	Tad Fane Waterfall
5	Pindaya Caves	32	Phu Toej
6	Sung Sot Cave	33	Taal Volcano
7	Thien Long Cave	34	Khone PhaPeng Waterfall
8	Cat Ba Island	35	Phnom Chhngok Cave Temple
9	Hopong	36	Phnom Sorsia
10	Cat Ba National Park	37	Puerto Princesa Subterranean River
11	Trung Trang	38	Catigbian
12	Cuc Phuong National Park	39	Ao Nang
13	Pinlaung	40	cave à vin-Tham Le Khao Kob
14	Vangvieng Limestone	41	Phu Pha Phet Cave
15	Phonehong	42	Tharn Pliew Waterfall
16	Toulakhom	43	Gua Kelam, Perlis
17	Tad Leuk Waterfall	44	Langkawi Geopark
18	Viengkham	45	kelantan
19	Callao Cave	46	Batu Baloh
20	Phong Nha-Ke Bang	47	Gunung Mulu National Park
21	Son Dong Cave	48	Niah Cave
22	Paradise Cave	49	Selangor's Forest Reserve
23	Hin Nam No	50	Bukit Anak Takun
24	Xe Bang Fai Cave	51	Batu Cave
25	Bayin Nyi Cave	52	Gunung Gajah
26	Kaw Ka Thaung Cave	53	cave à vin-Ngeling
27	Kaw Gon Cave	54	cave à vin-Gunung Gilap

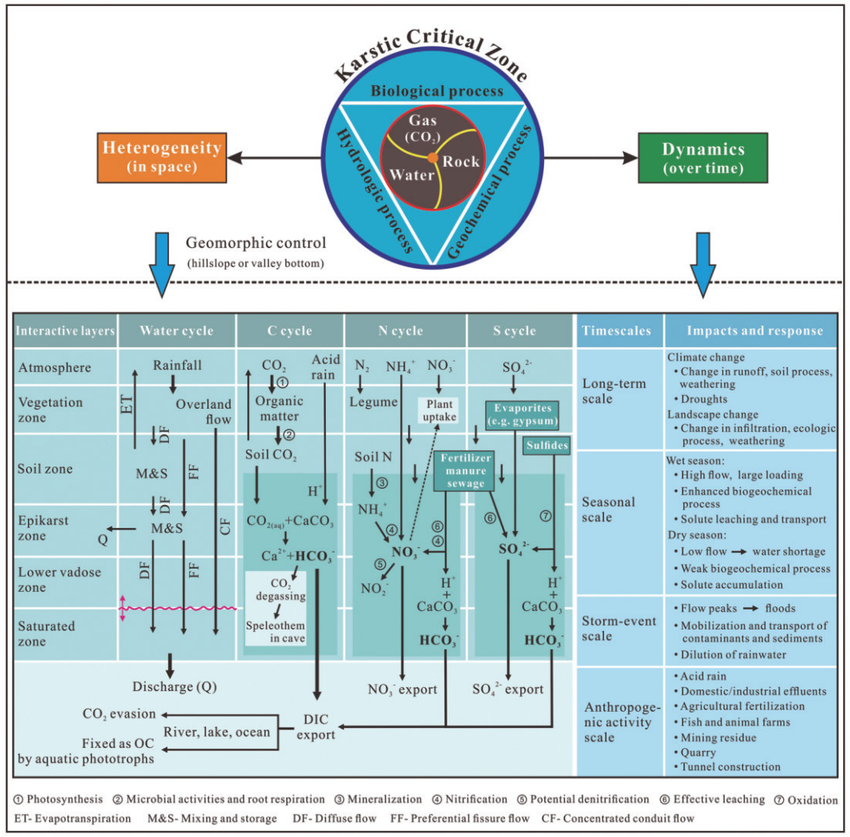
Kast distribution of Southeast Asia (Guanghui Jiang et al., Hydrogeology Journal, 2020)

Buoy-type layered observation platform for Dalongdong Reservoir

3) Subtropical karst critical zone

The Dalongdong karst reservoir monitoring station in Shanglin county of Guangxi, is set up aiming to solve the problems such as carbon cycle process and mechanism of karst reservoir, and ecological environment evolution of karst reservoir under the background of global change. Based on system science of CZ that has multi-spheres, multi-elements, and multi-scales, combined with the multidisciplinary and integrated research, the "water-rock-air-ecology" comprehensive observation network is set up to form an automation field scientific observation and research platform, covering the meteorology, hydrology, ecology, geochemistry, remote sensing, and other research fields. After years of construction and improvement, there is now one meteorological observation station, three buoy fixed observation platforms and one buoy stratified observation platform in the Dalongdong Reservoir. In order to achieve high-resolution continuous monitoring (0.5 h) of meteorological indicators (air temperature, humidity, pressure, rainfall, light intensity, wind speed, and wind direction), reservoir thermal stratification indicators (5-level water temperature monitoring: surface, 2.5 m, 5 m, 10 m, and bottom) and water quality indicators (pH, EC, and DO, etc.). In addition, the automatic underwater ecological tomography imaging instrument was used to carry out 6 times of water environmental monitoring along the route, and the multi-spectral UAV was used to carry out 2 times of remote-sensing monitoring on water quality.

Taking a typical subtropical karst catchment - Chongqing Qingmuguan as an example, the research has systematically studied the hydrochemistry and stable isotopes of soil moisture, surface water, cave dripping water, and underground river water, aiming to analyze the source, migration, and temporal and spatial characteristics of the water and solutes (C, N, and S) in this critical zone profile, then to conclude the hydrological and biogeochemical coupling cycle and its influencing factors. The results showed that the karst critical zone usually has higher heterogeneity and permeability, so that the hydrological process could respond to



Coupled cycle of hydrology and biogeochemistry in karst critical zone and its temporal and spatial changes (Zhijun Wang, et al., 2020, Science of the Total Environment)

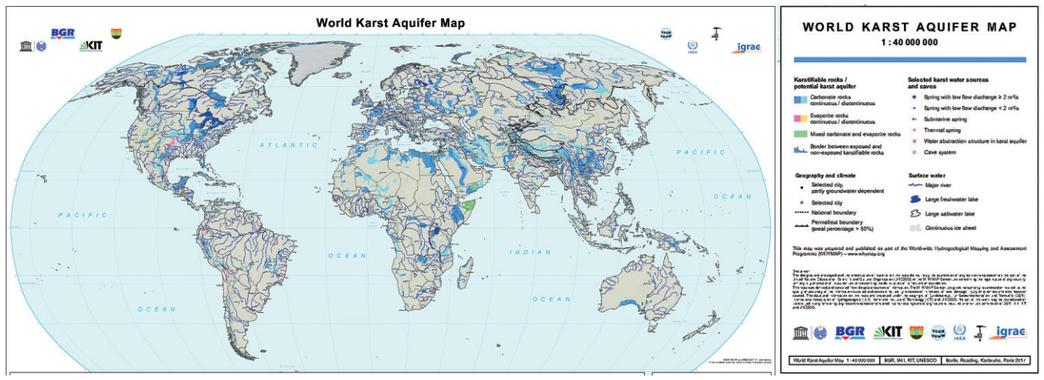
rainfall changes quickly. The $CaCO_3$-CO_2-H_2O interaction is very strong in different critical zones, and is affected by the seasonal changes of hydrological processes and surface biological activities; nitrogen and sulfur efficiently migrate from the surface to the saturation zone, closely related to input sources, element conversion, and water flow process. Human activities have affected groundwater quality and critical zone process differently, for example, the allogenic acid produced by acid rain and the application of nitrogen fertilizer in farmland participates in and affects the carbonate weathering, contributing 20%-30% weathering of the carbonates in the catchment. In karst critical zone, there is a strong coupling relationship between hydrology and biogeochemical process, and there is a close connection between different spheres. Therefore, it is necessary to carry out more systematic monitoring on critical zone profiles, and reveal the impact of climate change and human activities on the nature and function of the critical zones from their dynamic changes.

2.3 Other progress

2.3.1International advancement

1) Global distribution of karst aquifers

The World Karst Aquifer Map (WOKAM) was published in 2017 by the German Federal Institute for Geological Sciences and Natural Resources and the International Association of Hydrogeologists. It is the first detailed and complete global geodatabase concerning the distribution of karstifiable rocks (carbonates and evaporites) representing potential karst aquifers. In 2020, Nico Goldscheider, director of the Institute of Applied Geosciences, at Karlsruhe Institute of Technology (KIT),Germany, published an article "Global distribution of carbonate rocks and karst water resources", which presents a statistical evaluation of WOKAM, focusing entirely on karst in carbonate rocks and addressing four main aspects (1) global occurrence and geographic distribution of karst; (2) karst in various topographic settings and coastal areas; (3) karst in different climatic zones; and (4) populations living on karst. According to the analysis, 15.2% of the global ice-free continental surface is characterized by the presence of karstifiable carbonate rock. The largest percentage is in Europe (21.8%); the largest absolute area occurs in Asia (8.35 million km^2). Globally, 31.1% of all surface exposures of carbonate rocks occur in plains, 28.1% in hills and 40.8% in mountains, and 151,400 km or 15.7% of marine coastlines are characterized by carbonate rocks. About 34.2% of all carbonate rocks occur in arid climates, followed by 28.2% in cold and 15.9% in temperate climates, whereas only 13.1 and



World Karst Aquifer Map (German Federal Institute of Geological Sciences and Natural Resources, International Association of Hydrogeologists, Karlsruhe Institute of Technology, UNESCO, 2017)

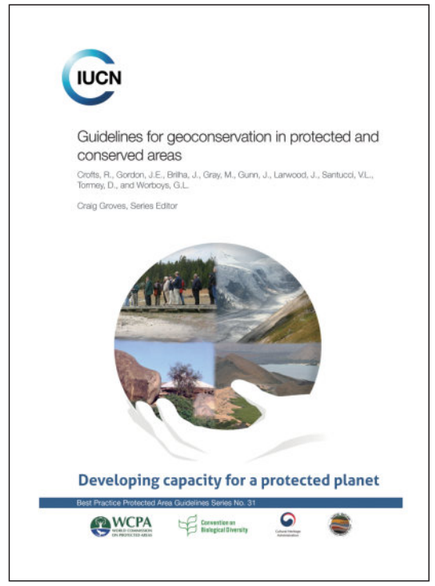
8.6% occur in tropical and polar climates, respectively. Globally, 1.18 billion people (16.5% of the global population) live on karst. The highest absolute number occurs in Asia (661.7 million), whereas the highest percentages are in Europe (25.3%) and North America (23.5%). These results demonstrate the global importance of karst and serve as a basis for further research and international water management strategies. In the field of water resources application, Professor Nico Goldscheider's study in a glaciated karst aquifer system in the Swiss Alps revealed that glacial meltwater contributes 20% to 35% to groundwater recharge and to the discharge of a karst springs used for water supply. The disappearance of glacier will lead to water shortages in summer and autumn, thus requiring adapted water resources management.

2) Ecological protection in karst areas

IUCN Guidelines: In 2020, Roger Crofts and John Gunn published *the Guidelines for Geoconservation in protected and conserved areas*, which is the first IUCN guide on geological protection areas, clarifying the importance of effective means to protect geological heritage, world natural heritage sites and UGGps. The guide is divided into nine chapters, focusing on key issues such as the purpose, definition, application, establishment, management, dealing with threat, and education etc. This book is of great significance to the geoconservation in protected and conserved areas in future.

Download link:

https://portals.iucn.org/library/sites/library/files/documents/PAG-031-En.pdf



The cover of the Guidelines

CaveMAB： CaveMAB is a network of biosphere reserves around global that treasure natural and cultural phenomena related to caves. This network will focus on connecting those of us working in caves and/or karst areas, recognizing that there are caves in multiple types of geologic environments that may benefit from participation. This net work will be multidisciplinary and address the similar challenges we all face, where social, educational, or scientific in protecting the biodiversity of the unique cave and karst environments within the Man and the Biosphere Program. While our mission and objective will be ultimately be decided among those interested in participating, our initial thoughts are to have a data driven network to promote protection of CaveMAB locations, further cave and karst education, enhance community involvement and sustainable development, and provide opportunities for shared experiences and research. Projects that we are anticipate would be development of a CaveMAB website, database of cave and karst resources within the MAB program, identification and analysis of economic, social, and environmental benefits and challenges, development of educational materials and workshops, and a network meeting every three year to present results, share experiences, and develop collaborative projects.

CaveMAB website: https://cavemab.com/

3) International Year of Caves and Karst

2021 International Year of Caves and Karst is an important

event in the karst field initiated by International Union of Speleology, the worldwide organization of cave and karst explorers, scientists, managers, and educators.

"Explore, understand and protect" is the main goal of the International Year of Caves and Karst. With your help, we seek to:

• improve public understanding of how caves and karst touch the daily lives of billions of people;

• promote the importance of caves and karst through sustainable development, particularly in water quality and quantity, agriculture, geotourism/ecotourism, and natural/cultural heritage;

• demonstrate how the study and proper management of caves and karst is critical to global economic and environmental health;

• build worldwide educational capacity through activities targeted on cave and karst science;

• promote awareness of the interdisciplinary nature of cave and karst science and management, and emphasize how interactions between different areas of science and management will be needed increasingly in future research, education, and environmental protection;

• establish durable partnerships to ensure that these activities, goals and achievements continue in the future beyond the International Year of Caves and Karst.

Official website :http://iyck2021.org/

2.3.2 Approval of relevant domestic research projects

In 2020, IRCK staffs actively applied for different projects with a total of 17 scientific research projects were approved, including 4 approved by national agencies, 10 approved by provincial and ministerial agencies, 1 approved by the prefectural and municipal agencies, and 2 granted by open funds. These projects focus on a series of severe environmental and geological problems in karst areas, such as karst collapse, karst rocky desertification, degradation of karst landscape resources, shortage of karst water resources, karst critical zones, climate change and other issues, aiming to contribute to SDGs defined by UN 2030 Agenda.

The newly approved projects include two strategic scientific and technological innovation cooperation projects funded by the Ministry of Science and Technology (MOST),Department of Science and Technology of Guangxi (DOST), and a technological innovation guidance project funded by the Guilin Science and Technology Bureau, which are conducive to international cooperation for karst science and the promotion of "Global Karst".

List of newly approved projects of IRCK in 2020 (Representative ones)

No.	Project title	Granted by	Serves to SDGs	Period	Category
1	China-Slovenia joint laboratory construction	MOST	Goal 15: Life on Land	2021-2023	International cooperation
2	Karst geology and water environment protection in Southeast Asian	Department of Science and Technology (DOST), Guangxi	Goal 6: Clean Water and Sanitation	2020-2024	International cooperation
3	Joint laboratory of development and sustainable management of karst landscape	Guilin Bureau of Science and Technology (GBST)	Goal 11: Sustainable Cities and Communities	2021-2023	International cooperation
4	Formation and collapse mechanism of water and air pressure fluctuation in karst cavity	National Natural Science Foundation (NSFC)	Goal 11: Sustainable Cities and	2021-2024	Scientific research
5	Spatial and temporal dynamics of rocky desertification in Guangxi	DOST Guangxi	Goal 15:Life on Land	2020-2023	Scientific research
6	Climate and environment change in northeast Guangxi since 1852 AD	DOST Guangxi	Goal 13:Climate Action	2020-2023	Scientific research
7	Research, development and demonstration of key technologies for sustainable utilization of typical karst landscape resources and coordinated development of ecological industries in the Lijiang River Drainage Basin	DOST Guangxi	Goal 1:No Poverty Goal 2:Zero Hungry Goal 11:Sustainable Cities and Communities	2020-2023	Scientific research
8	Contribution of microorganisms to soil organic carbon accumulation during karst vegetation restoration and its coupling mechanism	DOST Guangxi	Goal 15:Life on Land	2020-2023	Scientific research
9	Joint research center for new fertilizers and karst environment	DOST Guangxi	Goal 15:Life on Land	20212023	Scientific research

III

Academic Exchange

3.1 Hosts of important domestic seminars /workshops

In 2020, IRCK organized 11 important domestic conferences about the themes including "The Belt and Road" karst geology, sustainable utilization of karst landscape resources, karst rocky desertification control, and karst ecosystem nitrogen cycle.

3.1.1 The Second China Karst Experts Forum and the Seminar on the Comparison and Mapping of Karst Geological Environment in Key Areas along the Belt and Road

On November 19, 2020, the Second China Karst Experts Forum and the Seminar on the Comparison and Mapping of Karst Geological Environment in Key Areas along the Belt and Road was held in Guilin, aiming to exchange academic ideas and broaden the international vision. It was organized by IRCK , co-organized by National Innovation Alliance of

Prof.Jiang Zhongcheng,GB member of IRCK,gave a speech

Southwest Karst Desertification Control under National Forestry and Grassland Administration. Professor Cai Yunlong with Peking University presided over the seminar.

During the seminar, Prof. Jiang Zhongcheng, GB member of IRCK, stressed the importance of karst research along the Belt and Road, analyzed karst research advantages in China other than the other countries (regions), and highly expected more fruitful cooperation results with the countries along the Belt and Road. Prof. Cao Jianhua, executive deputy director of IRCK, Prof. Zhang Cheng, secretary general of IRCK, and Dr. Xuqi with IRCK introduced "The geology, climate and karst development along the Belt and Road", "China-Slovenia joint research on karst geology" and "The progress on 'The Comparison and Mapping of Karst Geological Environment in Key Areas along the Belt and Road'" respectively. Then, experts and scholars also had in-depth discussions and exchanges on the natural succession law of vegetation in karst areas, the water and nutrient limits of vegetation restoration, the ecological effect of comprehensive rocky desertification control and its contribution to poverty reduction, the ecological utilization of featured plants in karst areas and vegetation restoration in rocky desertification areas.

More than 30 experts from institutions like Peking University, National Forestry and Grassland Administration, the Chinese Academy of Forestry, Beijing Forestry University, Xishuangbanna Tropical Botanical Garden of China Academy of Sciences, Institute of Hydrobiology of Chinese Academy of Sciences, Guangxi Institute of Botany of Chinese Academy of Sciences, and Yunnan Geological Survey etc participated in the meeting.

Above:Prof. Cao Jianhua, deputy director of IRCK gave a report
Below:The experts listened carefully to the reports during the seminar

Acknowledgements:

Key Laboratory of Karst Dynamics, MNR & Guangxi

Key Laboratory of Karst Ecosystem and Treatment of Rocky Desertification, MNR

3.1.2 The Seminar of "Guilin Practice: Sustainable Utilization of Typical Karst Landscape Resources and Coordinated Development of Ecological Industry" under the China-ASEAN International Forum on Sustainable Development and Innovation Cooperation

On November 28-29, at the China-ASEAN International Forum on Sustainable Development and Innovation Cooperation hosted by the Ministry of Science and Technology and the People's Government of Guangxi Zhuang Autonomous Region, organized by China-ASEAN Technology Transfer Center, Guangxi Zhuang Autonomous Region Science and Technology Department and Guilin Municipal People's Government, IRCK organized a seminar on the theme of "Guilin

Practice: Sustainable Utilization of Typical Karst Landscape Resources and Coordinated Development of Ecological Industry".

At the seminar, three project leaders who are responsible for the "Research and demonstration of key technologies for the sustainable use of karst landscape resources in the Lijiang River Basin", the "Research and demonstration of key technologies for the ecological industrialization of landscape resources in the Lijiang River Basin", and the "Research and demonstration of key technologies for the sustainable development and utilization of Guilin landscape water resources" report the research progress separately. Specially invited experts, project members, representatives from city, counties, and districts, as well as business representatives discussed lively on current status of karst landscape resources and sustainable development issues, ecological industry development bottlenecks, difficulties in water resources regulation and utilization, technical support and big data services, decision-making and government management etc.

On the afternoon of the 29th, the expert team of IRCK initially summarized the progress of key technologies for the sustainable utilization of karst landscape resources in the Lijiang River Basin, and gave a special report at a closed-door meeting hosted by Lan Yan, vice mayor of Guilin. The seminar held successfully.

3.1.3 Other important domestic meetings

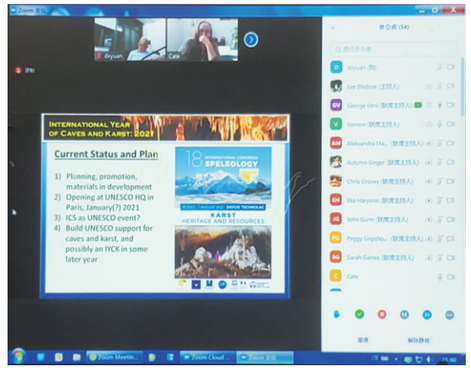
In 2020, according to work plan, IRCK organized 2 workshops on national key research and development projects, 5 seminars for academic exchange, and the annual meeting for key laboratories. These meetings conducted discussions and exchanges on the management of karst rocky desertification, sustainable utilization of karst landscape resources, and nitrogen cycle in karst ecosystems, which are of great significance to serve karst areas for poverty alleviation and ecological protection.

List of other important domestic seminars/workshops hosted by IRCK in 2020

No.	Meeting	Date	Main contents
1	Workshop on the research results of National key R & D project : Evolution of rocky desertification in karst graben basin and its comprehensive control and demonstration	July 20-22	Project progress
2	Kick-off seminar of National key R & D project: Development and demonstration of key technologies on sustainable utilization of karst landscape resources of Lijiang River Basin	July 23-24	Project introduction and work plan
3	Seminar on carbon and nitrogen cycles in karst ecosystem	August 13-14	Mechanism of soil organic carbon stabilization; soil microorganism and nitrogen cycles
4	Seminar on ecological civilization construction in karst area	September 27-29	Karstification and global change, development and evolution of karst landscape
5	Seminar on soil fertility improvement and soil carbon and nitrogen in karst areas	November 27-29	Soil nitrogen and microorganism
6	Annual meeting of Key Laboratory of Karst Dynamics, MNR/Guangxi Region & Key Laboratory of Karst Ecosystem and Treatment of Rocky Desertification , MNR	December 05-06	Karst carbon sink and karst rocky desertification control
7	Seminar on eco-geological innovation programme	December 11-12	Mechanism of karst-related geohazards, development and utilization of karst water resources

3.2 Attendance of important domestic and international meetings

In 2020, IRCK scientists participated in different conferences themed on karst ecological environment protection, resources development and utilization. They exchanged ideas with experts in water resources, ecology, soil, cave protection and other multidisciplinary subjects, publicized the work progress of IRCK, established extensive cooperation, and learned about the latest development.



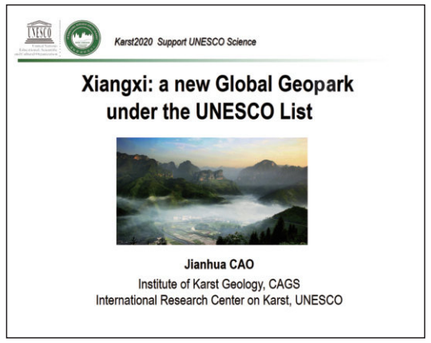
Above: Yuan Daoxian (right one) and Cao Jianhua (left one) attended the workshop online
Below: Professor George Veni introduced 2021 IYCK

3.2.1 KARST 2020 International Workshop on Conservation of Fragile Karst Resources

From August 18 to 20, 2020, the KARST 2020 International Workshop on Conservation of Fragile Karst Resources, organized by Western Kentucky University in the United States, was held online. Representatives from more than ten countries, including the United States, the the United Kingdom, Canada, Australia, Slovenia, Slovakia, and China, participated in the workshop, with an average of 50-70 people keeping online. Many of them have involved in the relevant activities of IRCK as training lecturers and trainees. Prof. Yuan Daoxian, GB Member/director of the Academic Committee of IRCK, and Prof. Cao Jianhua, attended the virtual meeting.

The convener of the conference, Professor Chris Groves of Western Kentucky University, gave a brief introduction and welcomed delegates from various countries. Professor George Veni, AC Member of IRCK, President of UIS/President of American Speleology Association, gave a detailed introduction to the 2021 International Year of Caves and Karst (IYCK).The event is planned to open at the UNESCO Headquarters in 2021, hoping to attract UNESCO's attention and support for caves and karst. At present, IYCK website has been preliminarily established, and the related information could be found at http://iyck2021.org/.

The main content of this workshop includes:1) academic reports and discussions on the fragility of karst environment, karst ecosystem rules, cave research, and karst hydrogeology; 2) gathering well-known experts in karst research internationally to conduct joint discussions on topics of common concern and strengthen the training of young talents; 3) to share the information of 2021 IYCK, uniting karst scientists to prepare together



IRCK introduced the Xiangxi UGGp

Introduction Video of Xiangxi UGGp

China Country Report 2020

and expand the influence of karst science.

Xiangxi UGGp, as a fresh UNESCO Global Geopark approved in July 2020, has attracted worldwide attention. At this meeting, IRCK introduced the generalities of the geopark based on the application dossiers for UGGp, attracting wide attention of attendees, especially, Prof. John Gunn, participating in the preliminary work for the application of Xiangxi UGGp, gave high comments to IRCK's introduction.

3.2.2 China Annual Report on Karst Geology and the 56th CCOP Annual Meeting

On November 3-4, the 56th Annual Meeting of the Coordinating Committee for Geosciences in East Asia and Southeast Asia (CCOP) was held online. The attendees include: 12 member states, 9 partner countries like Australia, Belgium, Canada, Denmark and so on, as well as 9 international organizations like UNESCO, the International Union of Geological Sciences (IUGS) and the Young Earth Scientists (YES). At the meeting, the Chinese representative made a wonderful national report and systematically introduced the achievements of 2020 geological work in China. Two representatives from IRCK attended the meeting and learned about the research results and work trends of different countries. The China Annual Report on Karst Geology compiled by IRCK is an important part of Country Report (China), covering major achievements in karst geological survey, scientific research, international exchanges and cooperation, informatization, and science popularization. Among them, the researches on karst carbon cycle and global climate change, water resources development and management, landscape resources survey and

conservation, and rocky desertification control etc. not only contribute to the 2030 Agenda effectively, but also significant to regional cooperation organized by CCOP.

3.2.3 Other domestic meetings

In 2020, IRCK attended 5 important karst-related meetings, with the karst research results in water, soil, biology and tourism exchanged. IRCK's researches served the social needs, sorted out the effective results and shortcomings, provided suggestions to sustainable resources development and ecological restoration, and guaranteed balanced output of socio-economic and

List of important domestic meetings attended by IRCK in 2020

No.	Meeting	Sponsor	Date	Main contents
1	Workshop on poverty alleviation supported by geological survey in Lushui City, Yunnan	Natural Resources Bureau of Lushui City	August 7	Poverty alleviation and special geological investigation in karst mountain area; karst resources development and ecological restoration and protection
2	Seminar on soil ecology frontiers	Soil Biology and Bio-Chemistry Committee of Soil Sciences Society of China	October 25-27	New problems and opportunities in the field of soil microbial ecology
3	The 8th China water ecology conference	Hohai University, Yellow River Basin Ecological Environment Supervision and Administration Bureau, Ministry of Ecology and Environment; North China University of Water Resources and Hydropower; Water Resources Committee of Chinese Society of Natural Resources	October 29-31	Build happy rivers and lakes, promote harmony between human and water
4	The 24th national congress of speleology	Geological Society of China, Shangli County CPC Committee; Shangli County Government	October 30 - November 1	Speleology, cave tourism and exploration, investigation system and method of Hanzhong karst tiankeng group, dating of karst sediments and evolution history of paleoclimate, as well as cave monitoring and protection
5	2020 Consultation seminar on the construction of Guilin national innovation demonstration zone for sustainable development agenda	Department of Science and Technology of Guangxi Zhuang Autonomous Region	December 9-10	Investigation, conservation and scientific development and utilization of karst landscape resources in Lijiang River Basin

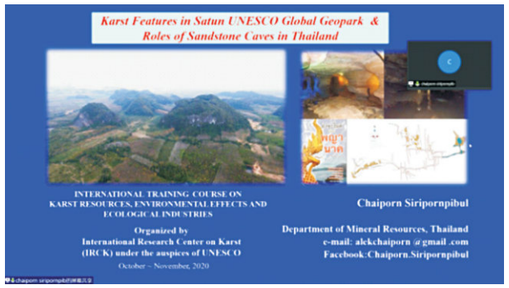
IV

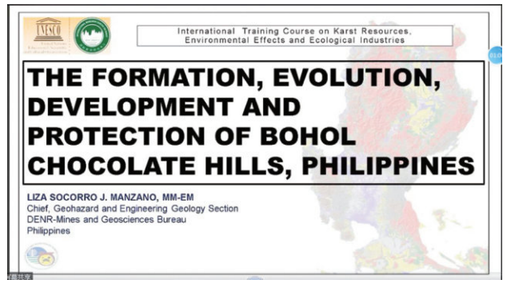
International Training Course

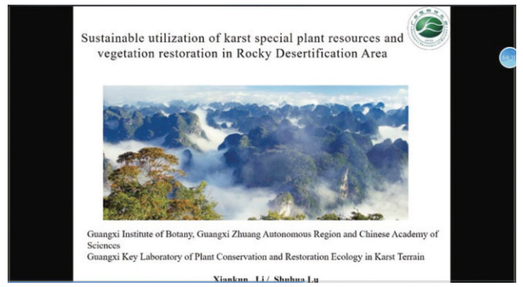
On Octorber 26-30, and November 9-13 2020, IRCK organized the 12th International Training Course on "Karst Resources, Environmental Effects and Ecological Industry" online in two phases. Due to the impact of COVID-19, this is the first time for IRCK to held virtual training course. A total of 17 well-known karst scientists from US, Serbia, Poland, and Philippines etc. were invited to give lectures, while 36 foreign trainees from 16 countries applied to attend this training course.

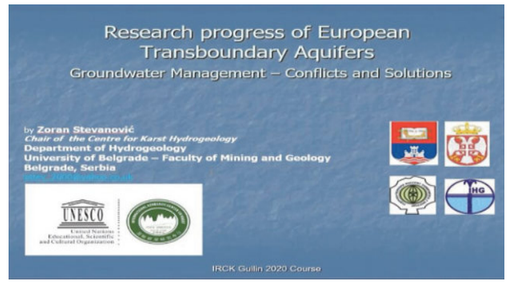
The trainees learned abundant karst science from the online lectures, including: the development of karst-related UGGps, the joint development and protection of karst water resources, the formation and evolution of typical karst landforms and its current status of development and protection, vegetation and ecological restoration in karst areas, trans-boundary aquifers, and ecological industry construction based on karst geological characteristics, etc. The effective organization of the training course ensures efficient communication between trainees and lecturers.

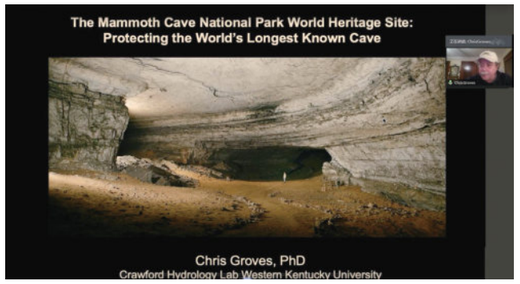
On October 30 and November 13, the trainees attended final defense, introducing the karst generalities of their countries and the main progress of their study. After the evaluation of the evaluators, 8 outstanding students from Slovenia, Philippines, Morocco, China, Brazil, Myanmar and Iran were selected. The successful holding of this online training course has provided good experience for IRCK to explore more diversified training modes. The excellent reports of the lecturers and trainees have greatly enriched the karst research materials from the world, laying a solid foundation for multilateral cooperation in the future.

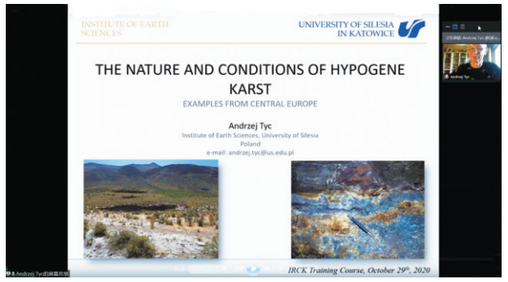


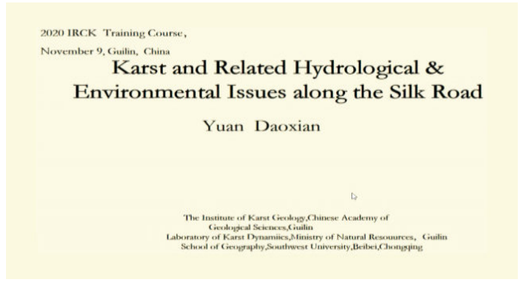


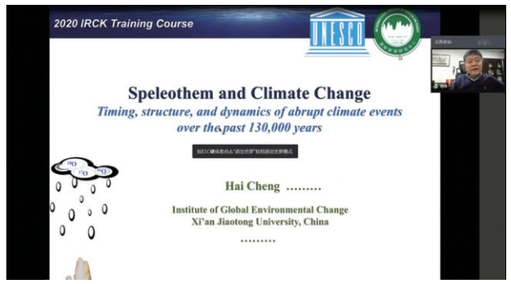


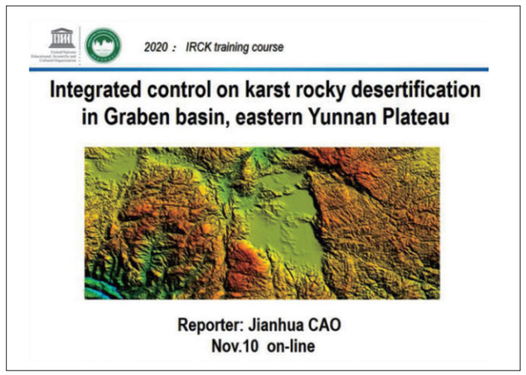




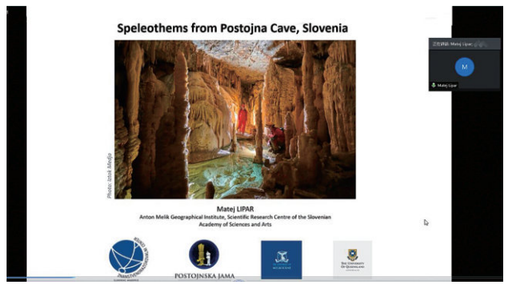


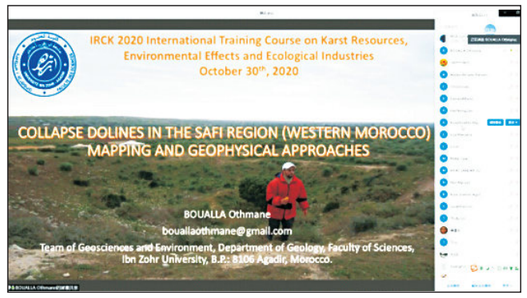


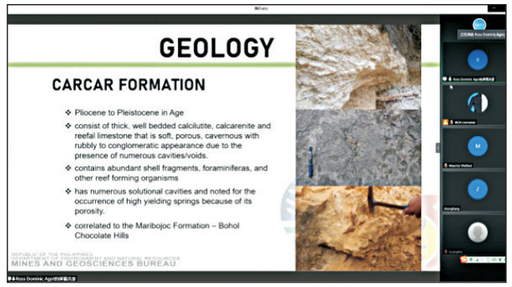


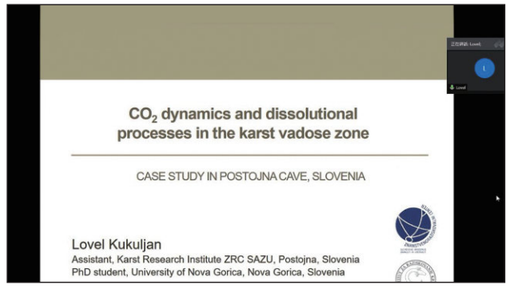


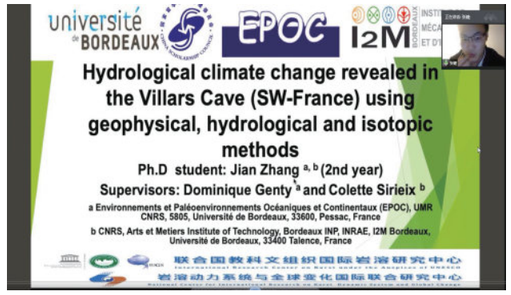
Online lectures (According to the training course schedule)

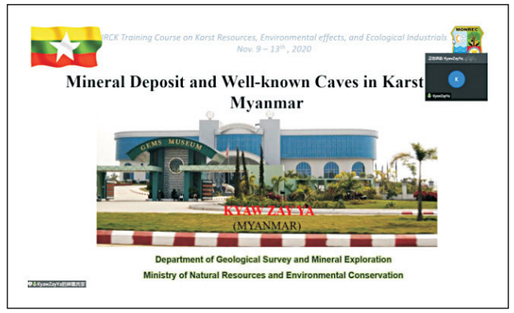


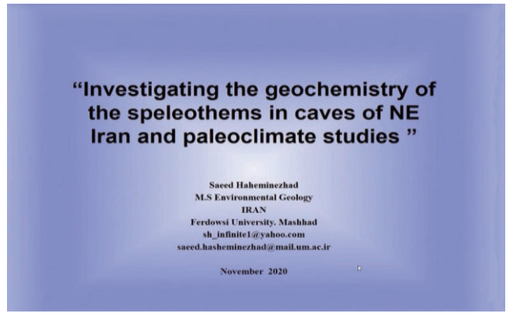












Outstanding presentations from the trainees

V

Sciences Popularization and Consultation

In 2020, IRCK continuously strengthened science popularization, by organizing 5 “virtual + on-spot” interesting activities, and generating 31 easy-to-understand popular science products. IRCK made full use of the WeChat public account, geo-cloud and other network platforms to disseminate a large number of karst popular science articles, albums, and micro-videos, expanding the approaches for the public to access to karst.

5.1 Theme science popularization activities

In 2020, IRCK carried out a total of 30 science popularization activities (including 5 theme ones) with about 6,800 people involved. Thematic activities are diverse in forms and rich in content, including popular science lectures, online competitions, and "virtual + on-spot" exhibitions.

List of theme popular science activities

No.	Theme	Time	Site	Activity form	Particip-ants
1	The 51st Earth Day	April 20-26	IKG	Lectures	About 6400
2	Let popular science education go to the schools, let all of us protect the green mountains and rivers	April 20-26	Zhaojue County, Liangshan Prefecture	Lectures	
3	The 49th World Environment Day: “Scientific Protection of Lijiang River ” Painting Competition	May20-June 5	IKG	Online competition	50
4	The 30th National Land Day	June 25	Guohua Experimental Base for Rocky Desertification Control	Exhibition	60
5	National Science and Technology Week	August 23-29	IKG	Online Exhibition	224

5.1.1 The 51st Earth Day

April 20-26 was the popularizing week for the 51st Earth Day. IRCK carefully planned and organized a series of activities with the theme "Cherish the earth, Seeking harmonious coexistence with nature". Affected by the epidemic, these activities were carried out online with students from Guilin taking part in some on-spot events. Through variety patterns, major achievements on karst were displayed thouroughly.

Yuan Daoxian, academician with the Chinese Academy of Sciences, and Chen Weihai, chief scientist of a national key R&D program, as well as other experts were invited to give lectures online. After that, the online contest on karst popular science knowledge was organized. Moreover, popular science articles on karst groundwater, geological relics, and karst collapse, etc. were placed on the website and official WeChat account, so that the public may learn about karst science knowledge indoor.

In addition, the scientists also brought popular karst science to the National Key Boarding Primary School in Zhaojue county, Liangshan prefecture, Sichuan province. The popular science knowledge was introduced through various patterns such as lectures, videos, flyers, posters, and other mutual events. Li Jikui, deputy section chief of the Education Bureau of Zhaojue County, and Sunzi Tuha, principal of the school, took part in the related activities.

5.1.2 The 49th World Environment Day: “Scientific Protection of Lijiang River” a public welfare painting competition for pupils

IRCK held a public welfare painting competition for pupils with the theme

Above:Yuan Daoxian, academician of the Chinese Academy of Sciences, gave online lectures

Middle:Guilin's first "Geologist Li Siguang Squadron" attended the online lectures in their classroom

Below:The 51st Earth Day science popularization activity in the National Key Boarding Primary School in Zhaojue County, Liangshan Prefecture, Sichuan Province

Awarded painting: A Wonderland

Awarded painting: Protecting the Earth

as "Scientific Protection of Lijiang River" from May 20 to June 5. The objectives were to disseminate earth science knowledge, raise public awareness to protect Lijiang River scientifically, cherish Guilin landscape, and cherish ecological environment of earth and cherish the resources, enabling the general public to understand karst geological knowledge and ecological environment in karst areas. This event was incorporated into Guilin's 2020 science popularization activities and was granted by Guilin Science and Technology Bureau.

The event attracted great attention from pupils and their parents in Beijing, Jiangxi, Guangxi and other provinces (regions). After online voting and expert review, a total of 21 paintings were selected. This competition helped the pupils to understand current situation of the Lijiang River's ecological environment, stimulating them to learn more about karst geology, and raising their awareness to “cherish the resources and protect the environment". There is a saying that “Young are strong, the country strong”. Good popularization education for young would establish an important foundation for ecological civilization construction in China.

5.2 Popular science products

In 2020, IRCK completed a total of 8 popular science papers, 5 popular science articles, 6 popular science albums, 2 popular science textbooks, 1 popular science education route and 9 popular science micro-videos, established a tutor team, and applied for top geoscience popular science education courses and top geoscience popular science education tour of Geological Society of China actively.

IRCK systematically summarized the causes and prevention of karst geological disasters, the aesthetic value and protection of karst landscape resources, the efficient use and development of karst water resources, and karst-related on climate change, and compiled them into various educational products. Then, different groups may obtain key information in an easy way and realize the benefits of science and technology.

List of Representative Popular Science Products

No.	Title	Author	Product Type
1	Explore the "home" of new energy shale gas and how“we”can use it	Ba Junjie	Paper
2	The causes of water bursting in karst tunnels	Lin Yongsheng	Paper
3	Sanqiao Natural Bridge: the creation of a marvel, Wulong of Chongqing	Wang Zhe	Paper
4	Ancient spring made by nature: a case study of the drum well in Danzhai county, Guizhou province	Li Lele	Paper
5	Extreme climate and sinkhole	Dai Jianling	Paper
6	Waterfall-the beating note on the river	Shi Wenqing	Article(in IKG WeChat public account)
7	Album of geological relics in the key areas of Wumeng Mountain (Jiudongtian, Dafang County, Guizhou)	Luo Shuwen	Album
8	South China Karst-Guilin landscape tops the world	Karst Geology Committee	Textbook
9	"Guilin landscape tops the world -Guilin Karst World Natural Heritage Site" education tour	Karst Geology Committee	Research investigation route
10	The formation and evolution of the main types of the carbonate rock geo-relics (karst peak cluster and peak forest)	Shi Wenqiang	Micro video

VI Appendix

6.1 The Schedule for the Training Course

Schedule for the first phase training course
(Mainly for students from Europe, Africa and Asia)

Date	Time	Lecturer	Title
Oct. 26	15:00-16:30	Chaiporn Siripornpibul	Karst Features in Satun UNESCO Global Geopark & Roles of Sandstone Caves in Thailand
	16:30-18:00	Saša Milanović	Karst water development and protection bycooperation with water supplier companies in Serbia
Oct. 27	15:00-16:30	Liza Socorro J. Manzano	Formation, Evolution, Development and Protection of theBohol Chocolate Hills, Philippines
	16:30-18:00	Lu Shuhua	Sustainable utilization of karst special plant resources andvegetation restoration in Rocky DesertificationArea
Oct. 28	15:00-16:30	Zoran Stevanović	Research progress of European Transboundary Aquifers: Groundwater Management – Conflicts and Solutions
	17:30-18:30	Chris Groves	The Mammoth Cave National Park World Heritage Site
Oct. 29	15:00-16:30	Cao Jianhua	Comprehensive treatment on karst rocky desertification
	16:30-18:00	Andrzej Tyc	The nature and conditions of hypogene karst – on the example of Central Europe
Oct.30	09:00-11:30	Assessment: Trainees' presentation	

Schedule for the second phase training course
(Mainly for students from America,Oceania and Asia)

Date	Time	Lecturer	Title
Nov. 9	08:30-09:45	Yuan Daoxian	Karst and water environment issue along the Silk Road
	09:45-11:00	Chris Groves	The Mammoth Cave National Park World Heritage Site
Nov.10	08:30-09:45	Jiang Zhongcheng	Ecological industries development based on karstgeological features
	09:45-11:00	Zheng Yuanyuan	UGGp in China – Activities and Events
Nov.11	08:30-09:45	Cheng Hai	Speleothem and Climate Change
	09:45-11:00	Zhang Yuanhai & Shen Lina	Technology and Methodology of Tiankeng Survey
Nov.12	08:30-09:45	Andrzej Tyc	The nature and conditions of hypogene karst – on the example of Southern Peru
	09:45-11:00	Chaiporn Siripornpibul	Karst Features in Satun UNESCO Global Geopark & Roles of Sandstone Caves in Thailand
Nov.13	09:00-11:30	Assessment: Trainees' presentation	

6.2 List of Participants

List of Lecturers
(According to alphabet order of nationalities and names)

Name	Gender	Nationality	Employer and Position
Cao Jianhua	Male	China	Deputy Chief Engineer of IKG
Lu Shuhua	Male	China	Assistant researcher of Guangxi Institute of Botany
Jiang Zhongcheng	Male	China	Professor of IKG
Shen Lina	Female	China	Associate professor of IKG
Yuan Daoxian	Male	China	Academician of Chinese Academy of Sciences
Zhang Yuanhai	Male	China	Senior engineer of IKG
Zheng Yuanyuan	Male	China	Senior engineer of National Geopark Network Center, Chinese Academy of Geological Sciences
Liza Socorro J. Manzano	Female	Philippines	Supervising Science Research Specialist of Department of Environment and Resources, Mines and Geosciences Burean
Andrzej Tyc	Male	Poland	Professor of Poland University of Silesia
Saša Milanović	Male	Serbia	Professor of University of Belgrade
Zoran Stevanović	Male	Serbia	Professor of University of Belgrade
Chaiporn Siripornpibul	Male	Thailand	Member of Thailand National Cave Management Committee
Cheng Hai	Male	USA	Professor of Xi'an Jiaotong University
Christopher Groves	Male	USA	Professor of Western Kentucky University

List of Trainees (According to alphabet order of nationalities and names)

Name	Gender	Nationality	Employer
Alberto Barioni	Male	Brazil	University of São Paulo
Beatriz Hadler Boggiani	Female	Brazil	University of Munich
Isabella Brito Andrade	Female	Brazil	INSTITUTO DO CARSTE
Thiago Ferreira Lima	Male	Brazil	Speleological Observatory
Zhang Jian	Male	China	University of Bordeaux
Romza Fauzan Agniy	Male	Indonesia	Universitas Gadjah Mada
Taat Setiawan	Male	Indonesia	Geological Agency, Ministry of Energy and Mineral Resources
Reza Khoshraftar	Male	Iran	University of Zanjan
Sarah Edalatian Arasteh	Female	Iran	Kharazmi University
Seyed Saeed Hasheminezhad	Male	Iran	Ferdowsi University
Alexcia Cornelia Gray	Female	Jamaica	Water Resources Authority
Wallace Maurice Andre	Male	Jamaica	Water Resources Authority
Jessie Mzati Kanyerere	Female	Malawi	University of the Western Cape
Jelena Krstajić	Female	Montenegro	University of Belgrade
Abderrahmane Wanaim	Male	Morocco	Ibn Zohr University
Asmae Aichi	Female	Morocco	Ibn Zohr University
Boualla Othmane	Male	Morocco	Ibn Zohr University
EN-NASIRY Mohamed	Male	Morocco	Ibn Zohr University
Han Naing Zaw	Male	Myanmar	Department of Geological Survey and Mineral Exploration, DGSE
Kyaw Zay Ya	Male	Myanmar	Department of Geological Survey and Mineral Exploration, DGSE
Myat Snadar Oo	Female	Myanmar	Pyay University
Myo Min Thank	Male	Myanmar	Ministry of Natural Resources and Environment Conservation

List of Trainees (According to alphabet order of nationalities and names)

Name	Gender	Nationality	Employer
Su Mon Than	Female	Myanmar	Pyay University
Thida Oo	Female	Myanmar	Pyay University
Bertram John Swartz	Male	Namibia	Ministry of Agriculture, Water and Land Reform
Ndubuisi Godstime Igwebuike	Male	Nigeria	University of Belgrade
Ross Dominic Darang Agot	Male	Philippines	Mines and Geosciences Bureau
Russyl Bryile Anthony Q. Lanzaderas	Male	Philippines	Mines and Geosciences Bureau
Daniela Alexandra Teixeira da Costa Ribeiro	Female	Portugal	Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute
Majola Kwazikwakhe	Male	South Africa	University of the Western Cape
Paula Finini	Female	South Africa	University of the Western Cape
Lovel Kukuljan	Male	Slovenia	Karst Research Institute ZRC SAZU
Matej Lipar	Male	Slovenia	Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute
Jorge Ramon PeÑarada Salgado	Male	Spain/Brazil	UNIVERSIDADE DE SÃO PAULO
Le Canh Tuan	Male	Vietnam	Hanoi university
Nguyen Xuan Nam	Male	Vietnam	Vietnam institute of Geoscience and mineral resource - Vietnam center on karst and Geoheritage
Nguyen Van Hong	Male	Vietnam	Institute of Geography, Viet Nam Academy of Science and Technology