World Karst Aquifer Map

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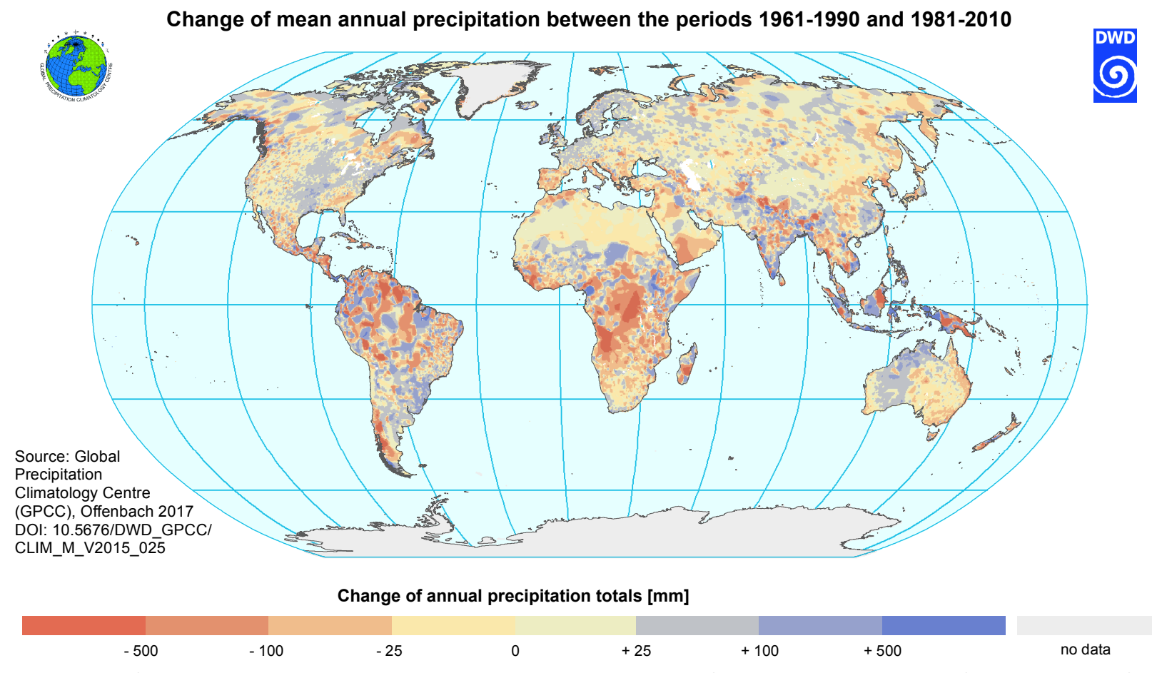
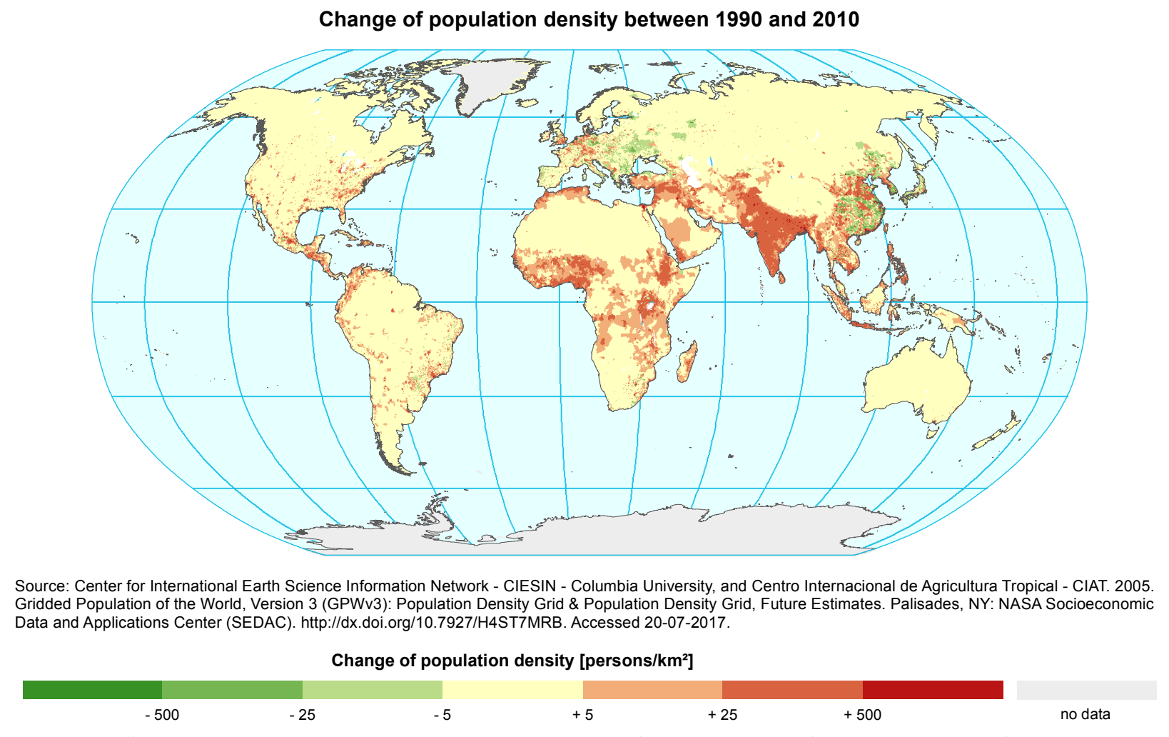

Change of mean annual precipitation between the periods 1961-1990 and 1981-2010

Source: Global Precipitation Climatology Centre (GPCC), Offenbach 2017 DOI: 10.5676/DWD_GPCC/CLIM_M_V2015_025

The change of the mean annual precipitation is calculated based on the land surface precipitation climatology from rain gauges of the reference periods 1961 to 1990 and 1981 to 2010. Note that the number of rain gauge stations is highest for the 1980s and 1990s, with up to 50 000 stations, while this number decreases below 30 000 until the year of 2010.


Change of population density between 1990 and 2010

Source: Center for International Earth Science Information Network - CIESIN - Columbia University, and Centro Internacional de Agricultura Tropical - CIAT. 2005. Gridded Population of the World, Version 3 (GPWv3): Population Density Grid & Population Density Grid, Future Estimates. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4ST7MRB. Accessed 20-07-2017.

The change of population density between 1990 and 2010 is based on the Gridded Population of the World, Version 3 (GPWv3), consisting of estimates of human population for the years 1990 and 2010 by 2.5 arc-minute grid cells. A proportional allocation gridding algorithm, utilizing more than 300 000 national and sub-national administrative units, is used to assign population values to grid cells. The population density grids are derived by dividing the population count grids by the land area grid and represent persons per square kilometer.

The global importance of karst aquifers

Karst aquifers constitute valuable freshwater resources for hundreds of millions of people worldwide. In many countries and regions, groundwater from karst aquifers is the major source of freshwater for drinking water supply and agricultural irrigation. Many large cities, such as Vienna, Rome, San Antonio, Damascus and Taiyuan, rely entirely or predominantly on karst groundwater. In the context of climate change and population growth (see inset maps), the pressure on these freshwater resources is expected to increase.

Many karst aquifer systems are connected over large areas and constitute transboundary groundwater resources. For example, the Dinaric Karst System is shared between northeast Italy, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, Montenegro, Macedonia and Albania. The Southwest China Karst, one of the world's largest karst regions, is shared between seven Chinese provinces and extends across the border into Vietnam. These examples highlight the need for transboundary water management and fully integrated water resources maps.

Karst aquifers and karst terrains

Karst aquifers form in chemically soluble bedrock, mostly carbonate rock, such as limestone and dolomite. In these rocks, the chemical action of flowing water containing carbon dioxide from the atmosphere or soil zone generates a network of hydraulically connected fractures, conduits and caves. Evaporite rocks, such as gypsum, anhydrite and halite, are also highly soluble, but their dissolution does not require carbon dioxide. At the land surface, karst landscapes often develop characteristic geomorphological features, such as solutional sculpting of the bedrock (karren), dolines or sinkholes, and large closed depressions (poljes), but also positive landforms such as rock towers, cones and pinnacles. Most of the rain and snowmelt water infiltrates underground and contributes to groundwater recharge, whereas surface runoff is scarce or entirely absent. Rivers and streams from adjacent non-karst areas often sink underground at the contact with exposed, karstifiable rock.

Characteristics and challenges of water resources in karst

Karst aquifers often drain towards large springs. Most of the largest springs on our planet are karst springs. The springs generally display marked discharge variations in response to rainfall events or snowmelt. Some karst springs have maximum flow rates exceeding 100 cubic meters per second, but run dry in drought periods. This high degree of hydrologic variability is a major challenge in the utilization and management of karst aquifers, because water suppliers and consumers need relatively constant and reliable freshwater sources. Karst water can also be abstracted from pumping wells, drainage galleries, or from underground cave streams. Deep carbonate rock aquifers may constitute important reservoirs of thermal and mineral water, which can be used for bathing or geothermal energy production. The thermal springs and baths of Budapest are a prime example of thermal water resources in karst.

Exposed karst aquifers are particularly vulnerable to contamination. Chemical and microbiological pollutants can easily enter the aquifer and spread rapidly through the network of fractures and conduits, often without effective processes of filtration and self-purification. Therefore, karst aquifers require specific protection and management approaches. Karst terrains are also challenging in terms of hydraulic engineering and natural hazards. Reservoirs in karst often face the problem of large-scale leakage through fractures and cavities. Sinkholes and collapses of underground cavities are a major problem in large areas of the Eastern USA and elsewhere.

The wider significance of carbonate rocks and karst aquifers

As the process of carbonate rock dissolution involves carbon dioxide from the atmosphere and the soil zone, karst processes are natural sinks for this greenhouse gas and play an important role in the carbon cycle. Furthermore, many karst landscapes host high biodiversity, both at the land surface and underground, including a large number of rare and endemic species. Karst aquifers also supply baseflow to rivers and groundwater-dependent ecosystems. Soils on karst are used for agricultural food production, but are particularly vulnerable to erosion. For example, in China, more than one hundred thousand square kilometers of karst terrain are affected by soil erosion and rocky desertification. Karst landscapes and caves have high recreational, cultural and historical values: more than 50 karst sites are on the list of UNESCO World Heritage Sites, for reasons, such as landscape, culture and biodiversity. Last but not least, carbonate rocks are extensively exploited in quarries and used as building material and for various technical purposes. All these values and resources underline the importance of a global assessment of carbonate rocks and karst aquifers.

WOKAM: basic concepts

The World Karst Aquifer Map (WOKAM) is intended to increase the awareness of these valuable but vulnerable freshwater supplies and to help to address global water resources management. WOKAM was prepared in the framework of the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP). The digital Global Lithological Map (GLiM) by Hartmann and Moosdorf (2012) served as an important basis for WOKAM. Many other regional geological and hydrogeological maps, cross-sections and literature were consulted to improve the map, which was also validated by a large number of regional experts. However, as the type and quality of information, as well as the availability of regional experts, is very different in different parts of the world, the reliability of WOKAM is spatially variable (as is shown on the small inset map).

WOKAM: the mapping approach

The World Karst Aquifer Map focuses on groundwater resources in karst aquifers, which are developed primarily in carbonate rocks. Evaporites also constitute important karst aquifer systems, but high sulfate concentrations often hamper their direct utilization as drinking water. Rocks that contain at least 75 % of soluble minerals are typically karstifiable. The actual degree of karstification can vary greatly as a function of various geological, hydrological and climatological factors; however, it is safe to assume that exposed carbonate rocks are karstified at least to some degree, unless proven otherwise. It is important to note that even a slight degree of underground chemical rock dissolution can result in a typical karst aquifer with rapid groundwater flow and contaminant transport, even when no accessible caves and geomorphological karst features are present.

WOKAM: mapping units and legend

The mapping units "carbonate rocks" and "evaporite rocks" represent potential karst aquifers. Their actual degree of karstification and hydraulic properties cannot be determined consistently at a global scale, but it is a defensible approach to assume that most exposed carbonate and evaporitic rocks represent karst aquifers. Limestone and dolomite are the most widespread karstifiable carbonate rocks. Chalk is a fine-grained biogenic carbonate rock, which develops less prominent karst features than classical limestone karst. However, in many regions, for example in the UK and France, chalk aquifers contribute substantially to freshwater supplies. Marble and other metamorphic carbonate rocks also form important karst aquifers in some regions, for example in Ethiopia and South Africa.

Carbonate and evaporite areas were subdivided into continuous and discontinuous categories, based on an area's share of the respective rock type. In general, areas with more than 65 % of carbonate or evaporite rock were mapped as "continuous", whereas areas between 15 and 65 % were mapped as "discontinuous". Areas that contain more than 15 % of each rock type were mapped as "mixed carbonate and evaporite rocks". Zones where exposed karstifiable rocks plunge beneath adjacent non karstifiable formations are highlighted by red triangles pointing to the direction of non-exposed karstifiable rocks, which may constitute deep or artesian aquifers with fresh or thermal groundwater.

The digital version of WOKAM, and the previously released karst aquifer map of Europe (Chen et al. 2017), also display two other mapping units representing non-karstifiable formations. However, for the sake of clarity, this printed world map focuses on karstifiable rocks and therefore uses a modified color scheme.

WOKAM: Additional karst aquifer information presented

WOKAM also presents a selection of important karst water sources and caves (see tables). Karst water sources include conventional karst springs, thermal springs, submarine springs, wells and other water abstraction structures. Water sources were primarily selected on the basis of their discharge during low-flow conditions, which is more relevant in terms of water supply than the maximum discharge. The regional importance was also considered. For example, a spring in an arid region that is used for water supply has a higher regional importance than an unused spring in a humid region. There are several examples of large karst springs that ran dry due to overexploitation, such as the famous springs of Bahrain. However, such ancient springs are not displayed on the map.

Caves were selected based on a combination of their dimensions and their regional importance. Caves associated with important freshwater resources and caves that are the longest or deepest in a large karst region, were assigned a high regional importance. The selection of water sources and caves is to some degree subjective and also reflects the regional differences in data availability. In regions with high spatial density of large karst springs and caves, many important features cannot be displayed.

Conclusion

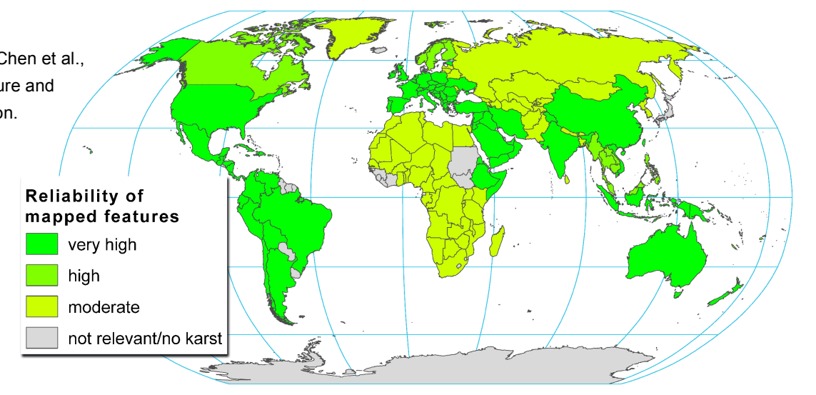
WOKAM allows a more precise global quantification of karst systems. The map will help to increase awareness of karst groundwater resources in the context of global water issues and will serve as a basis for other karst-related research questions at global scales: for example those related to climate change, biodiversity, food production, geochemical cycles and urbanization.

This text is based on a paper by the WOKAM team (Chen et al., 2017), which describes the detailed mapping procedure and includes a detailed reference list for further information.

References:

Chen et al. (2017) The World Karst Aquifer Mapping project: concept, mapping procedure and map of Europe. Hydrogeology Journal.

Hartmann & Moosdorf (2012) The new global lithological map database GLiM: A representation of rock properties at the Earth surface. Geochemistry Geophysics Geosystems.



Selected karst water sources and caves

Karst springs

ID	Name	Low [m³/s]	High [m³/s]
A1	White Spray Spring	2.5	n.d.
A4	Maligne	15.2	40
A6	Big Spring	5	7
A10	McGill Spring	0.2	0.4
A11	Swallow Canyon Spring	0.1	3
A12	Hot Creek Spring	0.03	0.6
A14	Cascade Springs	0.5	n.d.
A17	Spring Creek Springs	1.5	n.d.
A18	Ottawa River Caves	10	n.d.
A21	San Solomon Springs	0.9	2
A22	Comanche Springs	0.3	3
A23	Goodenough Springs	4.1	n.d.
A24	Las Moras Springs	0.3	3
A26	Leona Springs	0.3	3
A27	Salado Springs	0.03	0.3
A28	Barton Springs	1.8	n.d.
A30	Comal Springs	0.01	14
A31	Roaring River Spring	0.2	5
A32	Bennett Spring	2.5	5
A34	Big Spring	6.7	37
A35	Maramec Spring	1.6	18
A39	Tuscumbia Spring	0.2	0.9
A40	Huntsville Spring	0.01	0.3
A42	Cave Springs	0.6	1.2
A44	Coldwater Spring	0.2	n.d.
A45	Buffalo Spring	0.3	0.7
A47	Morrell Spring	0.3	0.9
A48	Locust Creek Spring	0.03	0.6
A50	Culverson Creek Springs	1.3	n.d.
A52	Lacey Spring	0.1	0.8
A53	Opequon Spring	0.3	0.4
A54	Gilmore Spring	0.2	n.d.
A55	Rock Springs	0.1	n.d.
A56	Osewichee Spring	0.1	0.5
A57	Radium Spring	0.5	4
A58	Jackson Blue Spring	1.6	8
A60	Nutall River Rise	10.2	10
A61	Alapaha River Rise	14.4	20
A63	Silver Springs Main	15.3	37
A64	Rainbow Spring	13.8	35
A65	Volusia Blue Spring	1.8	6
A72	Nacimiento de Rio Frio	0.6	515
A73	El Zacaton	0.1	5
A74	Nacimiento del Rio Mante	8	343
A75	Nacimiento del Rio Choy	1.5	100
A76	Nacimiento del Rio Coy	13	236
A77	Grutas de Tolantongo	3.4	n.d.
A81	Boiling Hole	0.7	7
A82	Chiquibul Spring	2	n.d.
A87	Siburua	0.4	n.d.
A89	Timbuj Spring	4	n.d.
A91	Negro River Spring	15	n.d.
A93	Chiflonkhakha	0.5	n.d.
A98	São Bernardo	5	n.d.
A100	Jaguara	0.6	0.8
A101	Águas Quentes	0.2	2
A104	Caicayen	0.01	0.03
B1	Cong Springs	5	n.d.
B5	Cheddar Springs	1	n.d.
B8	Paderquellen	3	9
B9	Rhumequelle	2	6
B11	Pozo Azul Spring	0.03	4.7
B12	Muriel Spring	0.05	0.97
B13	Ses Fonts Ufanes Spring	n.d.	70
B16	Touvre	6	40
B18	Ouysse	0.6	200
B21	Fontaine de Vaucluse	4	150
B23	Source de l'Areuse	0.7	39
B24	Source de l'Orbe	2	80
B27	Aachquelle	1.1	28
B32	Pießlingursprung	2.2	40
B34	Livenza Group	11.4	n.d.
B36	Timavo	30.2	n.d.
B37	Kamniška Bistrica	2.1	63
B38	Ljubljanica	1.5	120
B40	Rječina	0	150
B43	Crno vrelo	4.5	n.d.
B44	Pliva	8	n.d.
B45	Jadro	2.2	29
B47	Klokun	3.5	19
B48	Buna	3	380
B49	Vrelo Bosne	1.5	18
B50	Ombla	4	138
B51	Glava Zete Spring	2	100
B53	Bolje Sestre Spring	2.3	6
B54	Nera Springs	15	n.d.
B55	Peschiera	18	n.d.
B57	Gari Group	18	n.d.
B60	Uji Ftohte	1.8	4
B61	Bistrica	12	36
B62	St Naum	2.5	15
B63	Aravissos	0.9	3
B66	Tapolcafő Spring	0.3	1.3
B68	Lazce	0.3	1.4
B69	Blekitne Zródla	0.4	0.6
B73	Jósvafő Spring	0.1	7
B74	New Well Miskolctapolca	0.3	2
B75	Izbândiș	0.05	4
B77	Izverna	1	3
B79	Vrelo Mlave	0.2	17
B81	Raška	0.9	7
B82	Radavac (Beli Drim)	0.9	21
B84	Iskrets Spring	0.01	55
B85	Glava Panega	0.4	36
B86	Kumanitsa	0.5	3
B89	Almyros	3.3	30
B92	Karasu-Bashi	0.1	39
B93	Atzgara	1.5	5
B95	Goluboe Ozero	0.5	2
C2	Kırkgöz	7.1	63
C3	Dumanli	38	50
C4	Munzur	8.9	30
C5	Gökova	10.2	14
C6	Gökpınar	6.2	15
C7	Khabour Ras el Aïn	38.6	n.d.
C8	Zarka Spring	6.9	24
C9	Figeh Spring	2.5	13
C10	Jordan River Sources	15.9	n.d.
C11	Rosh Ha'ayin Springs	6.4	n.d.
C13	Mchishta	9.5	197
C14	Gali Shirana	1.6	3
C15	Saruchawa	1.8	8
C17	Sarchinar	0.6	7
C22	Chehel cheshmeh	1.9	n.d.
C25	Bobrovaya	1.5	3
C26	Panzethnag	2.2	3
C27	Bolshaja Iret	12	n.d.
C28	Taliza	1.5	n.d.
C29	Shentouquan	6.8	n.d.
C32	Niangziguan	8.5	n.d.
C33	Jinanquan	3.5	4
C35	Yanzibang	0.6	n.d.
C36	Yangjiatai	3	n.d.
C38	Chexinwan	32.8	n.d.
C40	Longtan	0.6	n.d.
C41	Yunpan	3	n.d.
C44	Banqiao	4.1	n.d.
C46	Xincun	4.8	n.d.
C47	Zhijindaquan	0.4	n.d.
C48	Wangjiadajing	1.3	n.d.
C49	Dalongjing	0.2	n.d.
C51	Daxiaojing	4.7	n.d.
C53	Waimengtang	6.6	n.d.
C54	Luofan	8.4	n.d.
C55	Dagengcun	7	n.d.
C56	Fuwucun	0.5	n.d.
C57	Disu	4.9	n.d.
C58	Lingshui	4	n.d.
C59	Zuodeng	21.3	n.d.
C61	Liulangdong	23.2	n.d.
C62	Nandong	9.5	n.d.
C63	Baishiyan	34.5	n.d.
C64	Zhongzhai	37.2	n.d.
C65	Nam La Spring	0.8	53
C68	Krem Mahabon	1.3	n.d.
C74	Gua Besar	2.2	n.d.
D5	Siwa Springs	0.01	n.d.
D7	Ain El Gudeirat	0.02	n.d.
E2	Tobio	100	n.d.
E3	Te Waikoropupu Spring	5.8	21
E4	Cave Creek Springs	3	35
E5	Blue Waterholes	0.17	2.2

Submarine karst springs

ID	Name	Low [m³/s]	High [m³/s]
A62	Crescent Beach	40	n.d.
A66	Biscayne Bay	n.d.	n.d.
A68	Puerto Morelos	n.d.	n.d.
A69	Celestun Lagoon	n.d.	n.d.
B19	Source de la Vise	0.5	n.d.
B26	Mortola Springs	n.d.	n.d.
B46	Vrulja Bay	n.d.	n.d.
B56	Fondi Lake	2	n.d.
B58	Presidiana	0.7	n.d.
B59	Chidro	2.5	n.d.
B87	Kiveri Springs	n.d.	n.d.
B88	Stoupa	n.d.	n.d.
C71	Santiago Island	n.d.	n.d.
C76	Pantai Ngrenehan	8	n.d.
D4	Ayn Zayanah	5	n.d.
E1	Guam	n.d.	n.d.

Thermal karst springs

ID	Name	Low [m³/s]	High [m³/s]
A7	Banff Hot Springs	0.1	n.d.
A8	Fairmont Hot Springs	0.04	n.d.
B6	Bath Springs	0.02	n.d.
B65	Hévíz Lake Spring	0.3	0.6
B90	Devnya Spring	2.3	4
C34	Tangquan	0.1	n.d.
C43	Zhougongshan	0.1	n.d.
C45	Muaijing	0.01	n.d.

Water abstraction structures in karst aquifer

ID	Name	Low [m³/s]	High [m³/s]
B29	Buchbrunnenquelle	0.6	1.5
B33	Kläfferquelle	0.4	34
B71	Zakopane-Banska PGP-1	0.2	n.d.
B91	Cişmea 1	1.6	n.d.
C19	Sasan	1.1	n.d.
C20	Margoon Waterfall	1	2
C21	Masarm	1.7	n.d.
C23	Tirebagh	1.2	2
C24	Bonab	1.1	1.4
C30	Liulinquan	2.8	n.d.
C31	Lancunquan	n.d.	n.d.
C52	Huanghou	0.4	n.d.
D6	Ain El Gabal	0.5	n.d.
D8	Borama	0.2	0.5
D9	Jijiga	0.2	0.4

Cave systems

ID	Name	Length [km]	Depth [m]
A2	Weymer C.S.	12.7	370
A3	Arctomys Cave	3.5	536
A5	Castleguard Cave	21	384
A9	Yorkshire Pot	13.8	389
A13	Wind Cave	228.2	194
A15	Groaning Cave	18	45
A16	Mystery C.S.	20.6	31
A19	Fort Stanton Cave	43.3	134
A20	Lechuguilla Cave	222.6	489
A25	Powell's C.S.	26.1	24
A29	Honey Creek Cave	33.2	38
A33	Fitton Cave	28.2	95
A36	Crevice Cave	47.6	n.d.
A37	Binkley's C.S.	63.3	43
A38	Mammoth C.S.	643.7	124
A41	Blue Spring Cave	61.5	94
A43	Ellisons Cave	19.5	324
A46	Omega System	47.1	385
A49	Friars Hole C.S.	73.3	191
A51	Hellhole System	67.1	212
A59	Wakulla-Leon Sinks C.S.	51.5	107
A67	Gran Caverna de Palmarito	54	n.d.
A70	Sac Actun C.S.	310.7	78
A71	Purificacion C.S.	93.8	953
A78	Cuetzalan-Atepolihuit C.S.	37.7	658
A79	Huautla C.S.	66.9	1 545
A80	Soconusco C.S.	23.9	513
A83	Chiquibul C.S.	39	160
A84	Faro-Isla de Mona C.S.	19.1	36
A85	Rio Encantado C.S.	21.8	344
A86	Cueva El Samán	18.2	n.d.
A88	Cueva del Guácharo	10.2	n.d.
A90	Cueva de Palestina	3	n.d.
A92	Sima Pumacocha	1.4	n.d.
A94	Toca da Boa Vista	110	n.d.
A95	Lapa Doce II	16.5	n.d.
A96	Gruta do Padre	16.4	n.d.
A97	Lapa São Vicente I	15.0	n.d.
A99	Boqueirão	n.d.	n.d.
A102	Caverna de Santana	8.3	n.d.
A103	Las Brujas	1.3	n.d.
B2	Poulnagollum - Poulelva	16	140
B3	Three Counties System	102	211
B4	Ogof Draenen	70	151
B7	Grotte de Han-sur-Lesse	5.7	50
B10	Mortillano C.S.	127	950
B14	Pas de Vallgornera Cave	70.6	21
B15	Pierre Saint-Martin C.S.	80.2	1 408
B17	Coume Ouarnède C.S.	105.8	975
B20	St-Marcel d'Ardéche Cave	51.2	233
B22	Clot d'Aspres C.S.	40	1 066
B25	Jean Bernard C.S.	20.5	1 602
B28	Hölloch	200.4	939
B30	Riesending-Schachthöhle	19.1	1 148
B31	Schönberg C.S.	140.1	1 061
B35	Čehi 2	5.3	1 502
B39	Postojnska jama	20.6	115
B41	Lukina jama-Trojama C.S.	3.7	1 431
B42	Kita Gacesina C.S.	26.4	737
B52	Željezna jama	2.8	1 027
B64	Punkevní jeskyně Cave	3.9	138
B67	Molnár János Cave	6	130
B70	Wielka Śnieżna Cave	23.7	824
B72	Baradla - Domica C.S.	26	112
B76	Sistemul Vărăşoaia	19.3	653
B78	Pestera Topolnita	20.5	127
B80	Zlotska pećina	9.8	60
B83	Duhlata	18.2	73
B94	Tjoarvekrajgge	25.1	502
C1	Gökgöl	3.4	11
C12	Krubera Cave	16.1	2 197
C16	Kuna Kamtiar	5.1	n.d.
C18	Ali Saadr Cave	11	n.d.
C37	Teng Long Dong	22.2	231
C39	San Wang Dong	70.1	343
C42	Shuanghe Dongqun	151.9	534
C50	Getuhe Dong	11.9	418
C60	Jiangzhou C.S.	46.7	283
C66	The Nam Dôn C.S.	42.1	200
C67	Hang Khe Rhy	18.9	n.d.
C69	Krem Kotsati	21.5	215
C72	Saint Paul Cave	32	100
C73	Clearwater System	215.3	483
C75	Luweng Jaran	18.2	158
D1	Wit Tamdoun	19.1	30
D2	Rhar Bou Ma'za	18.4	35
D3	Annou Ifflis	2	1 170
D10	Sof Omar	15.1	15
D11	Nandembo C.S.	7.5	114
D12	Apocalypse Pothole	12.3	n.d.
E6	Old Homestead Cave	28	n.d.
E7	Burke's Back Yard	120.4	23
E8	Exit Cave	23	220

The first letter of the IDs refers to the continental location: A = the Americas, B = Europe, C = Asia, D = Africa, E = Australia/Oceania
Abbreviations: C.S. = cave system, n.d. = no data

Please note that the number of selected springs and caves displayed on the map is dictated by cartographic constraints. A more extensive database is available through the WHYMAP viewer at www.whymap.org/whymap-viewer.

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Topographic base map: Data & Maps (ESRI, 2012); Rivers & Lakes (GRDC, 2012); Shuttle Radar Topography Mission SRTM30 (NASA/USGS, 2006); Permafrost Boundary (NSIDC, 2002); Cartographic Data (UN, 2011)
modified by BGR (2017)

Map projection: Robinson projection, longitude of central meridian 11°E, spheroid WGS84

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This map was created to the best knowledge of the WOKAM team. Nevertheless, we would appreciate comments, suggestions and scientific input to contribute to the continuous improvement of the WHYMAP products, including the present version of this map. Contact information for the submission of any notes and drafts related to this map is available at www.whymap.org/wokam-contact.

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WORLD KARST AQUIFER MAP

1 : 40 000 000

Karstifiable rocks / potential karst aquifer

- 🟦 Carbonate rocks continuous / discontinuous
- 🟪 Evaporite rocks continuous / discontinuous
- 🟩 Mixed carbonate and evaporite rocks
- ▲ Border between exposed and non-exposed karstifiable rocks

Selected karst water sources and caves

- ● Spring with low flow discharge ≥ 2 m³/s
- • Spring with low flow discharge < 2 m³/s
- ●~ Submarine spring
- ⊙ Thermal spring
- ▣ Water abstraction structure in karst aquifer
- Ω Cave system

Geography and climate

- ● Selected city, partly groundwater dependent
- ○ Selected city
- ------ National boundary
- ┴┴┴ Permafrost boundary (areal percentage > 50%)

Surface water

- ~ Major river
- Large freshwater lake
- Large saltwater lake
- Continuous ice sheet

This map was prepared and published as part of the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) – www.whymap.org

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World Karst Aquifer Map 1 : 40 000 000	BGR, IAH, KIT, UNESCO	Berlin, Reading, Karlsruhe, Paris 2017