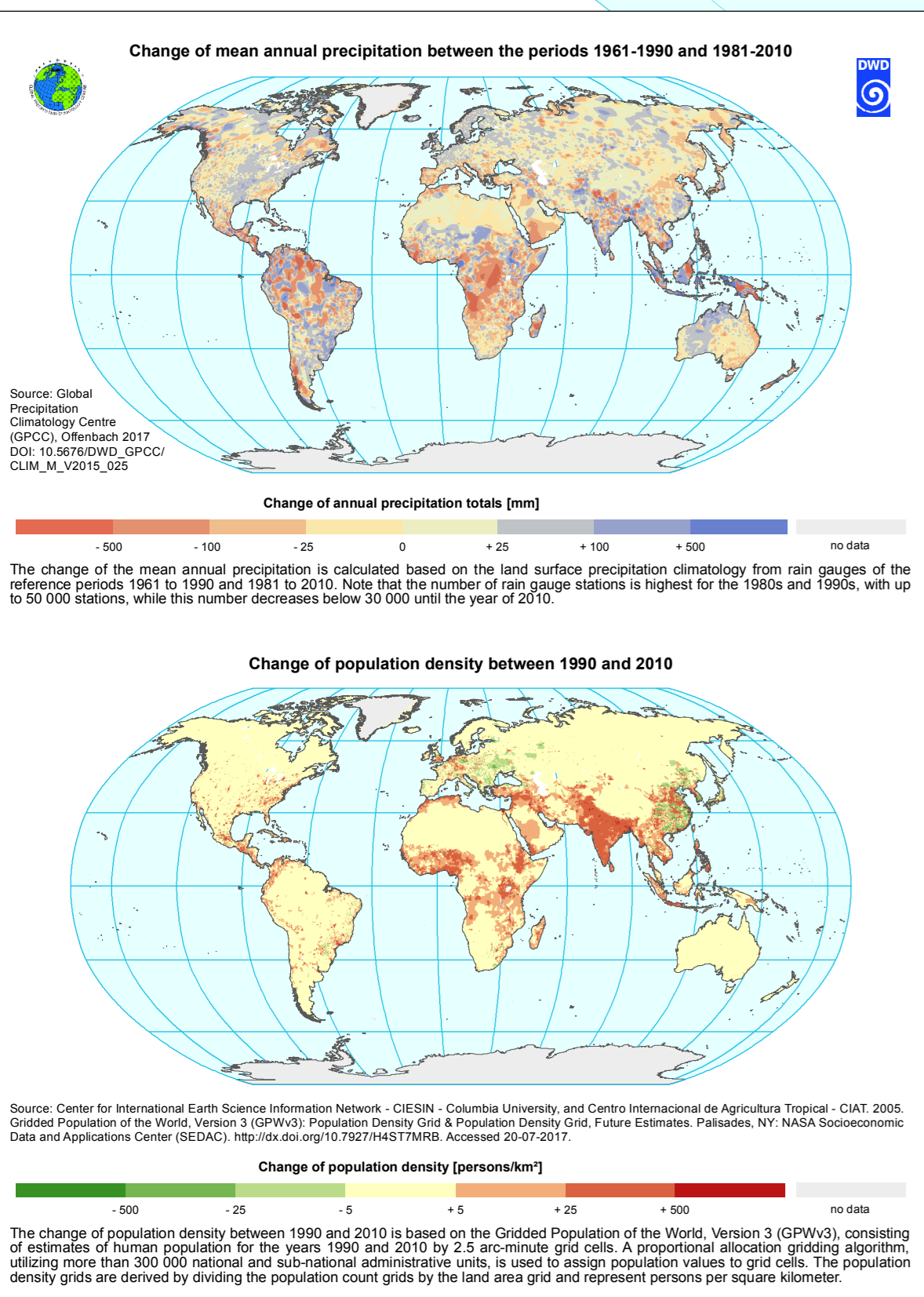
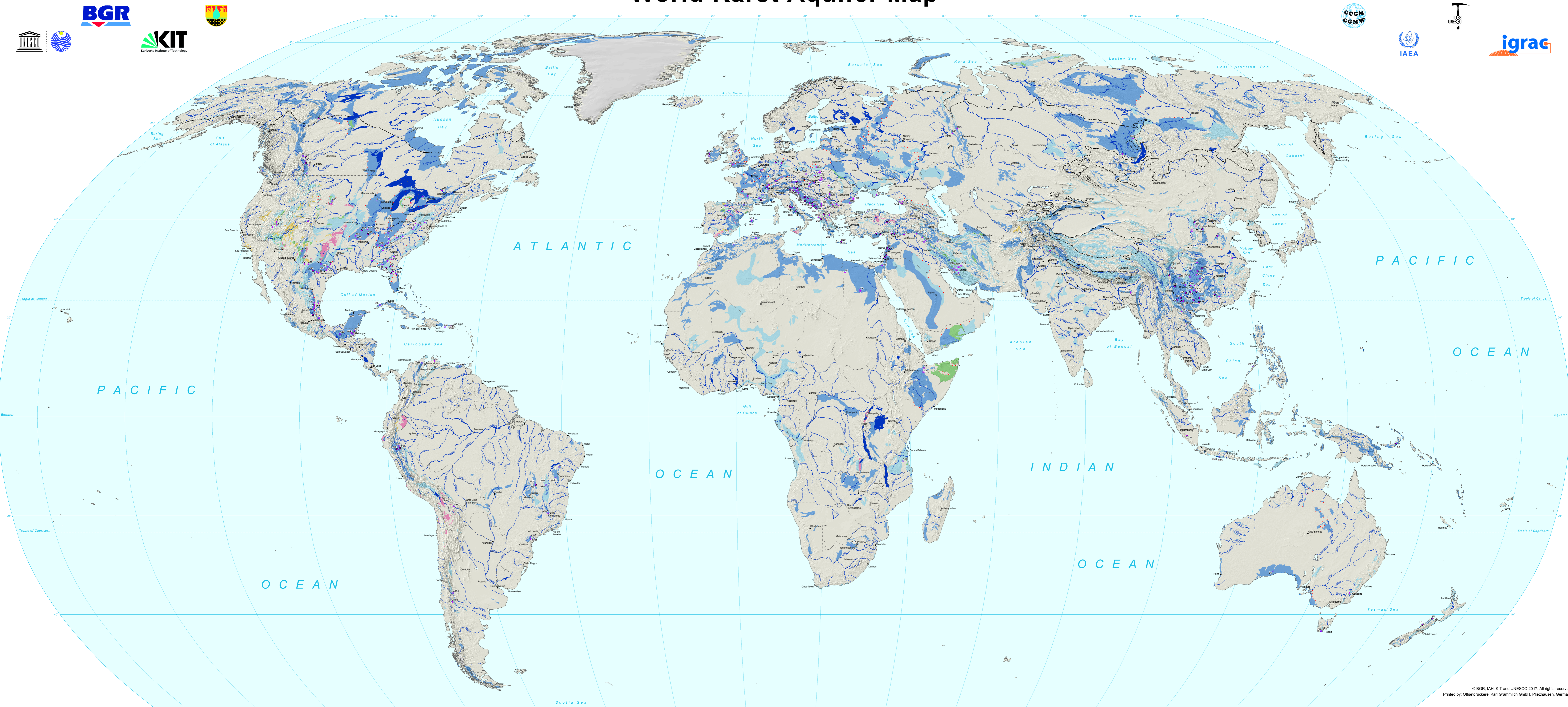


# World Karst Aquifer Map



**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 Taysan, 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 Dnieper 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 terraces**

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 (potholes), 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 supplies. 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 systems are also changing in terms of hydrologic 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 the 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, landscape and historical values: more than 50 karst sites are on the list of UNESCO World Heritage Sites, for reasons, such as culture, culture and biodiversity. Last but not least, carbonate rocks are extensively exploited for 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 Moorosi (2012) serves 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, the type and quality of information, as well as the availability of regional experts, is very different in different parts of the world, and the reliability of WOKAM is spatially variable (see a-stown 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 evaporite 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 list 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 run dry due to overexploitation, such as the famous springs of Balnain. 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 web is based on a paper by the WOKAM team (Chen et al., 2017), which describes the detailed mapping procedures and includes a detailed reference list for further information.

**References:**

Chen et al. (2017) The World Karst Aquifer Map (WOKAM) is a programme of the Geological Map of the World (GMW), the International Association of Hydrogeologists (IAH) and the International Association of Geographers (IAGG). The map is available at [www.whymap.org/wokam](http://www.whymap.org/wokam).

Hartmann & Moorosi (2012) The new global lithological map database GLIM: A representation of rock properties at the Earth surface. *Geochimica et Cosmochimica Acta*, 76, 1-11.

**Selected karst water sources and caves**

ID	Name	Length [km]	Height [m]	ID	Name	Length [km]	Height [m]	ID	Name	Length [km]	Height [m]	ID	Name	Length [km]	Height [m]
01	Wuyang Spring	2.5	4.6	82	Phlegon Spring	2.2	4.2	161	Chang Spring	0.2	4.8	301	Wuyang Spring	1.2	4.8
02	Wuyang Spring	2.5	4.6	83	Phlegon Spring	2.2	4.2	162	Chang Spring	0.2	4.8	302	Wuyang Spring	1.2	4.8
03	Wuyang Spring	2.5	4.6	84	Phlegon Spring	2.2	4.2	163	Chang Spring	0.2	4.8	303	Wuyang Spring	1.2	4.8
04	Wuyang Spring	2.5	4.6	85	Phlegon Spring	2.2	4.2	164	Chang Spring	0.2	4.8	304	Wuyang Spring	1.2	4.8
05	Wuyang Spring	2.5	4.6	86	Phlegon Spring	2.2	4.2	165	Chang Spring	0.2	4.8	305	Wuyang Spring	1.2	4.8
06	Wuyang Spring	2.5	4.6	87	Phlegon Spring	2.2	4.2	166	Chang Spring	0.2	4.8	306	Wuyang Spring	1.2	4.8
07	Wuyang Spring	2.5	4.6	88	Phlegon Spring	2.2	4.2	167	Chang Spring	0.2	4.8	307	Wuyang Spring	1.2	4.8
08	Wuyang Spring	2.5	4.6	89	Phlegon Spring	2.2	4.2	168	Chang Spring	0.2	4.8	308	Wuyang Spring	1.2	4.8
09	Wuyang Spring	2.5	4.6	90	Phlegon Spring	2.2	4.2	169	Chang Spring	0.2	4.8	309	Wuyang Spring	1.2	4.8
10	Wuyang Spring	2.5	4.6	91	Phlegon Spring	2.2	4.2	170	Chang Spring	0.2	4.8	310	Wuyang Spring	1.2	4.8
11	Wuyang Spring	2.5	4.6	92	Phlegon Spring	2.2	4.2	171	Chang Spring	0.2	4.8	311	Wuyang Spring	1.2	4.8
12	Wuyang Spring	2.5	4.6	93	Phlegon Spring	2.2	4.2	172	Chang Spring	0.2	4.8	312	Wuyang Spring	1.2	4.8
13	Wuyang Spring	2.5	4.6	94	Phlegon Spring	2.2	4.2	173	Chang Spring	0.2	4.8	313	Wuyang Spring	1.2	4.8
14	Wuyang Spring	2.5	4.6	95	Phlegon Spring	2.2	4.2	174	Chang Spring	0.2	4.8	314	Wuyang Spring	1.2	4.8
15	Wuyang Spring	2.5	4.6	96	Phlegon Spring	2.2	4.2	175	Chang Spring	0.2	4.8	315	Wuyang Spring	1.2	4.8
16	Wuyang Spring	2.5	4.6	97	Phlegon Spring	2.2	4.2	176	Chang Spring	0.2	4.8	316	Wuyang Spring	1.2	4.8
17	Wuyang Spring	2.5	4.6	98	Phlegon Spring	2.2	4.2	177	Chang Spring	0.2	4.8	317	Wuyang Spring	1.2	4.8
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20	Wuyang Spring	2.5	4.6	101	Phlegon Spring	2.2	4.2	180	Chang Spring	0.2	4.8	320	Wuyang Spring	1.2	4.8
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26	Wuyang Spring	2.5	4.6	107	Phlegon Spring	2.2	4.2	186	Chang Spring	0.2	4.8	326	Wuyang Spring	1.2	4.8
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35	Wuyang Spring	2.5	4.6	116	Phlegon Spring	2.2	4.2	195	Chang Spring	0.2	4.8	335	Wuyang Spring	1.2	4.8
36	Wuyang Spring	2.5	4.6	117	Phlegon Spring	2.2	4.2	196	Chang Spring	0.2	4.8	336	Wuyang Spring	1.2	4.8
37	Wuyang Spring	2.5	4.6	118	Phlegon Spring	2.2	4.2	197	Chang Spring	0.2	4.8	337	Wuyang Spring	1.2	4.8
38	Wuyang Spring	2.5	4.6	119	Phlegon Spring	2.2	4.2	198	Chang Spring	0.2	4.8	338	Wuyang Spring	1.2	4.8
39	Wuyang Spring	2.5	4.6	120	Phlegon Spring	2.2	4.2	199	Chang Spring	0.2	4.8	339	Wuyang Spring	1.2	4.8
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43	Wuyang Spring	2.5	4.6	124	Phlegon Spring	2.2	4.2	203	Chang Spring	0.2	4.8	343	Wuyang Spring	1.2	4.8
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47	Wuyang Spring	2.5	4.6	128	Phlegon Spring	2.2	4.2	207	Chang Spring	0.2	4.8	347	Wuyang Spring	1.2	4.8
48	Wuyang Spring	2.5	4.6	129	Phlegon Spring	2.2	4.2	208	Chang Spring	0.2	4.8	348	Wuyang Spring	1.2	4.8
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54	Wuyang Spring	2.5	4.6	135	Phlegon Spring	2.2	4.2	214	Chang Spring	0.2	4.8	354	Wuyang Spring	1.2	4.8
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60	Wuyang Spring	2.5	4.6	141	Phlegon Spring	2.2	4.2	220	Chang Spring	0.2	4.8	360	Wuyang Spring	1.2	4.8
61	Wuyang Spring	2.5	4.6	142	Phlegon Spring	2.2	4.2	221	Chang Spring	0.2	4.8	361	Wuyang Spring	1.2	4.8
62	Wuyang Spring	2.5	4.6	143	Phlegon Spring	2.2									