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How to meet the increasing demands of water, food and energy in the future?

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Outline

- Background
- Materials and methods
- Results and discussion
- Conclusions

Background

- Regarded as a driving force in demands of water, food, and energy, the world's population has been increasing rapidly in last century and will reach 9.7 billion by 2050 according to the medium-growth projection scenario of the United Nations (2015).
- Water is the key factor in consideration of its various uses, e.g., drinking, irrigation, and hydropower (Chen et al., 2016).
- At present, water scarcity occurs worldwide (Molden et al., 2007).
- Infrastructures (e.g., large dams) have been constructed to increase water withdrawals from rivers and groundwater in order to meet the needs of an expanding population, enhancing the societies' capabilities in the management of water resources and the related issues of food and energy security.

Background

What do we want to know?

- Status quo: supply and demand
- Countermeasures to deal with future challenges
- Outlook for global sustainable development

Background

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Population, water, food, energy and dams

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- Addressed the question if the construction of large dams should continue
- Argued that construction of additional large dams will have to be considered as one of the best available options
- Preliminarily projected the development of future dams (the number of dams by 2050)

Materials and methods

Groups of countries (UNDP, 2010; UNFPA, 2011):

- 44 developed countries
- 49 LDCs (i.e., the least developed countries)
- Developing countries
  - ✓ BRICS (Brazil, Russia, India, China, and South Africa)
  - ✓ Excluding BRICS

Materials and methods

Research data:

- Population (UN reports)
- Water resources (World Bank)
- Gross Domestic Product (GDP) (World Bank)
- Water consumption (World Resource Simulation Center)
- Food consumption (United States Department of Agriculture)
- Energy consumption (International Energy Agency)
- Dam construction (International Commission on Large Dams & Global Reservoir and Dam Database)

Materials and methods

Classification method of countries with different water scarcity situations

- Per capita available water resources (PCAWR)
  - ✓ 1,700 m^3 per capita per year (WWAP, 2012) - threshold
- The number of dams
  - ✓ World average - threshold
- Per capita GDP (PCGDP)
  - ✓ More ➔ high incoming, upper middle incoming
    Less ➔ lower middle incoming, low incoming (World Bank)

Type	Water scarcity situation	Indicator
I	Little or no water scarcity	More PCAWR, fewer dams, more PCGDP More PCAWR, more dams
II	Economic water scarcity	More PCAWR, fewer dams, less PCGDP
III	Physical water scarcity	Fewer PCAWR

Materials and methods

Projection method of socio-economic data:

- The population projections for 2020, 2030, 2040 and 2050 are obtained from the UN
- The projections of dam development (the number of dams and the reservoir capacity) are obtained by analyzing the temporal trends
- The projections of the other variables (namely water, food and energy consumption) are obtained by using a multiple regression method based on the projections of population and dam development

Materials and methods

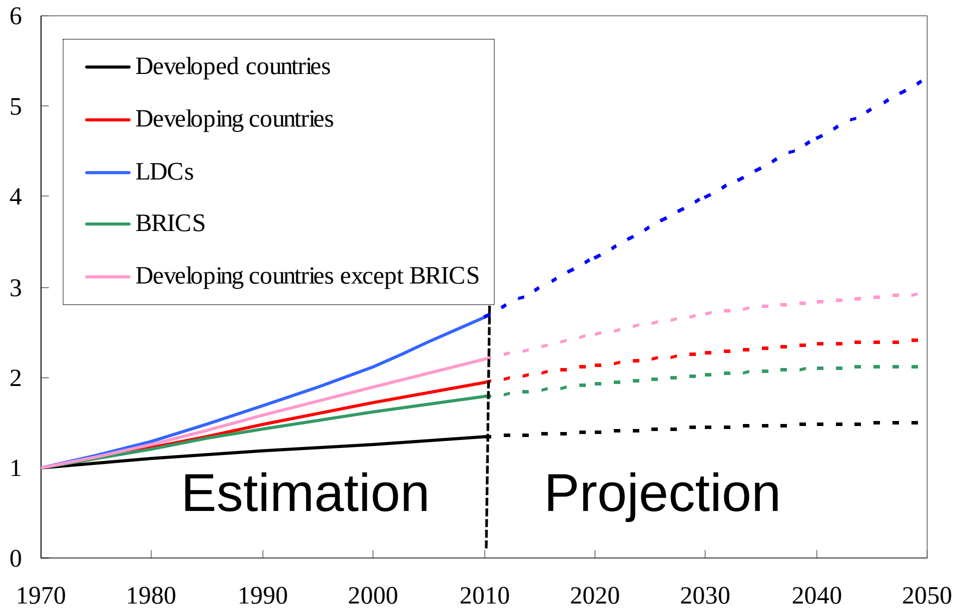
Projection method of future large dam locations

- Population growth - major driving force
  - Evaluate the trend of the population density during 1990-2015, attempting both the linear and quadratic polynomial regressions
  - Extrapolated the population density during 2020-2050 with this trend
  - Calculate the percentage change of the population density (2050/2015)
- Water availability - basic supporting factor
  - Represented by the value of the multi-year average annual precipitation derived from the CRU TS dataset (NCAR, 2014)
- Topography - important constraint
  - Represented by the catchment areas and slopes of the river reaches in the 30 m resolution global drainage network named Tsinghua Hydro30 (http://www.hydro30.org/)

Population growth

Growth rate

- Developed countries: steady and low
- The LDCs: steady but high
- Developing countries: between the above two



Water, food and energy consumption

Water consumption

- Irrigated agriculture: about 80%
- Industrial production, domestic use, ecosystem service

Food consumption

- Increase steadily
- A dramatic decrease in the proportion of hungry people

Energy consumption

- A nearly linear increasing trend in recent decades
- Supposed to maintain increasing in the near future

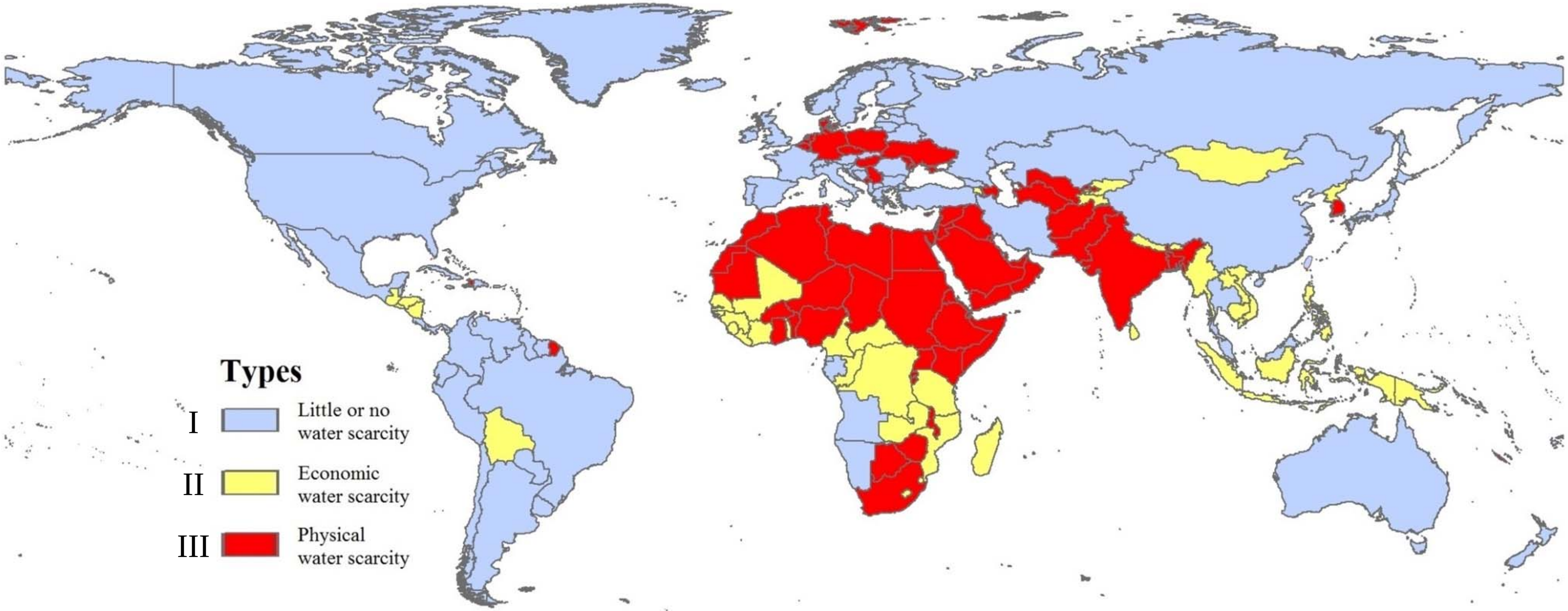
➔ Water: the key factor

Global water scarcity

Current situation

- >70% countries
- Most countries of Africa, the south and west Asia, and the central Europe

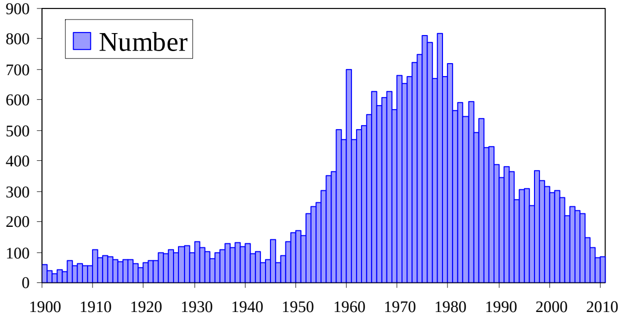
Type	Total number	Developed countries	Developing countries	The LDCs
I	71	24	45	2
II	43	0	20	23
III	129	20	85	24

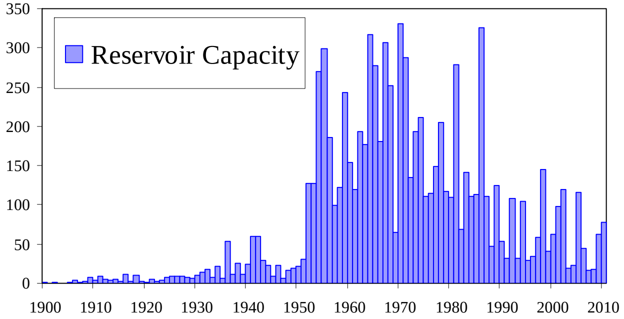


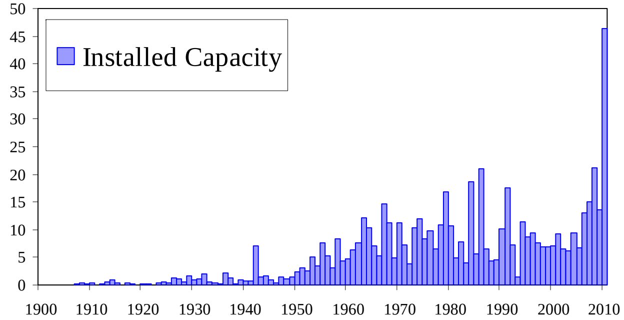
Dam development

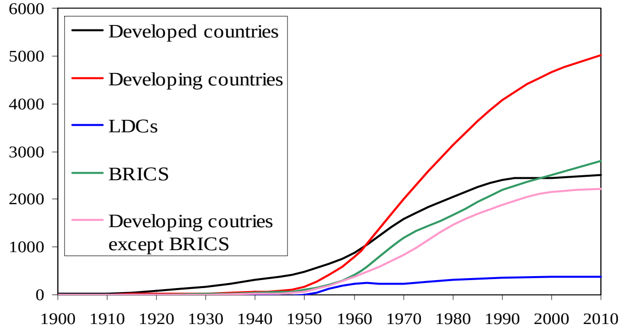
Dams constructed during 1900-2010

- A list of 32,473 dams from the ICOLD and GRanD databases





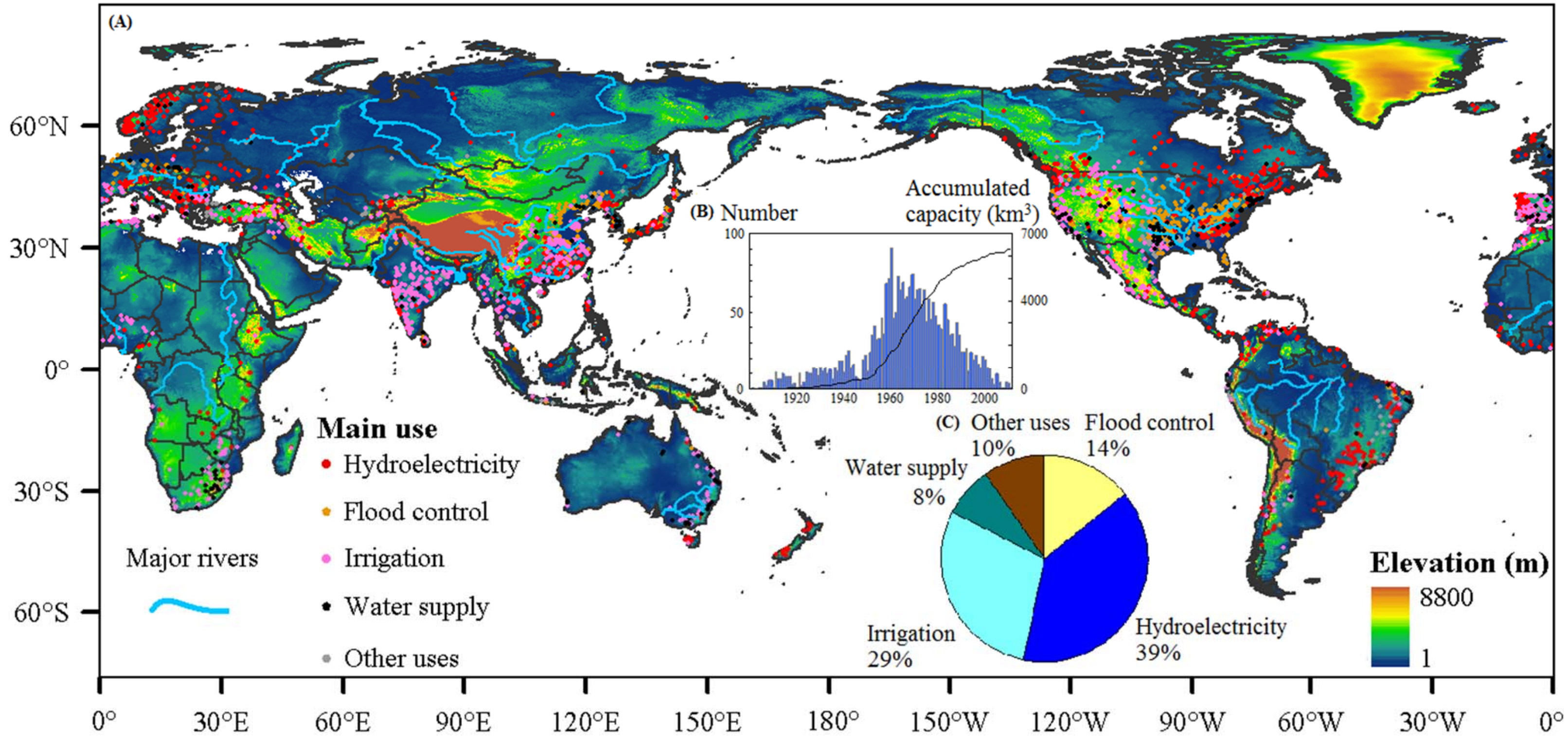




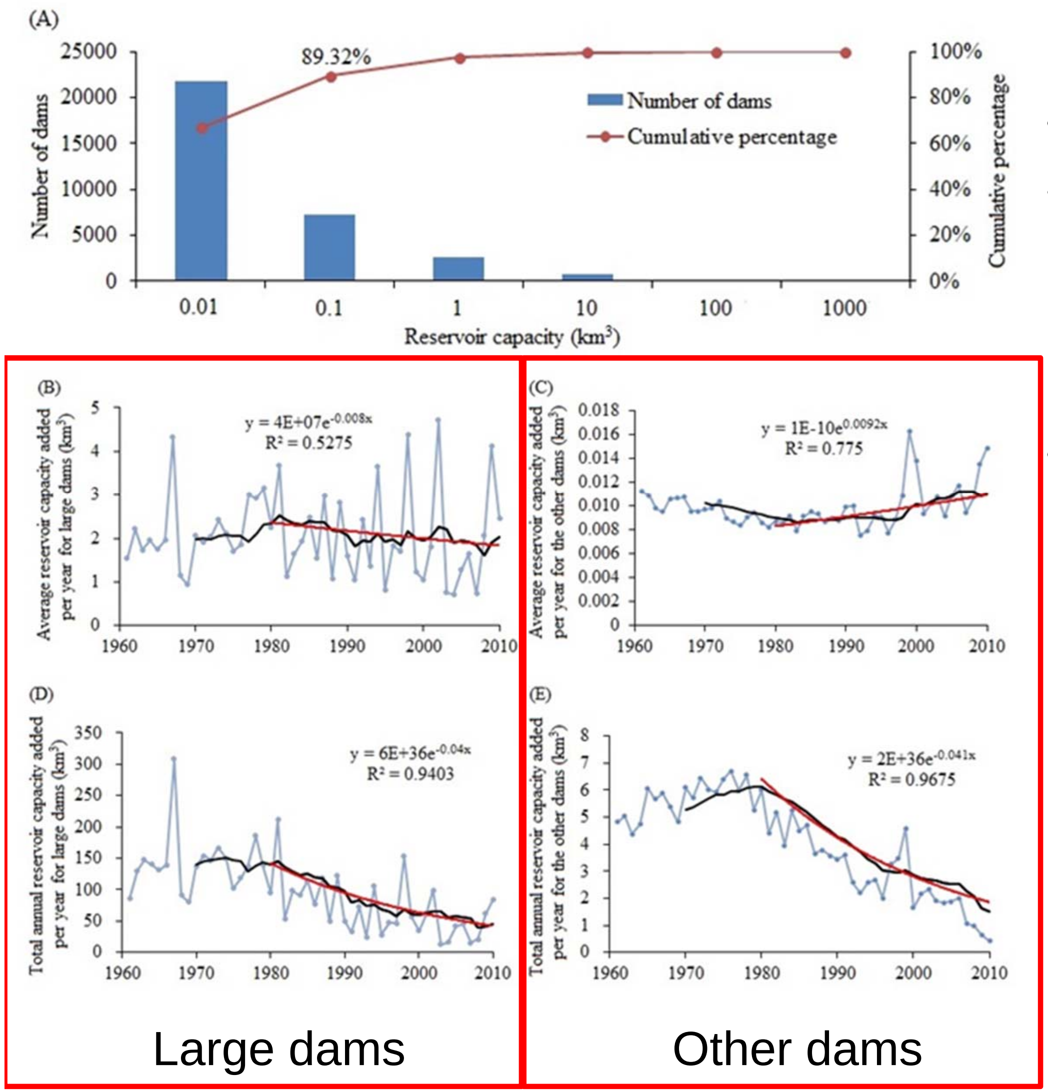
Dam development

Large dams constructed during 1900-2010

- Storage capacity > 0.1 km^3 & height > 10 m
- 2,815 large dams selected from the GRanD database



Projections: 2010-2050



Dam development:

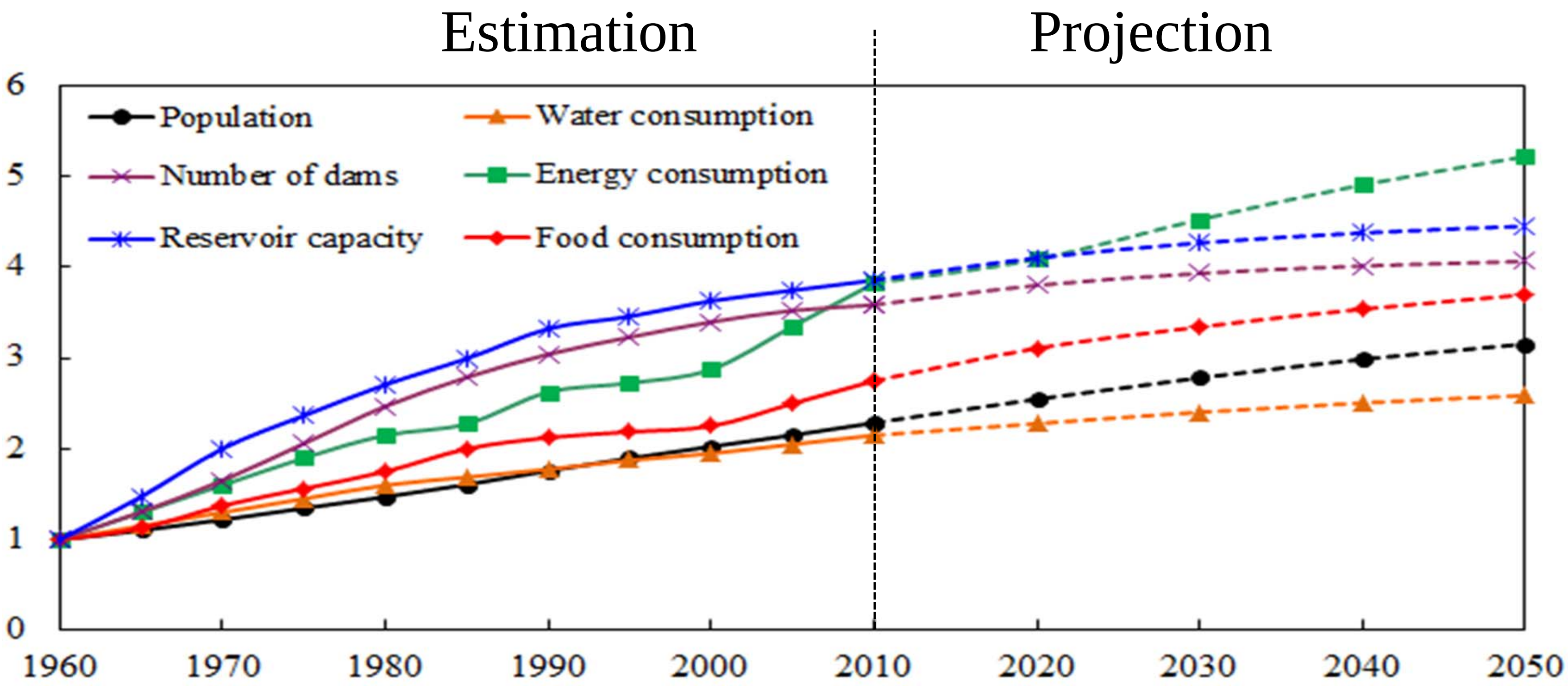
Variable	2010–2020	2020–2030	2030–2040	2040–2050
Growth rate of annual incremental reservoir capacity (1000 km³/yr)	0.051	0.034	0.023	0.015
Incremental average reservoir capacity of each new dam for each year (km³)	0.260	0.284	0.310	0.337
Growth rate of number of dams (/yr)	195	120	74	45

Other variables:

Variable	Equation	R^2
Energy consumption (1000 TWh)	$= -28.1 + 21.2 \times P + 0.0009 \times RC$	0.978
Food consumption (billion ton)	$= -0.04 + 0.22 \times P + 0.0001 \times RC$	0.986
Water consumption (km³)	$= 814.5 + 252.9 \times P + 0.21 \times RC$	0.997

Note: P = population; RC = reservoir capacity.

Projections: 2010-2050



Variable	2010	2020	2030	2040	2050	2050/2010
Population (billion)	6.92	7.71	8.42	9.04	9.5	1.37
Energy consumption (1000 TWh)	134	143	159	172	183	1.37
Food consumption (billion ton)	2.2	2.49	2.67	2.83	2.96	1.34
Water consumption (km^3)	4,300	4,557	4,809	5,014	5,175	1.20
Number of dams	32,473	34,423	35,623	36,363	36,813	1.13
Reservoir capacity (km^3)	7,975	8,483	8,823	9,051	9,204	1.15

Projections: 2010-2050

It is projected that additional 4,340 dams will be constructed by 2050 all over the world.

Question

- Where should/will future dams be located?

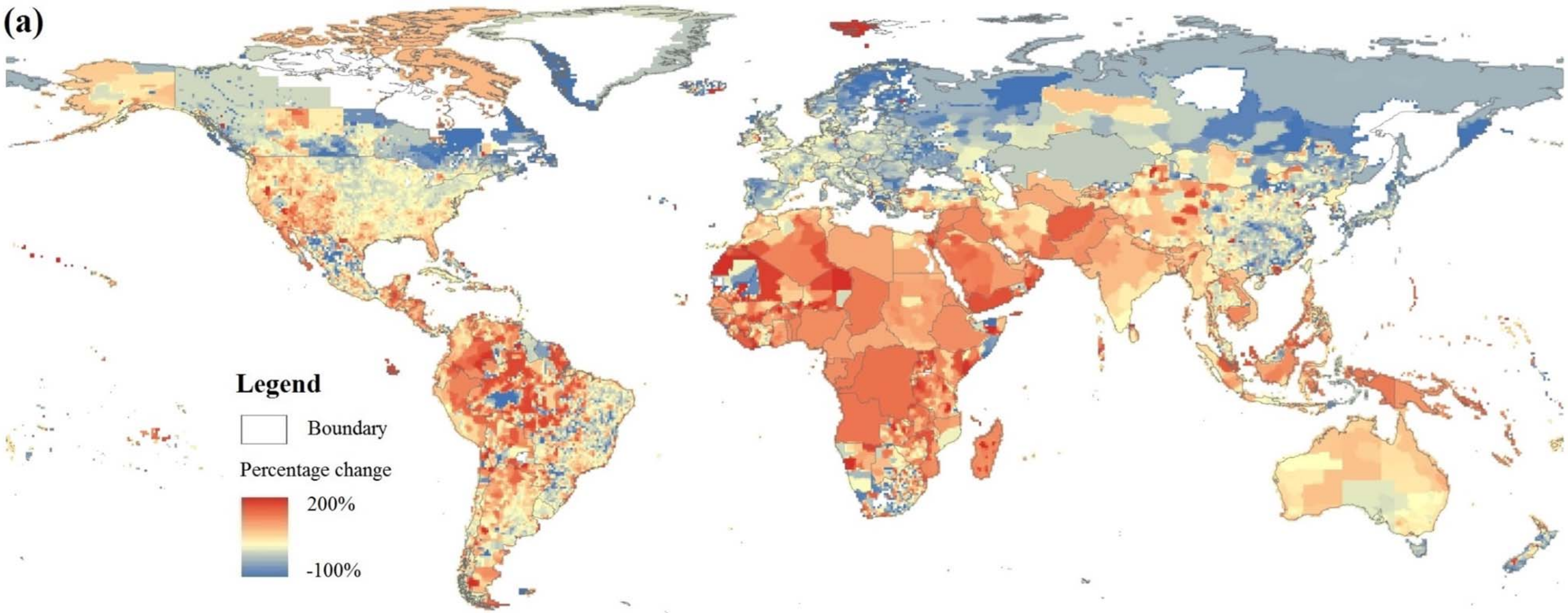
This study only focuses on large dams.

- ✓ Because the catchment areas and slopes of the existing 2,815 large dams were regarded as references

Development of future dams

Population growth

- The percentage change of the population density (2050/2015)
- The projected world's population in 2050 will reach 9.76 billion, which is very close to the value of the medium-growth (9.7 billion) projection scenario of the UN (2015)

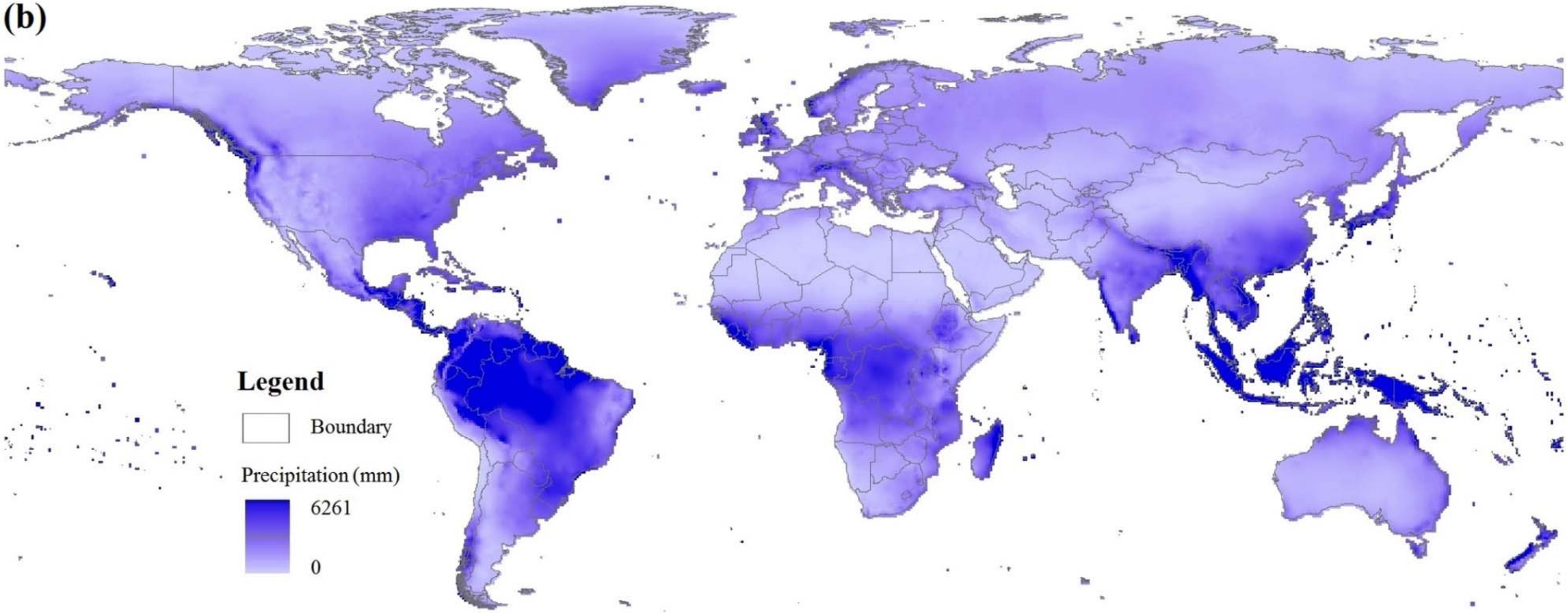


Development of future dams

Water availability

- The multi-year average annual precipitation during 1960-2010
- Higher annual precipitation in the tropical zone, including the southern part of Asia, the western part of Africa, the southern part of North America, and the northern part of South America

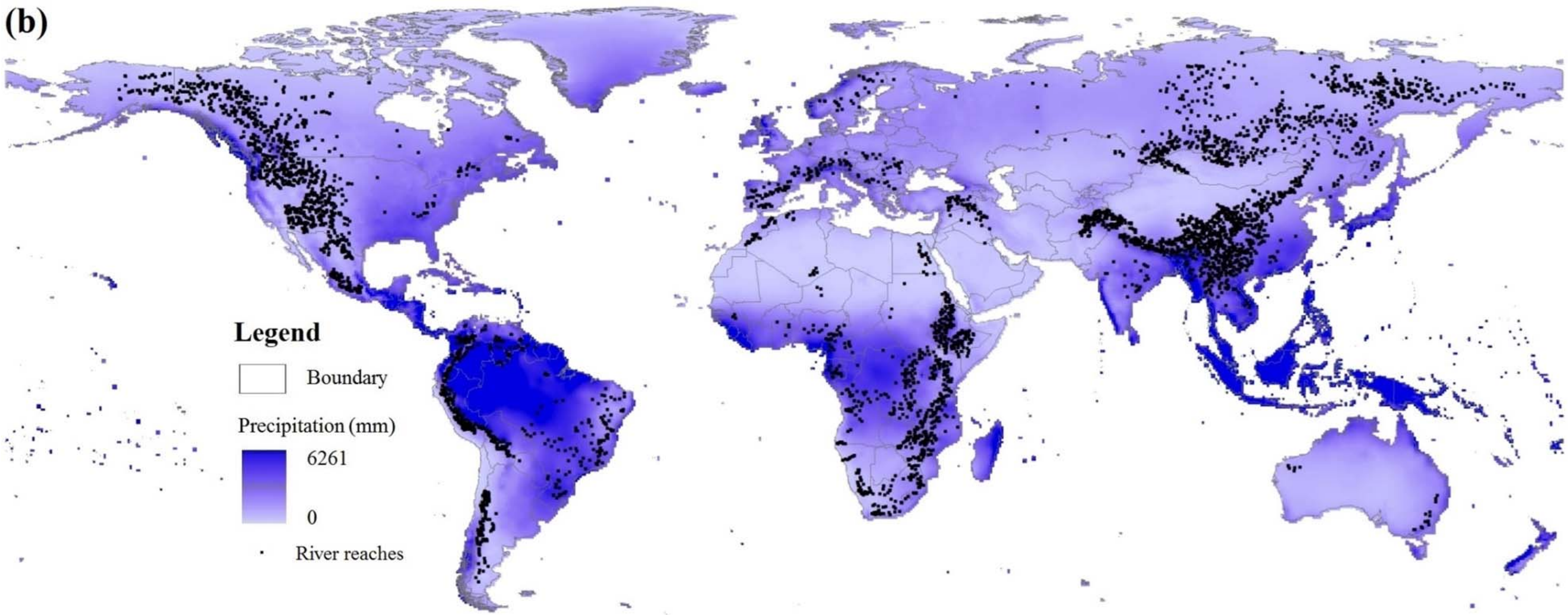
(b)



Development of future dams

Topography

- The locations of the river reaches with both larger catchment areas and slopes, mainly in the Tibet Plateau, the Alps, the East African Plateau and the Ethiopian Plateau, the Rocky Mountains, and the Andes Mountains (5,630 in total)



Development of future dams

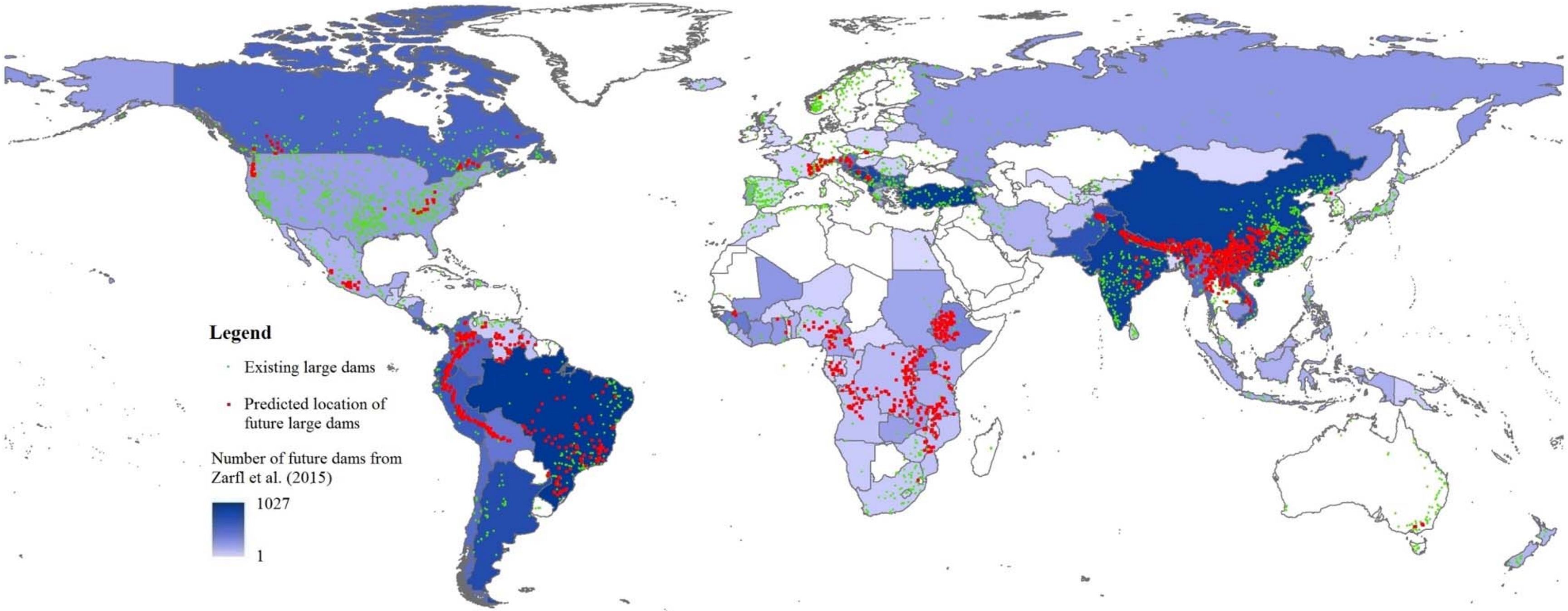
Locations suitable for building dams

- Comprehensively considering both more water resources and suitable conditions of topography
  - ✓ Adequate water availability
  - ✓ Large hydropower resources
- Moreover, dam construction would not be likely in
  - ✓ Some arid regions (e.g., the Siberia region in Asia)
  - ✓ Regions with higher existing exploitation rates (e.g., the United States in North America and Norway in Europe)
  - ✓ Regions with lower population growth (e.g., the Siberia region in Asia and the eastern part in North America)
  - ✓ **1,433** of the 5,630 river reaches were suitable for dam construction

Development of future dams

Predicted locations of future dams

- Compared with the study of Zarfl et al. (2015)



These dams will be constructed mainly in the *Tibet Plateau* and the *Yunnan-Guizhou Plateau* in Asia, in the *East African Plateau* and the *western part of Africa*, in the *Andes Mountains* and the *Brazilian Plateau region* in South America, in the *Rocky Mountains* in North America, in the *Alps* in Europe, and in the *Murray-Darling Basin* in Oceania.

Development of future dams

Predicted locations of future dams

- Compared with the study of Zarfl et al. (2015)

Continent	Number	Possible locations of future large dams
Asia	551	The Tibet Plateau, the Yunnan-Guizhou Plateau
Africa	421	The East African Plateau, the western part
South America	334	The Andes Mountains, the Brazilian Plateau region
North America	80	The Rocky Mountains
Europe	43	The Alps
Oceania	4	The Murray-Darling Basin

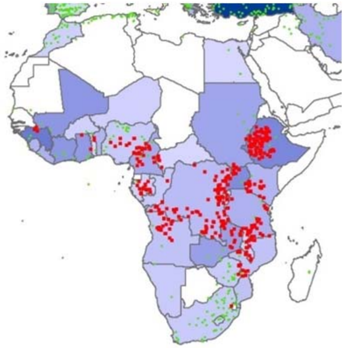
Large dams
VS
Dams

Type		I	II	III	Total
Number of large dams predicted by this study	Amount	721	396	316	1,433
	Per country	17	6	2	6
Number of dams reported by Zarfl et al. (2015)	Amount	2,554	645	501	3,700
	Per country	36	15	4	15

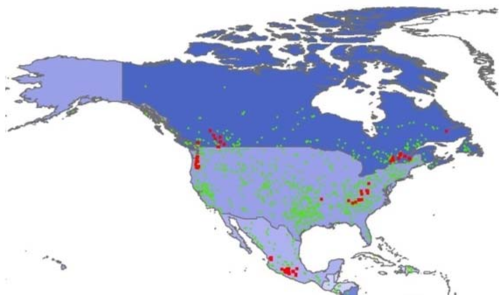
According to Zarfl et al. (2015), there will be 1,361, 200, 1,302, 177 and 652 dams built in the future in Asia, Africa, South America, North America and Europe, respectively.

Development of future dams

Predicted locations of future dams



- Compared with the study of Zarfl et al. (2015)
  - ✓ Have consistent results (Asia and South America)
  - ✓ Have large differences in Africa
    - 421 large dams (our study) vs 200 dams (Zarfl et al., 2015)
    - A large number of the predicted locations of future large dams in Africa are in countries suffering from "economic water scarcity", where lack of investment has limited the plans of dam construction in future, e.g., Democratic Republic of the Congo (81~5), Zambia (15~10), Tanzania (33~7), and Mozambique (22~4)
  - ✓ As expected, dam construction will not be so common in North America
    - Both our study and the study of Zarfl et al. (2015) indicate that the number of future dams in this continent is the smallest
    - 80 large dams (our study) vs 177 dams (Zarfl et al., 2015)
    - USA: 23 large dams (our study) vs 10 dams (Zarfl et al., 2015)



Conclusions

- Water scarcity exists in most countries around the world, especially for Asia and Africa
- Whether dam construction should continue is no longer a question, as the need is obvious
- It is projected that additional 4,340 dams will be constructed by 2050 all over the world, among which 1,433 are large dams
- Taking into account of the current situation of global water scarcity, these large dams are most likely to be constructed in countries that have abundant total available water resources or per capita available water resources

References

Biswas AK. Dams: cornucopia or disaster? International Journal of Water Resources Development 2004; 20(1): 3-14.

Chen J, Shi HY, Sivakumar B, Peart MR. Population, Water, Food, Energy and Dams. Renewable & Sustainable Energy Reviews 2016; 56: 18-28.

International Water Management Institute (IWMI). International Water Management Institute analysis done for Comprehensive Assessment of Water Management in Agriculture using the Watersim model, Chapter 2. 2007.

Kummu M, Ward PJ, de Moel H, Varis O. Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. Environmental Research Letters 2010; 5(3): 034006.

Molden D, et al. Summary, In Molden, D. (Ed.). Water for Food, Water for Life: A Comprehensive Assessment of Water management in Agriculture. 2007.

Organization for Economic Co-operation and Development (OECD). Mitigating Droughts and Floods in Agriculture: Policy Lessons and Approaches, OECD Studies on Water. 2016.

United Nations (UN). World Population Prospects, the 2015 Revision. 2015.

World Water Assessment Programme (WWAP). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. 2012.

Zarfl C, Lumsdon AE, Berlekamp J, Tydecks L, Tockner K. A global boom in hydropower dam construction. Aquatic Sciences 2015; 77(1): 161-170.

Thanks for your attention.

See “*Chen J, Shi HY, Sivakumar B, Peart M. 2016. Population, water, food, energy and dams. Renewable and Sustainable Energy Reviews, 56, 18-28. Doi: 10.1016/j.rser.2015.11.043*” for more details.