全球流域城市扩展的格局和分布

Patterns and distributions of urban expansion in global watersheds

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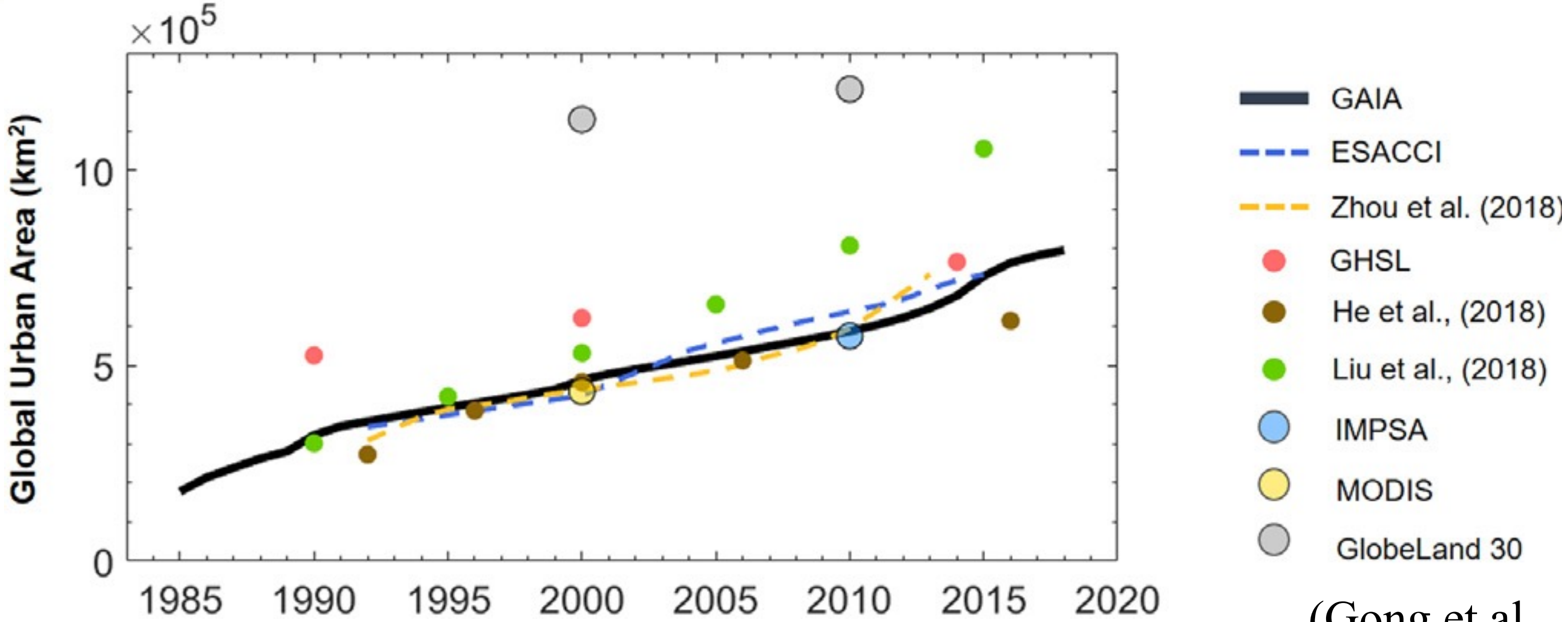
CONTENTS

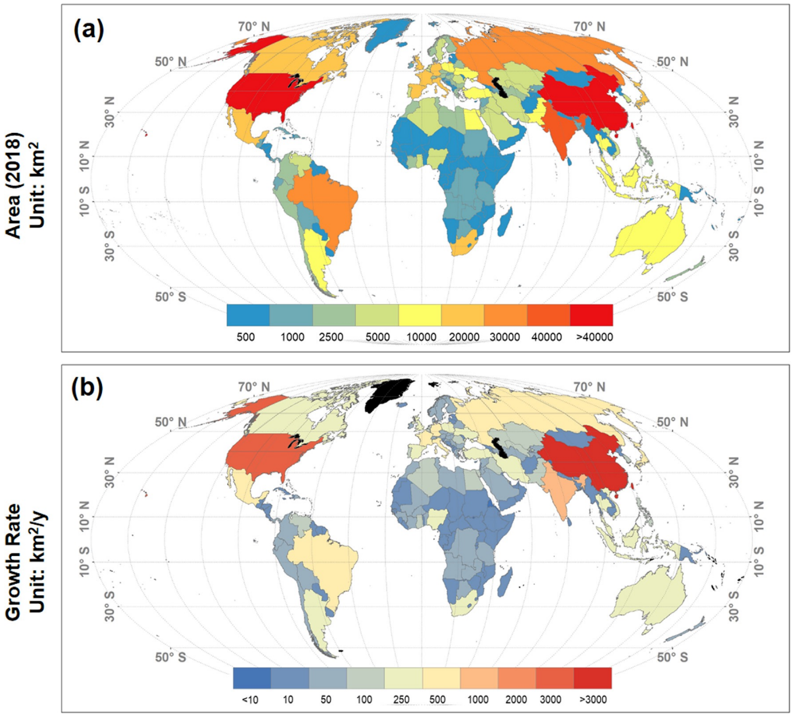
Characterizing the trend of urban expansion is of great significance



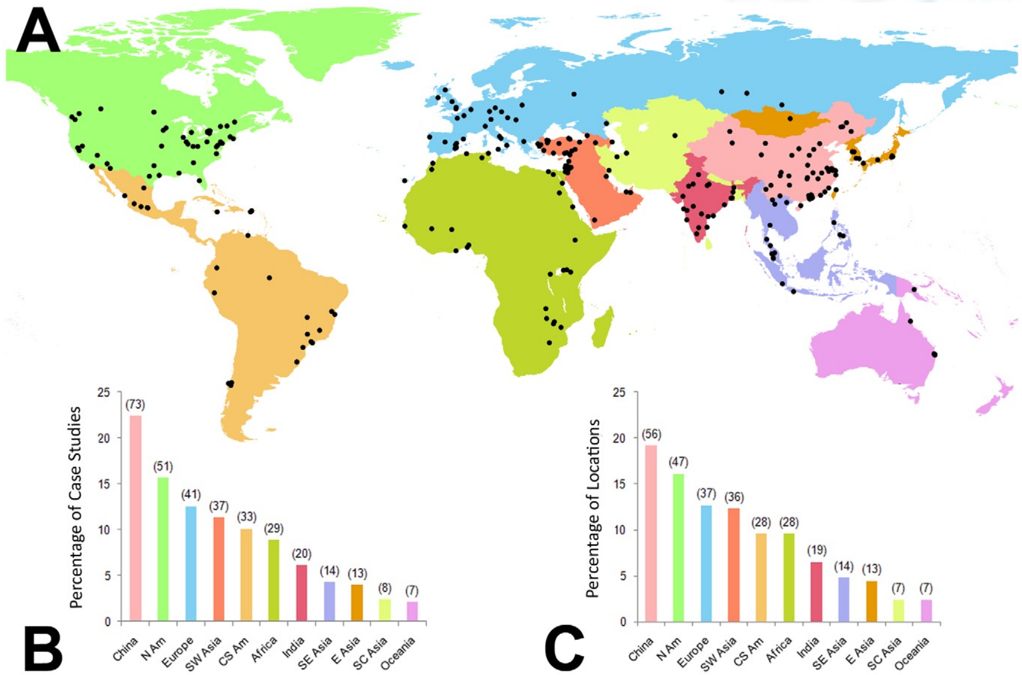
(Gong et al., 2020)

- In 2018, the global urban land area reached 797.1×10^3 km^2, 1.5 times that in 1990
- By 2030, the global urban land area will be three times that in 2000
- Urban expansion provides opportunities for residents to improve their well-being, it also puts enormous pressure on the regional environment

Existing studies are mainly based on administrative divisions



(Gong et al., 2020)



(Seto et al., 2011)

- Total area: North America and Asia show the largest increase
- Speed: China and India ranked high
- Trend of urban expansion speed: developing countries in Asia, Africa, and South America experienced accelerating urban expansion, while developed countries in North America, Europe and Australia started to slow down

Assessing urban development within watersheds would provide a valuable addition to earlier findings

(1) The amount and speed of urban expansion can indicate the level of **human activities** and **their reliance** on natural resources in a given watershed

Urban expansion relies on watersheds to continuously provide indispensable natural resources.

Such a quantitative measure of urban expansion at the watershed scale is still lacking, globally.

Amount, speed and trend

Assessing urban development within watersheds would provide a valuable addition to earlier findings

(2) Urban expansion exerts **in situ** and **far-reaching** ecological and environmental impacts, especially regional hydrological and biogeochemical cycles

It not only occupies natural habitat and threaten local biodiversity and food security, but also alter regional hydrological and biogeochemical cycles and lead to elevated flood risk and air- or water-pollutant discharge

Heterogeneity of urban expansion within a watershed are indispensable for a watershed-scale governance shift.

heterogeneity

Assessing urban development within watersheds would provide a valuable addition to earlier findings

(3) Urban expansion in some **endoreic watersheds** was catching up with **exoreic watersheds**, which may render unprecedented pressures on local ecosystems and human well-being

- Most endoreic watersheds located in arid and semi-arid climates,
- Urban expansion in endorheic watersheds is commonly restricted by topographic and hydrological conditions.
- Urban expansion in these endorheic watersheds may manifest in a way of low-density and low-efficient form

It is imperative to compare **the modes** and **efficiency** of urban expansion between the endorheic and exoreic watersheds

mode and sprawl

Research target

Research target

This research analyzes the spatiotemporal dynamics of urban expansion among global watersheds and compare their characteristics between endorheic and exoreic watersheds?

(1) we quantified **speed, trend, heterogeneity, mode** and **efficiency** of urban expansion for five periods of the last 24 years based on the 1992-2016 global urban land dataset.

(2) we discussed the implications of the watershed-scale results and their potential applications in future studies.

CONTENTS

2.1 Data

- **Multitemporal** urban land dataset from 1992 to 2016 (He et al., 2019)
  - 1992, 1996, 2000, 2006, 2010 and 2016
- HydroSHEDS drainage dataset developed by the World Wildlife Fund for watershed division
  - Third, fourth, fifth-level divisions (200+, 800+, 2000+)
- Urban population data from HYDE 3.2 dataset
  - 1990, 2000, 2006, 2010 and 2016
- City boundaries from Global Administrative Area Dataset

2.2 Quantifying the speed of urban expansion

Considering the large variations in watershed areas, we used a normalized indicator, the watershed-standardized annual average rate of urban expansion, to compare urban expansion speeds among watersheds (He et al., 2014).

$$K_{t_2-t_1} = \frac{Area_{t_2} - Area_{t_1}}{S(t_2 - t_1)}$$

Area: urban land area
S: watershed area.
K: urban expansion speed with an unit of km^2/km^2 per year

2.3 Examining trends in urban development

To identify whether urban expansion within watersheds was **accelerating** or **decelerating**, we used an index, called the deceleration factor M.

$$\mathbf{M} = \frac{\boldsymbol{K}_{10-16}}{\boldsymbol{K}_{92-16}} \times 100\%$$

0 < M < 100% : deceleration

- fluctuant decelerating watersheds
- continuous decelerating watersheds

M > 100%: acceleration

- fluctuant accelerating watersheds
- continuous accelerating watersheds

Others

2.4 Analyzing the heterogeneity in urban expansion within watersheds

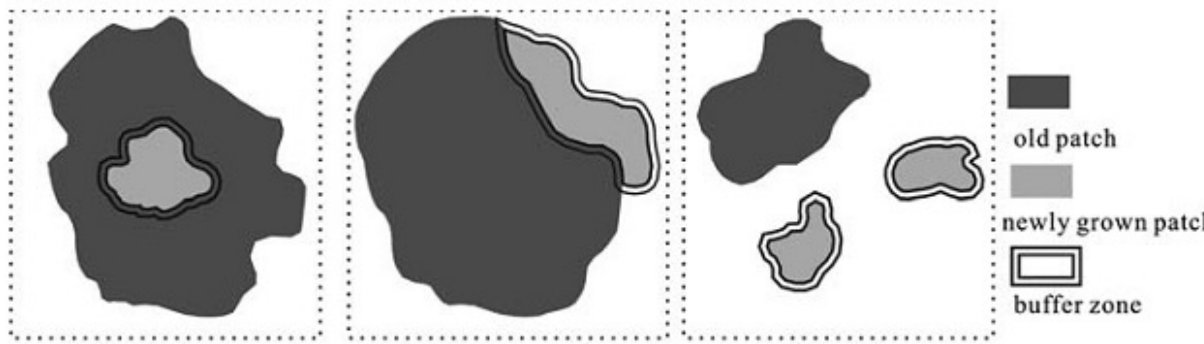
Urban development may vary substantially between the **upper-**, **middle-** and **lower-reaches** of a watershed, which could result in spatially heterogeneous impacts on regional ecosystems and environment

- We calculated the Gini coefficient of the speeds of urban expansion (k) within each watershed
- We used the administrative boundaries because the finer scale watershed boundary may include multiple cities and cause incomparability among watersheds
- we only included watersheds having at least **five cities** defined in the GADM data set. After the screening, 446 out of 877 fourth-level watersheds and 764 out of 2,274 fifth-level watersheds were left in for analysis.

2.5 Analyzing urban expansion mode

Changes in urban expansion mode are closely related to the process of urban development. We used the landscape expansion index (LEI) to classify urban expansion modes (Liu et al., 2010) to either leapfrog, edge-expansion, or infilling growth.

$$\mathrm{LEI} = \frac{A_0}{A_0 + A_\gamma} \times 100$$



(a) Infilling (b) edge-expansion (c) leapfrog

LEI=0: leapfrog
0< LEI <=50: edge expansion
50< LEI <=100: infilling growth

2.6 Investigating urban expansion efficiency

Low-density urban expansion (i.e., urban sprawl) was blamed for its adverse environmental and ecological impacts. Thus, we further used an urban sprawl index to identify urban sprawl (Gao et al., 2016),

$$\mathrm{USI} = \frac{\mathrm{Area}_{t2} - Area_{t1}}{Area_{t1} \times (t_2 - t_1)} - \frac{UP_{t2} - UPt_1}{UP_1 \times (t_2 - t_1)}$$

$\mathrm{USI}_{2010\text{-}2016} < \mathrm{USI}_{1992\text{-}2016}$

- Continuous decline
- Fluctuant decline

$\mathrm{USI}_{2010\text{-}2016} > \mathrm{USI}_{1992\text{-}2016}$

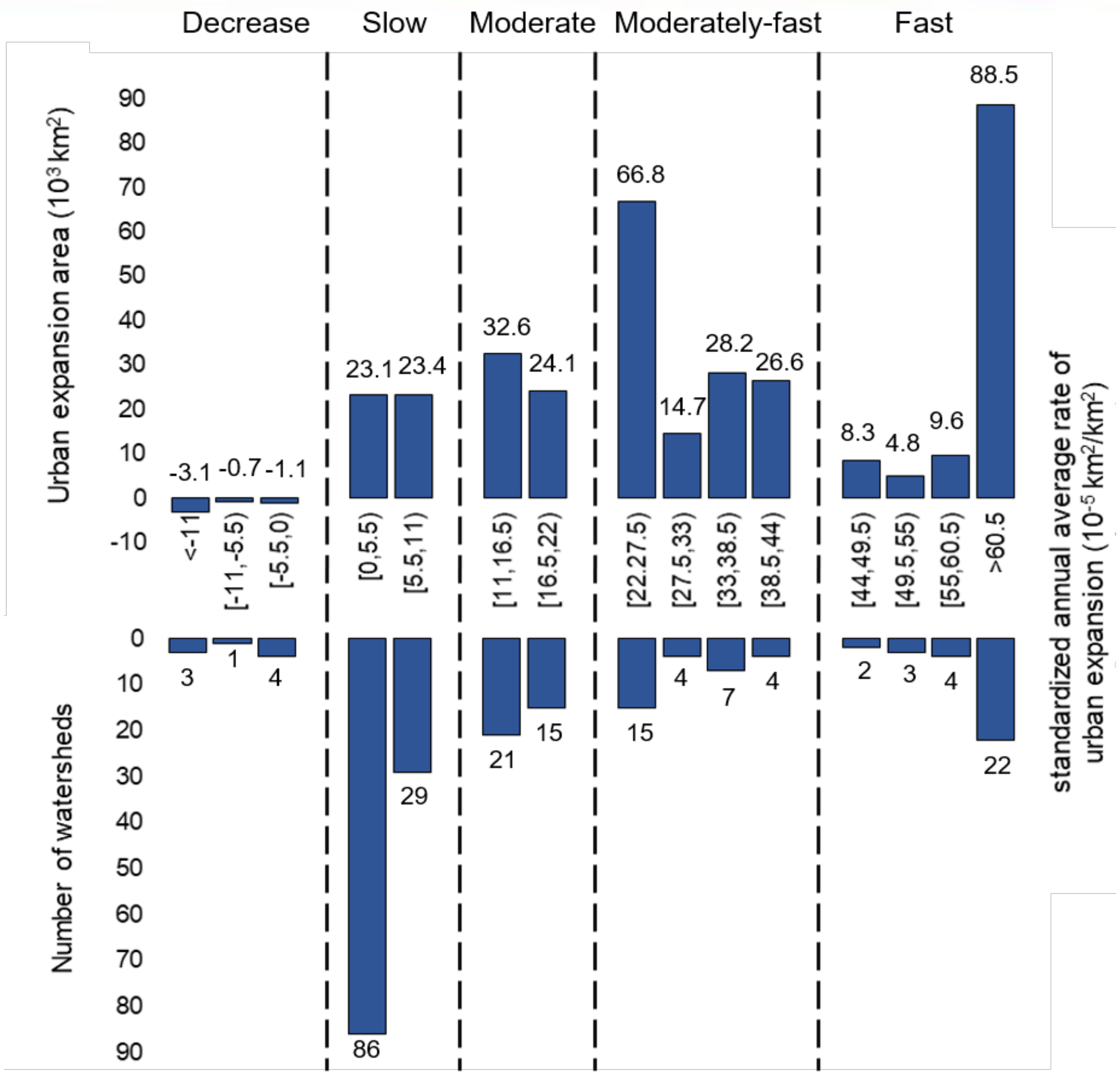
- Continuous increase
- Fluctuant increase

CONTENTS

3.1 Speed: Asia and North America's urban land expanded the fastest

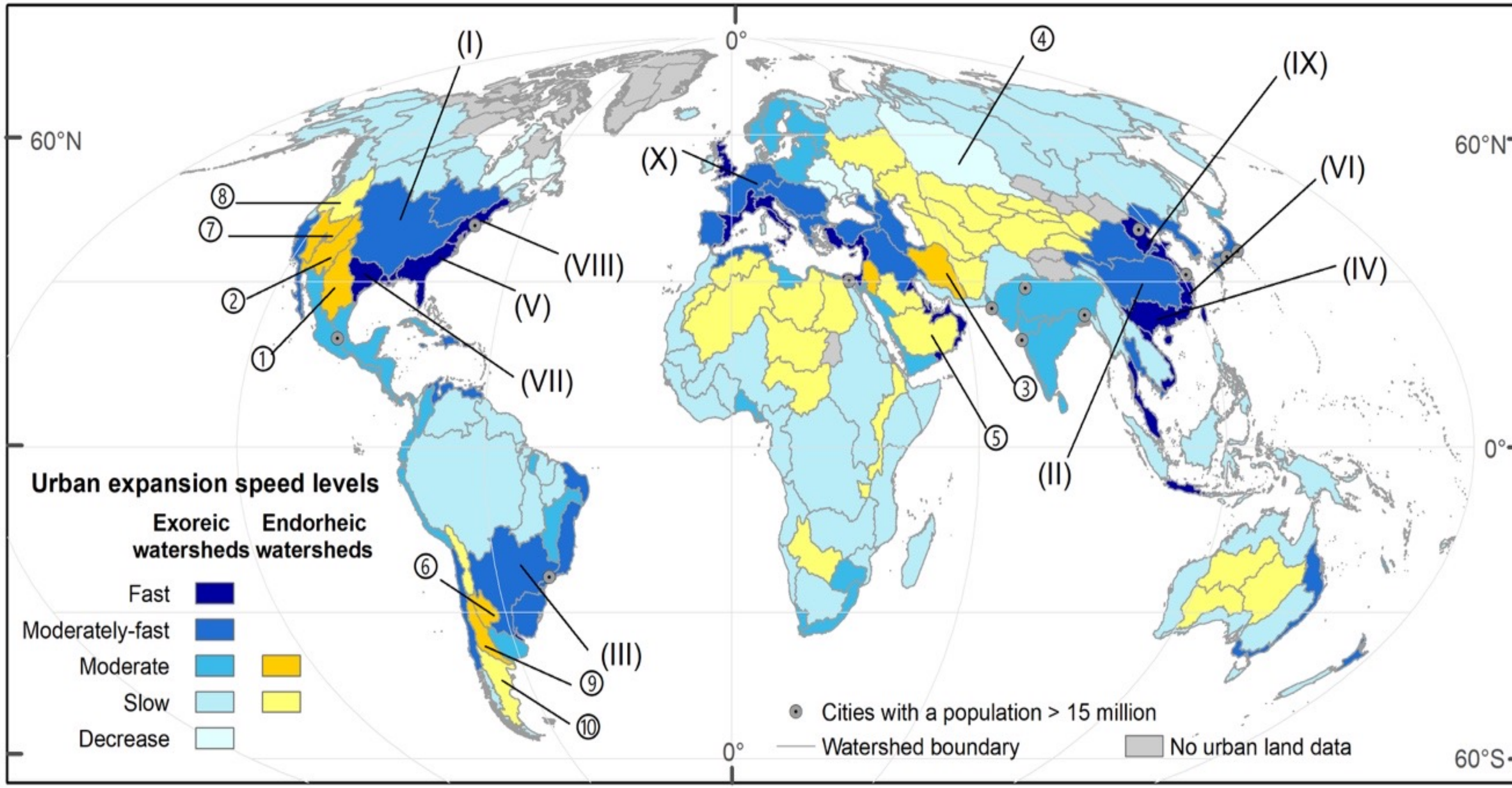
Area	Urban land area ($10^3 km^2$)						Standardized annual average rate of urban expansion K (10^{-5} km^2/km^2)					
	1992	1996	2000	2006	2010	2016	1992-1996	1996-2000	2000-2006	2006-2010	2010-2016	1992-2016
Global	275.36	388.83	462.3	518.39	576.18	621.24	22.25	14.41	7.33	11.33	5.89	11.31
Asia	53.15	80.94	101.75	126.57	147.23	**163.05**	33.36	24.98	19.86	24.80	12.66	**21.99**
North America	85.74	112.72	132.4	140.6	153.67	**164.5**	42.38	30.91	8.59	20.53	11.34	**20.62**
Europe	86.02	111.81	130.58	140.84	149.45	**153.46**	36.10	26.28	9.58	12.05	3.74	**15.73**
South America	29.4	50.42	58.61	66	74.76	83.05	29.43	11.47	6.90	12.27	7.74	12.52
Africa	7.86	13.11	16.57	19.61	23.97	27.92	4.38	2.89	1.69	3.64	2.20	2.79
Australia	7.28	13.29	15.88	18.44	20.64	22.57	13.91	5.99	3.95	5.09	2.98	5.90
Arctic of North America	0.05	0.34	0.37	0.4	0.42	0.45	1.17	0.12	0.08	0.08	0.08	0.27
Siberia	5.87	6.21	6.15	5.94	6.04	6.24	0.66	-0.12	-0.27	0.19	0.26	0.12

3.1 Urban land expansion among third-level watersheds is distributed rather unequally



- Among the 220 watersheds, most experienced a slow speed of urban expansion (115)
- Vast majority of all urban expansion is included in a small number of moderately-fast and fast growing watersheds

3.1 Spatial distribution of speed



- Fast expanding watersheds are mainly distributed in eastern and southern Asia, northwestern North America, Europe, and southeastern South America

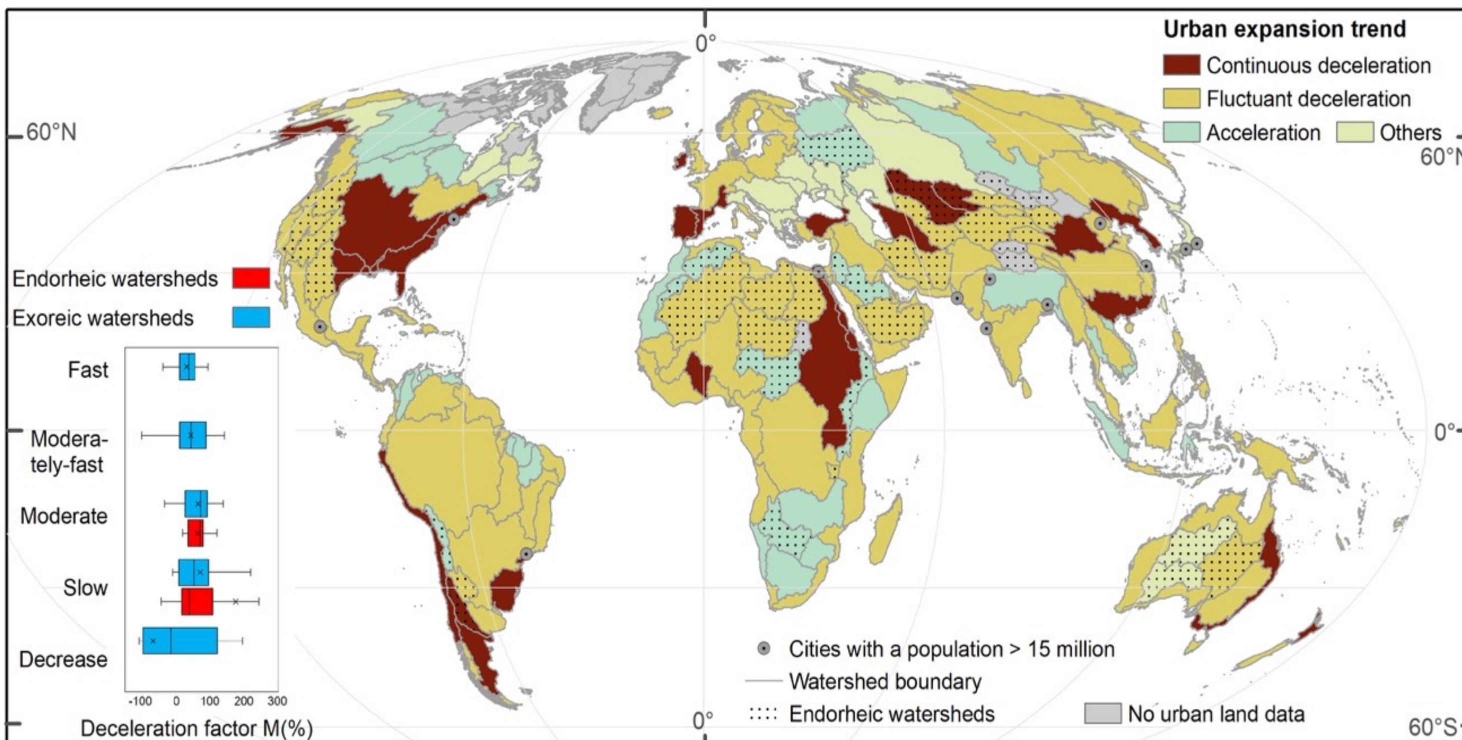
3.1 The speed of urban expansion was slower in endorheic watersheds than in exoreic watersheds

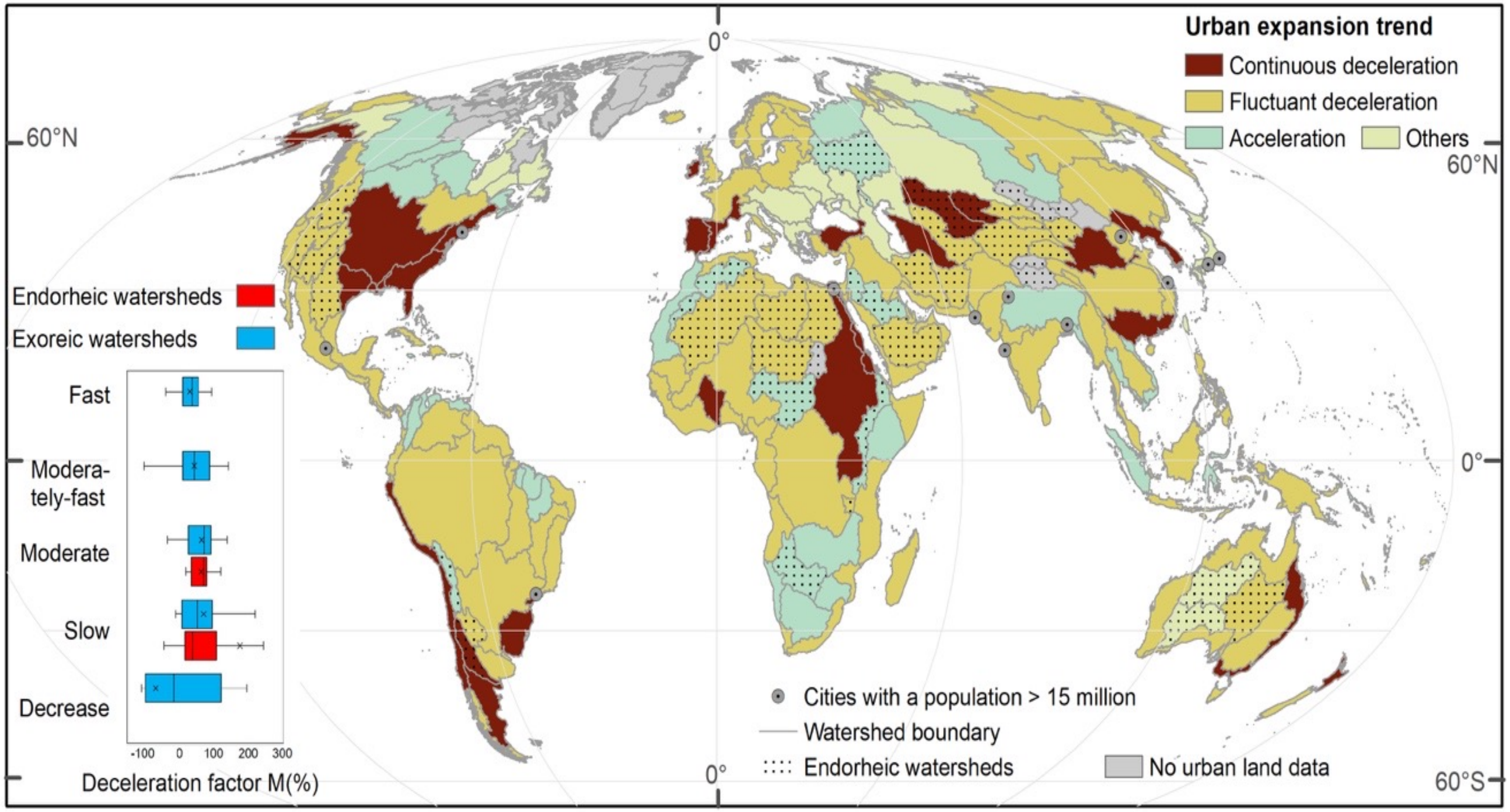
M (%)	1992 to 1996	1996 to 2000	2000 to 2006	2006 to 2010	2010 to 2016	1992 to 2016
All the watersheds	22.3 (89.3)	14.4 (66.0)	7.3 (40.2)	11.3 (61.4)	5.9 (25.8)	11.3 (43.8)
Endorheic watersheds	6.8 (13.8)	5.30 (9.8)	2.3 (4.7)	3.8 (3.8)	2.2 (4.3)	**3.8 (6.0)**
Exoreic watersheds	26.6 (95.7)	17.0 (71.1)	8.7 (43.5)	13.4 (44.4)	6.9 (28.1)	**13.4 (47.0)**

- the average annual rate of urban expansion in endorheic basins was 3.77×10^{-5} km^2/km^2, which was only approximately 1/4 of the rate in the exoreic basin

3.2 Deceleration of urban expansion

- From 1992 to 2016, urban expansion decelerated. M=52.2%.
- Europe, the Arctic of North America, and Australia decelerated the most (23.8%, 30.0% and 50.5%).
- Among the 220 watersheds, the urban expansion of 154 slowed down





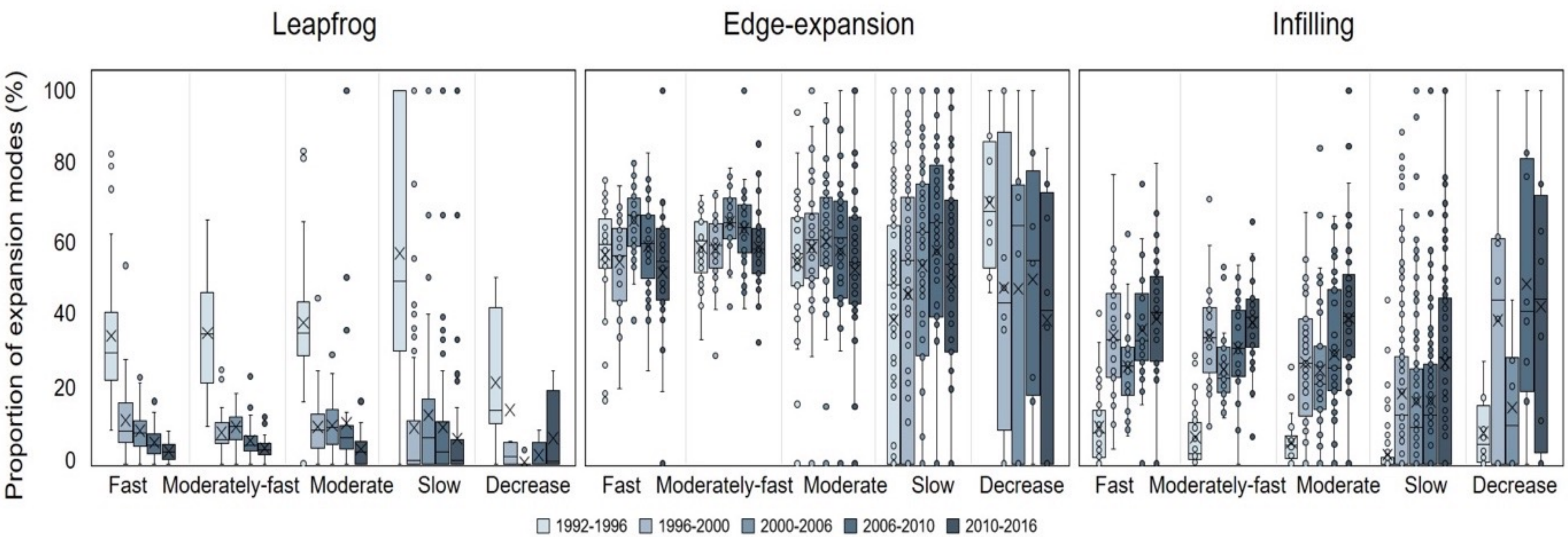
- Urban expansion in both endorheic and exoreic watersheds showed a decelerating trend
- Urban expansion in endorheic watersheds decelerated slower than that in exoreic watershed (58.5% vs. 51.6%)
- Urban expansion in a few endorheic watersheds did not slow down or even accelerated

3.3 Heterogeneity in urban expansion

- The unevenness of urban expansion speeds within watersheds increased over time
- Urban land expanded **more unevenly** in exoreic watersheds
- It is worth noting that the gap in uneven urban development between exoreic and endorheic basins **narrowed** over time

Gini coefficient)	1992 to 1996	1996 to 2000	2000 to 2006	2006 to 2010	2010 to 2016	1992 to 2016
All the watersheds	0.63 (0.25)	0.76 (0.19)	0.76 (0.20)	0.76 (0.21)	0.76 (0.19)	0.64 (0.23)
Endorheic watersheds	0.59 (0.29)	0.73 (0.22)	0.74 (0.20)	0.77 (0.19)	0.75 (0.23)	0.65 (0.25)
Exoreic watersheds	0.64 (0.24)	0.77 (0.19)	0.77 (0.20)	0.76 (0.21)	0.77 (0.18)	0.63 (0.22)

3.4 Urban expansion mode



- The leading mode of urban expansion was **edge expansion**, and the proportion of edge expansion in all 220 watersheds exceeded 50%, between 56.8% and 60.7%
- Leapfrog urban expansion decreased and infilling urban expansion increased

3.4 Urban expansion is dominated by edge expansion in both endorheic and exoreic watersheds

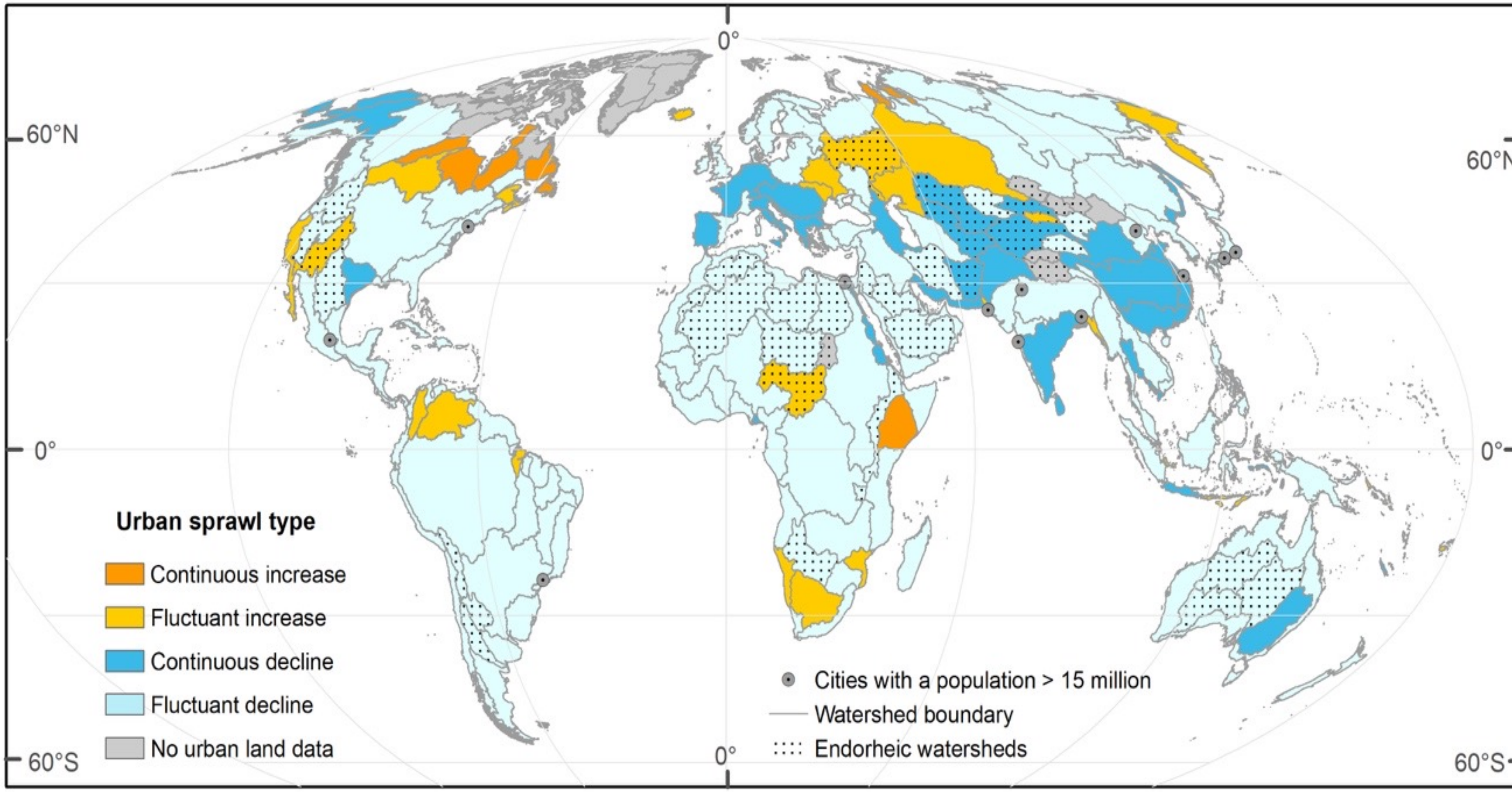
	Exoreic watersheds			Endorheic watersheds		
	Leapfrog	Edge-expansion	Infilling	Leapfrog	Edge-expansion	Infilling
1992-1996	34.6%	55.8%	9.6%	35.8%	56.8%	7.4%
1996-2000	10.2%	58.7%	31.1%	14.7%	58.9%	26.4%
2000-2006	10.9%	66.6%	22.5%	10.0%	55.9%	34.1%
2006-2010	6.8%	62.7%	30.5%	6.2%	59.6%	34.2%
2010-2016	4.3%	54.9%	40.8%	4.3%	45.8%	49.9%
1992-2016	17.8%	59.1%	23.1%	19.1%	55.8%	25.1%

- The degrees of reduction in leapfrog expansion and increase in infilling expansion are stronger in endorheic basins than in exoreic basins.

3.5 Urban expansion efficiency

		1992-2000	2000-2006	2006-2010	2010-2016	1992-2016
All watersheds (n=220)	number of watersheds with an USI>0	166	120	151	100	167
	average USI	0.181	0.009	0.016	0.007	0.109
	standard deviation of USI	0.280	0.047	0.039	0.095	0.210
Endorheic watersheds (n=36)	number of watersheds with an USI>0	26	22	18	14	**29**
	average USI	0.225	0.004	0.008	-0.001	**0.139**
	standard deviation of USI	0.426	0.021	0.032	0.036	0.290
Exoreic watersheds (n=184)	number of watersheds with an USI>0	140	98	133	86	138
	average USI	0.172	0.010	0.018	0.009	0.103
	standard deviation of USI	0.240	0.050	0.041	0.103	0.191

- Urban land grew faster than the urban population in 75.9% of the world's watersheds
- The trend of low-density urban sprawl in the endorheic watersheds is **more prominent**
- Urban sprawl in global watersheds has shown a downward trend



- Urban sprawl still manifested in a few endorheic watersheds, such as the Colorado river basin in the United States, Volga river basin in Russia, and Ili river basin in China

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4.1 The watershed perspective for understanding the impacts of urban development

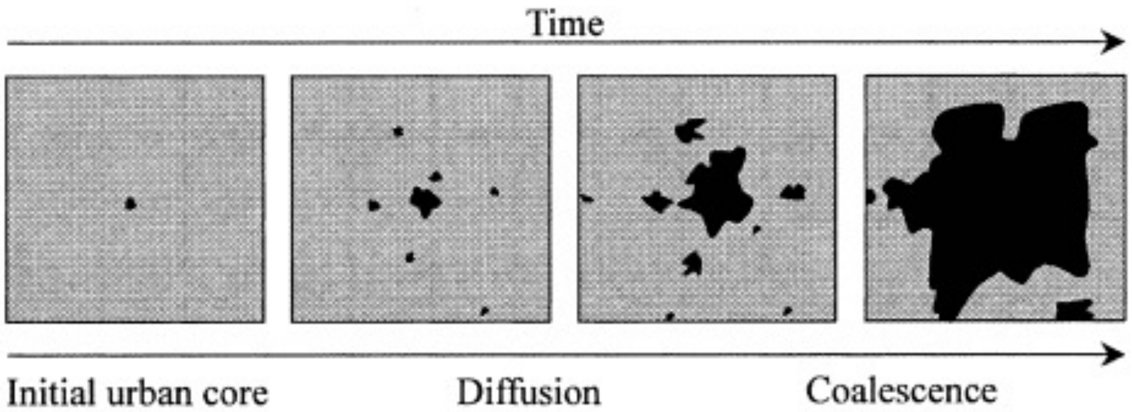
- **The watershed-scale results in this study not only corroborated previous findings, but also shed light on understanding the dynamics of urban expansion at watershed scale**

(1) While we know from previous studies that most urban expansion is concentrated in the United States, China and Europe (Seto et al., 2011; Liu et al., 2020), this study shows that it is in fact concentrated in only a few watershed, which are mostly within these countries and regions

- Approximately 40% of the total urban expansion is located in only a few moderately-fast expanding watersheds distributed in northwestern North America (e.g., Mississippi River Basin), eastern Asia (e.g., Yangtze River basin), and southeastern South America (La Plata River Basin).

amount

4.1 The watershed perspective for understanding the impacts of urban development



(Dietzel et al., 2005)

(2) Our results also supported the “diffusion-aggregation” dynamics of urban expansion found by previous researchers

- Decrease in leapfrog and increase in Infilling growth
- Global scale also found that urban expansion conforms to this diffusion-aggregation process (Liu et al, 2016).

mode

4.1 The watershed perspective for understanding the impacts of urban development

(3) 154 out of the 220 tertiary watersheds exhibited a trend of **deceleration** in urban expansion speed

- This trend is **more evident in developed economies**, such as the Mississippi River basin, the North Atlantic coast basin in North America, and the Rhine River basin in Europe, than the developing economies, e.g. in the Yangtze River basin in east Asia and the La Plata River basin in South America
- This deceleration in developed economies could be a good news for reducing the adverse in situ impacts of urban expansion. However, the distant (or tele-coupled) impacts of urban expansion imposed by the developed economies to the developing economies cannot be ignored

trend

4.1 The watershed perspective for understanding the impacts of urban development

T-test for the characteristics of urban expansion between the endorheic and exoreic watersheds from 1992 to 2016

	Urban expansion speed (k)	Deceleration factor (M)	Heterogeneity of urban expansion speeds (Gini)	Urban sprawl (USI)	Percentage of leapfrog	Percentage of edge expansion	Percentage of infilling
3rd level	<0.001	0.313	0.681	0.331	0.849	0.681	0.291
4th level	0.002	0.381	0.036	0.34	0.045	0.877	0.001
5th level	<0.001	0.781	0.006	<0.001	0.903	0.222	0.169

(4) Endorheic watershed differ significantly from exoreic watersheds in terms of their expansion speed and inequality of expansion within these watersheds

- endorheic watersheds' urban expansion are catching up
- endorheic watersheds was still at the stage of rapid growth in few large cities
- endorheic watersheds' urban expansion are catching up and following the trends of exoreic watersheds in a sprawling manner

Speed and heterogeneity

4.2 Implications of watershed-scale urban expansion

Urban expansion and its speed are important proxies for anthropogenic activities

- researchers have developed a number of fine-scale, long-term databases for examining the dynamics of global watersheds
- However, most of these databases only include a snapshot of urban land cover data. Thus, using these databases to estimate the anthropogenic stresses on global watersheds may lead to **biased results**

SCIENTIFIC DATA

OPEN

DATA DESCRIPTOR

Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution

Simon Linke[1*], Bernhard Lehner[2*], Camille Ouellet Dallaire[2], Joseph Ariwi[2], Günther Grill[2], Mira Anand[2], Penny Beames[2], Vicente Burchard-Levine[2], Sally Maxwell[2], Hana Moidu[2], Florence Tan[2] & Michele Thieme[3]

SCIENTIFIC DATA

OPEN

Data Descriptor: FLO1K, global maps of mean, maximum and minimum annual streamflow at 1 km resolution from 1960 through 2015

Received: 3 October 2017
Accepted: 8 February 2018
Published: 27 March 2018

Valerio Barbarossa[1], Mark A.J. Huijbregts[1,2], Arthur H.W. Beusen[3], Hylke E. Beck[4], Henry King[5] & Aafke M. Schipper[1,2]

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES
» Freshwater ecology
» Biogeography
» Macroecology
» Biodiversity

Near-global freshwater-specific environmental variables for biodiversity analyses in 1 km resolution

Sami Domisch[1], Giuseppe Amatulli[1] & Walter Jetz[1]

Environmental Research Letters

LETTER

An index-based framework for assessing patterns and trends in river fragmentation and flow regulation by global dams at multiple scales

Günther Grill[1], Bernhard Lehner[1], Alexander E Lumsdon[2,3], Graham K MacDonald[4], Christiane Zarfl[2,6] and Catherine Reidy Liermann[5]

speed

4.2 Implications of watershed-scale urban expansion

The impacts of urban expansion are not restricted by city boundary

- Previous studies have found that urban activities and urban expansion could incur heat islands (Manoli et al., 2019), acid islands (Du et al., 2015), and fog islands (Zhu et al., 2020), which are not constrained by city boundaries and can **reach up to 10 km to 60 km** away from the periphery of existing built-up land.
- The traditional territorially-based urban governance system, which is confined by political boundaries, has been continuously challenged by the "**silo effects**" stemmed from problems of inter-jurisdictional, cross-level and inter-departmental fragmentation.
- The "**watershed approach**", which indicates a paradigmatic shift from political boundaries to hydrological ones, has been widely prescribed for carrying out more ecologically meaningful forms of governance (Cohen and Davidson, 2011).

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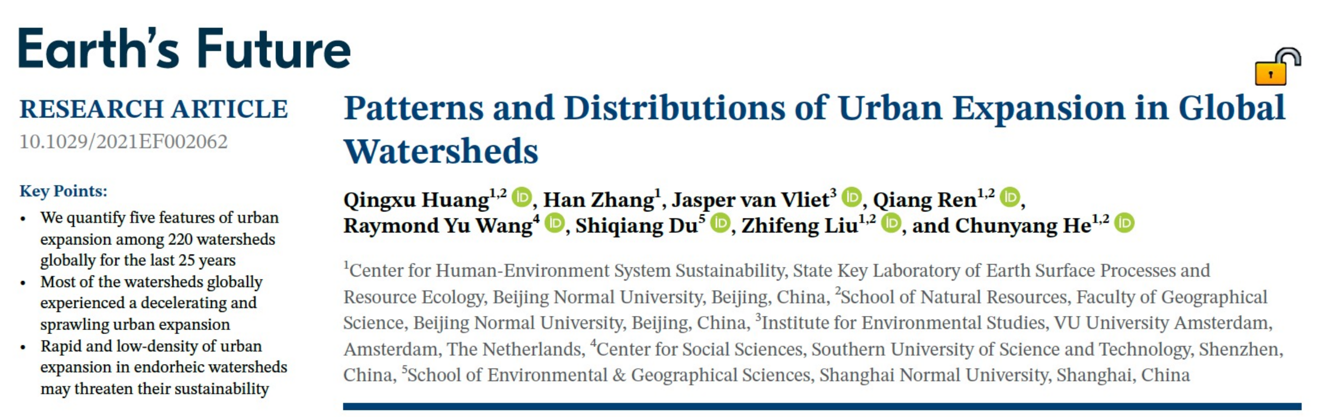
Conclusions

- Global urban expansion is **decelerating** at the watershed scale from 1992 to 2016. The average annual rate of urban expansion dropped from 22.3×10^{-5} km^2/km^2 per year in 1992-1996 to 5.9×10^{-5} km^2/km^2 per year in 2010-2016, which equals a decrease of 74%.
- Urban expansion in endorheic watersheds **lagged behind** that in exoreic watersheds. The average annual rate of urban expansion in endorheic watersheds was approximately 1/4 of the corresponding value in the exoreic watersheds. Moreover, urban expansion in endorheic watersheds was still at the stage of rapid growth in few large cities, while developments in exoreic watershed became gradually more spread over different cities.
- Urban land increased faster than the urban population in approximately 75% of all the watersheds globally. **Urban sprawl** in a **few endorheic watersheds** was still evident, such as in the Colorado river basin, the Volga river basin, and Ili river basin. In these watersheds, it is necessary to control the low-density growth of urban sprawl and encourage the improvement of the efficiency of urban land use.


Earth's Future

RESEARCH ARTICLE
10.1029/2021EF002062

Key Points:
- We quantify five features of urban expansion among 220 watersheds globally for the last 25 years
- Most of the watersheds globally experienced a decelerating and sprawling urban expansion
- Rapid and low-density of urban expansion in endorheic watersheds may threaten their sustainability

Patterns and Distributions of Urban Expansion in Global Watersheds

Qingxu Huang[1,2], Han Zhang[1], Jasper van Vliet[3], Qiang Ren[1,2], Raymond Yu Wang[4], Shiqiang Du[5], Zhifeng Liu[1,2], and Chunyang He[1,2]

[1]Center for Human-Environment System Sustainability, State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, China, [2]School of Natural Resources, Faculty of Geographical Science, Beijing Normal University, Beijing, China, [3]Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands, [4]Center for Social Sciences, Southern University of Science and Technology, Shenzhen, China, [5]School of Environmental & Geographical Sciences, Shanghai Normal University, Shanghai, China

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资助项目：

国家重点研发项目（2019YFA0607203）

Original global multitemporal urban land data set from 1992 to 2016 (https://doi.pangaea.de/10.1594/PANGAEA.892684).
Watershed scale results, expected to join the HYDROSHEDS website (https://hydrosheds.org)

Table S2 Urban expansion speed among the fourth and fifth-level watersheds

		Fast	Moderately fast	Moderate	Slow	Decrease
Fourth level watersheds (n=877)	Number of watersheds	127	95	124	485	46
	Expanded urban land (10^3 km^2)	166.7	83.8	56.5	41.6	-6.1
Fifth level watersheds (n=2274)	Number of watersheds	381	284	330	1143	136
	Expanded urban land (10^3 km^2)	202.8	73.3	41.0	33.3	-7.7

Table S3 The trend of urban expansion among the third-, fourth-, and fifth-level watersheds

	Continuous deceleration	Fluctuant deceleration	Acceleration	Others
Third-level watersheds (n=220)	29	125	37	29
Fourth-level watersheds (n=877)	25	570	183	99
Fifth-level watersheds (n=2274)	42	1441	532	259

Note: the division of the four types of urban expansion trend can be found in the Methods section.

Table S4 The heterogeneity of urban expansion speeds within watersheds

	1992 to 1996	1996 to 2000	2000 to 2006	2006 to 2010	2010 to 2016	1992 to 2016
Fourth level watersheds						
All the 877 watersheds	0.66 (0.13)	0.70 (0.13)	0.76 (0.13)	0.78 (0.12)	0.78 (0.11)	0.77 (0.11)
Endorheic watersheds	0.69 (0.13)	0.72 (0.11)	0.79 (0.12)	0.81 (0.11)	0.81 (0.09)	0.79 (0.10)
Exoreic watersheds	0.65 (0.12)	0.70 (0.13)	0.76 (0.13)	0.78 (0.12)	0.78 (0.11)	0.76 (0.11)
Fifth level watersheds						
All the 2274 watersheds	0.66 (0.14)	0.74 (0.14)	0.76 (0.13)	0.76 (0.12)	0.73 (0.13)	0.62 (0.13)
Endorheic watersheds	0.66 (0.16)	0.77 (0.13)	0.77 (0.13)	0.81 (0.09)	0.77 (0.12)	0.66 (0.13)
Exoreic watersheds	0.66 (0.13)	0.74 (0.14)	0.75 (0.13)	0.75 (0.12)	0.73 (0.13)	0.61 (0.13)

Table S7 Changes in urban sprawl among watersheds globally from 1992 to 2016

		1992-2000	2000-2006	2006-2010	2010-2016	1992-2016
Fourth level watersheds (n=877)	number of watersheds with an USI>0	574	476	460	369	572
	average USI	0.375	0.021	0.017	0.006	0.204
	standard deviation of USI	1.153	0.094	0.070	0.064	0.525
Endorheic watersheds (n=36)	number of watersheds with an USI>0	90	84	84	57	96
	average USI	0.284	0.020	0.019	0.013	0.167
	standard deviation of USI	0.844	0.078	0.065	0.0789	0.489
Exoreic watersheds (n=184)	number of watersheds with an USI>0	484	392	376	312	476
	average USI	0.395	0.021	0.016	0.005	0.212
	standard deviation of USI	1.209	0.097	0.071	0.061	0.532
Fifth level watersheds (n=2274)	number of watersheds with an USI>0	1353	1113	1185	976	1338
	average USI	0.269	0.022	0.021	0.006	0.167
	standard deviation of USI	0.932	0.121	0.113	0.113	0.998
Endorheic watersheds (n=336)	number of watersheds with an USI>0	172	147	161	110	171
	average USI	0.142	0.012	0.015	-0.006	0.075
	standard deviation of USI	0.475	0.065	0.064	0.238	0.245
Exoreic watersheds (n=1938)	number of watersheds with an USI>0	1181	966	1024	866	1167
	average USI	0.291	0.024	0.022	0.008	0.183
	standard deviation of USI	0.989	0.128	0.119	0.073	1.076

Figure S1 Comparison of urban expansion speeds between the endorheic and exoreic watersheds for the 877 fourth-level watersheds

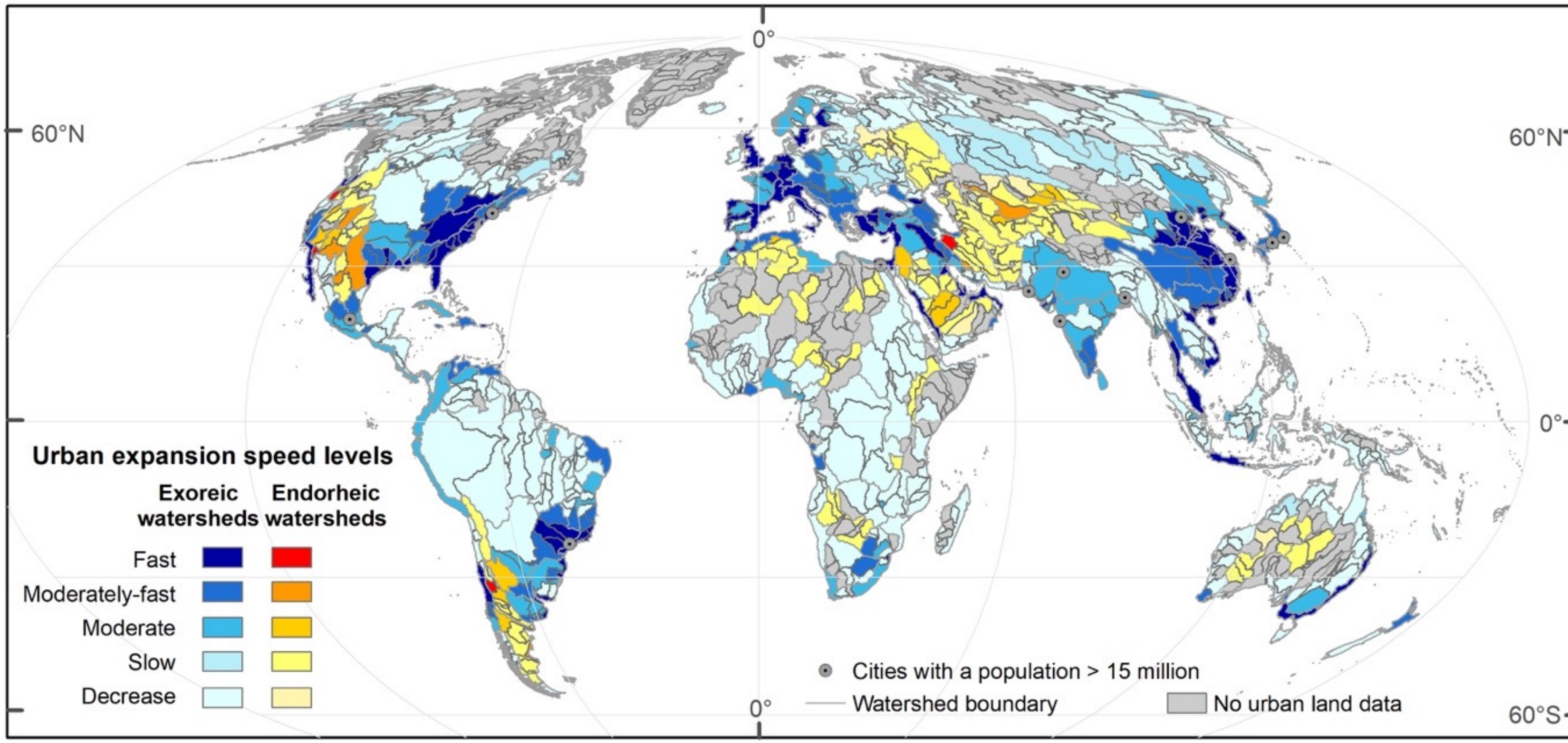

Figure S2 Comparison of urban expansion speeds between the endorheic and exoreic watersheds for the 2274 fifth-level watersheds

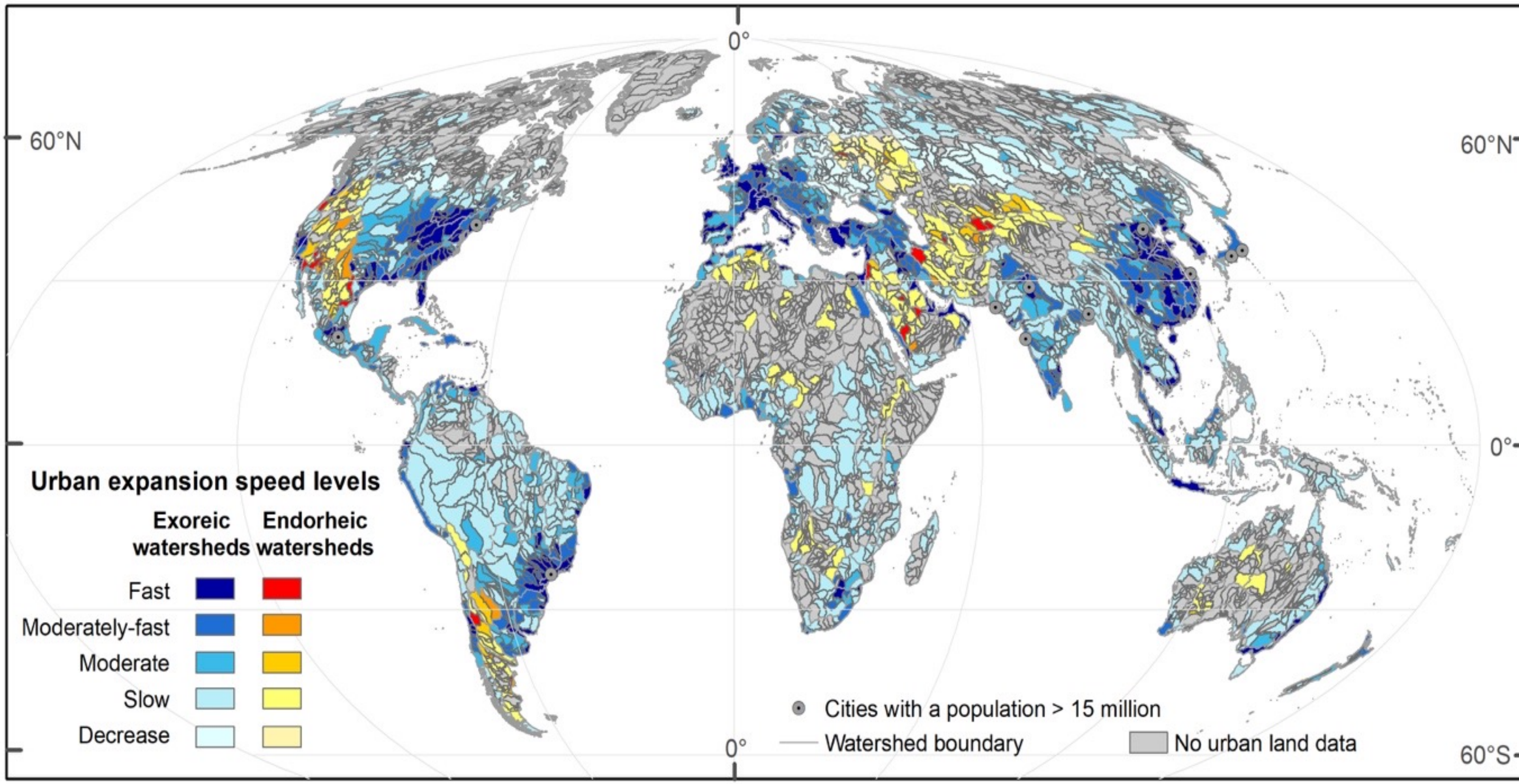

Figure S3 Comparison of urban expansion trends between the endorheic and exoreic watersheds for the 877 fourth-level watersheds. Note: the classification of the four urban expansion trends can be found in the Methods section.

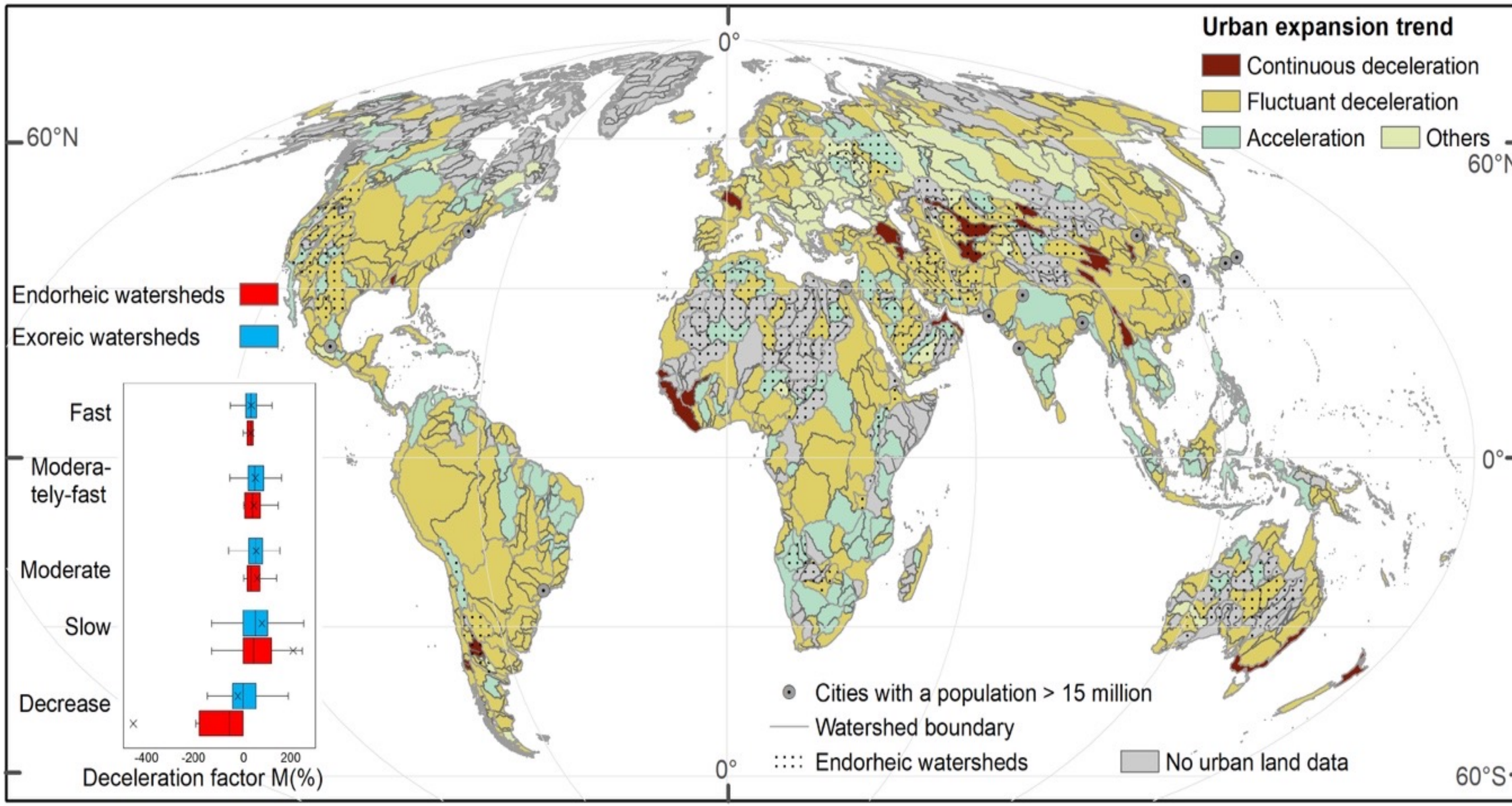

Figure S4 Comparison of urban expansion trends between the endorheic and exoreic watersheds for the 2274 fifth-level watersheds. Note: the classification of the four urban expansion trends can be found in the Methods section.

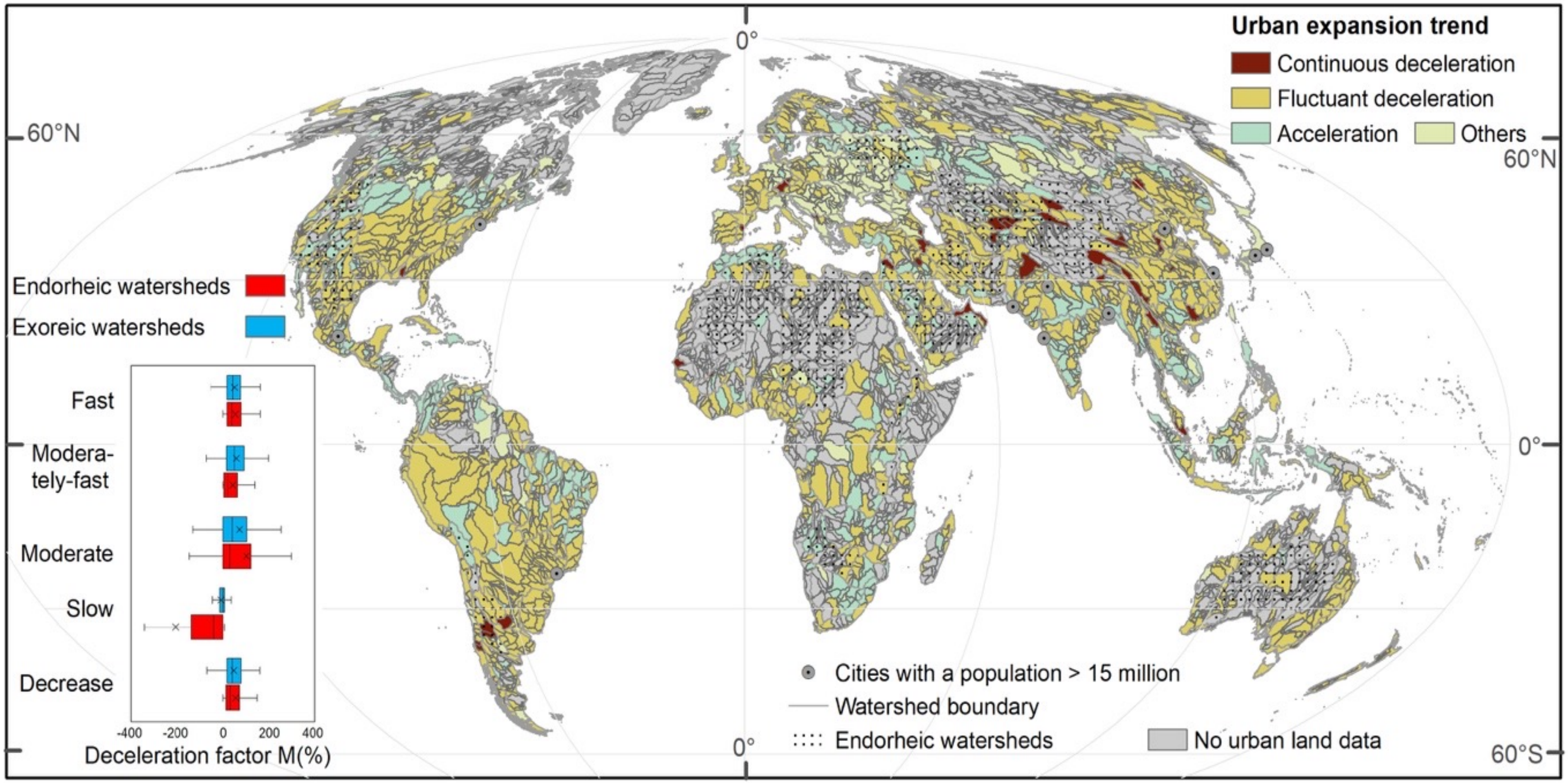

Figure S5 Proportion of urban expansion modes at the continental watershed scale