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(OSSP)

Global water gap hotspots

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- Introduction: The global water gap
- Hotspot mapping
- DPSIR analysis
- Data analysis
- Discussion & summary

Navigation: click on buttons for more information

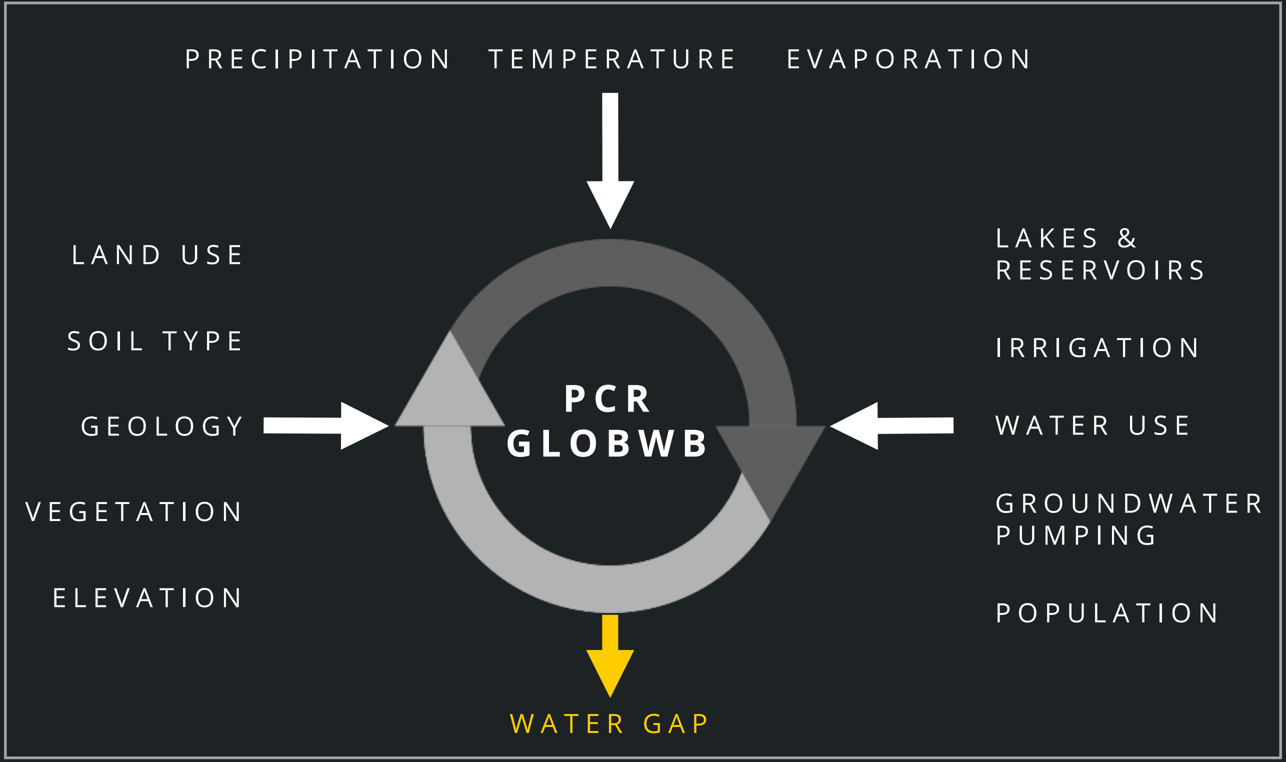
Manu, Peru, 2015 – Matsigenka boys fishing with barbasco root. Photo by Charlie Hamilton James

Introduction – The global water gap

The global water gap is defined as **the total demand that is not met by sustainable water resources.**

$$WG = WD_{total} - WA_{total} + GW\ A_{fossil}$$

WG = Water gap
WD = Water demand
WA = Water abstraction
GW A = Groundwater abstraction



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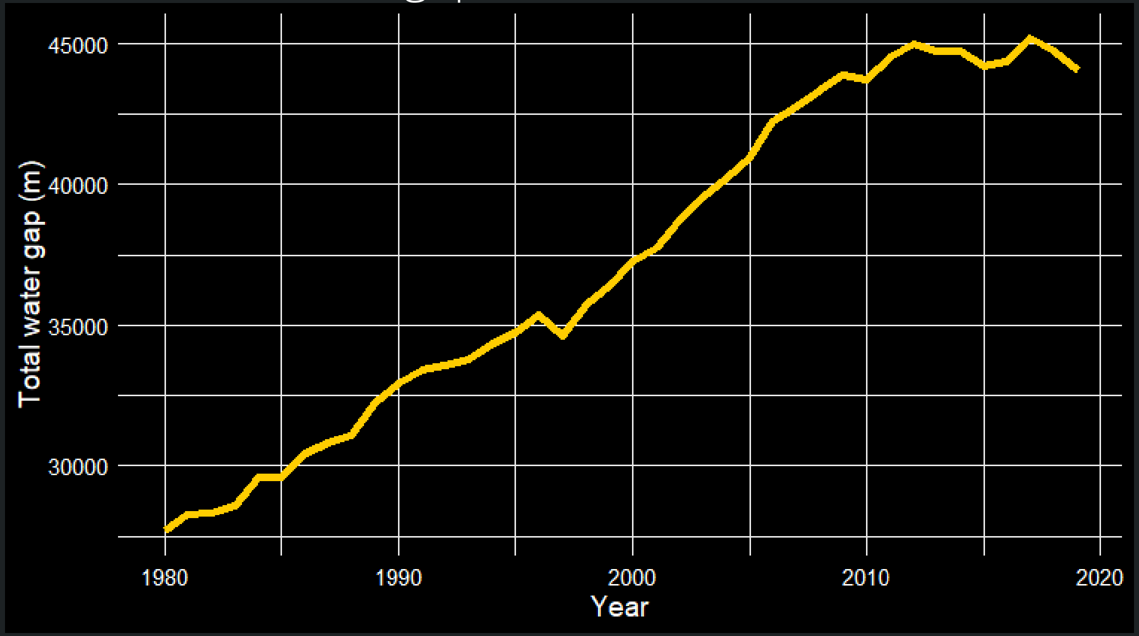
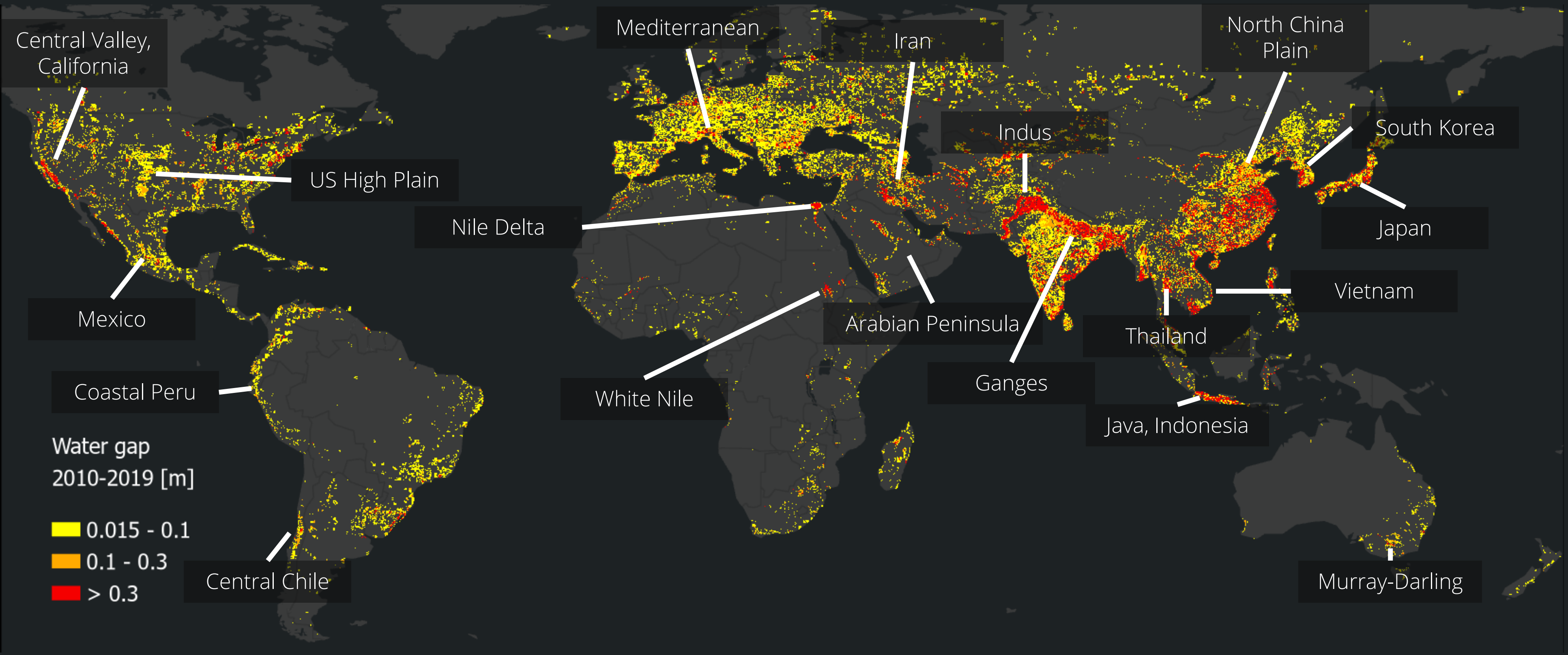
Global total water gap



Methods – Hotspot mapping



- Hotspots are identified if water gap > 0.015 m/y and is widely confirmed by literature.
- This results in identification of 22 hotspots around the world.

Methods – DPSIR analysis

- DPSIR (Driver-Pressure-State-Impact-Response) framework[1]:
- Combines natural, social, and economic information to identify Driving forces and resulting Pressures that have deteriorated the State (quality or quantity) of water resources. Also, societal and ecological Impacts resulting from the changes in the state of the water resources and the societal Response on these changes are disclosed by the framework.

- Scopus string search at each hotspot
- Compiled bibliography of > 200 case studies
- Counted each DSPIR component per case study

[1] Smeets, E., & Weterings, R. (1999). *Environmental indicators: Typology and overview* (Vol. 19). Copenhagen: European Environment Agency.

Methods – DPSIR components

Drivers

Anthropogenic drivers
- Economic growth
- Population growth
- Tourism

Natural drivers
- Precipitation
- Evaporation
- Aridification

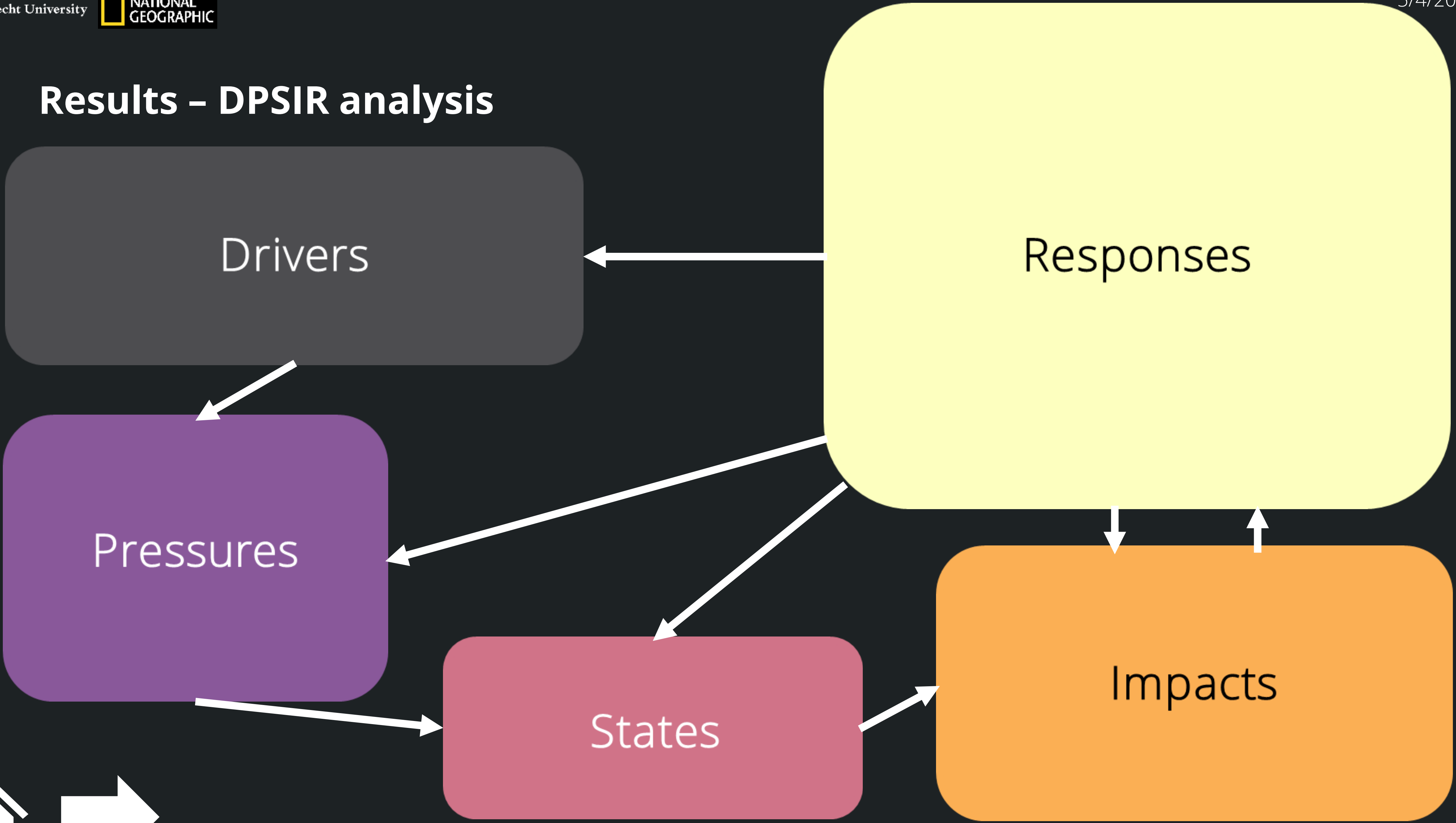
Pressures
- Agricultural water use
- Industrial water use
- Domestic water use
- Livestock water use
- Land use change
- Ecosystem water demand

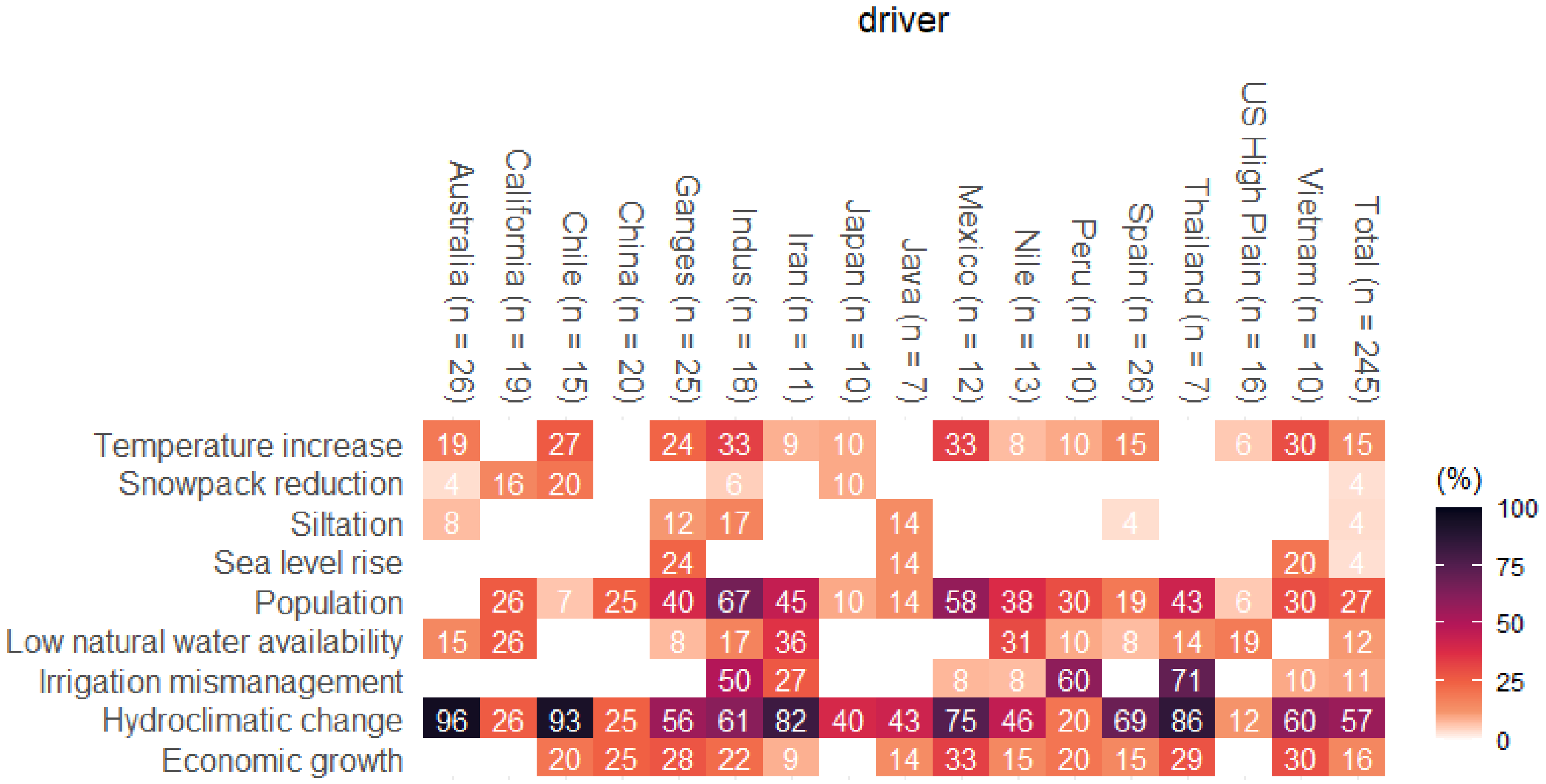
States
- Surface water quantity
- Groundwater quantity
- Water quality
- Status of ecosystems

Impacts
- Social challenges
  migration, poverty, inequality, conflict
- Deterioration of human health
- Deterioration of ecosystem
- Subsidence
- Desertification
  agricultural production, deforestation

Responses
- Water resource restrictions
  - Groundwater regulation
  - Water rights/pricing
- Water import
  - Dam construction
  - Channel construction
  - Virtual water trade
- Non-conventional water resources
  - Desalination plants
- Water use efficiency
  - Water conservation
  - Water recycling
  - Crop water footprint
  - Leakage rate
- Forest/ecosystem restoration

Results – DPSIR analysis




driver
Australia (n = 26)
California (n = 19)
Chile (n = 15)
China (n = 20)
Ganges (n = 25)
Indus (n = 18)
Iran (n = 11)
Japan (n = 10)
Java (n = 7)
Mexico (n = 12)
Nile (n = 13)
Peru (n = 10)
Spain (n = 26)
Thailand (n = 7)
US High Plain (n = 16)
Vietnam (n = 10)
Total (n = 245)
Temperature increase 19 27 24 33 9 10 33 8 10 15 6 30 15
Snowpack reduction 4 16 20 6 10 4
Siltation 8 12 17 14 4 4
Sea level rise 24 14 20 4
Population 26 7 25 40 67 45 10 14 58 38 30 19 43 6 30 27
Low natural water availability 15 26 8 17 36 31 10 8 14 19 12
Irrigation mismanagement 50 27 8 8 60 71 10 11
Hydroclimatic change 96 26 93 25 56 61 82 40 43 75 46 20 69 86 12 60 57
Economic growth 20 25 28 22 9 14 33 15 20 15 29 30 16
(%)
100
75
50
25
0

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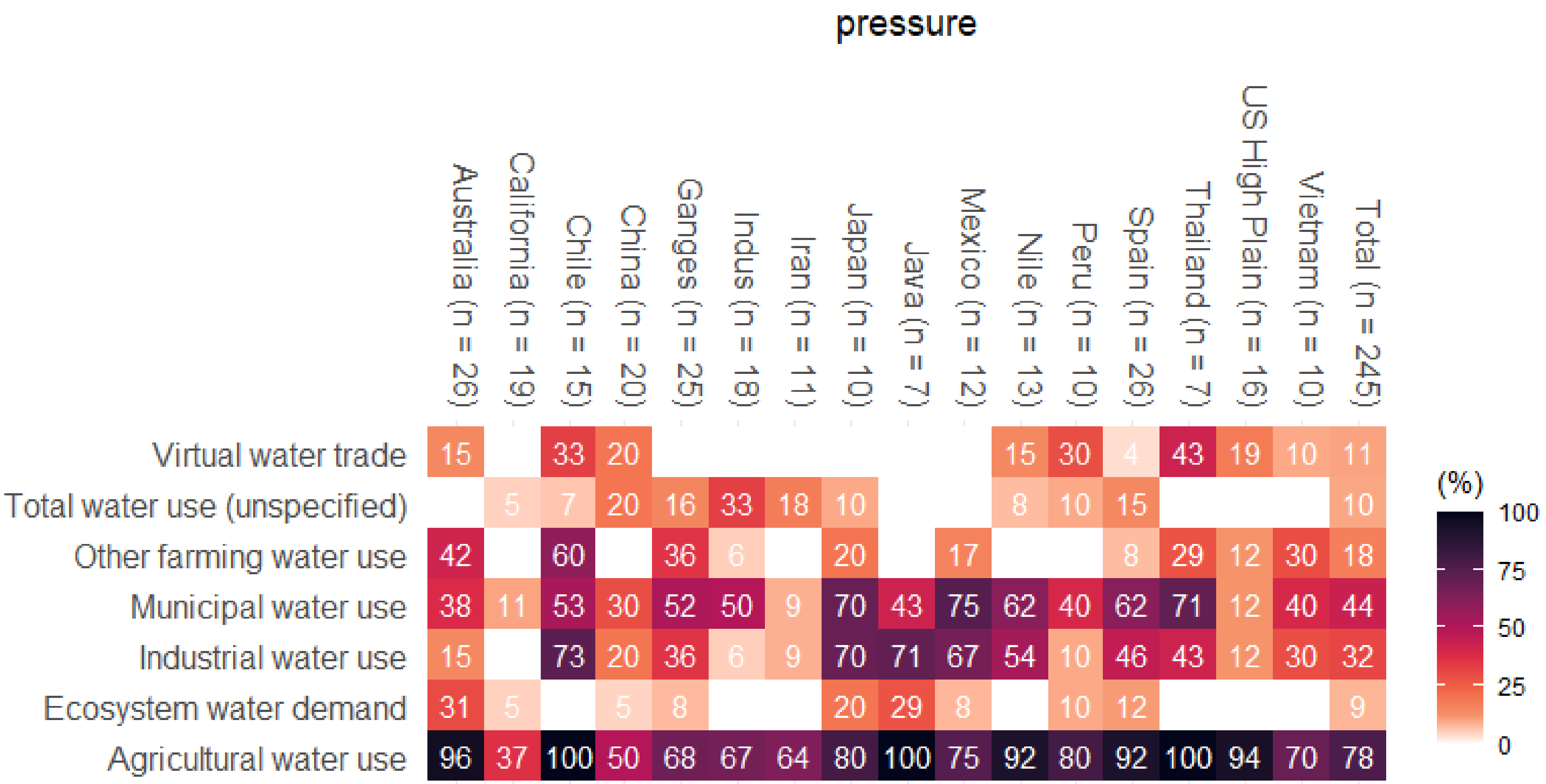
pressure
Australia (n = 26)
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Indus (n = 18)
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Japan (n = 10)
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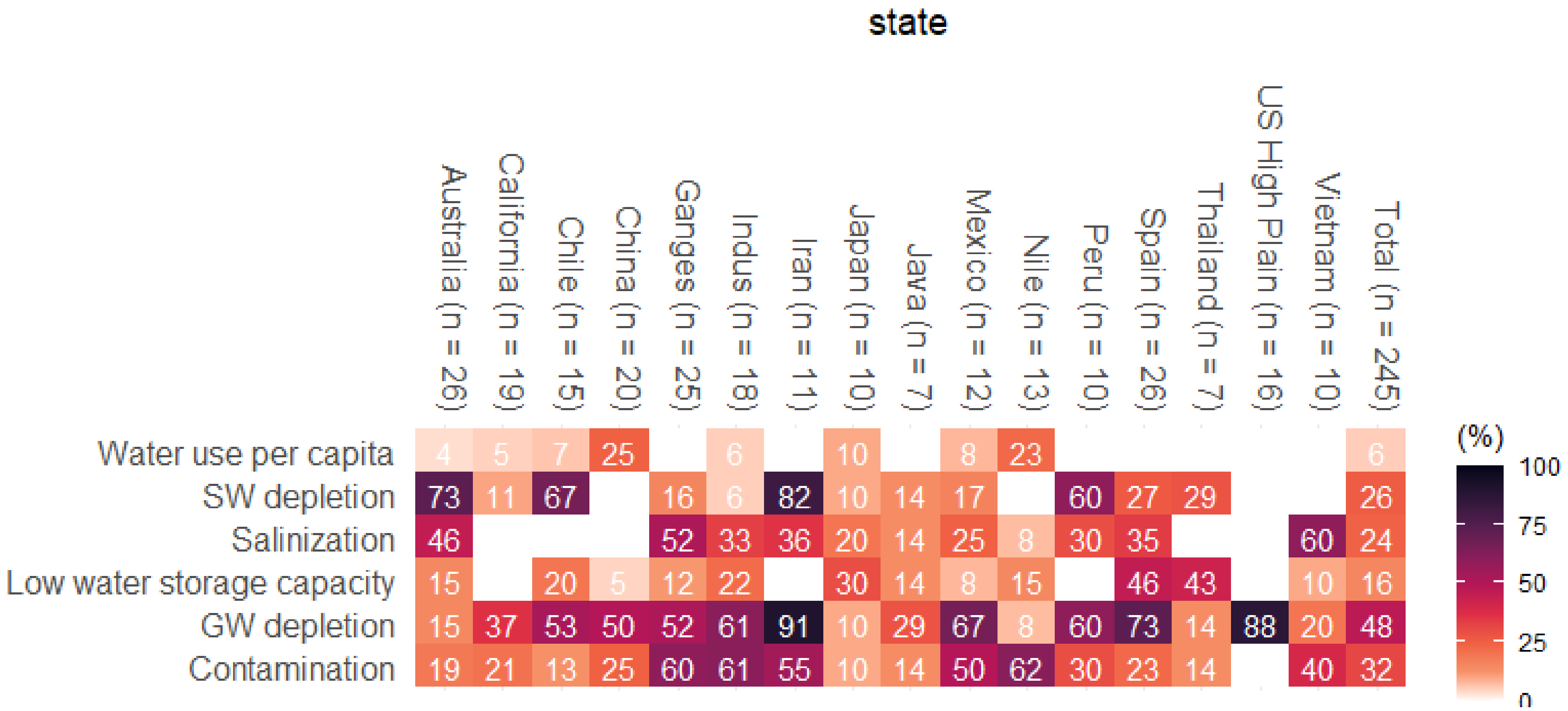
Nile (n = 13)
Peru (n = 10)
Spain (n = 26)
Thailand (n = 7)
US High Plain (n = 16)
Vietnam (n = 10)
Total (n = 245)
Virtual water trade 15 33 20 15 30 4 43 19 10 11
Total water use (unspecified) 5 7 20 16 33 18 10 8 10 15 10
Other farming water use 42 60 36 6 20 17 8 29 12 30 18
Municipal water use 38 11 53 30 52 50 9 70 43 75 62 40 62 71 12 40 44
Industrial water use 15 73 20 36 6 9 70 71 67 54 10 46 43 12 30 32
Ecosystem water demand 31 5 5 8 20 29 8 10 12 9
Agricultural water use 96 37 100 50 68 67 64 80 100 75 92 80 92 100 94 70 78
(%)
100
75
50
25
0


state
Australia (n = 26)
California (n = 19)
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China (n = 20)
Ganges (n = 25)
Indus (n = 18)
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Peru (n = 10)
Spain (n = 26)
Thailand (n = 7)
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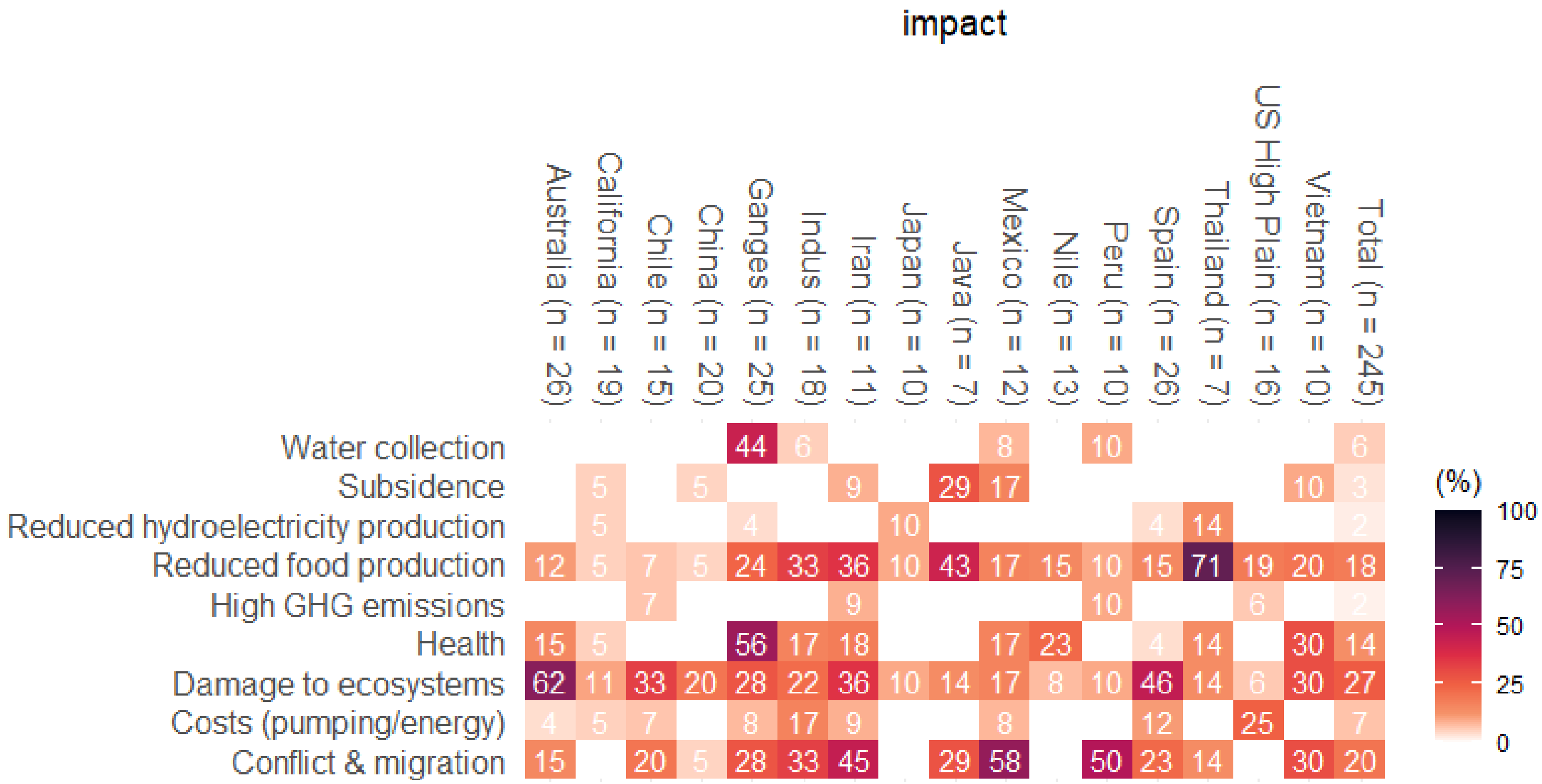
Vietnam (n = 10)
Total (n = 245)
Water use per capita 4 5 7 25 6 10 8 23 6
SW depletion 73 11 67 16 6 82 10 14 17 60 27 29 26
Salinization 46 52 33 36 20 14 25 8 30 35 60 24
Low water storage capacity 15 20 5 12 22 30 14 8 15 46 43 10 16
GW depletion 15 37 53 50 52 61 91 10 29 67 8 60 73 14 88 20 48
Contamination 19 21 13 25 60 61 55 10 14 50 62 30 23 14 40 32
(%)
100
75
50
25
0


impact
Australia (n = 26)
California (n = 19)
Chile (n = 15)
China (n = 20)
Ganges (n = 25)
Indus (n = 18)
Iran (n = 11)
Japan (n = 10)
Java (n = 7)
Mexico (n = 12)
Nile (n = 13)
Peru (n = 10)
Spain (n = 26)
Thailand (n = 7)
US High Plain (n = 16)
Vietnam (n = 10)
Total (n = 245)
Water collection
Subsidence
Reduced hydroelectricity production
Reduced food production
High GHG emissions
Health
Damage to ecosystems
Costs (pumping/energy)
Conflict & migration
(%)
100
75
50
25
0

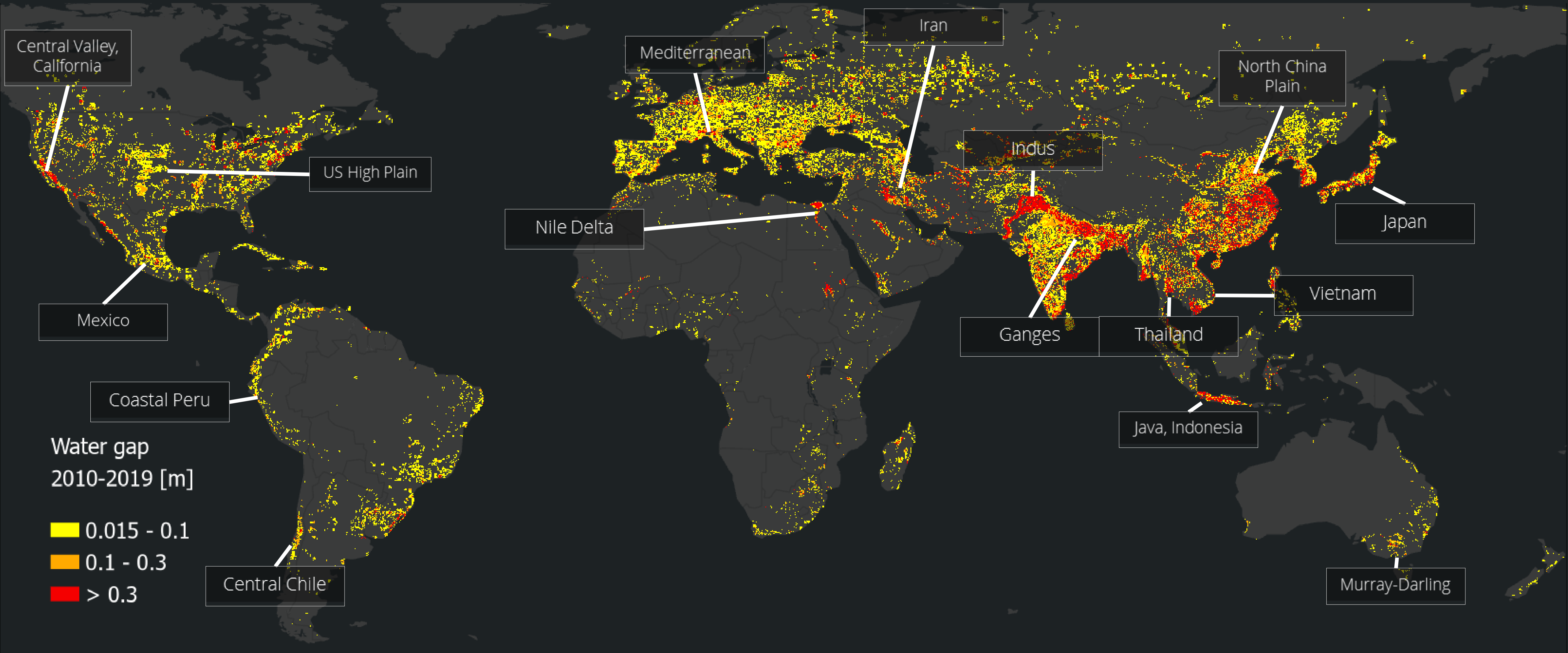
response

	Australia (n = 26)	California (n = 19)	Chile (n = 15)	China (n = 20)	Ganges (n = 25)	Indus (n = 18)	Iran (n = 11)	Japan (n = 10)	Java (n = 7)	Mexico (n = 12)	Nile (n = 13)	Peru (n = 10)	Spain (n = 26)	Thailand (n = 7)	US High Plain (n = 16)	Vietnam (n = 10)	Total (n = 245)
Water treatment (+)	12	16	13	30	24			30	14		54		50		6		18
Water transfer (+)	4	32	27	40	8		18	30		25		40	35				17
Water transfer (-)	4						18			17			4			10	3
Water rights (+)	69		13	5	4	6		10		8			12		6		12
Water rights (-)	4	5	40		8	17	18			25	23	50	8		19		13
Water pricing (+)		5		15			9	10		8			8		6		4
Water pricing (-)		5		15		11	36		14	8		10	12			10	7
Water conservation (+)	4	21		25			27	10				10	8	14	12		8
Unregulated GW (-)	4				28	50	55	10	14			20	15		12	30	15
Stakeholder involvement (+)			13		24			10		8		10	23		12		8
Stakeholder involvement (-)	8				8		27			8		60	12	14	6	10	8
Regulated GW (+)	38	21		10	8			40			15	20	19		25		14
Increased storage capacity (dam construction) (-)	4				24	6	18	10			8	10	4			10	6
Increased storage capacity (+)	42	11	27	5	40	6	18	60	57	58	8	30	23				24
Improved water use efficiency (+)	27	11		55	12	11	9	10	43			50	27		25		19
Efficiency paradox (-)	4	5	7				18							14	12	40	5
Desalination plants (+)	8	11	7					10		8			54				9

(%) 100 75 50 25 0

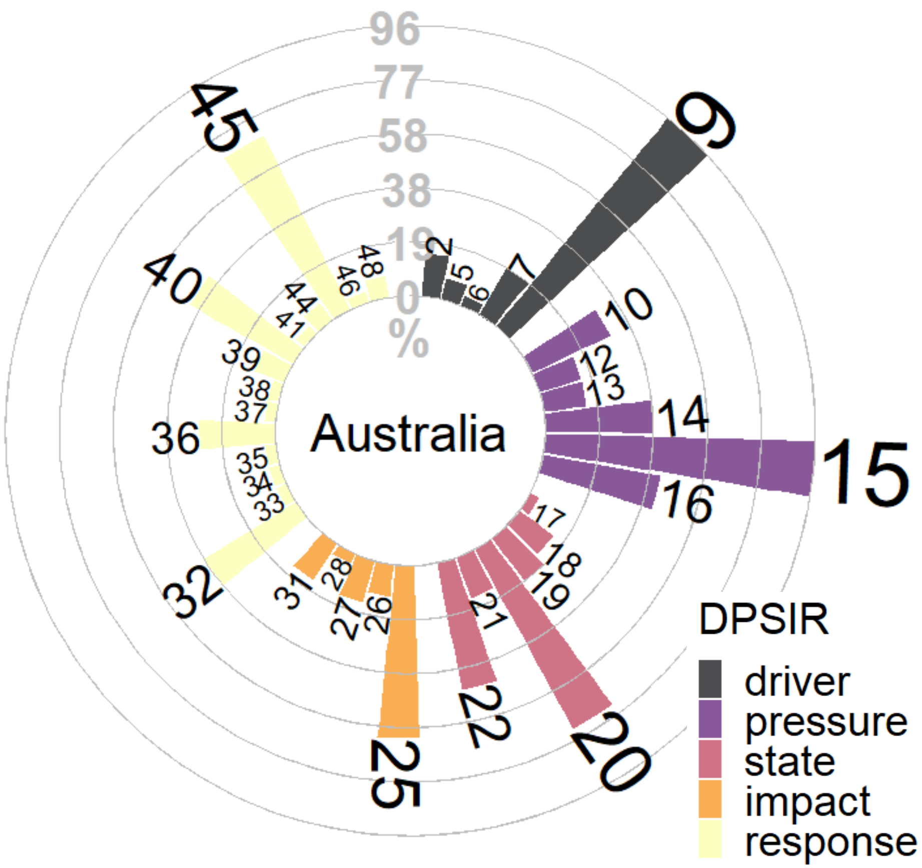
Results – DPSIR analysis per hotspot

Navigation: click on hotspot for more information



Results – Murray-Darlin Basin, Australia

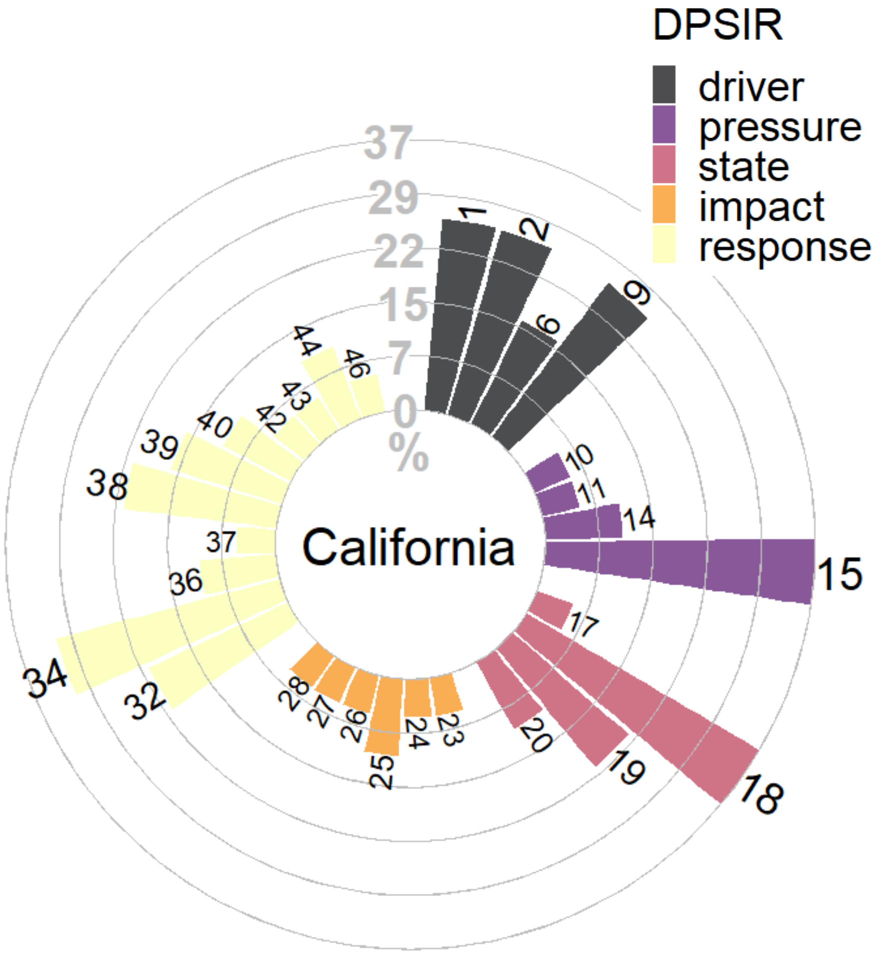
- Semi-arid area, rainfall is declining, and water availability of rivers is decreasing.
- The Millennium Drought was a harsh time in terms of water availability and is a major reason for water scarcity.
- Agriculture (irrigation) is the largest consumer of water in the basin, including livestock, fruit cultivation and viticulture.
- Groundwater is not regulated as it historically was not used as much in the basin. But since water availability is declining, more farmers have been switching to irrigation with groundwater.
- Water scarcity has negative impacts on ecosystems.
- Water scarcity has led to (mental) health problems for farmers due to stress.
- Australia has an effective water market in place for water trade.
- As the environmental water requirement was exceeded frequently, the government monopolized some of the water rights from the locals.



1 Population	25 Damage to ecosystems
2 Low natural water availability	26 Reduced food production
3 Economic growth	27 Health
4 Irrigation mismanagement	28 Costs (pumping/energy)
5 Siltation	29 High GHG emissions
6 Snowpack reduction	30 Water collection
7 Temperature increase	31 Conflict & migration
8 Sea level rise	32 Regulated groundwater (+)
9 Hydroclimatic change	33 Unregulated groundwater (-)
10 Ecosystem water demand	34 Water transfer (+)
11 Total water use (unspecified)	35 Water transfer (-)
12 Industrial water use	36 Improved water use efficiency (+)
13 Virtual water trade	37 Efficiency paradox (-)
14 Municipal water use	38 Water conservation (+)
15 Agricultural water use	39 Water treatment (+)
16 Other farming water use	40 Increased storage capacity (+)
17 Water use per capita	41 Increased storage capacity (-)
18 Groundwater depletion	42 Water pricing (+)
19 Contamination	43 Water pricing (-)
20 Surface water depletion	44 Desalination plants (+)
21 Low water storage capacity	45 Water rights (+)
22 Salinization	46 Water rights (-)
23 Subsidence	47 Stakeholder involvement (+)
24 Reduced hydroelectricity production	48 Stakeholder involvement (-)

Results – Central Valley California

- Population growth and agricultural intensification are the main drivers.
- Water availability decreases due to reducing annual snowpack and increasing drought frequency.
- Groundwater depletion is severe, causing contamination of groundwater and land subsidence.
- Although over the years many different actions to reduce water scarcity have been implemented in California (water import and recycling), current complex and inflexible policies hinder sustainability improvements in water management.
- Water conservation measures only withstand during or directly after the occurrence of droughts and thus have a temporary impact.



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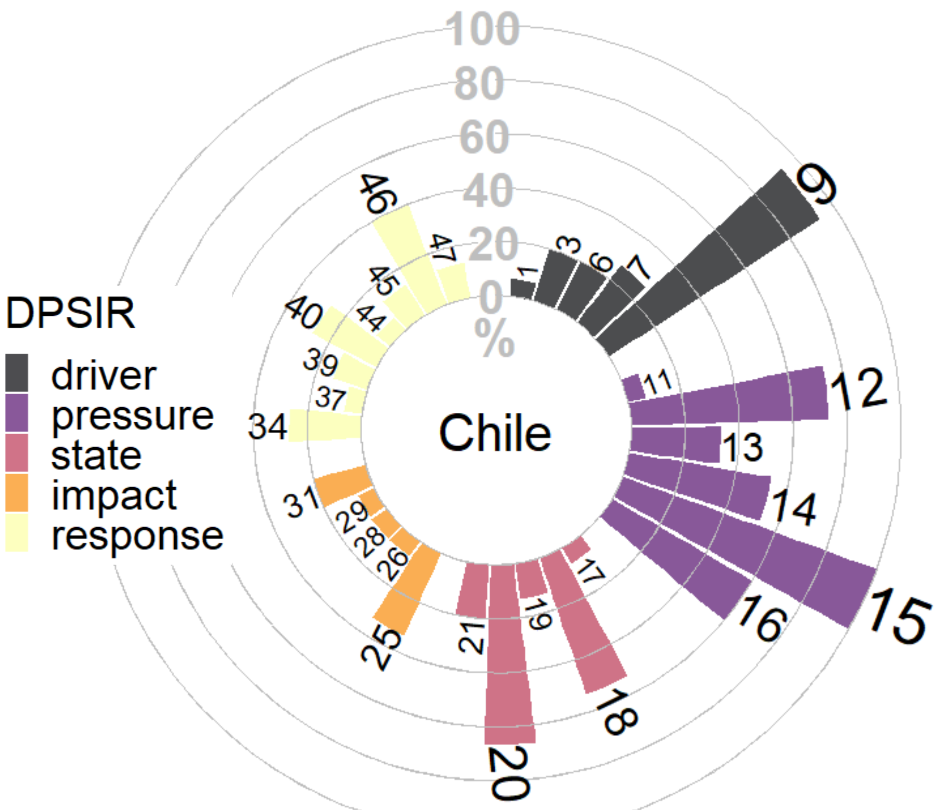
45 Water rights (+)
46 Water rights (-)
47 Stakeholder involvement (+)
48 Stakeholder involvement (-)

Results – Central Chile

- Agriculture, forestry, and urbanization cause land use change. Due to these changes, the infiltration rate has decreased, leading to less groundwater recharge.
- Crop change to fruits.
- Megadrought (2010-current)
- Chile works with a water rights system, in which individuals who own land receive a licence to use freshwater, free of charge. However, not everyone is connected to the pipelines, especially rural areas. Such communities are supplied by water trucks.
- There is lack of supervision of the water rights, which results in people applying for multiple licences, which drives up the price for reselling (water hoarding).



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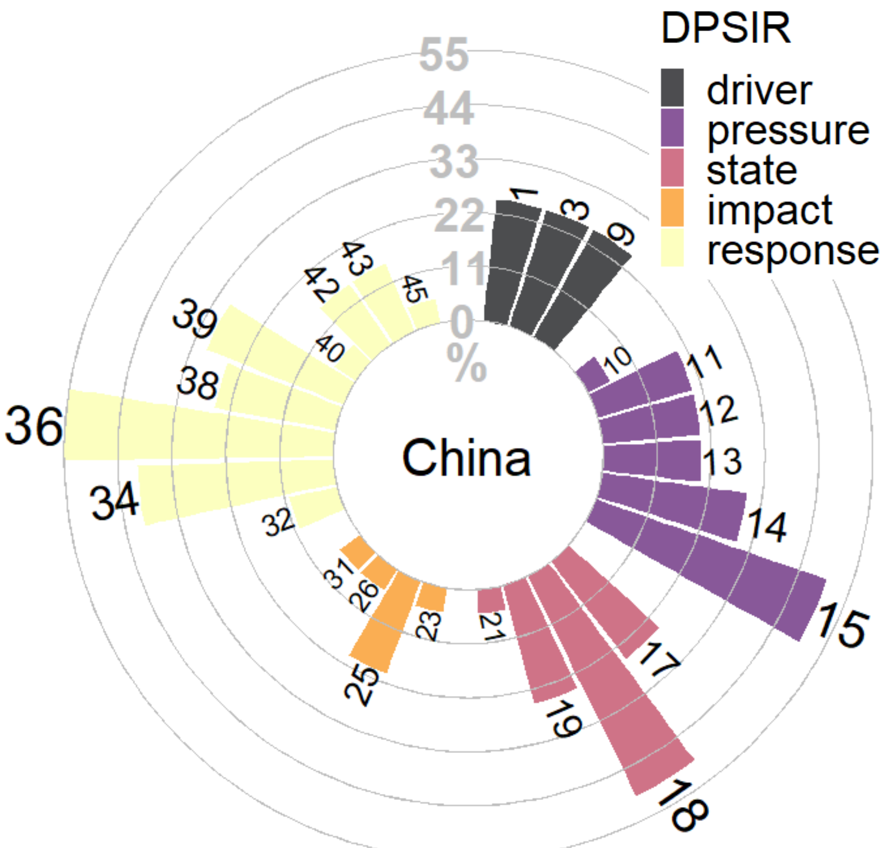
45 Water rights (+)
46 Water rights (-)
47 Stakeholder involvement (+)
48 Stakeholder involvement (-)

Results – North China Plain

- Groundwater depletion is severe, and contamination is a large problem.
- Water scarcity has been alleviated due to climate variability.
- China has initiated many projects concerning water conservation and increasing water availability (SNWT)



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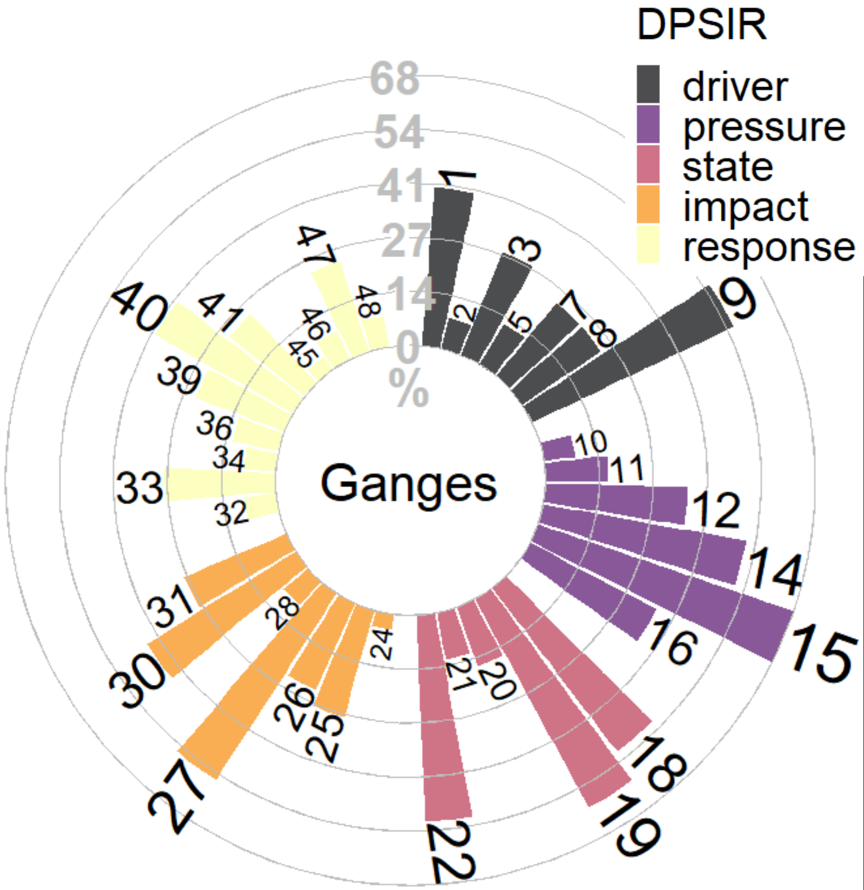
47 Stakeholder involvement (+)
48 Stakeholder involvement (-)

Results – Ganges-Brahmaputra Basin

- Saltwater intrusion in coastal Bangladesh due to sea level rise, upstream dam construction, water overexploitation.
- Salinization results in negative health impacts, longer travel distance to collect water and conflict between states.
- Migration or change in occupation occurs when farming is not profitable anymore due to water scarcity, failed harvests, and economic hardship.
- Bottom-up approaches of water treatment including pond sand filtration or rainwater harvesting.
- Lack of public participation.
- Need for improved water resource management plans.



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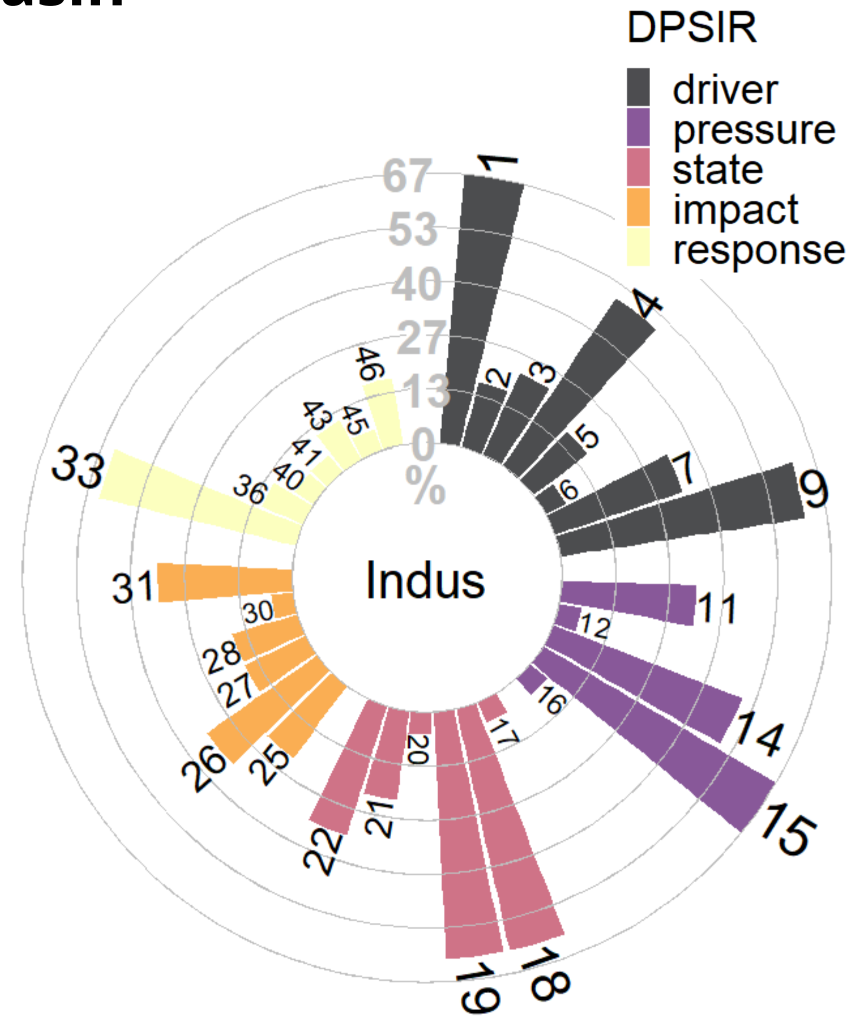
47 Stakeholder involvement (+)
48 Stakeholder involvement (-)

Results – Indus Basin

- Agriculture is largest water consumer.
- Unregulated groundwater use due to private wells of farmers.
- Rapid groundwater depletion.
- Lack of water governance, policies and investments in the water system, making water use inefficient.



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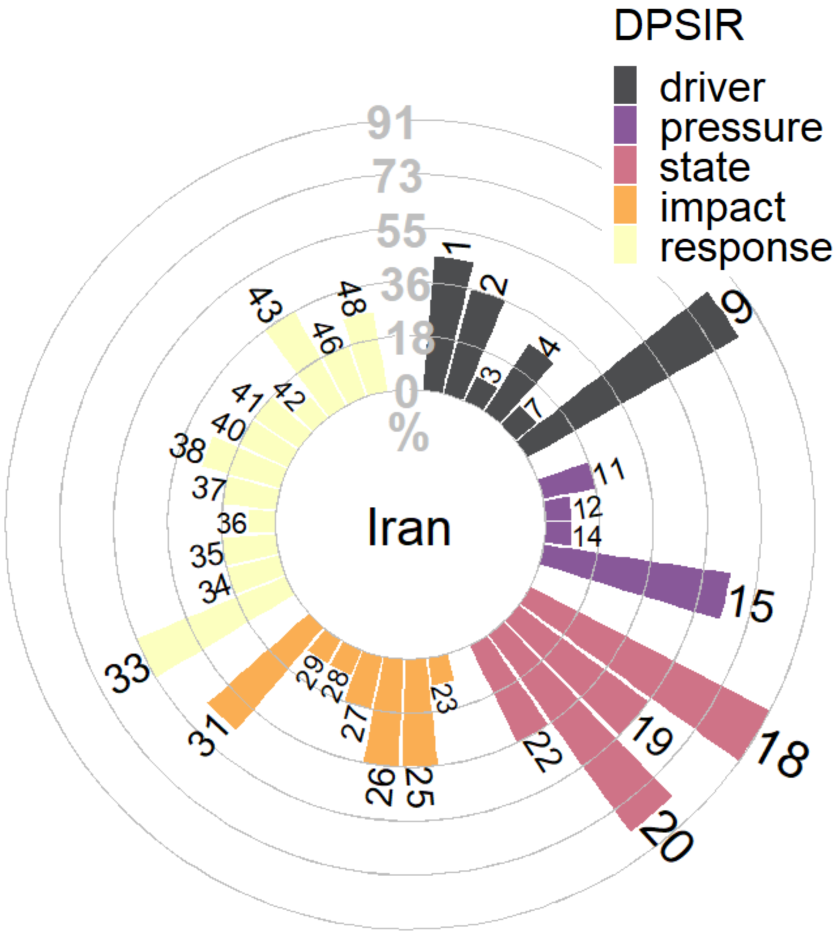
Results – Iran

- Serious lack of water resource management by the government leading to overexploitation and contamination of surface and groundwater resources.
- Dam constructions to increase capacity but on hold due to environmental degradation. Existing dams experience reduced inflow. Capacity is too low for total demand.
- Migration is prevalent within Iran, especially from rural areas to cities for social, political or environmental reasons.
- Irrigation system is outdated, therefore inefficient and leaking.



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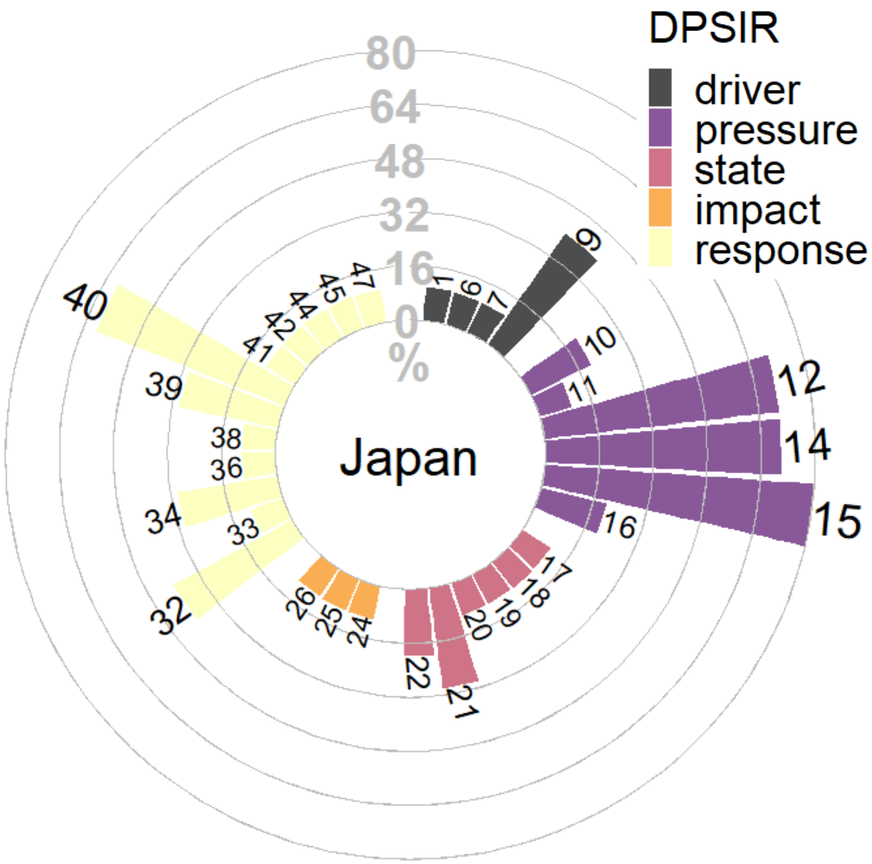
48 Stakeholder involvement (-)

Results – Japan

- Some regions use mainly groundwater, whereas other regions use surface water.
- Japan has a lot of rainfall, but scarcity is a problem due to the high per capita water use.
- Main water user is agriculture, but a large part of the economy consists of the industrial sector.
- Water governance in Japan is abundant and well-organised.



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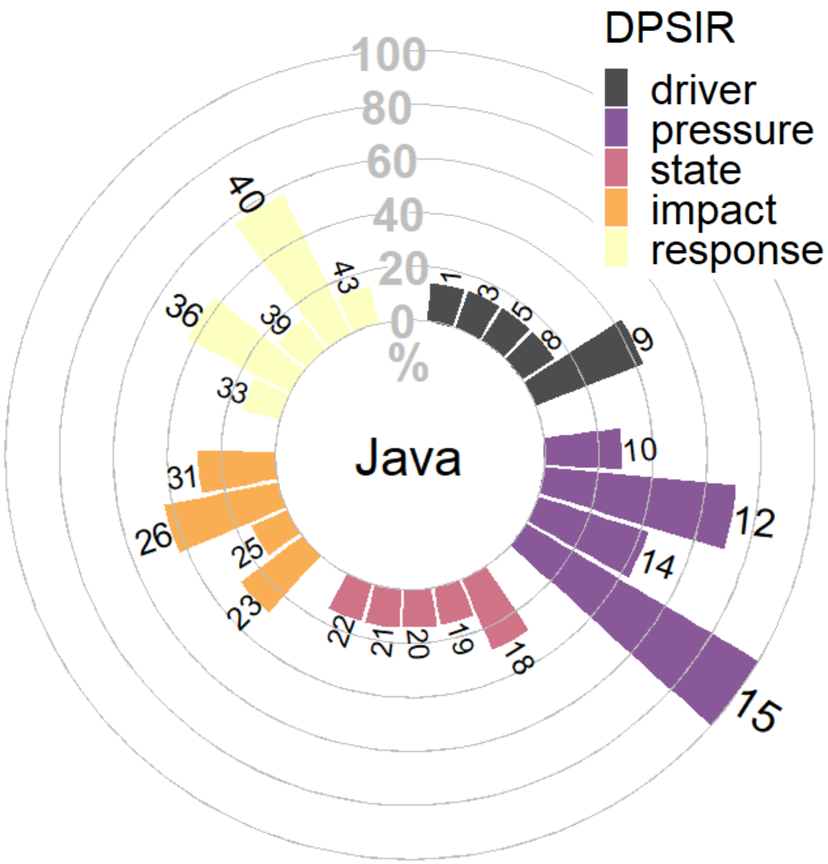
Results – Java

- Exact reasons for water scarcity unclear from the literature.
- (Rice) farming is the largest user of water.
- As a result of water scarcity, land subsidence is observed on Java.
- Home industries of Batik production cause water contamination.



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42 Water pricing (+)
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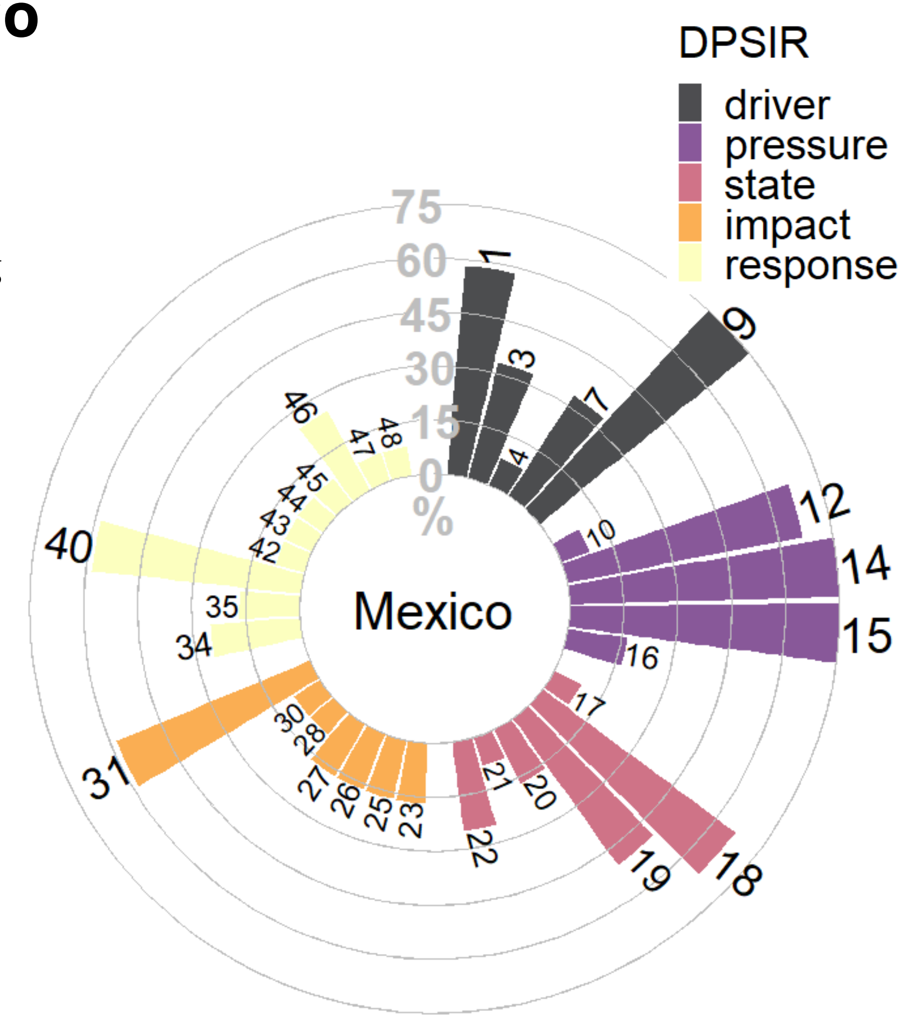
44 Desalination plants (+)
45 Water rights (+)
46 Water rights (-)
47 Stakeholder involvement (+)
48 Stakeholder involvement (-)

Results – Mexico

- Heavily affected by climate change, with increasing temperatures and decreasing annual rainfall. Replenishment is reducing and does not meet the demand anymore, depleting groundwater resources.
- Water scarcity occurs mainly in the larger Mexican cities.
- Mostly poor citizens are affected, living in informal settings that are not attached to a water network and buying water from trucks or installing storage tanks in their homes.
- The government does not provide much help to counteract the problems of water scarcity. Some regulations are in place, but mainly benefitting the wealthy.



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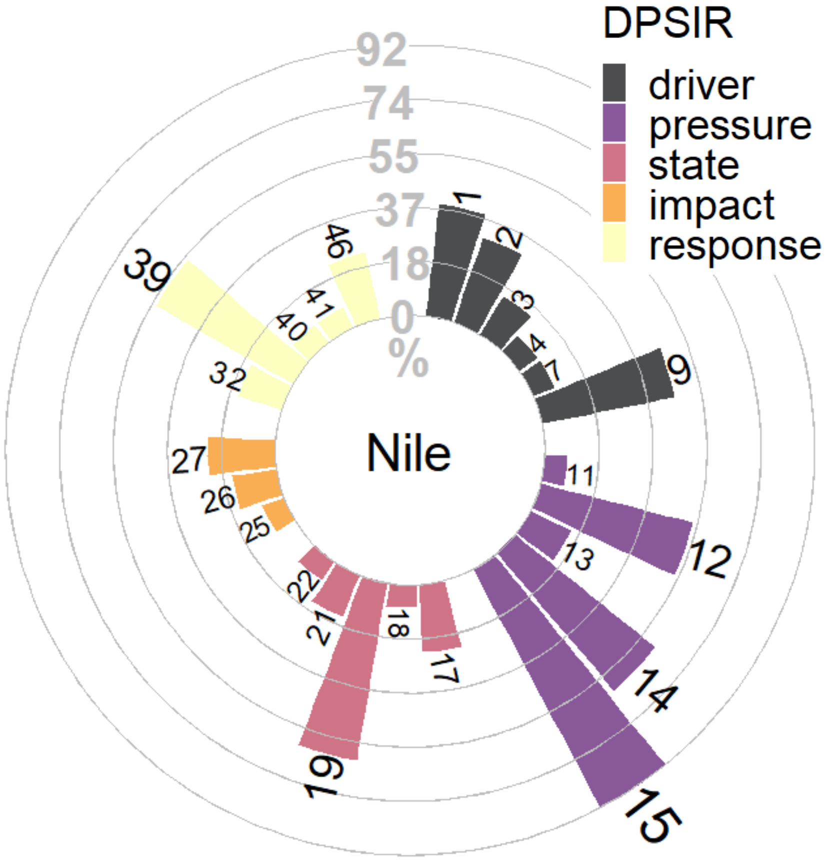
Results – Nile River Delta

- Agriculture is dependent on water from the Nile, as annual rainfall is >200 mm/y. Recharge of groundwater is too low to be a viable source for irrigation water.
- Since building of the Aswan Dam in 1970 all Nile flow is controlled, allowing for year-round agricultural cropping through irrigation.
- However, Egypt receives only a share of the total Nile water, which is no longer enough to provide all agricultural practices.
- Initiatives have been starting to recycle irrigation water, of which many are effective. However, due to industrial, domestic and urban wastewater mixing, the water quality of the irrigation water becomes too low for reuse. Due to consumption of this polluted water, negative health effects are observed.



1 Population	25 Damage to ecosystems
2 Low natural water availability	26 Reduced food production
3 Economic growth	27 Health
4 Irrigation mismanagement	28 Costs (pumping/energy)
5 Siltation	29 High GHG emissions
6 Snowpack reduction	30 Water collection
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9 Hydroclimatic change	33 Unregulated groundwater (-)
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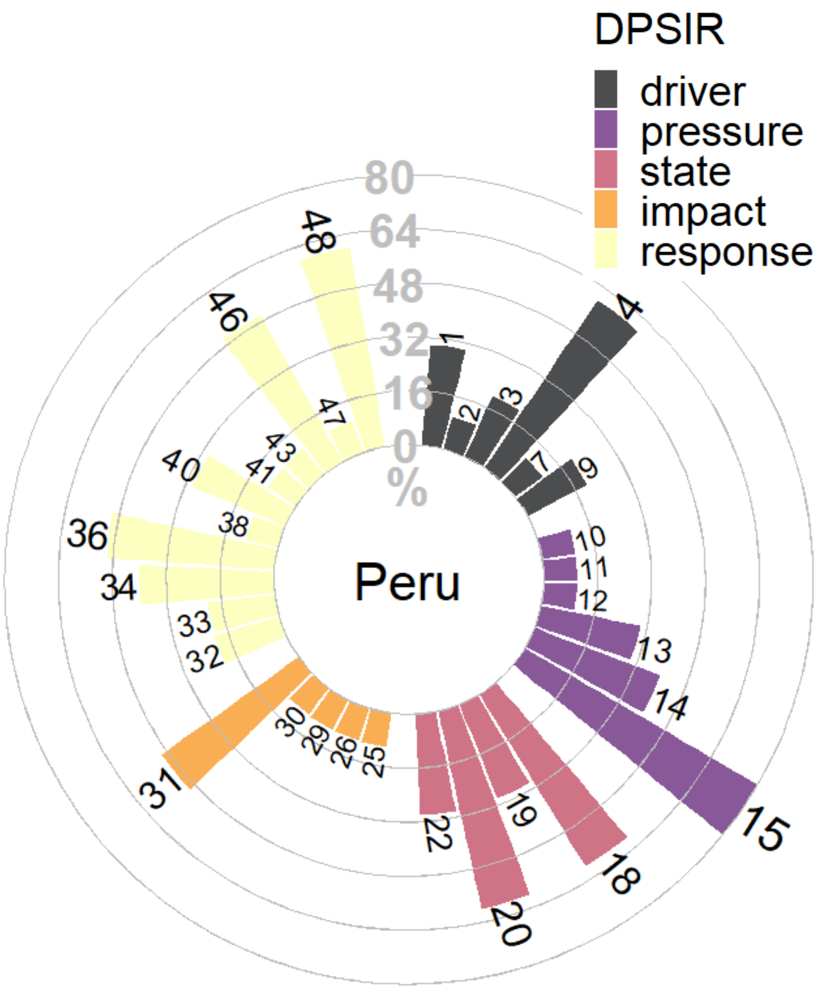
15 Agricultural water use	39 Water treatment (+)
16 Other farming water use	40 Increased storage capacity (+)
17 Water use per capita	41 Increased storage capacity (-)
18 Groundwater depletion	42 Water pricing (+)
19 Contamination	43 Water pricing (-)
20 Surface water depletion	44 Desalination plants (+)
21 Low water storage capacity	45 Water rights (+)
22 Salinization	46 Water rights (-)
23 Subsidence	47 Stakeholder involvement (+)
24 Reduced hydroelectricity production	48 Stakeholder involvement (-)

Results – Peru

- Unregulated groundwater extractions and illegal wells.
- Serious lack of water resources leading to overexploitation and contamination of surface and groundwater resources.
- Also lack of public participation. Agricultural sector has largest influence, even in the political sphere affecting water governance.
- Efficiency of irrigation systems are increasing, but not viable for small farmers that are being bought out land by large agri-export companies.



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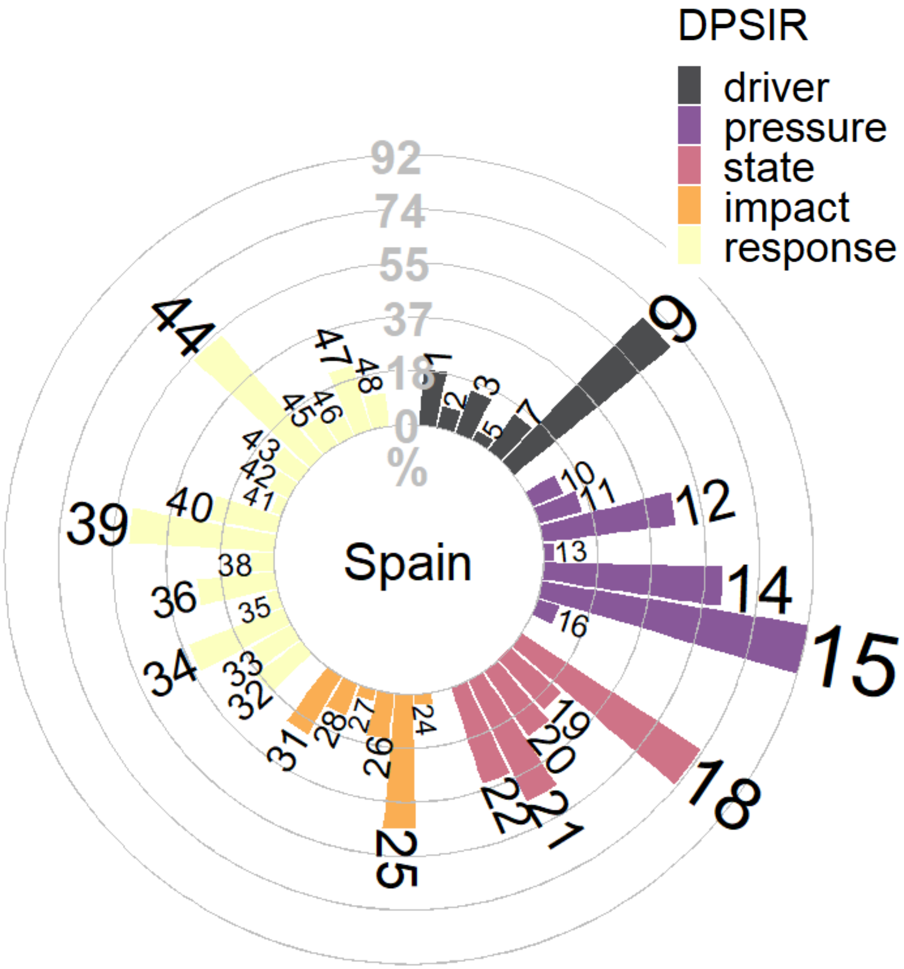
48 Stakeholder involvement (-)

Results – Spain

- Arid region characterised by droughts. Total rainfall is on a declining trend.
- Agriculturally intense area, including horticulture.
- Depletion of groundwater basins due to overexploitation and salinization of these aquifers.
- Spain is one of the leading countries in using unconventional water resources.
- Although Spain has many agreements and acts in place to guide a sustainable use of water resources, enforcement and management is not always adequate.



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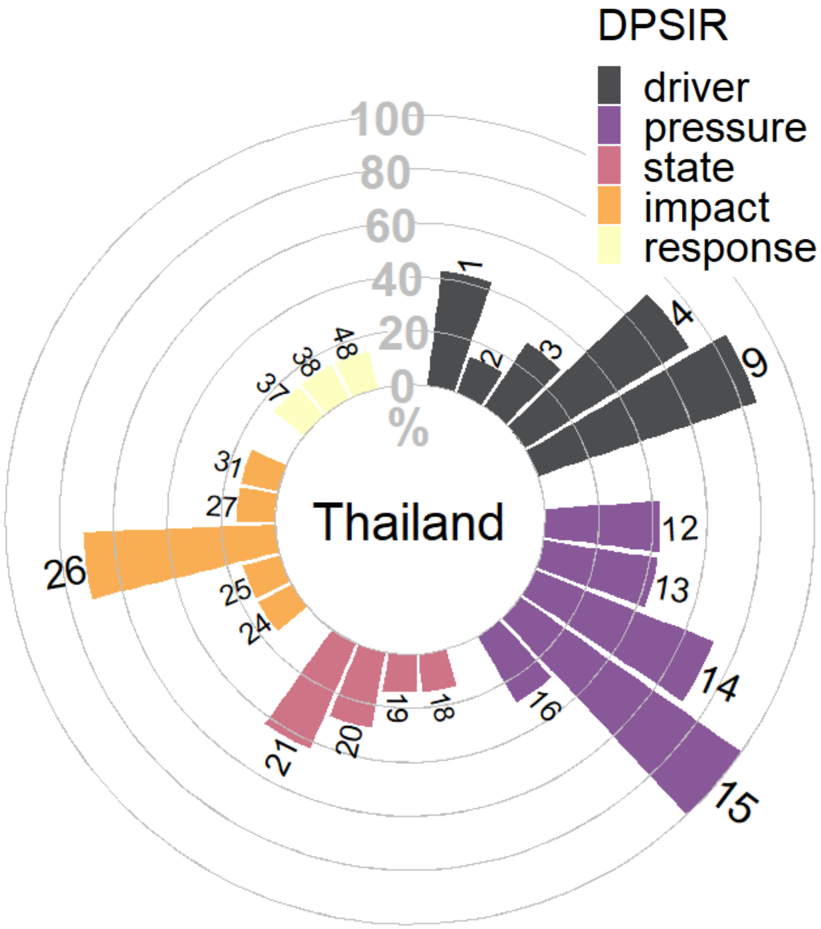
Results – Thailand

- Agriculture (rice) is the main water user, that is fed through irrigation dry months.
- Climate drivers are not always stated clearly, but water scarcity is mostly accounted to low rainfall during dry months.
- Although Thailand relies on its groundwater sources, there is no depletion identified.
- Need for increase in irrigation efficiency.
- Need for appropriate water resource management plans.



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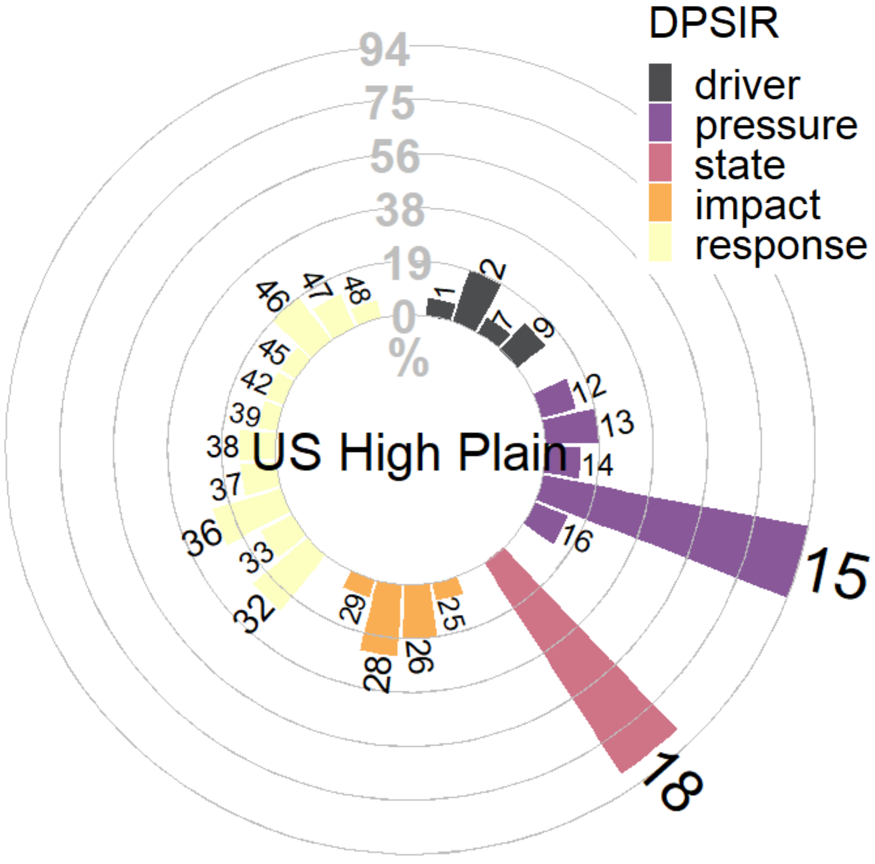
Results – US High Plain

- Since the discovery of the Ogallala aquifer in the 1930s and the development of irrigation technologies, the semi-arid US High plain has become the most important agricultural region in the US.
- The water rights system is “first in time, first in right” and a minimum use of the water rights is necessary to keep the right. This hinders water conservation during wet periods.
- Many measures have been taken, such as LEMA (subsidizing more efficient irrigation systems) and stakeholder involvement in water governance. However, depletion of the aquifer is still ongoing.



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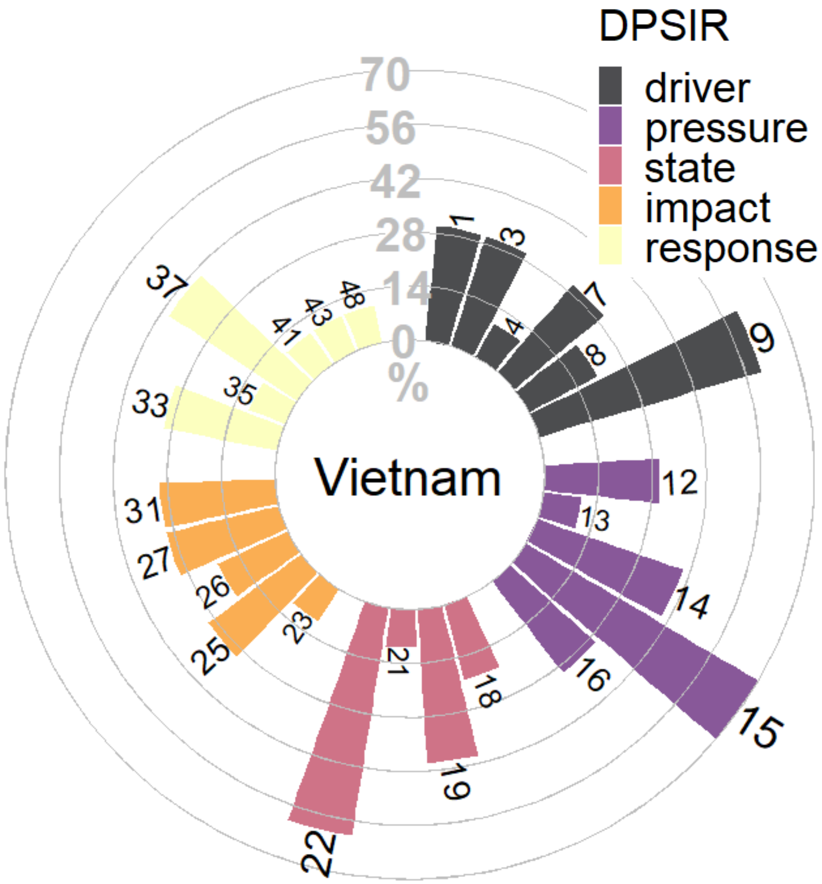
Results – Vietnam

- Water scarcity occurs due to unregulated water usage in agricultural sector. Municipal use and (rice) farming are the largest user of water, including livestock and aquaculture.
- Lack of proper wastewater treatment leads to contamination of surface water.
- Saltwater intrusion occurs due to intense agricultural practices, unregulated groundwater extractions, and sea level rise.
- Conflicts with upstream countries due to water usage inequalities.
- Lack of proper water management at all governance levels.



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Methods – Data analysis

- Global gridded datasets were consulted representing the most important drivers, pressures and states involved at the water gap hotspots.
- The temporal scale of all data sources was aggregated to a yearly timestep.
- Clipped according to the defined hotspot regions.
- Either summed or averaged over that region, depending on the variable of the dataset
- To result in timeseries for each variable at each hotspot.

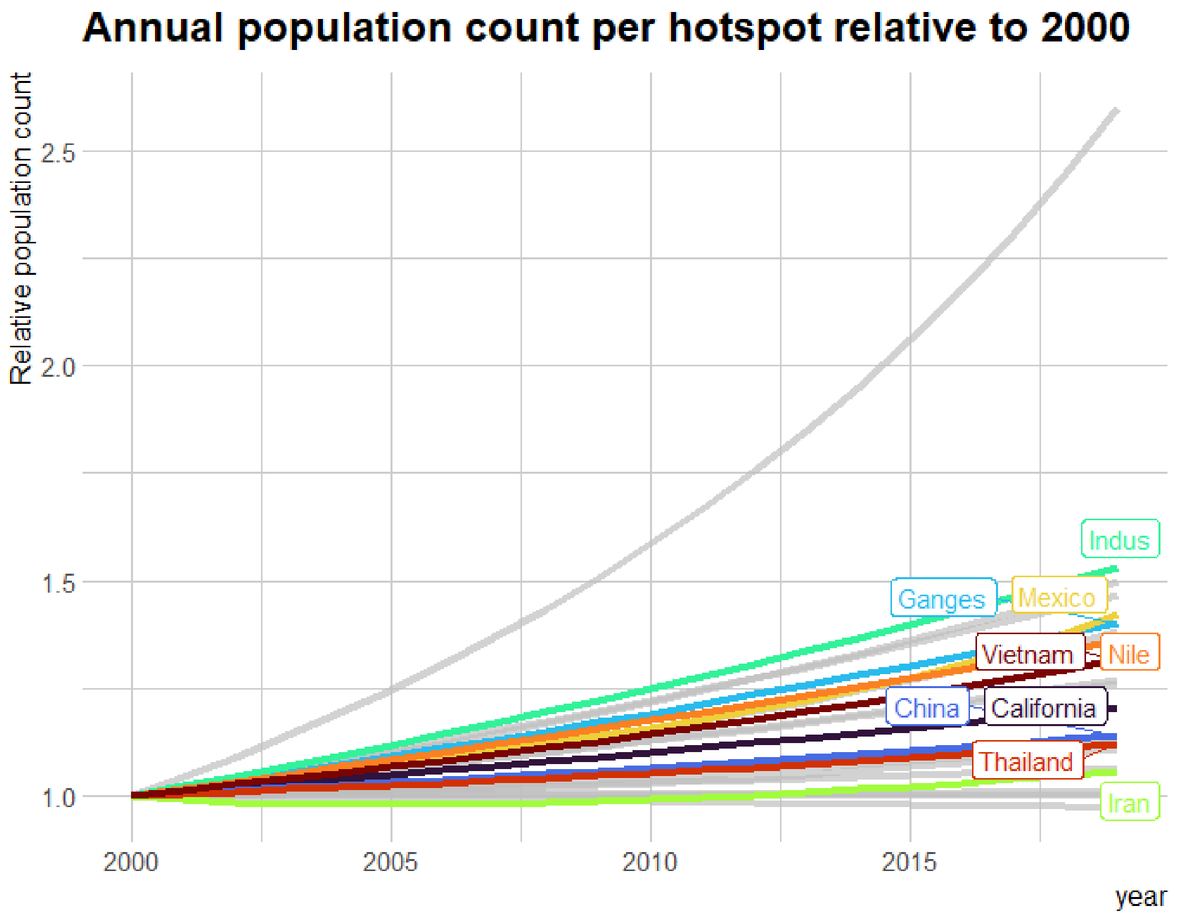
Results – Data analysis

Group	Indicator	Australia (n = 26)	California (n = 19)	Chile (n = 15)	China (n = 20)	Ganges (n = 25)	Indus (n = 18)	Iran (n = 11)	Japan (n = 10)	Java (n = 7)	Mexico (n = 12)	Nile (n = 13)	Peru (n = 10)	Spain (n = 26)	Thailand (n = 7)	US High Plain (n = 16)	Vietnam (n = 10)	Total (n = 245)
Drivers	Population		26	7	25	40	67	45	10	14	58	38	30	19	43	6	30	27
Drivers	Low natural water availability	15	26			8	17	36				31	10	8	14	19		12
Drivers	Economic growth			20	25	28	22	9		14	33	15	20	15	29		30	16
Drivers	Irrigation mismanagement						50	27			8	8	60		71		10	11
Drivers	Siltation	8				12	17			14				4				4
Drivers	Snowpack reduction	4	16	20			6		10									4
Drivers	Temperature increase	19		27		24	33	9	10		33	8	10	15		6	30	15
Drivers	Sea level rise					24				14							20	4
Drivers	Hydroclimatic change	96	26	93	25	56	61	82	40	43	75	46	20	69	86	12	60	57
Pressures	Ecosystem water demand	31	5		5	8			20	29	8		10	12				9
Pressures	Total water use (unspecified)		5	7	20	16	33	18	10			8	10	15				10
Pressures	Industrial water use	15		73	20	36	6	9	70	71	67	54	10	46	43	12	30	32
Pressures	Virtual water trade	15		33	20							15	30	4	43	19	10	11
Pressures	Municipal water use	38	11	53	30	52	50	9	70	43	75	62	40	62	71	12	40	44
Pressures	Agricultural water use	96	37	100	50	68	67	64	80	100	75	92	80	92	100	94	70	78
Pressures	Other farming water use	42		60		36	6		20		17			8	29	12	30	18
Pressures	Water use per capita	4	5	7	25		6		10		8	23						6
States	GW depletion	15	37	53	50	52	61	91	10	29	67	8	60	73	14	88	20	48
States	Contamination	19	21	13	25	60	61	55	10	14	50	62	30	23	14		40	32
States	SW depletion	73	11	67		16	6	82	10	14	17		60	27	29			26
States	Low water storage capacity	15		20	5	12	22		30	14	8	15		46	43		10	16
States	Salinization	46				52	33	36	20	14	25	8	30	35			60	24

(%) 100 75 50 25 0

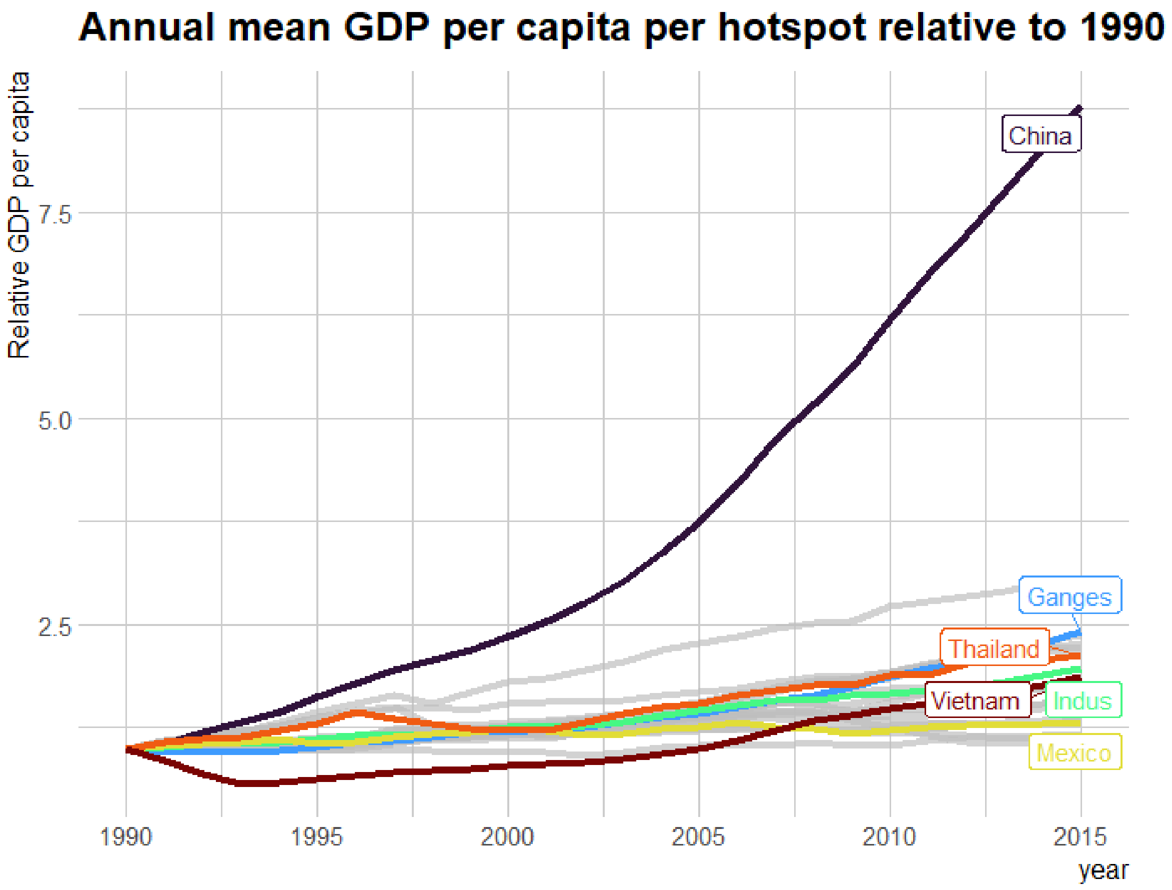
Navigation: click on indicator box for more information

Results – Population



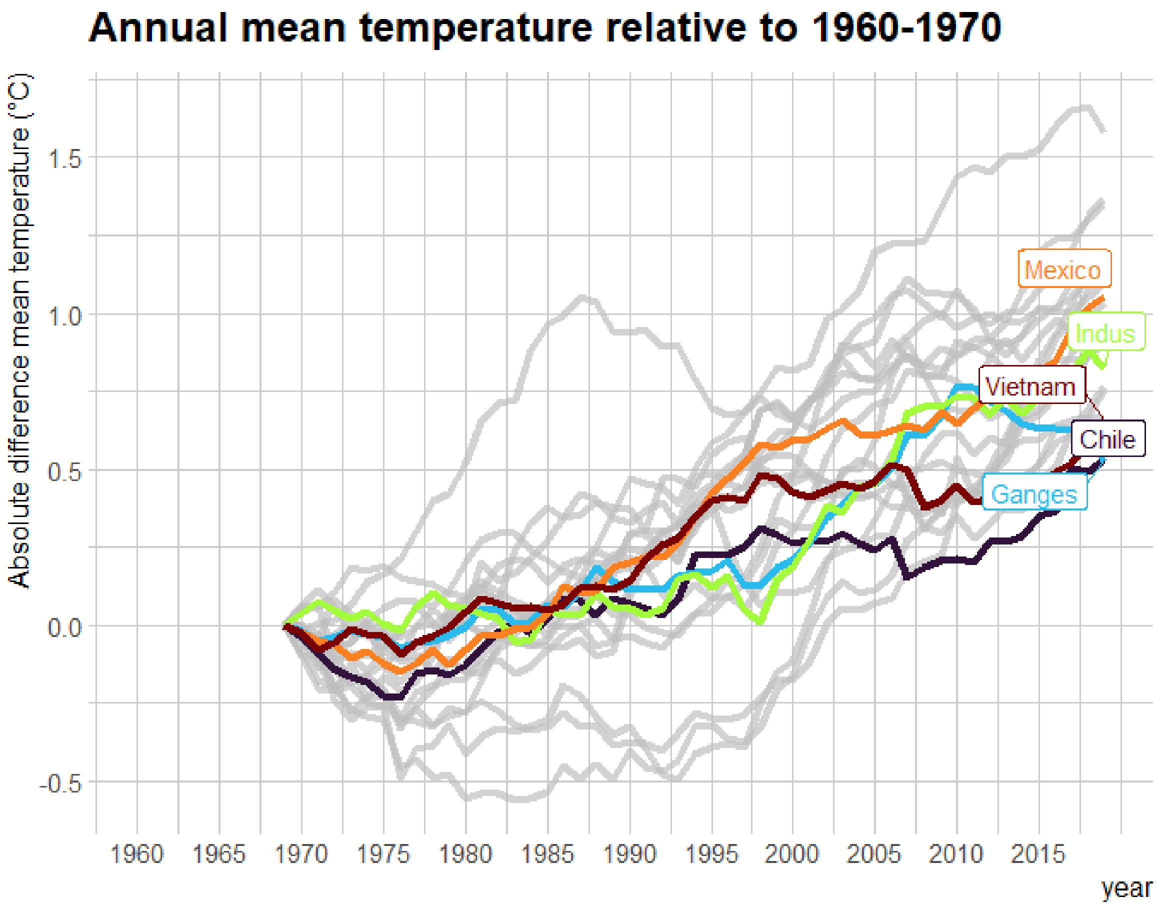
Source: WorldPop

Results – Economic growth



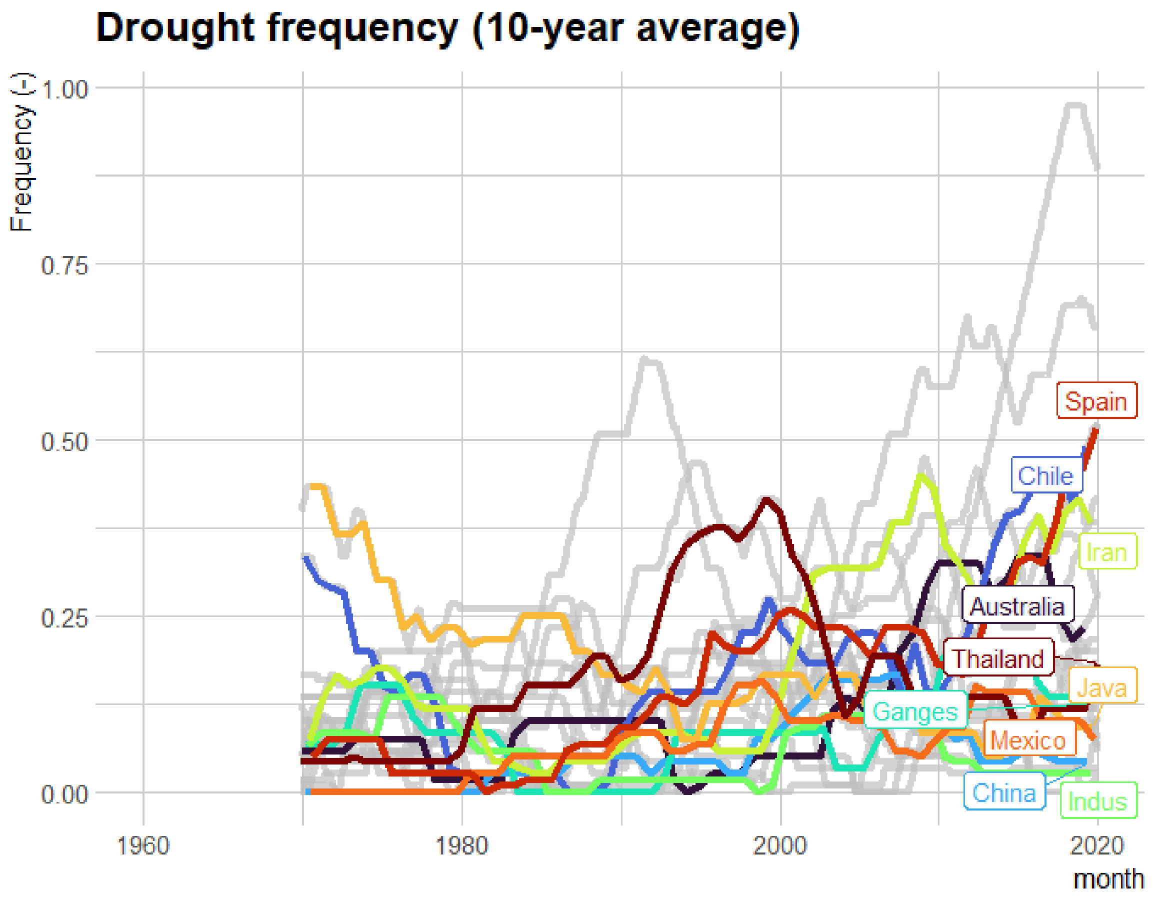
Source: Kummu et al (2020)

Results – Temperature increase



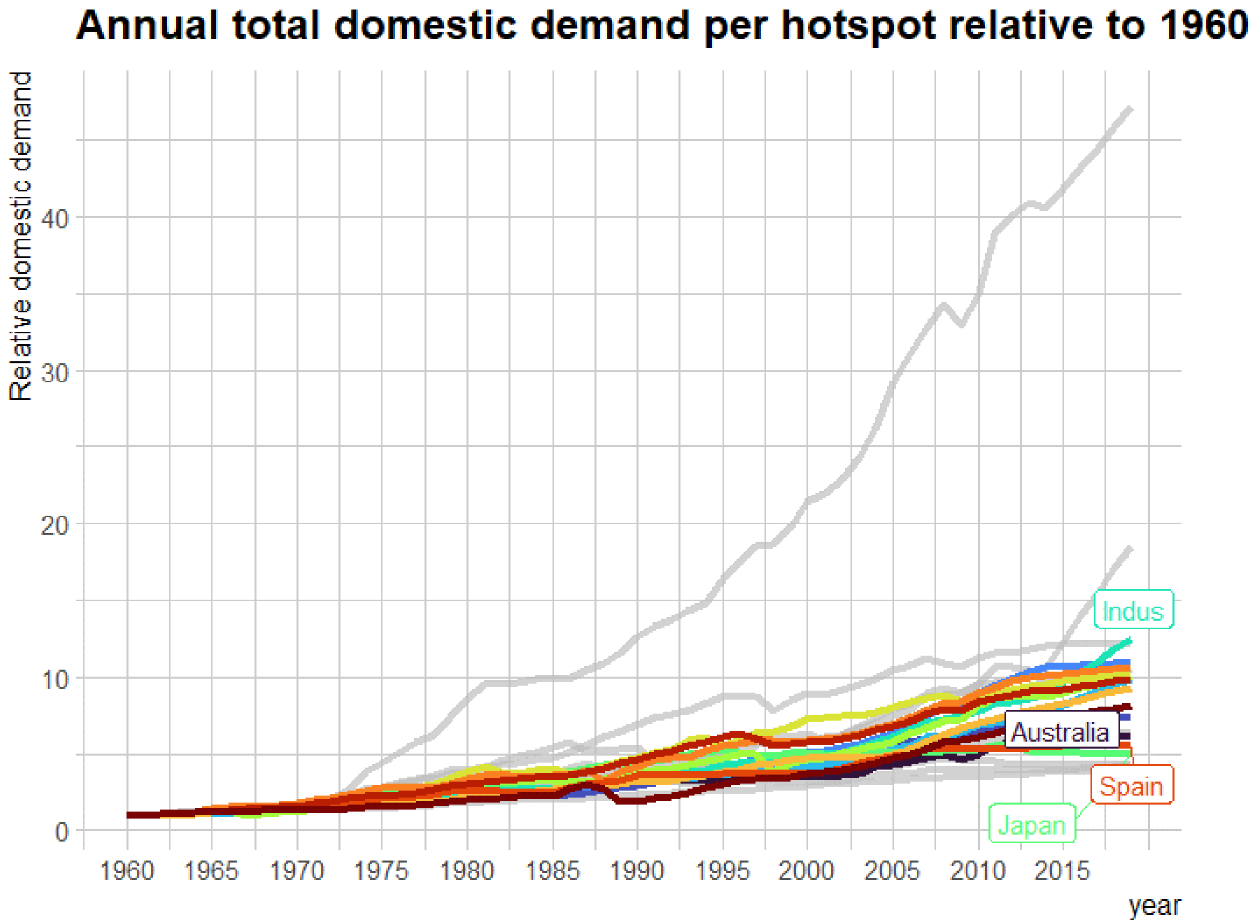
Source: CRU-TS 4.06

Results – Hydroclimatic change



Source: SPEIbase v2.7

Results – Municipal water use



Source: PCRGLOB WB

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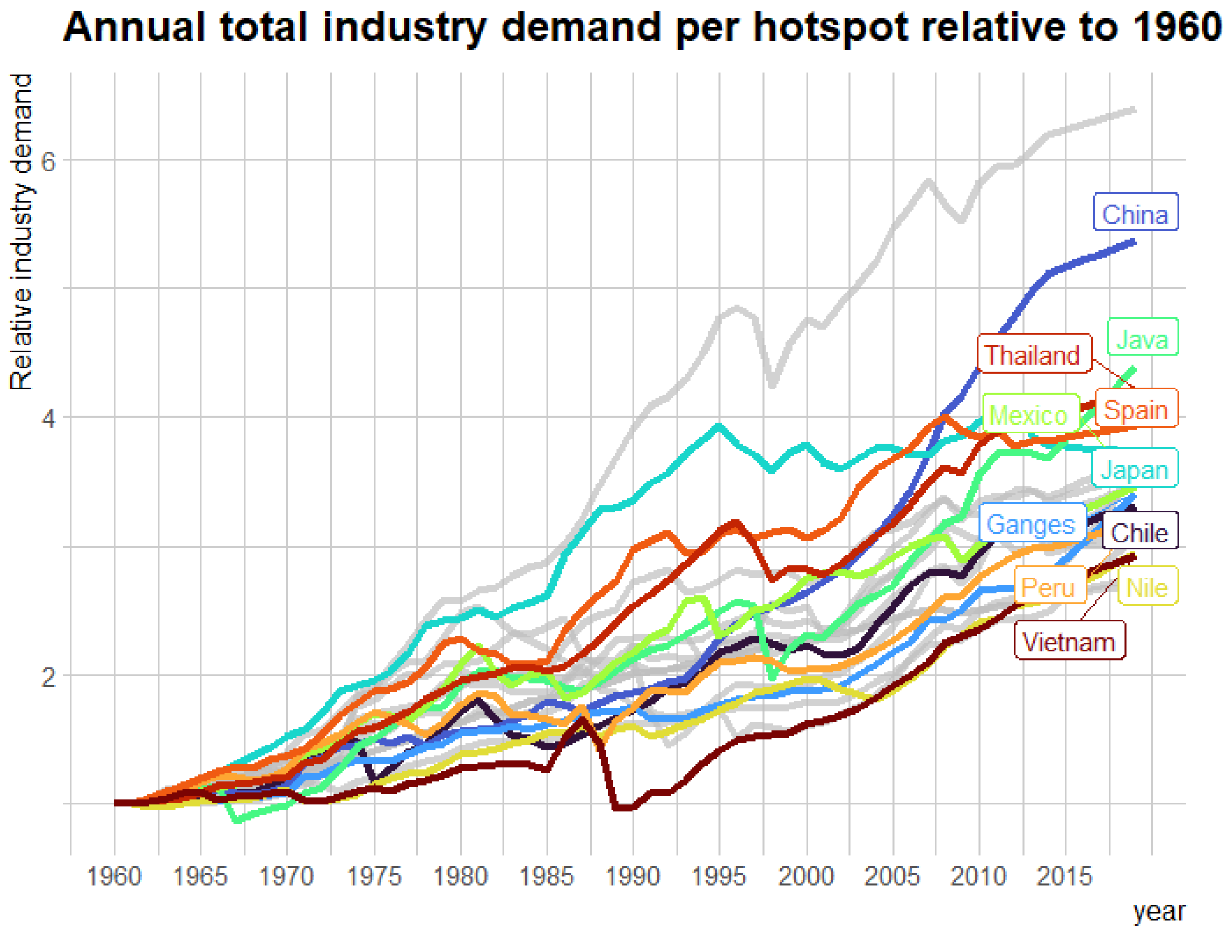
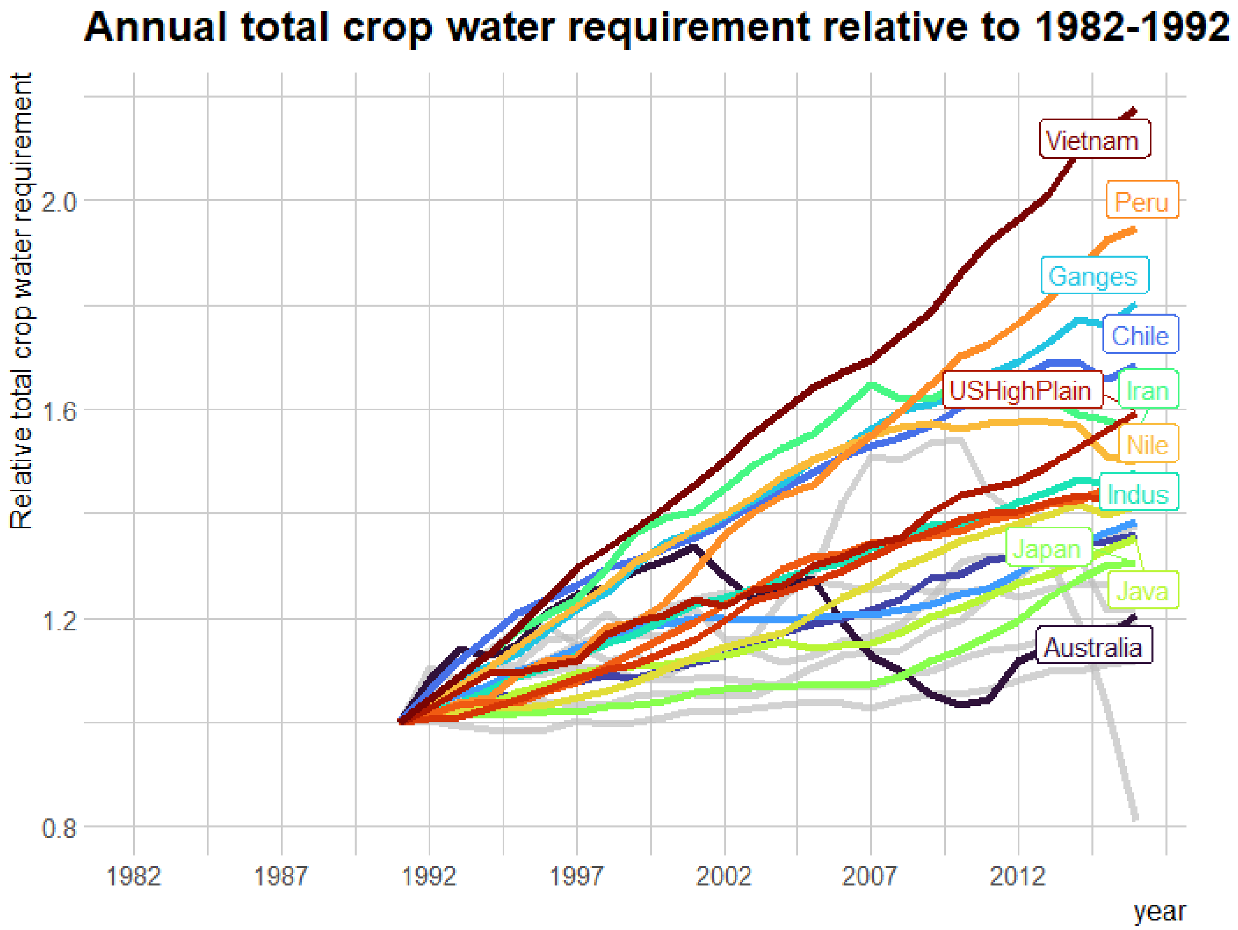
Results – Industrial water use



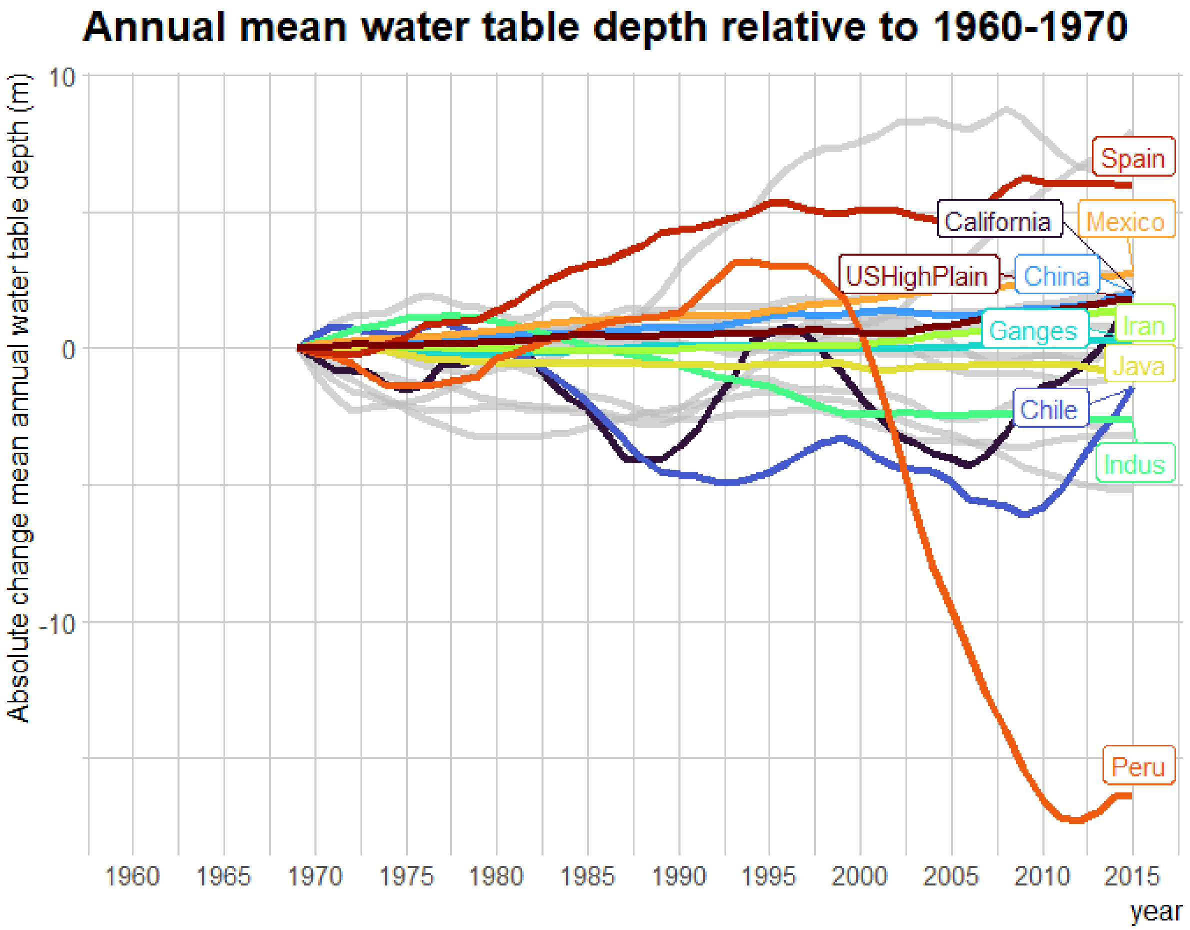
Source: PCRGLOB WB

Results – Agricultural water use



Source: GDHY

Results – Groundwater depletion



Source: GLOBGM

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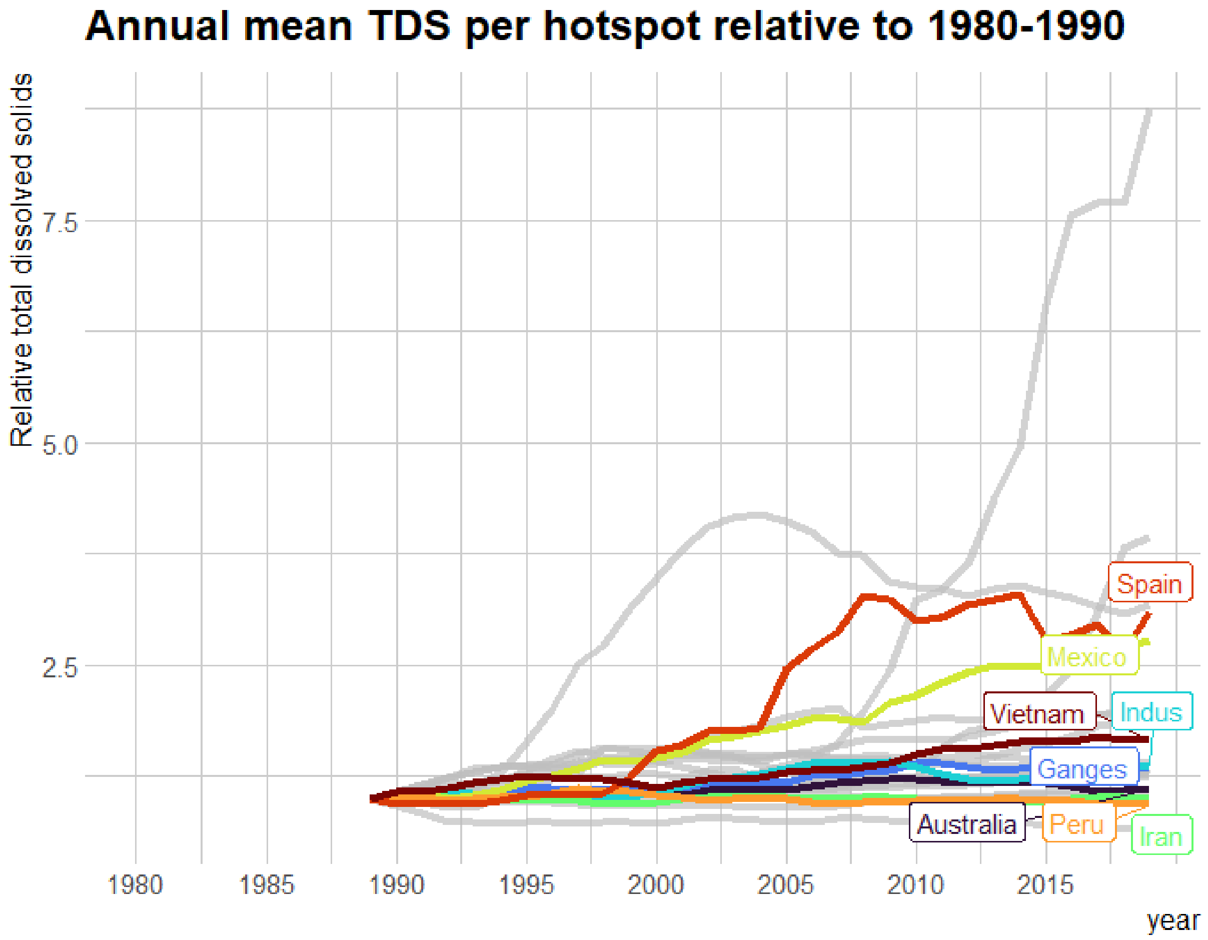
Results – Salinization



Source: DynQual

Discussion

- Location of water gap hotspots in agreement with other global assessments
  - Huggins et al. 2022; Wada & Bierkens, 2014; van Vliet et al. 2021; Huang et al., 2021; Greve et al. 2018
- DPSIR analysis is subject to bias
  - At hotspots with an abundancy of research, we used only a limited sample of all case studies for DPSIR analysis
  - At hotspots that are research deprived, there is a lack of cases studies available for DPSIR analysis
- DPSIR results and data do not always agree
  - Hotspots where drivers and pressures are increasing most rapidly according to data, do not necessarily have the highest scores from DPSIR analysis
  - Data of states based on models, do show the detrimental changes in the state for all hotspots

Summary

- Agricultural water use and hydroclimatic change are the most important drivers and pressures of water scarcity at the hotspots
- The most important drivers, pressures and states show increasing trends at all hotspots in the data
- This study reveals the complexity and diversity of water scarcity problems, especially regarding the variety of impacts involved and governmental responses in place

Utrecht University

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Contact: m.leijnse@uu.nl

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To visit the World Water Map

To visit the online presentation page (OSPP)