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A geospatial analysis of water-related risk to international security: an assessment of five countries

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Abstract This paper assesses countries with transboundary water resources that are at risk for instability. Water security, a term we use in our work to refer to an individual's, community's or state's access to freshwater resources at the right time, quality, and quantity, is becoming of increasing concern due to rising populations, development, and climate change. Building upon the Basins at Risk project at Oregon State University, we used updated Transboundary Freshwater Dispute Database geospatial physical, social, and hydrological data to assess the water-related stability of countries in transboundary freshwater basins. We selected five countries to conduct case studies by assessing three parameters: percentage of territory within a shared basin, number of shared basins, and/or dependency ratio of a country on water resources originating from outside its borders. Given the availability of data and to cover a wider geographic distribution, we selected Afghanistan, China, Iraq, Moldova, and Sudan as our case studies. We created a series of 30 maps at 2 scales to spatially analyze the population density, institutional capacity, and water withdrawals, in addition to assessing each country's water profile. We developed a resiliency tool to analyze these parameters and scored each country to determine whether a country is at risk for water-related instability. We found that while China has a high water-related resilience, Iraq has a low water-related resilience and Afghanistan, Moldova, and Sudan fall within a low to mid-low resilience range.

Keywords Water · Transboundary · Risk · Security · International · Geospatial · Resilience

Introduction

There are 310 transboundary freshwater basins in the world, covering almost half of the earth's land surface (McCracken and Wolf 2019). Approximately 148 countries have territory in these basins, 39 countries have more than 90% territory in one or more of these basins, and 21 countries have 100% territory within a transboundary basin (UN Water 2014). Shared water resources offer a platform for international diplomacy, but also pose an opportunity for conflict, making water a global security issue (e.g. Gleick 1993; Homer-Dixon 1999; Brochmann and Hensel 2009).

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In 2008, the United States Government issued an intelligence assessment that suggested "climate change could threaten domestic stability in some states, potentially contributing to intra- or, less likely, inter-state conflict particularly over access to increasingly scarce water resources" (National Intelligence Assessment 2008). In 2012, the US Office of the Director of National Intelligence released an Intelligence Community Assessment titled 'Global Water Security' Report (ICA 2012). That report suggested that water problems combined with poverty, social tensions, weak political institutions could lead to state failure or instability. Similar observations have been made by the 2015 Worldwide Threat Assessment of the US Intelligence Community, claiming that "extreme weather, climate change and public policies that affect food and water supplies will probably create and exacerbate humanitarian crisis and instability risks" (Worldwide Threat Assessment 2015). Most recently, the CNA Corporation (2017) highlights how water stress can be central to inciting violence in civil unrest increasing the risk that fragile governments will be unable to respond thus opening the door to escalation and government destabilization. Furthermore, Reed (2017) concludes that both U.S. security and prosperity are under rising pressure resulting from the economic and social impacts caused by water scarcity and water-driven ecological change in key geographies around the world.

This paper aims to contribute to international security assessments regarding water challenges by introducing a geospatial analysis tool and a related resilience analysis tool to better understand a country's risk to water-related instability within transboundary freshwater basins. We developed three parameters to limit the number of countries that could potentially serve as case studies and selected Afghanistan, China, Iraq, Moldova, Sudan. We geospatially analyze demand, development, and level of basn-wide coordination regarding transboundary water sharing through the use of data proxies of population density, water withdrawals, and institutional capacity. We create a resilience tool based on a scoring continuum related to the geospatial results as well as the country's water profile. The result is a case study analysis of a country's resilience to water-related instability. The research complements other mapping exercises that have focused on identifying so-called "basins at risk" or "hot spots" for water-related instability and conflict as well as other environmentally-related crises (Wolf et al. 2003; De Stefano et al. 2010, 2012, 2017; Busby et al. 2013; Peek 2014; Busby and von Uexkull 2018). However, in contrast to past studies on transboundary water, this research focuses on country-level case studies.

We conclude that Iraq has a low water-related resilience, China has high water-related resilience, and our other three case studies of Sudan, Moldova, and Afghanistan fall in the low to mid-low ranges of water-related resilience. Specific reasons for each country's scoring are analyzed and discussed in our Results and Conclusion sections.

Background

Transboundary freshwater basins pose unique challenges to cooperative resources management, diplomacy, and international security. Water security, a term we use in our work to refer to an individual's, community's or state's access to freshwater resources at the right time, quality, and quantity, is becoming of increasing concern due to population growth, development, and climate change (WCD 2000; Vörösmarty et al. 2000; Richter et al. 2010; Veilleux et al. 2014; Veilleux and Anderson 2016; Lufkin 2017). Given differing national objectives and demands for water that are shaped and exacerbated by culture, politics, environments, geographies, and economies, conflict could potentially arise (Wolf et al. 2003; Gleick 1993). Water conflict can take various forms starting with non-violent political disputes that could potentially escalate into armed exchanges and perhaps even, although not as likely, all-out-war (Wolf et al. 2003).

Research into the role of freshwater in the context of international security and stability largely began in the 1980s and focused mostly on arid and semi-arid regions' likelihood of armed conflict due to water scarcity (Cooley 1984; Starr 1991). These early studies also consider how water is used as a weapon or target of war (Gleick 1993). Work specific to water also coincided with the emerging sub-field of environmental security, which became particularly salient after the end of the Cold War (Myers 1993; Kaplan 1994). This relatively new sub-field generally explored the causal pathways to conflict and instability emanating from environmental factors (Homer-Dixon 1994, 1999; Gleditsch 1997, 1998). Water security also complements other security paradigms including human security (UNDP 1994) and the securitization theories of the Copenhagen School (Buzan et al. 1997). While research on the politics of freshwater was associated with more non-traditional security paradigms, scholars trained in such disciplines as international relations were employing traditional theories and concepts of international relations (e.g. 'interdependence', 'relative and absolute gains', 'projectable power' etc.) to understand conflict and cooperation in specific freshwater basins (Frey and Naff 1985; Frey 1993; Lowi 1993; Naff 1994; Elhance 1999).

The water conflict-related writings of the 1980s and 1990s were largely limited to case studies. In the 2000s, scholarship expanded to analyze global trends motivated by the availability of large cross-national data (large-n) sets on a variety of relevant variables. Specific to water, the Peace Research Institute of Oslo was, arguably, first to generate a large-n study investigating the relationship between water scarcity and international conflict (Toset et al. 2000). Other studies soon followed, posing different hypotheses about conflict and water and utilizing different explanatory variables that were aided by the availability of the improved data (Wolf et al. 2003; Gleditsch et al. 2006; Furlong et al. 2006; Hensel et al. 2006; Brochmann and Hensel 2009).

While studies on water and conflict had interesting results, another set of scholars focused on cooperation over shared water resources, claiming that the same factors motivating conflict could likewise motivate cooperation (Barnett 2000; Alam 2002; Dinar 2009). Inspired by the work of Aaron Wolf and his expansive database on international water treaties (TFDD n.d.), scholars turned to theories of international relations and economics, and tested factors that could potentially explain the emergence of water-related treaties and their design (Espey and Towfique 2004; Song and Whittington 2004; Drieschova et al. 2008; Tir and Ackerman 2009; Gerlak and Grant 2009; Dinar et al. 2010, 2011; Brochmann and Hensel 2011; Zawahri and Mitchell 2011; Brochmann 2012; Zentner 2012; Tir and Stinnett 2012; Dinar et al. 2015; Mitchell and Zawahri 2015; Zawahri et al. 2016). Other scholars have suggested that the existence of a treaty or even high institutional capacity score does not necessarily correlate with effective cooperation (Zawahri 2008; Zeitoun and Warner 2006; Conca 2002; Bernauer 1997).

Table 1 Water frameworks for selected countries

Country	% Extent country covered (TFDD shapefile derived)	Dependency ratio (FAO Aquastat)	Number of shared basins
Afghanistan	99.7	29	8
China	34.8	1	18
Iraq	90.7	61	1
Moldova	99.2	91.4	4
Sudan	78	96.1	4

In addition to the case study work and large-n empirical studies, research on freshwater resources also utilized geospatial analysis on conflict and cooperation. Work includes Oregon State University's Basins at Risk project, which considers a variety of physical, economic, and political indicators to suggest basins with potential for political stressors or conflicting interests over water (Yoffe et al. 2003; Wolf et al. 2003; BAR 2018).[1] Expanding on this work, De Stefano et al. (2010, 2012, 2017) use large-n datasets to map the institutional resilience of river basins combined with a variety of factors. Using geospatial mapping tools to layer institutional, climatic/environmental and social parameters, the studies identify basins at potential risk of water-related tensions. The scientific popular press has likewise considered conflict and cooperation over water through mapping. Peek (2014), for example, provided a geospatial analysis considering conflictive and cooperative water events alongside other non-water resource related disputes to ascertain regions most likely to experience future conflicts over water. Other studies focusing more generally on environmentally-related political crises have also used maps to identify areas or countries of instability. Busby et al. (2013) assess the vulnerability of Africa to climate change induced instability combined with other socio-economic indicators. Most recently, Busby and von Uexkull (2018) identify countries most at risk from climate-related instability and humanitarian crisis in the near future

[1] While not utilizing mapping, Bernauer and Böhmelt (2014) build on the Basins at Risk project and partake in more advanced forecasting and prediction techniques to identify rivers basins that are prone to conflict and cooperation. See also Farinosi et al. (2018).

Table 2 Geospatial water-related analytical tool for assessing resilience

Low = 1	Mid-low = 2	Medium = 3	Mid-high = 4	High = 5
1 Main water resource	2 Available water resources	3 Available water resources	4 Available water resources	5 Or more available water resources
> 75% withdrawal from a shared basin(s)	75 to 50% of withdrawal from a shared basin(s)	50 to 25% of withdrawal from a shared basin(s)	< 25% of withdrawal from a shared basin	0
Population: > 81% in a shared basin	Population: 61–80% in a shared basin	Population: 41–60% in a shared basin	Population: 21–40% in a shared basin	Population: < 20% in a shared basin
No treaties, river basin organizations, or agreements	One treaty	One treaty with mechanism or river basin organization or two treaties	One treaty with mechanism and 1 more mechanism or river basin organization or 3 treaties	One treaty with 2 or more mechanisms and river basin organization or one treaty with > 2 mechanisms or 4 or more treaties

focusing on such indicators as high levels of agriculture, history of conflict, and discriminatory political institutions. Our analysis aims to contribute to these geospatial efforts by highlighting select countries, applying several layers of data, and to assessing each country's water-related resilience.

Methods

To identify countries at risk, we devised a series of steps to narrow our search to countries with particular water frameworks. We then mapped each country and associated transboundary basin, geospatially analyzed the maps to understand overlapping layers' relationships, and finally developed a resiliency tool to assess water resilience at a country level.

For the initial step, we used the Transboundary Freshwater Dispute Database georeferenced data and Aquastat's/FAO (2016) to determine three geographic and spatial aspects of water frameworks that could characterize a country's vulnerability related with its transboundary water resources (Espey and Towfique 2004; Gleditsch et al. 2006; Tir and Ackerman 2009).[2] In particular:

1. Percent transboundary freshwater basin coverage of a country's territory;
2. Percentage of dependency on water sourced from outside the country border (dependency ratio as designed by the UN's FAO to measure an aspect of water vulnerability); and/or
3. Number of transboundary freshwater basins shared by a given country.

We generated a list of countries that fell into these three criteria. We then selected countries based on regional and cultural variety, and availability of data. We selected Afghanistan, China, Iraq, Moldova, and Sudan for case studies based on our desire to examine a variety of countries with different aspects of our criteria. The data related to water frameworks are listed in Table 1.

Once we selected the countries using the three parameters listed above, we created a series of 30 maps using ArcGIS at 2 scales visualizing the relationship between the transboundary freshwater basins, the region, the country, and the basin country

[2] There may be additional criteria for determining hydro-political vulnerability that we did not include given the above reasoning. For example, according to Wolf et al. (2003) there may be rapid changes in the physical system that are at the root of water conflict. The proliferation of unilateral development projects is one such example. Climate variability or rapid environmental changes (such as disasters) may be another form of vulnerability complicating existing water management strategies with significant economic, social, environmental, and political consequences (see Adger et al. 2005; Walker et al. 2006; United Nations Environment Programme (UNEP) et al. 2009).

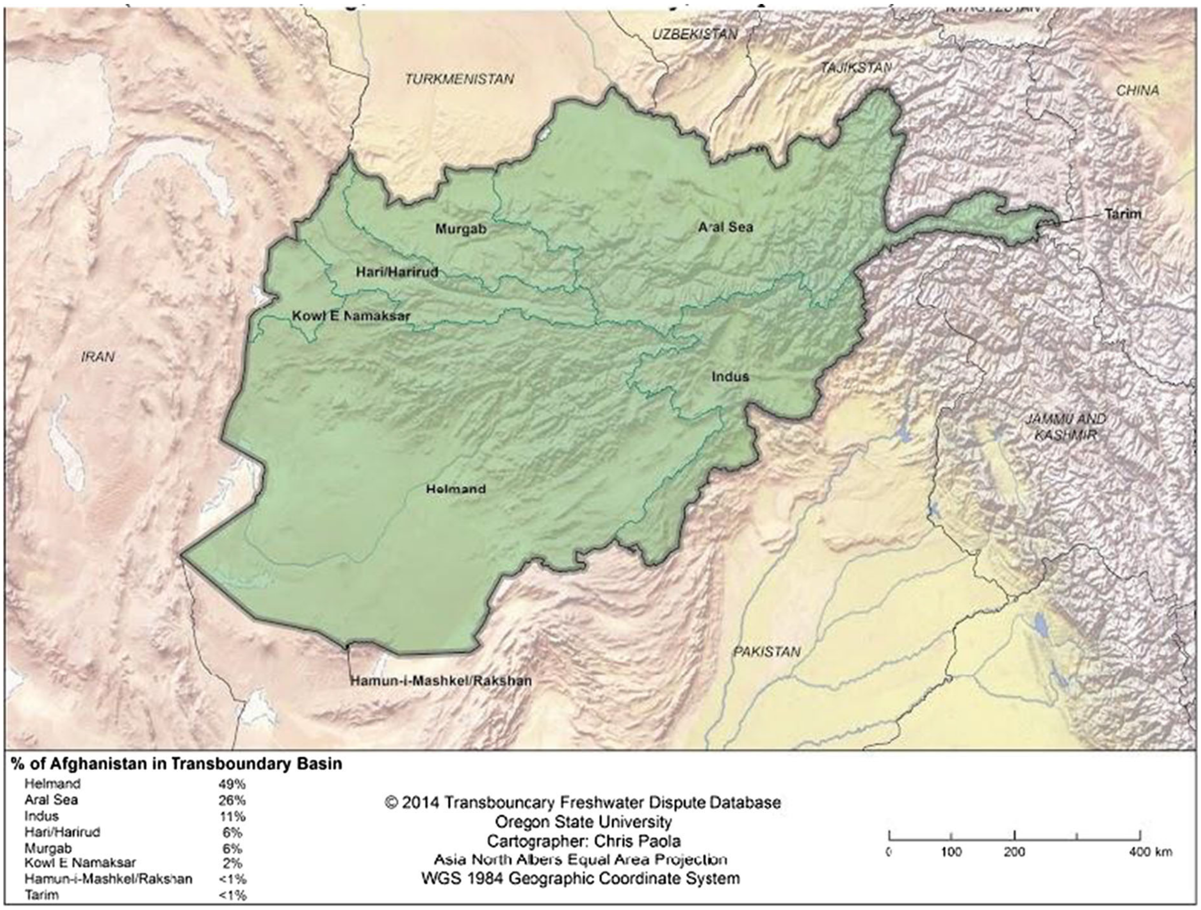

Fig. 1 Afghanistan's transboundary basins by basin country unit

units (a measurement of the portion of a transboundary basin that falls within one country as designed by TFDD team). Based on the extant literature, we examined layers of socio-political and environmental parameters. We decided to use available spatial data sets that represent four different elements of these parameters. These data sets specifically include institutional capacity and transboundary basin boundaries derived from TFDD's International Freshwater Treaties Database (2014), water withdrawals derived from University of Kassel data (UniKassel n.d.), and population density derived from Columbia University's CIESEN data (n.d).[3] We analyzed each individual layer and then the layers in combination. In addition, we consult the literature to determine the extent of available domestic freshwater resources both contained in transboundary and in non-shared water systems, for the creation of our resilience measurement tool (Table 2). We developed this water-related resilience analysis tool to provide a ranked assessment

[3] 'Power' is considered to be an important factor in understanding hydro-political dynamics in international river basins (Lowi 1993; Naff 1994; Homer-Dixon 1999; Dinar 2012). Our overall model of vulnerability and resilience does not include 'power' in the economic-political sense such as the material

Footnote 3 continued
capabilities of a given country or its economic strength in comparison to other basin countries. However, spatially- and geographically-speaking, power in our model is proxied via FAO's dependency ratio, which also considers upstream/downstream dynamics. This is an important factor in assessing physical/geographical vulnerability. In addition, when our model assesses resilience, a country's relative power is taken into account by considering its level of dependence on the international basin (using various parameters) as well as institutional capacity to deal with potential conflict. Dependence and interdependence are important factors when assessing 'sensitivity' and 'vulnerability' of countries (Keohane and Nye 1977).

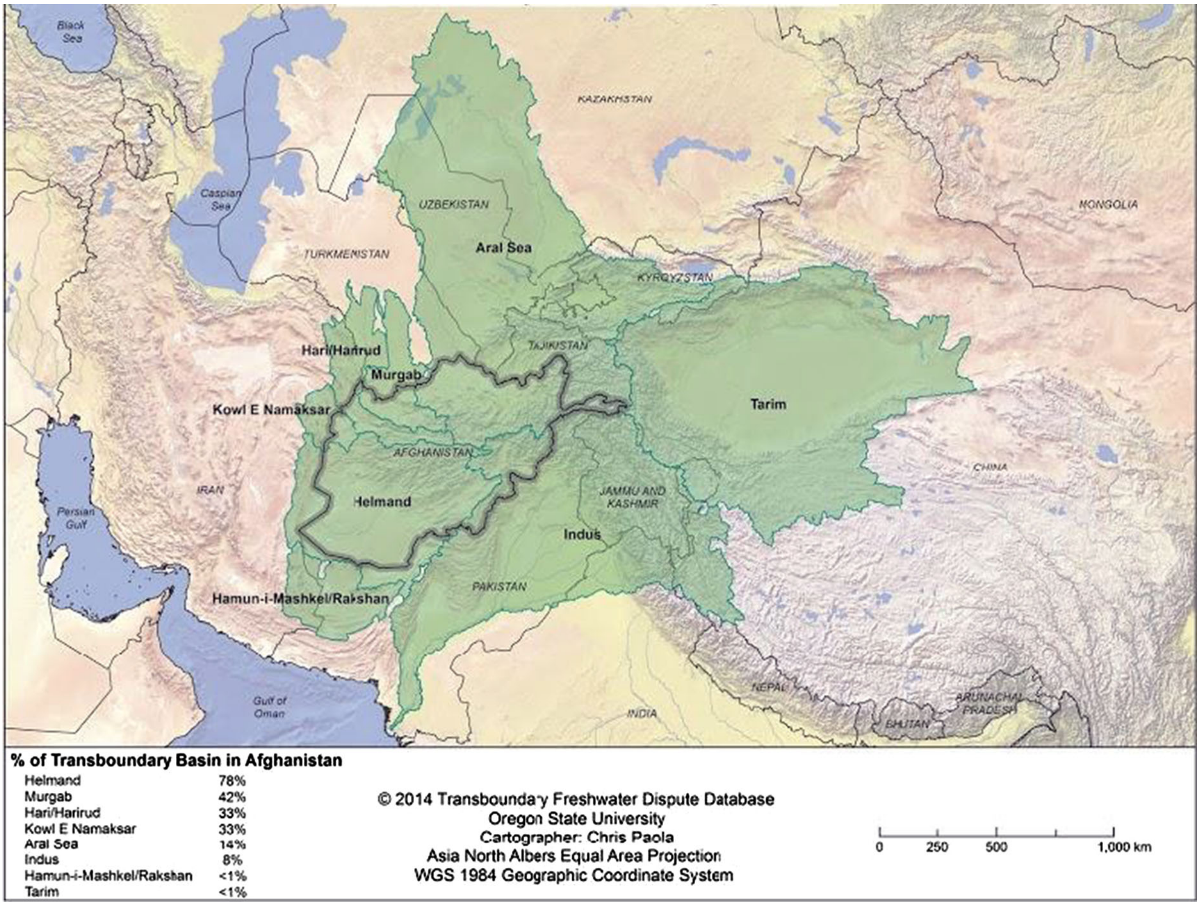

Fig. 2 Regional scale of Afghanistan's transboundary basins by basin country unit

of each country. It is important to note that while each layer is self-standing and thus not weighted in comparison to another layer, the different layers (and the datasets that are used to construct them) add up to a whole complex system. As such, the datasets complement each other to present a story of resilience (and risk).

Results

The general results of our analysis reveal that geography plays a central role in whether a country is at risk due to water-related stability given that country's placement in a transboundary water basin, the country's access to alternative water resources beyond the shared resources, and the nature of riparian relationships. The results by country are listed in the following sections along with the map sets.

Afghanistan

Afghanistan, a country plagued by international and domestic conflict for almost four decades, contains 8 transboundary water basins that account for 99.7% of the country's territory (TFDD 2014). These basins include the Helmand, Aral Sea, Indus, Hari/Harirud, Murgab, and Kowl E Namaksar. The maps in Figs. 1 and 2 show Afghanistan's 8 transboundary basins at the country scale and at the entire transboundary basin scale, including neighboring countries in the region. The country's mountainous terrain accounts for its upstream position in the majority, but not all, of its shared basins. Afghanistan's downstream neighbors include Pakistan, Iran, and those countries in the greater Aral Sea basin. Afghanistan's upstream neighbors include China and Tajikistan on the Amu Darya. Overall, Afghanistan boasts some 18 freshwater basins (and about 6 major drainage areas), either wholly

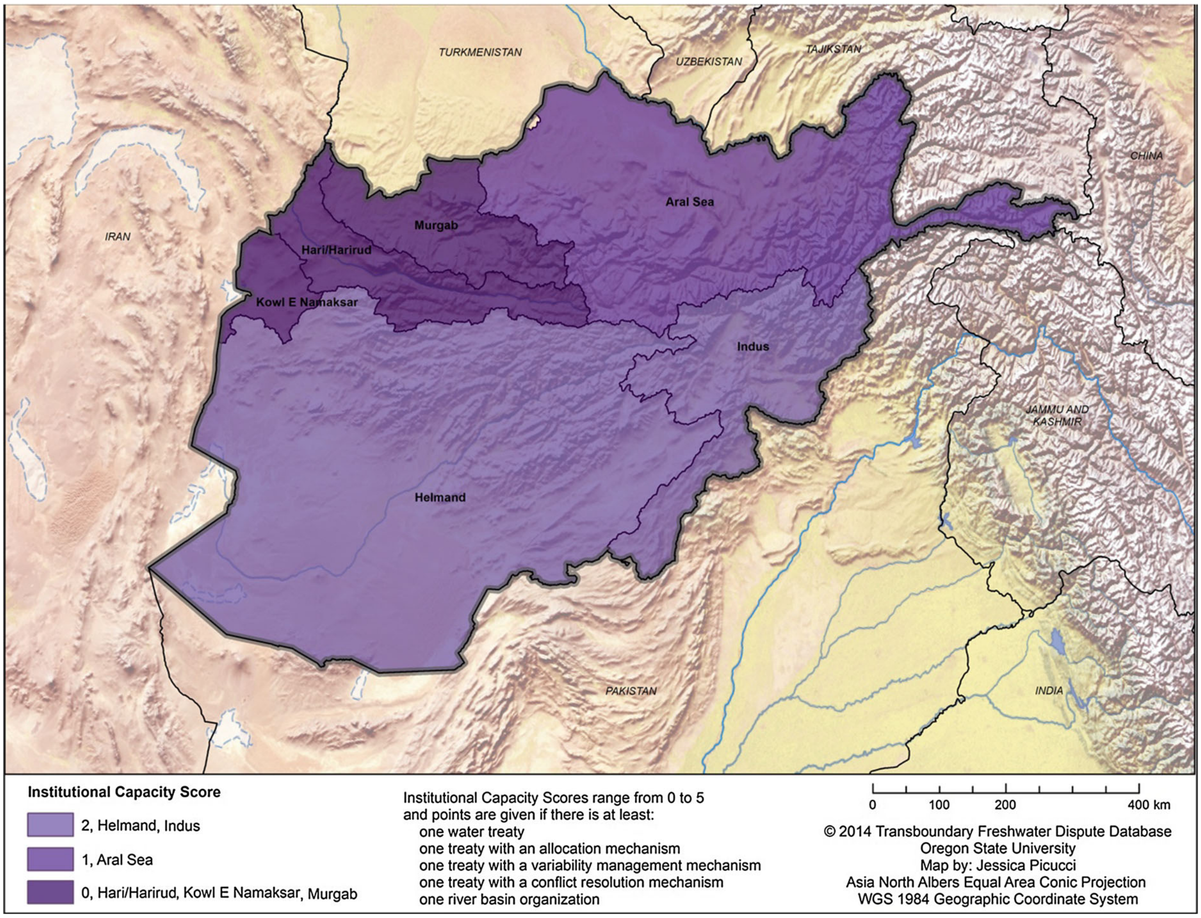

Fig. 3 Afghanistan's institutional capacity by basin country unit

contained in the country or shared with neighboring countries (USGS FEWS n.d.; UNEO/UNOSTAT 2017; Campbell 2015).

Institutional capacity

No official treaties exist between the current government of Afghanistan and its neighbors regarding water resources with the exception of a 1973 treaty (based on a 1950 Terms of Reference Treaty) on the Helmand River between Afghanistan and Iran. Afghanistan is upstream on the Helmand and the treaty allocations indicate Iran's water share. India and Pakistan established the Permanent Indus Water Commission with the Indus Waters Treaty of 1960, but Afghanistan was not included (nor were China and Nepal) in the treaty or River Basin Organization (RBO). In 2005, with assistance from India, Afghanistan planned to build a reservoir on the Kabul River. Although the Afghan government initially agreed to work towards an accord with Pakistan regarding the reservoir and its downstream impacts, tensions emerged when plans proceeded without any movement towards agreement or information sharing (TFDD 2014). Since the fall of the Taliban, international efforts are centered on post-conflict development of the country, specifically within the agricultural sector. Agricultural development is heavily water dependent (UNEP 2003; Weinthal, Troell and Nakayama 2014).

The following maps in Figs. 3 and 4 demonstrate a predetermined institutional capacity ranking, as created by Wolf et al. (2003) and his team at both the country and international basin scales.

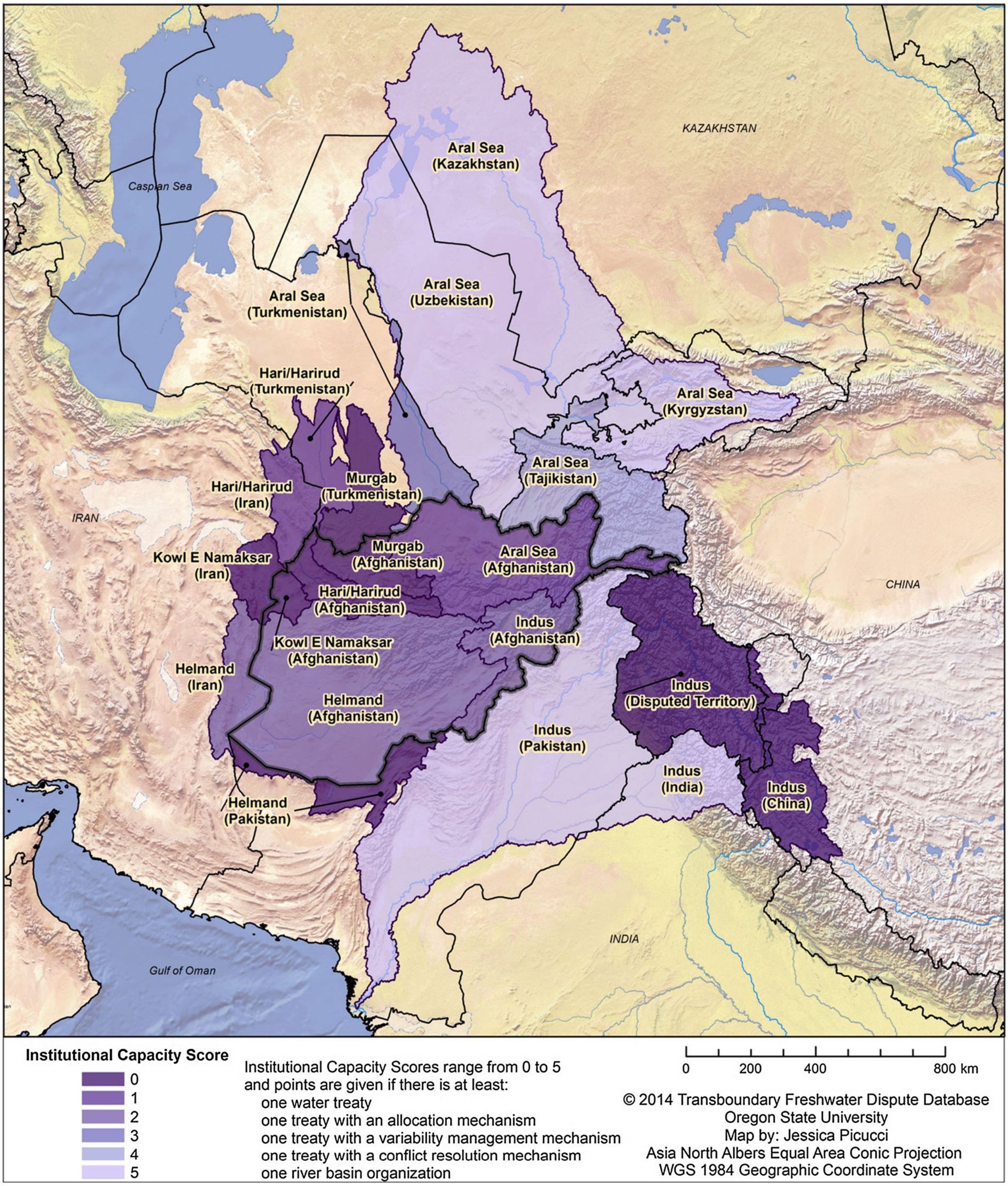

Fig. 4 Institutional capacity of the extent of Afghanistan's transboundary basins by basin country unit

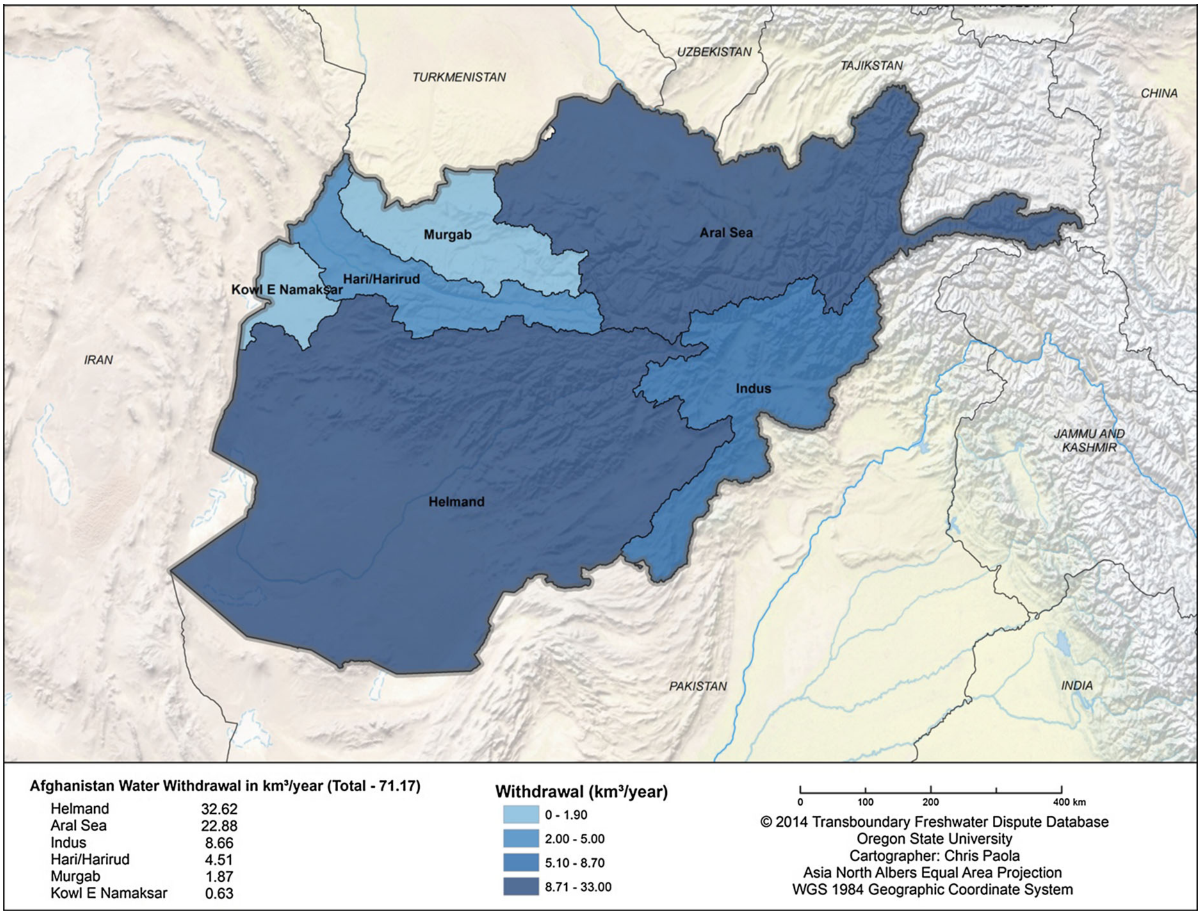

Fig. 5 Afghanistan water withdrawal by basin country unit

Water withdrawals

Twenty-nine percent of water resources used in Afghanistan are sourced from outside its territory. Data from 1998 showed that 98% of Afghanistan's total water withdrawals—surface and groundwater combined—were used for agriculture, with only 1% for each industry and municipal use. 25 While 75% of the population live in rural areas, only 12% of Afghanistan's land is arable, and only 40% of that is currently irrigated (World Bank 2011). Still, agriculture—primarily wheat, fruits, nuts, wool, mutton, sheepskins—contributes between 30 and 50% of the country's GDP. Yet, as of 2003, around half of the rural population was food insecure, lacking the resources to purchase adequate calories per person per day (World Bank 2011). Afghanistan's current priority is to develop its agricultural sector, taking advantage of its long underdeveloped water resources. However, rapid shifts without basin-level institutional capacity to absorb the change may lead to more conflict and violence in the region (Wolf et al. 2003; Schroder 2016). Figures 5 and 6 show water withdrawals at the country scale and at the entire transboundary basin scale, including neighboring countries in the region.

Population density

Demographically, Afghanistan is 80% Sunni and 19% Shiite Muslim. Its major ethic groups are Pashtun and Tajik (comprising 69% of the population), with smaller populations of Hazara, Uzbek, Aimak, Turkmen, and Baloch. Life expectancy is 50.5 years (fourth lowest, globally), and 42% of the country's entire population is under the age of 15. Afghanistan

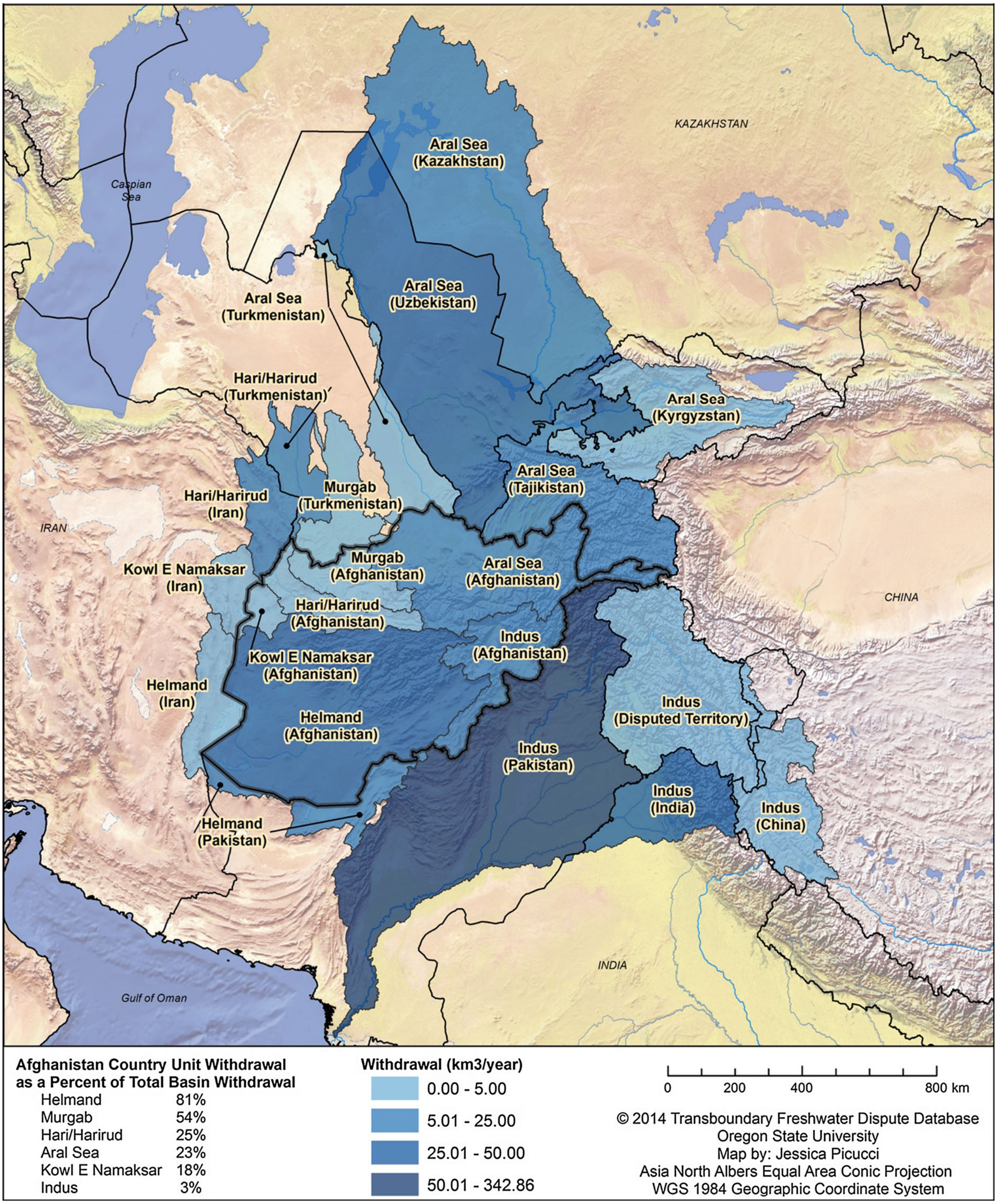

Fig. 6 Water withdrawals by extent of Afghanistan's transboundary basins by basin country units

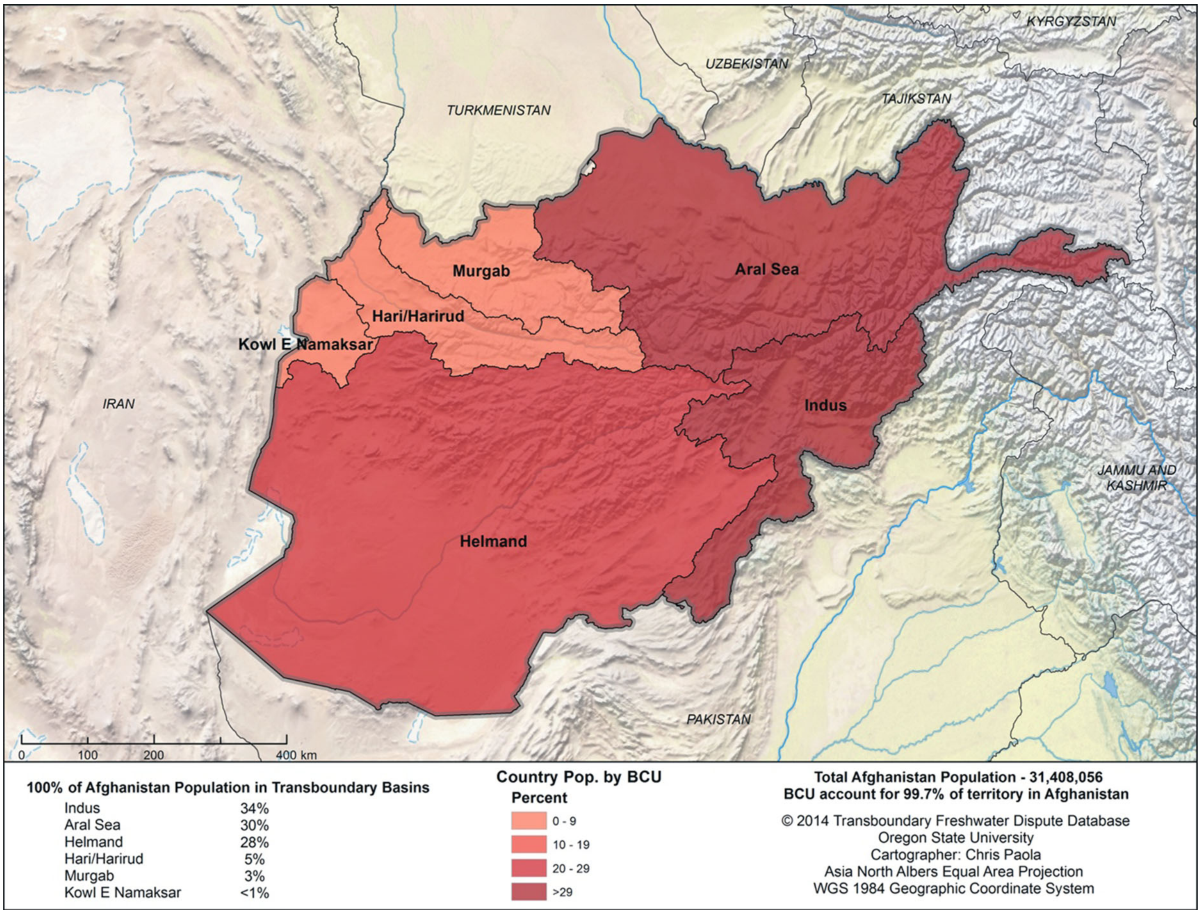

Fig. 7 Afghanistan's population density by basin country unit

has the worst infant mortality rate in the world at 11.7%. Thirty-six percent of the population falls below the poverty line, and 35% of working-aged adults are unemployed. Despite a decade of U.S. nation-building in Afghanistan, 39.4% of the population did not have access to an improved drinking water source and 71.5% of the population lacked adequate sanitation facilities in 2011 (CIA 2017). Figures 7 and 8 show the highest population densities in Afghanistan are found in the Aral and Indus basins, more than 29% of the population occurring in both respective basins. When considering the international basin scale, the downstream population in Uzbekistan's portion of the Aral Sea basin and Pakistan's portion of the Indus hold the highest basin percentage populations; both are found downstream of Afghanistan.

Resilience score

Afghanistan's scores between low and mid-low resilience as displayed in Table 3. This is due to Afghanistan's available water resources, more than 75% water withdrawals from shared basin, majority of the population found in the Aral and Indus river basins; the institutional capacity scores 3, because of agreements that exist with the former governments of Afghanistan and Iran in the Helmand basin. The majority of water withdrawals are taking place in the Aral and Helmand basins, largely due to agricultural projects centered in those zones by international aid projects.

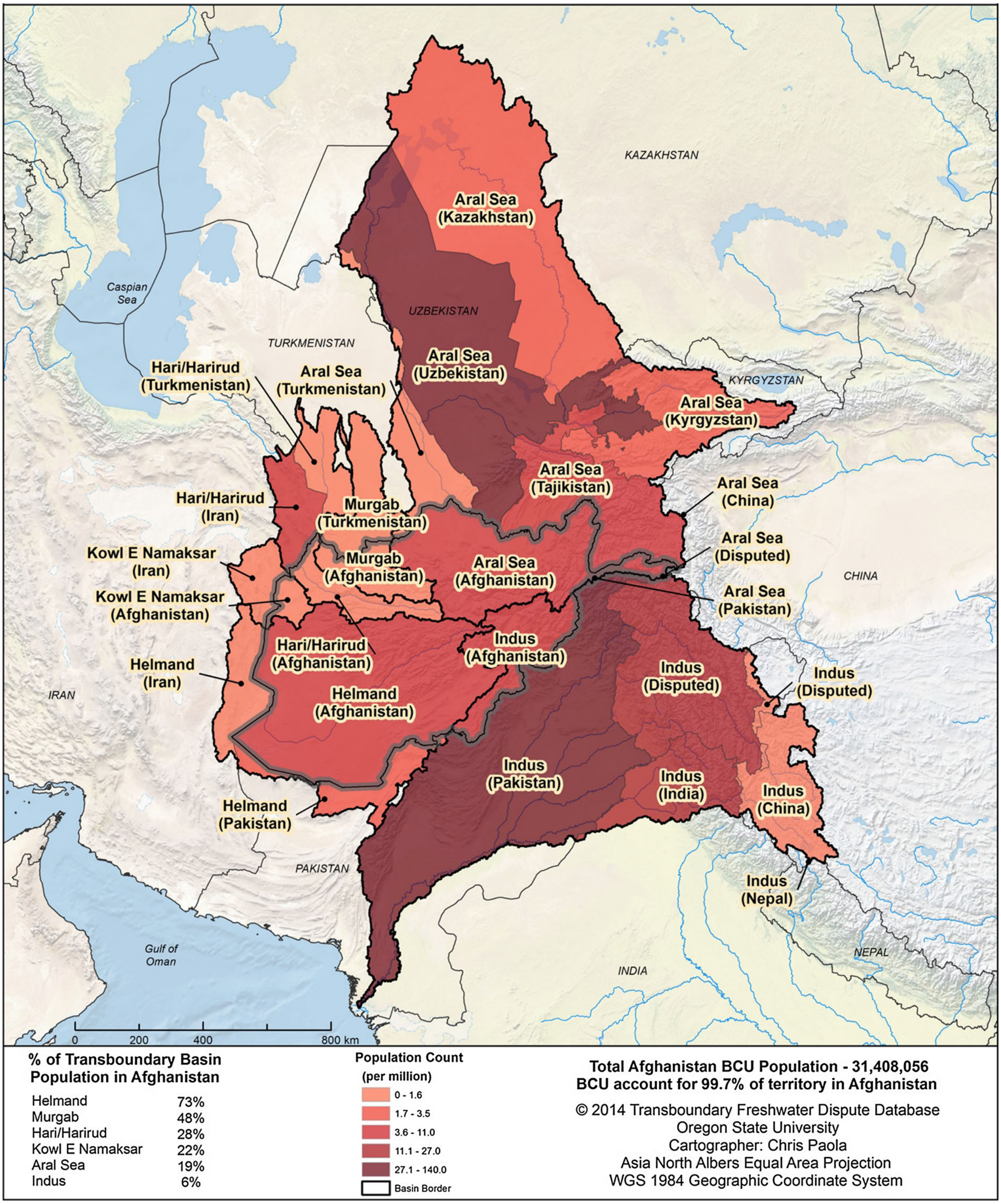

Fig. 8 Population density by extent of Afghanistan's transboundary basins by basin country units

Table 3 Afghanistan's water-related resilience

Afghanistan
Mode = 1
Median = 2
Low to Mid-low Resilience

Low = 1	Mid-low = 2	Medium = 3	Mid-high = 4	High = 5
1 main water resource	2 available water resources	3 available water resources	4 available water resources	5 or more available water resources
> 75% withdrawal from a shared basin(s)	75% to 50% of withdrawal from a shared basin(s)	50% to 25% of withdrawal from a shared basin(s)	<25% of withdrawal from a shared basin	0
Population: >81%	Population: 61%- 80%	Population: 41%-60%	Population: 21%-40%	Population: <20%
No treaties, river basin organizations, or agreements	One treaty	One treaty with mechanism or river basin organization or two treaties	One treaty with mechanism and 1 more mechanism or river basin organization or 3 treaties	One treaty with 2 or more mechanisms and river basin organization or One treaty with >2 mechanisms or 4 or more treaties

China

China is part of 18 transboundary water basins and constitutes the upstream country for many of Asia's transboundary rivers (Zhang and Li 2017). China is part of the following transboundary rivers: Amur, Sujfun, Tunebm Yalu, Bei Jian.Hsi, Red/Song Hong, Beilun, Irrawady, Mekong, Ganges–Brahmaputra–Meghna, Salween, Indus, Tarim, Aral Sea, Illi/Kunes He, Ob, Har Us Nur, and Pu Lun T'o. The maps in Figs. 9 and 10 depict China's transboundary basins at the country scale and at the entire transboundary basin scale. China's downstream neighbors include Laos, Thailand, Vietnam and Cambodia (Mekong), India, Nepal, Bhutan and Bangladesh (Ganges–Brahmaputra–Meghna), Pakistan and India (Indus) among others. In addition to its transboundary rivers basins, China boasts some 7 major domestic river systems including the Yangtze River, Yellow River, Huai River, Hai River, Pearl River, Songhua River and Liao River (MWR 2018).

Institutional capacity

After 1945, China is party to about ten separate agreements, treaties or protocols with its neighbors. No agreements govern some ten of China's shared basins. The Amur River, governed by several treaties, between China and Russia and China and Mongolia boasts the highest score in terms of institutional capacity. The Ob and Pu Lun T'o, Tumen, Mekong and Ili/Kunes He follow, respectively, in terms of institutional capacity scores. While China's relations with its northern neighbors is important (in particular China–Russia, China–Mongolia, China–North Korea and China–Kazakhstan water agreements), China's international water relations with its southern neighbors is particularly salient (Zhang and Li 2017). First, China is upstream on these rivers. Second, since the majority of China's water resources are located in the southern part of the country these headwaters are particularly important to satisfy growing Chinese demands in the rest of the country (Jiang 2009). However, these major river basins (Indus, Mekong and Ganges–Brahmaputra–Meghna) are not governed by any water sharing treaties that include China. Among these three river basins, where China is also upstream,

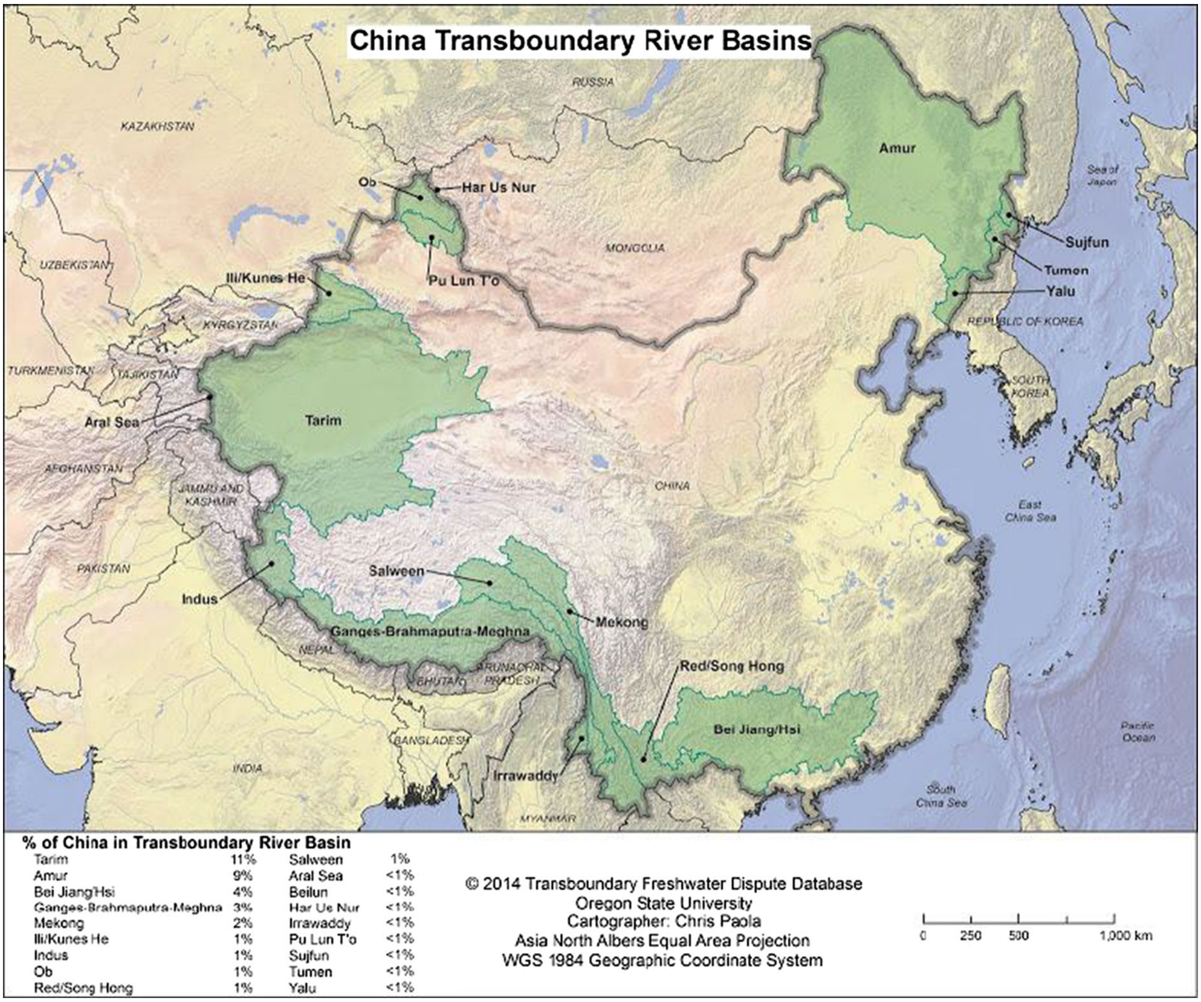

Fig. 9 China's transboundary basins by country basin units

the Mekong and Brahmaputra are of particular importance in terms of international hydro-politics and China's future utilization plans. Figures 11 and 12 depict institutional capacity ranking at both the country and international basin scales.

Water withdrawals

China's water use is divided 63% to agriculture, 23% to industry and 14% to the municipal sectors. Spatially speaking, China's northern region consumes 20% more water in the agricultural sector in comparison to the southern region. The industrial sector in the southern region of China consumes more than twice as much water than the industrial sector in the northern region (Chinese Academy of Science 2007; Jiang 2009). According to Jiang (2009), in 2006, the average rate of water resource use ranged from 31 to 91.7% for domestic river basins in the north compared to 1.7 to 19.5% in the south. Overall, China obtains about 81.5% of its renewable water resources from surface water and 18.5% from underground aquifers (MWR 2007). As mentioned above, the majority of China's water resources are located in the southern part of the country while the greatest demand for water is in northern and eastern China. Figures 13 and 14 show water withdrawals at the country scale and at the entire transboundary basin scale, including neighboring countries in the region.

Fig. 10 Regional scale of China's transboundary basins by basin country unit

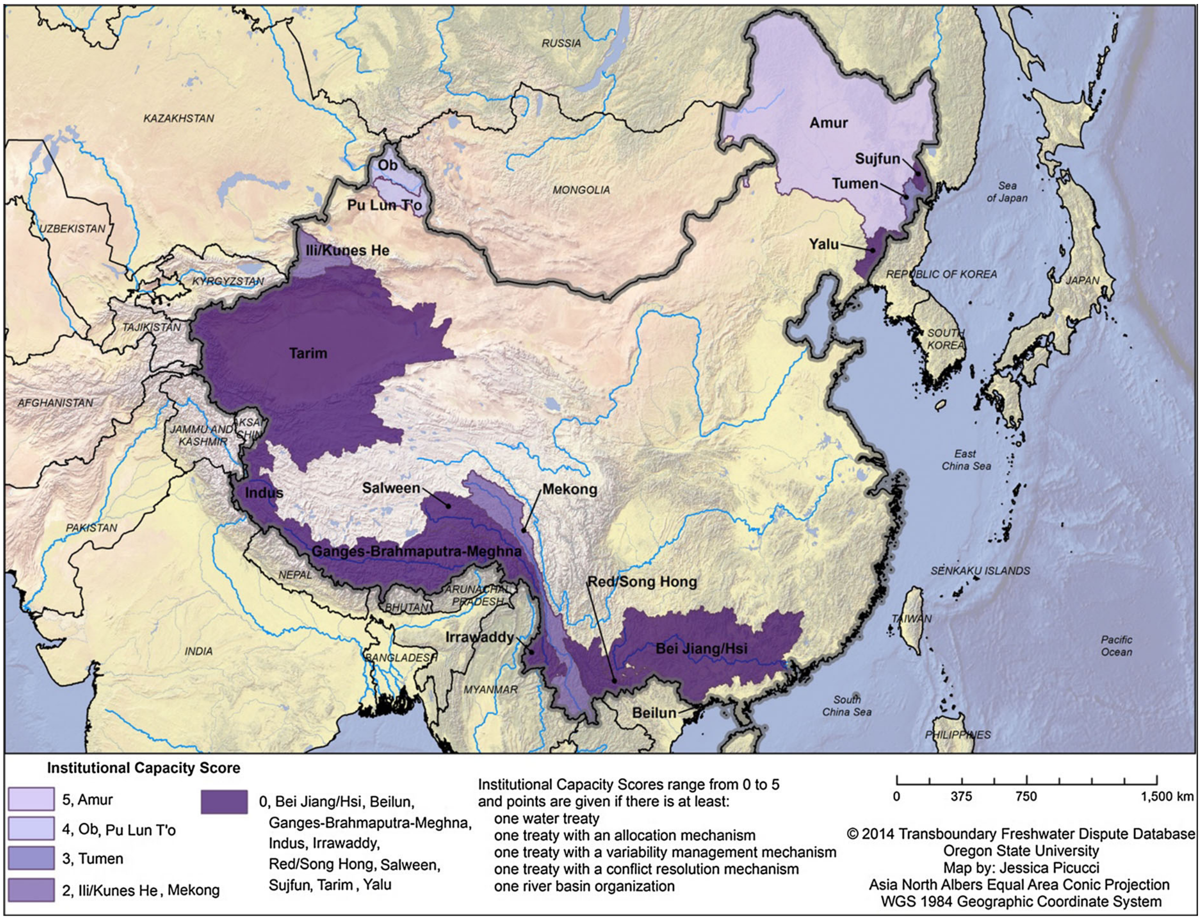

Fig. 11 China's institutional capacity by basin country unit

Population density

China's water stress is inextricably linked not only to its economic development, rapid urbanization, and spatial distribution but also a growing population dependent on drinking water as well as sufficient water resources for food production (Cai and Ringler 2007). In 2018, China's population was just under 20% of the global population yet China possesses only 6.5% of the world's total renewable freshwater resources (Jiang 2009). According to Li and Wu (2017), North China includes 65% of the country's land area and 45% of its total population, yet it has only 17% of the country's water resources. This is in comparison to the relatively low population density and development activity in the southern part of China; although the country intends to harness the hydropower potential of these southern rivers (Zhang and Li 2017). Population movement into the cities has also resulted in major water stress for China. According to Shalizi (2008), in 1980 urban residential water demand was 1.5% of the total while in 2002 that urban water share increased to 6%. In 2016, 55% of China's population resided in cities and although municipal water demand will increase due to such urbanization, agriculture will be the main consumer (Associated Press 2016; McKensie & Company 2009). That being said, it is the uneven spatial distribution of China's water that will create the

Fig. 12 Institutional capacity of the extent of China's transboundary basins by basin country unit

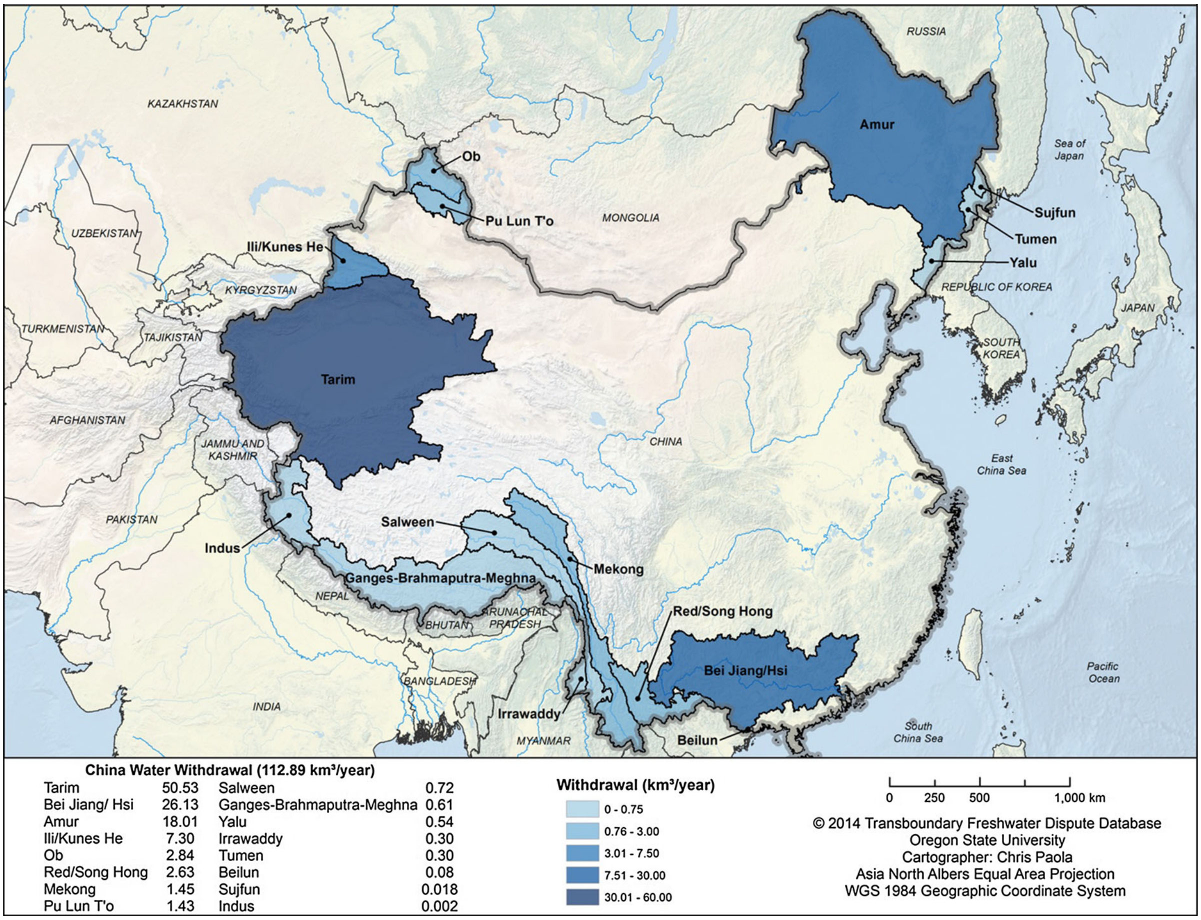

Fig. 13 China's water withdrawal by basin country unit

most pressure on urban centers such as Beijing and Tianjin (Jiang 2009; McKensie & Company 2009). Figures 15 and 16 show population densities by country and international basin scale, including neighboring countries in the region.

Resilience score

China scores high resilience as displayed in Table 4. This is due to China's relatively low withdrawal from shared basins, a small proportion of China's population lives in shared basins with the exception of the Tarim, Amur, Mekong, and Bei Jiang/His, and high overall institutional capacity. While China scores high on institutional capacity (due to the treaty governing the Amur River), many of its shared rivers basins are either devoid of a treaty or have a low institutional score. The majority of China's water withdrawals take place from basins that are not shared with the exception of the Tarim and Amur.[4]

[4] Per footnote 3, it is possible to argue that China's high resilience stems from its upstream and stronger military and economic position compared to its downstream neighbors. However, as our model demonstrates, China's resilience stems from its reduced level of interdependence, vis-à-vis water, on its neighbors as measured by an extensive number of (alternative) domestic water sources, a relatively low percentage of water withdrawals from internationally shared basins, a relatively small percentage of the country's population reliant on water from an international basin(s), and at least one international water agreement with a certain level of institutional capacity.

Fig. 14 Water withdrawals by extent China's of transboundary basins by basin country units

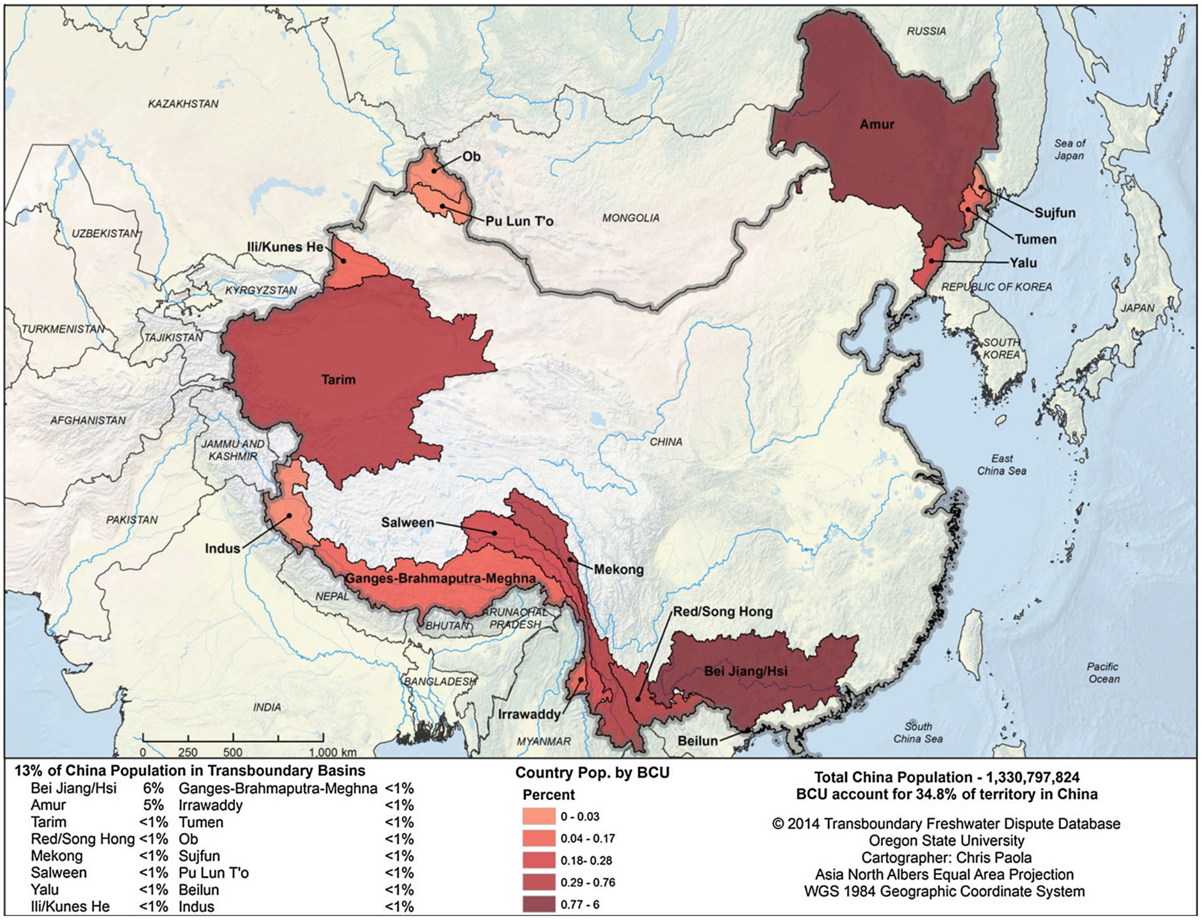

Fig. 15 China's population density by basin country unit

Fig. 16 Population density by extent of China's transboundary basins by basin country units

Table 4 China's water-related resilience

China Mode = 5 Median = 5 High Resilience				
Low = 1	**Mid-low = 2**	**Medium = 3**	**Mid-high = 4**	**High = 5**
1 main water resource	2 available water resources	3 available water resources	4 available water resources	5 or more available water resources
> 75% withdrawal from a shared basin(s)	75% to 50% of withdrawal from a shared basin(s)	50% to 25% of withdrawal from a shared basin(s)	<25% of withdrawal from a shared basin	0
Population: >81%	Population: 61%- 80%	Population: 41%- 60%	Population: 21%-40%	Population: <20%
No treaties, river basin organizations, or agreements	One treaty	One treaty with mechanism or river basin organization or two treaties	One treaty with mechanism and 1 more mechanism or river basin organization or 3 treaties	One treaty with 2 or more mechanisms and river basin organization or One treaty with >2 mechanisms or 4 or more treaties

Iraq

Iraq's major river basin and main water source is the Tigris–Euphrates/Shatt al Arab Basin (Al-Ansari 2013). Along the rivers' main stems, Iraq is downstream while Turkey and Syria are upstream and midstream, respectively. Other countries in the larger basin include Jordan, Saudi Arabia and Iran but these countries make up a much smaller portion of the basin. Historically, Iraq has been the largest user of the Tigris–Euphrates, yet development projects beginning in the 1960s and then 1980s, specifically in Syria and Turkey respectively, have constrained Iraq's water use from the basin (Kirschner and Tiroch 2012). In addition to competition for water from upstream neighbors, Iraq's water resources (and water infrastructure) have also been under threat from the Islamic State of Iraq and the Levant (ISIL or ISIS). Over the period of ISIS terror in the Levant from 2013 to 2016, the organization temporarily controlled nine dams and threatened to take two more (Dayton and Lacayo 2016; King 2016). While this important water infrastructure has been liberated, the impacts on Iraq's overall water situation and larger society is long lasting (Lafta et al. 2018). Iraq, as all of the Levant region, is also dealing with a severe drought (a function of the impacts of climate change in the region presently and in the future). In fact, as of June 2018, Iraq has been forced to suspend all cultivation of rice (Ensor 2018). Figures 17 and 18 show Iraq's transboundary basin at the country scale and at the entire transboundary basin scale.

Institutional capacity

Iraq is a signatory to five major agreements with Iran, Syria and Turkey (TFDD 2018). Yet, these are bilateral, limited, and in some cases relatively general agreements. In 1946, for example, Iraq and Turkey signed a Treaty of Friendship that includes a general clause on water and technical cooperation. In 1975, Iran and Iraq codified their shared waters by dividing up water allocations along the rivers that transverse their respective borders. In 1989, and based on a bilateral agreement in 1987 between Turkey and Syria ensuring Turkey's release of a set amount of water to Syria on the Euphrates given dam development in Turkey, Iraq and Syria agreed to their own percentage

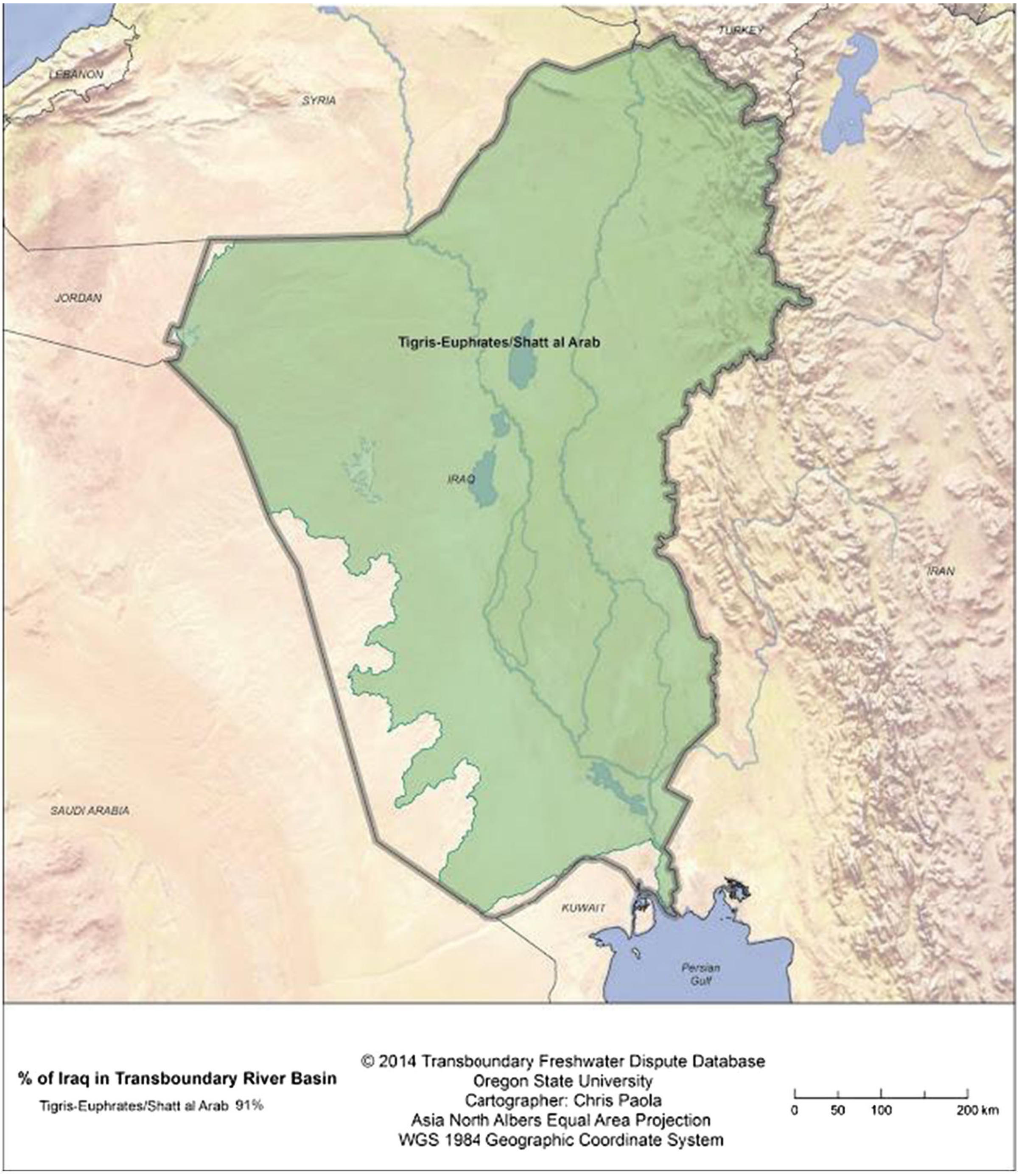

Fig. 17 Iraq's transboundary basin by basin country unit

Fig. 18 Iraq's regional scale of Afghanistan's transboundary basins by basin country unit

Fig. 19 Iraq's institutional capacity by basin country unit

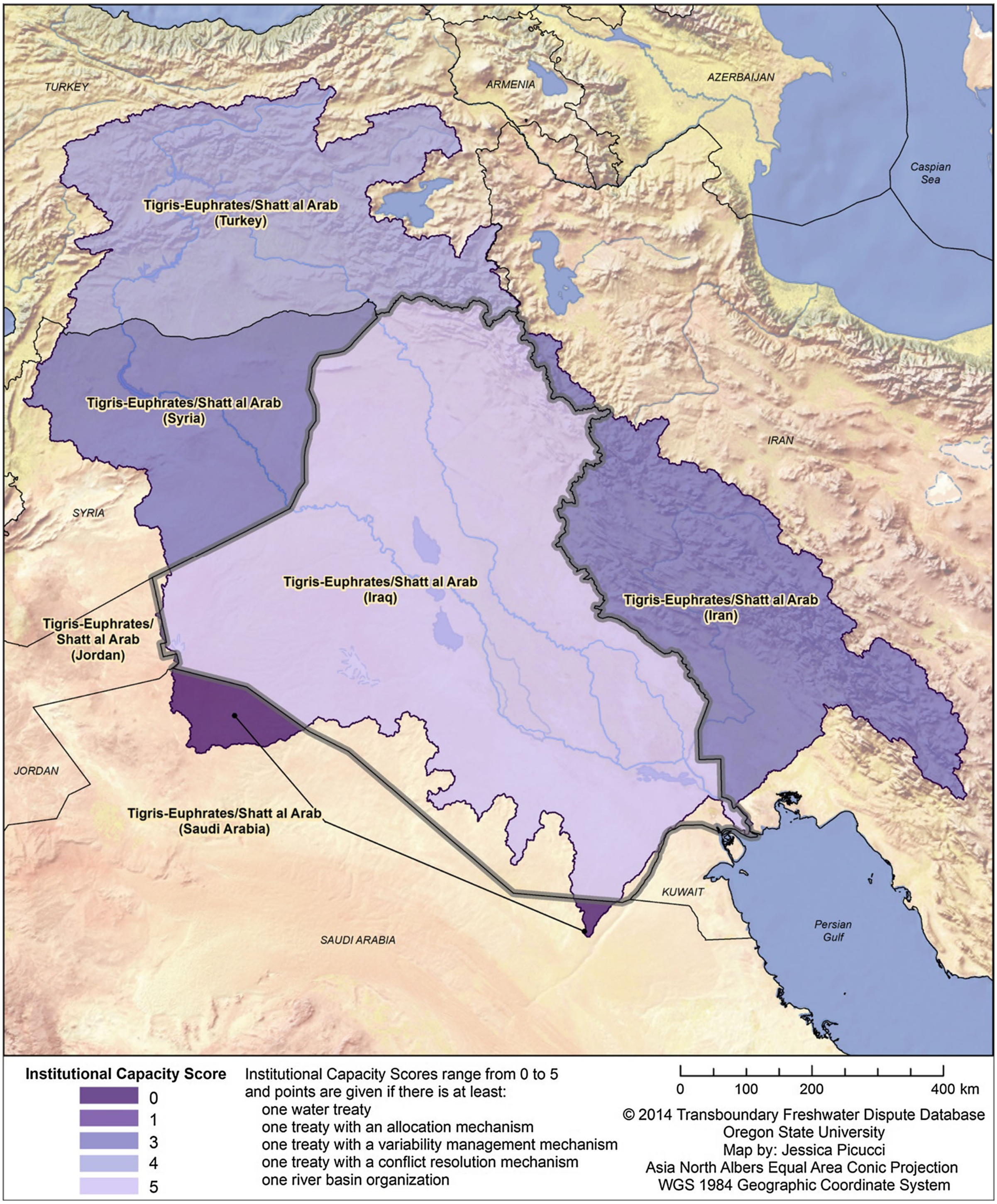

Fig. 20 Institutional capacity of the extent of Iraq's transboundary basins by basin country unit

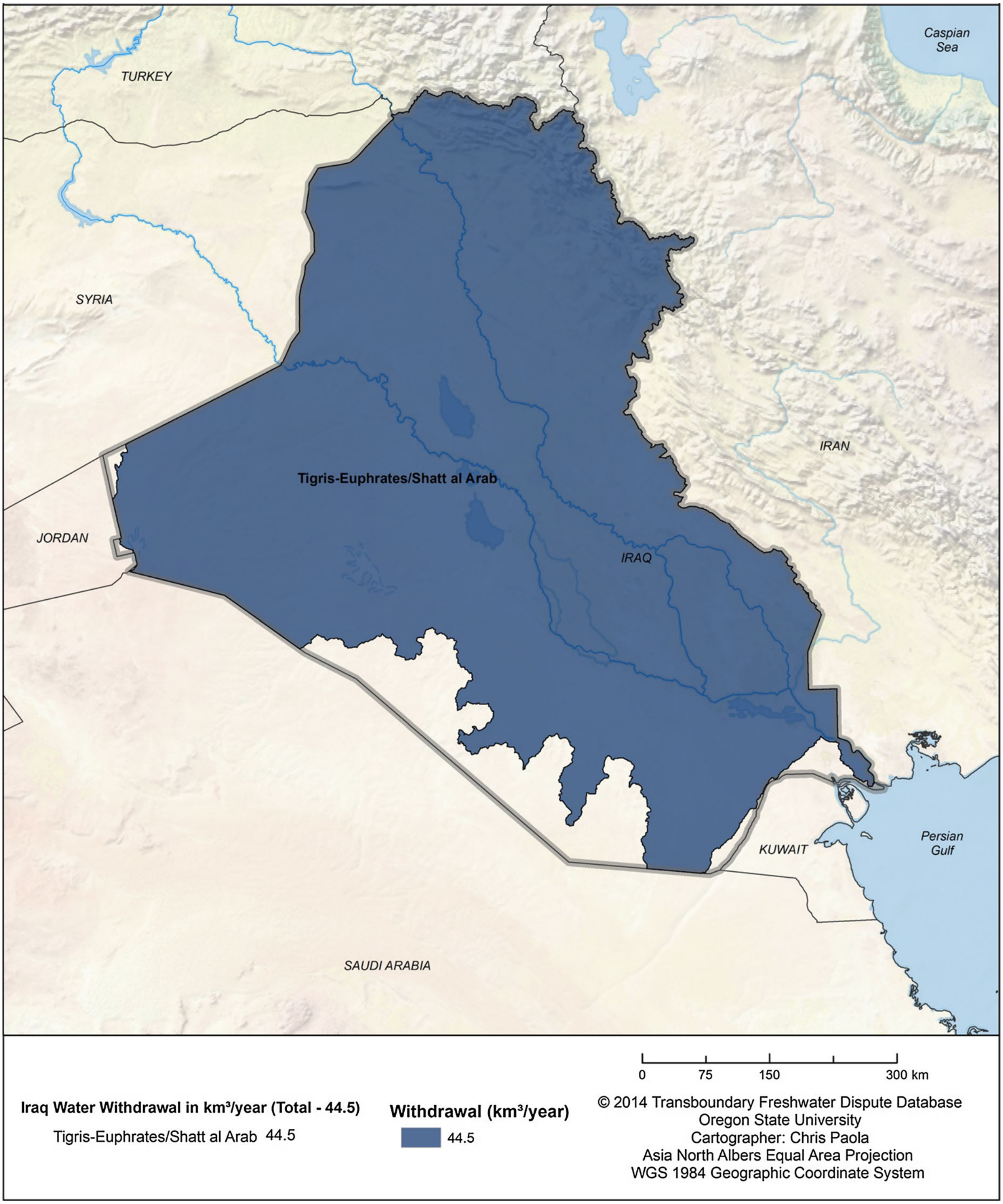

Fig. 21 Iraq's water withdrawal by basin country unit

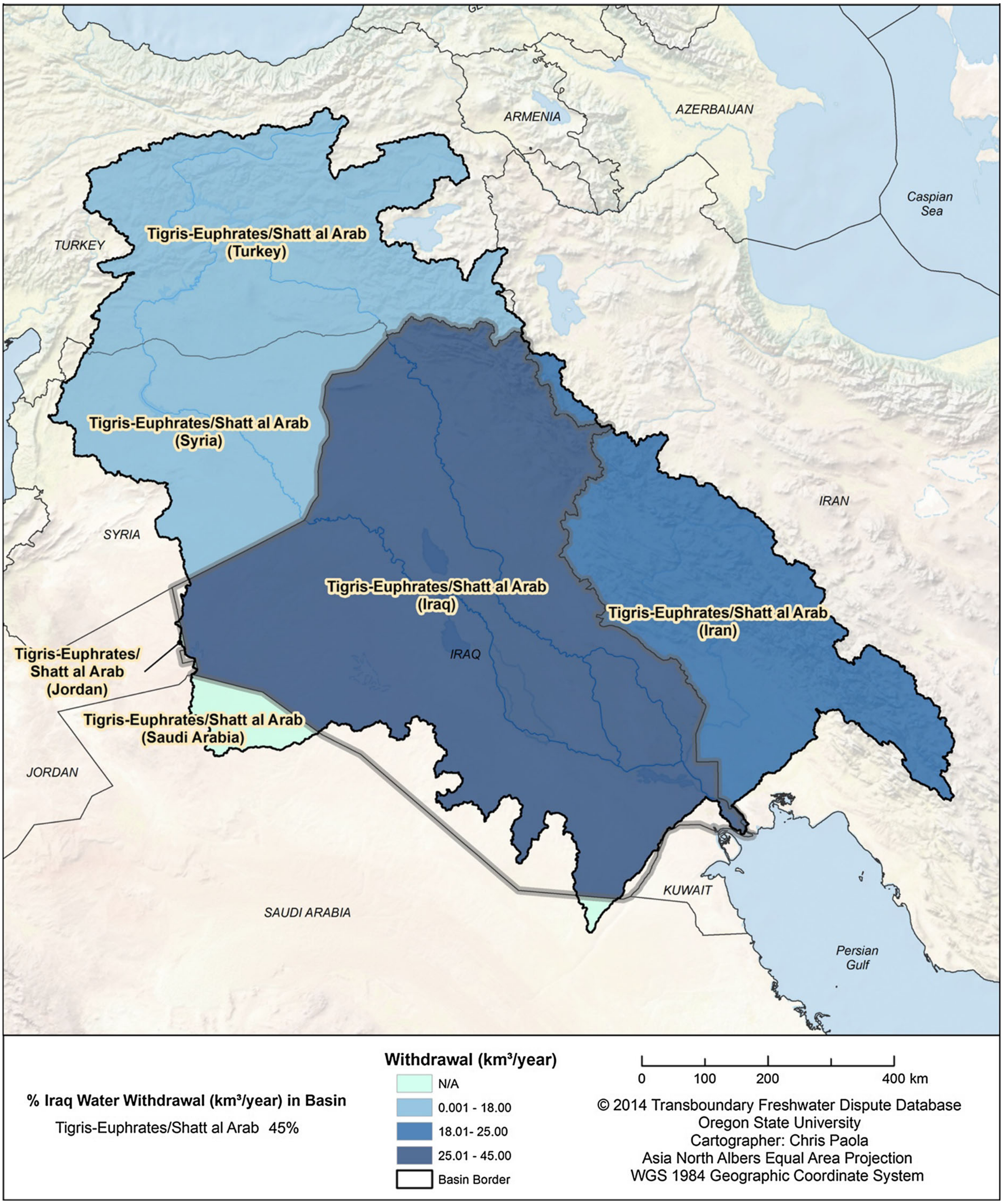

Fig. 22 Water withdrawals by extent of Iraq's transboundary basins by basin country units

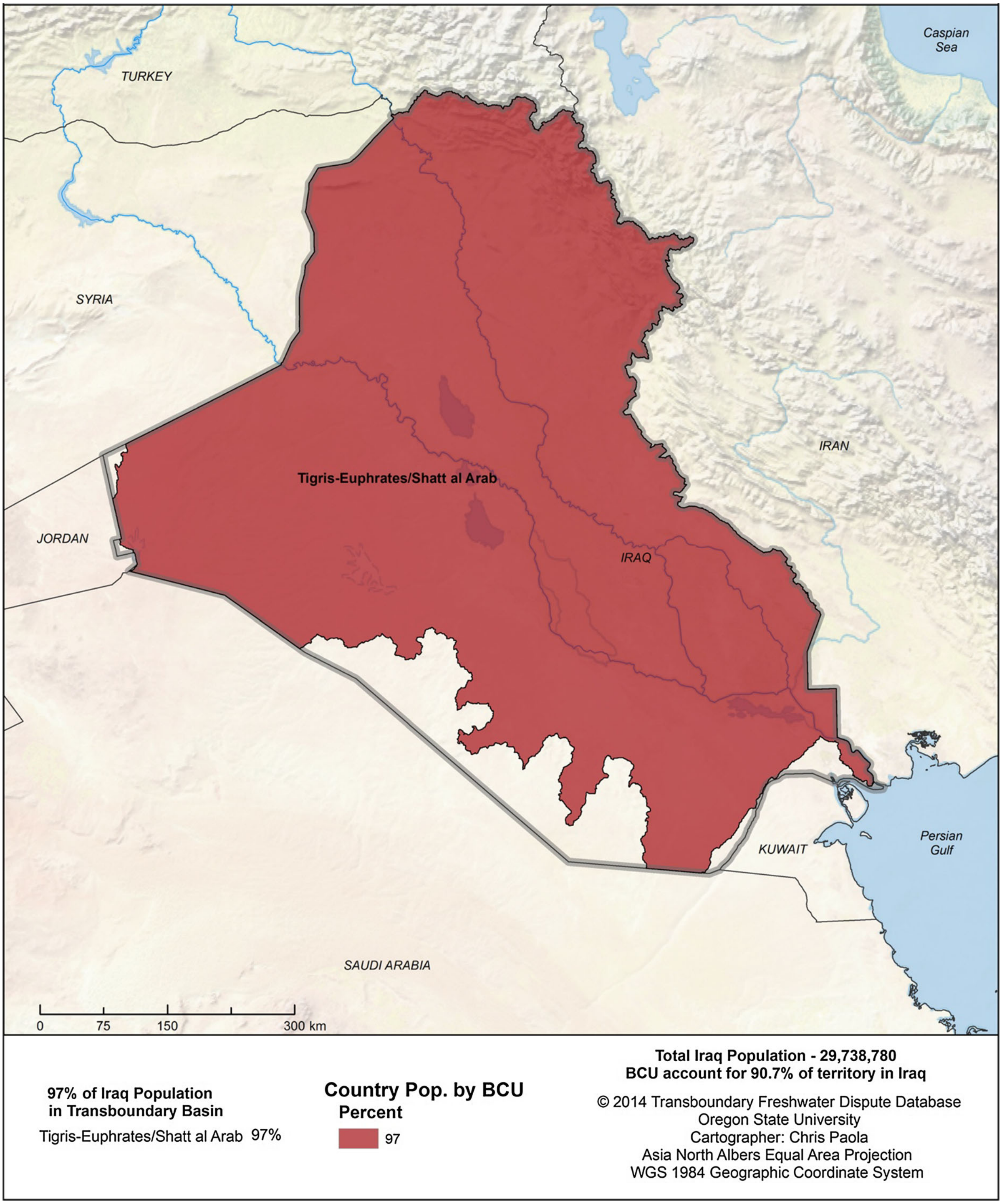

Fig. 23 Iraq's population density by basin country unit

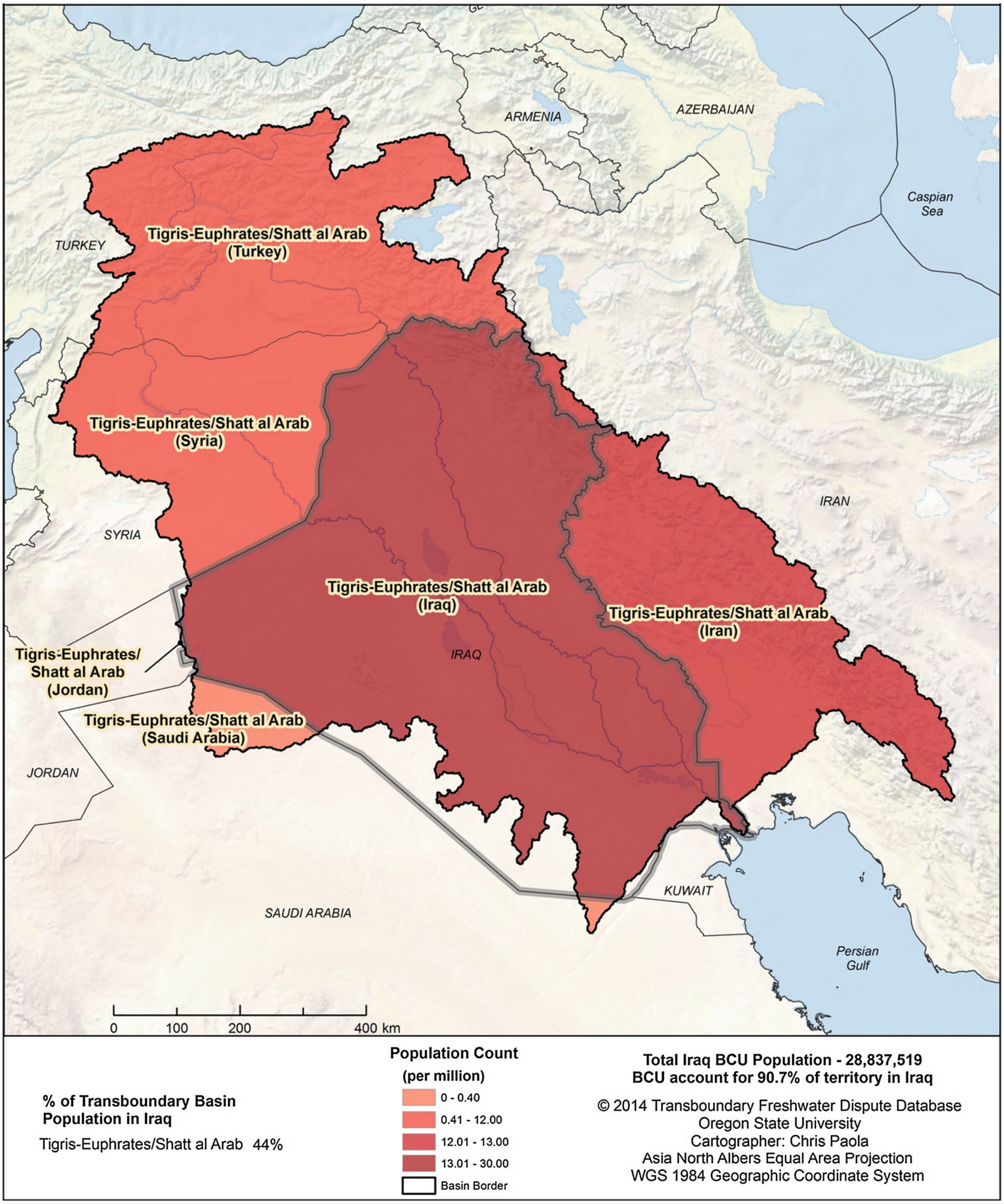

Fig. 24 Population density by extent of Iraq's transboundary basins by basin country units

Table 5 Iraq's water-related resilience

Iraq Mode = 1 Median = 1 Low Resilience				
Low = 1	**Mid-low = 2**	**Medium = 3**	**Mid-high = 4**	**High = 5**
1 main water resource	2 available water resources	3 available water resources	4 available water resources	5 or more available water resources
> 75% withdrawal from a shared basin(s)	75% to 50% of withdrawal from a shared basin(s)	50% to 25% of withdrawal from a shared basin(s)	<25% of withdrawal from a shared basin	0
Population: >81%	Population: 61%- 80%	Population: 41%- 60%	Population: 21%-40%	Population: <20%
No treaties, river basin organizations, or agreements	One treaty	One treaty with mechanism or river basin organization or two treaties	One treaty with mechanism and 1 more mechanism or river basin organization or 3 treaties	One treaty with 2 or more mechanisms and river basin organization or One treaty with >2 mechanisms or 4 or more treaties

division of Euphrates waters. Two framework cooperation agreements signed in 2003 and 2004 between Syria and Turkey on agriculture and health, respectively, included stipulations about water conservation in agricultural practices as well as efforts to combat waterborne diseases (Kibaroglu and Scheumann 2011). Memorandums of understanding were also signed between Syria and Turkey and Turkey and Iraq in 2009 pertaining to such issues as information exchange, water utilization, hydropower, drought, and water quality. While the Syrian Civil War and Turkey's changed orientation towards Syria certainly prevented continued cooperation, it is the absence of a trilateral water sharing agreement and coordination over the Tigris–Euphrates that continues to be the main issue of contention (Zawahri 2006). Figures 19 and 20 depict institutional capacity ranking at both the country and international basin scales.

Water withdrawals

The Tigris–Euphrates river system provides about 98% of Iraq's water demands (Abd-El-Mooty et al. 2016). In fact, Iraq is wholeheartedly dependent on the Tigris–Euphrates basin (Alkhafaji 2018). In terms of land area, the basin makes up 73% of Iraq's land mass (TFDD 2018). Given its arid climate and dependence on the Tigris and Euphrates Rivers, Iraq makes use of the Tharthar Canal which was constructed to transfer water from the Tigris River to the over-utilized Euphrates River (Kirschner and Tiroch 2012). In terms of current water use, irrigation and livestock use up 78% of the national water total, industry 15% and municipal 7%. The primary source of such water is surface and groundwater. For irrigation, groundwater makes up only 6% of the total (AQUASTAT/FAO 2016). According to some estimates, Iraq's water demand to 2020 (using 1990 as a base year) will increase by 162% overall. Domestic demand is predicted to increase by 700%, industrial sector demand by about 1000% and agricultural demand by only 96%. In terms of the industrial sector, Iraq's oil industry plays a particularly important role. Southern Iraq, specifically, includes 80% of Iraq's oil wealth and will witness major developments in industrial, agricultural, construction and commercial activities by the end of this decade. Notwithstanding the crucial role Baghdad plays in Iraq's industrial base, Al Basrah province in the south also plays an important role. Southern Iraq also contributes to Iraq's agriculture.

Currently, the agricultural sector in Southern Iraq accounts for some 81% of total water consumption, which is on average higher than the national total (Al-Furaiji et al. 2016). Figures 21 and 22 show water withdrawals at the country scale and at the entire transboundary basin scale, including neighboring countries in the region.

Population density

As of 2018, Iraq's population is approximately 40 million (CIA 2018). However, Iraq's population in the Tigris–Euphrates basin was about 23.75 million (TFDD 2018) and thus constitutes about 62% of Iraq's total population. In 2030, Iraq's population is predicted to be 53.4 million while in 2050 the population is predicted to be 76.5 million (PRB 2019). From 2018 to 2050 that is an increase of 91%. According to Al-Furaiji et al. (2016), Iraq's projected water increase will come not only from industrial growth but also population growth. Furthermore, and in relationship to increased demand and reduced supply that Iraq will likely continue to face, Iraq's population growth will contribute more than climate change and other environmental/physical realities (Chenoweth et al. 2011). In terms of the population's access to sanitation, about 92% of the population of Iraq is living in households using improved sanitation. However, only 48% have their toilets connected to pipe sewer systems in metropolitan areas, 57% have septic tanks in urban areas and 36% flush their toilets to latrines in rural areas. Overall, most of the sewage treatment plants and septic systems do not function properly and as a result there is an overflow of the effluent into the environment. According to Rawaf et al. (2014), the impact of poor conditions for sanitation in the country is directly related to ineffective disease control measures as well as the re-emergence of cholera. In terms of water distribution, Al-Ansari (2013), indicates that water supply to urban areas is 73% and in rural areas 40–45%. Furthermore, 79% of the population has access to drinking water (92% in urban areas and 52% in rural areas). According to the GAO (2005), prior to the 1991 Gulf War, Iraq was able to supply water to more than 95% of urban Iraqis and 75% of rural Iraqis. Iraq's deteriorating infrastructure, combined with population growth and climatic conditions will continue to challenge the country in the years to come. Figures 23 and 24 show population densities by country and international basin scale, including neighboring countries in the region.

Resilience score

Iraq scores a low resilience as displayed in Table 5. This is due to Iraq's withdrawals from a single river basin (Tigris–Euphrates), which makes up the lion's share of the country's population, though it does have high institution capacity. Beyond the Tigris–Euphrates basin, Iraq has very few additional sources of freshwater. While Iraq scores high on institutional capacity (due to some of its historic treaties with Turkey and Iran in particular) a trilateral treaty with Turkey and Syria over water allocation is absent.

Moldova

Moldova is a former part of the Soviet Union, which declared independence in 1991, and contains four transboundary freshwater basins that account for 99.2% of the country's territory (TFDD 2014). The basins are Dneister, Danube, Kogilnik, and Sarata rivers. The maps in Figs. 25 and 26 show Moldova's transboundary freshwater basins by country scale as well as the transboundary basin scale to include the surrounding country territories. Moldova is downstream of two major basins: Dneister and Danube, and this is where the majority of territory, economic activity, and population is concentrated. The country is upstream of the smaller two basins: Kogilnik and Sarata rivers. Since the majority of Moldova's water resources originate outside of the country territory, the dependency ratio is quite high, 91.4% (AQUASTAT/FAO 2016). Moldova is furthest downstream on the Dneister, sharing the basin mainly with Ukraine, while on the Danube the country shares the Prut River, a tributary that forms the border with Romania, before that river enters the Danube mainstem and continues to form the border with Ukraine and Romania. The main surface freshwater resources in Moldova are the Prut (which is part of the larger Danube basin) and Dniester (ROM 2012).[5]

[5] Groundwater constitutes another source of water in Moldova but it is not entirely clear if these groundwater resources are part of separate basins beyond the Dniester and Prut/Danube.

Fig. 25 Moldova's transboundary basins by basin country unit

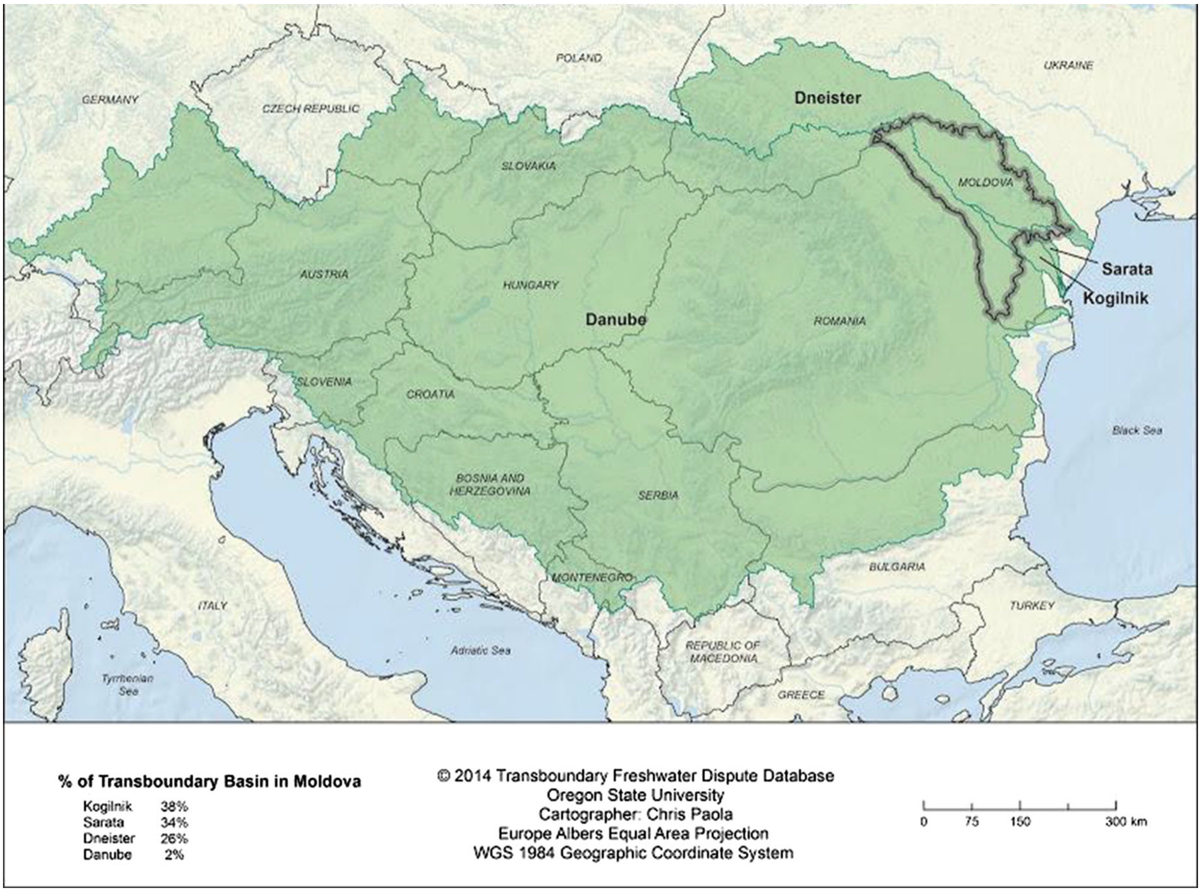

Fig. 26 Regional scale of Moldova's transboundary basins by basin country unit

Institutional capacity

While the Danube's upstream riparians have drafted dozens of transboundary agreements about the shared use of the river's waters, Moldova is a signatory on only one of these agreements the 1994 Convention on Cooperation for the Protection and Sustainable Use of the Danube. Moldova and Ukraine do not have a specific treaty governing the Dneister river, but have agreements regarding the joint management and water quality of shared rivers from November 1994. Moldova also signed an agreement with the Commonwealth of Independent States on the protection of transboundary waters in 1998, a general agreement not relegated to any one specific basin. Figures 27 and 28 depict institutional capacity ranking at both the country and international basin scales, including neigboring countries in the region.

Water withdrawals

Research shows that the majority of rural communities, that account for 62% of the total population, use shallow groundwater as their major source of water (AQUASTAT/FAO 2016). Of this groundwater sourcing, researchers report that upwards of 80% of these wells do not access safe drinking water (Nastasiuc et al. 2016). The country is host to drought for three out of every 10 years, though the agricultural sector that covers roughly 73% of the country, only amounts to less than 4% of water use, down from 40% in 1992 (Nastasiuc et al. 2016; AQUASTAT/FAO 2016; Trading Economics 2018). While industry accounts for 83% of water use, agricultural products remain the main exported good. About 73% of the country is arable land, only 14% of this is under permanent crop production (AQUASTAT/FAO 2016). Figures 29 and 30 show water withdrawals at the country scale and at

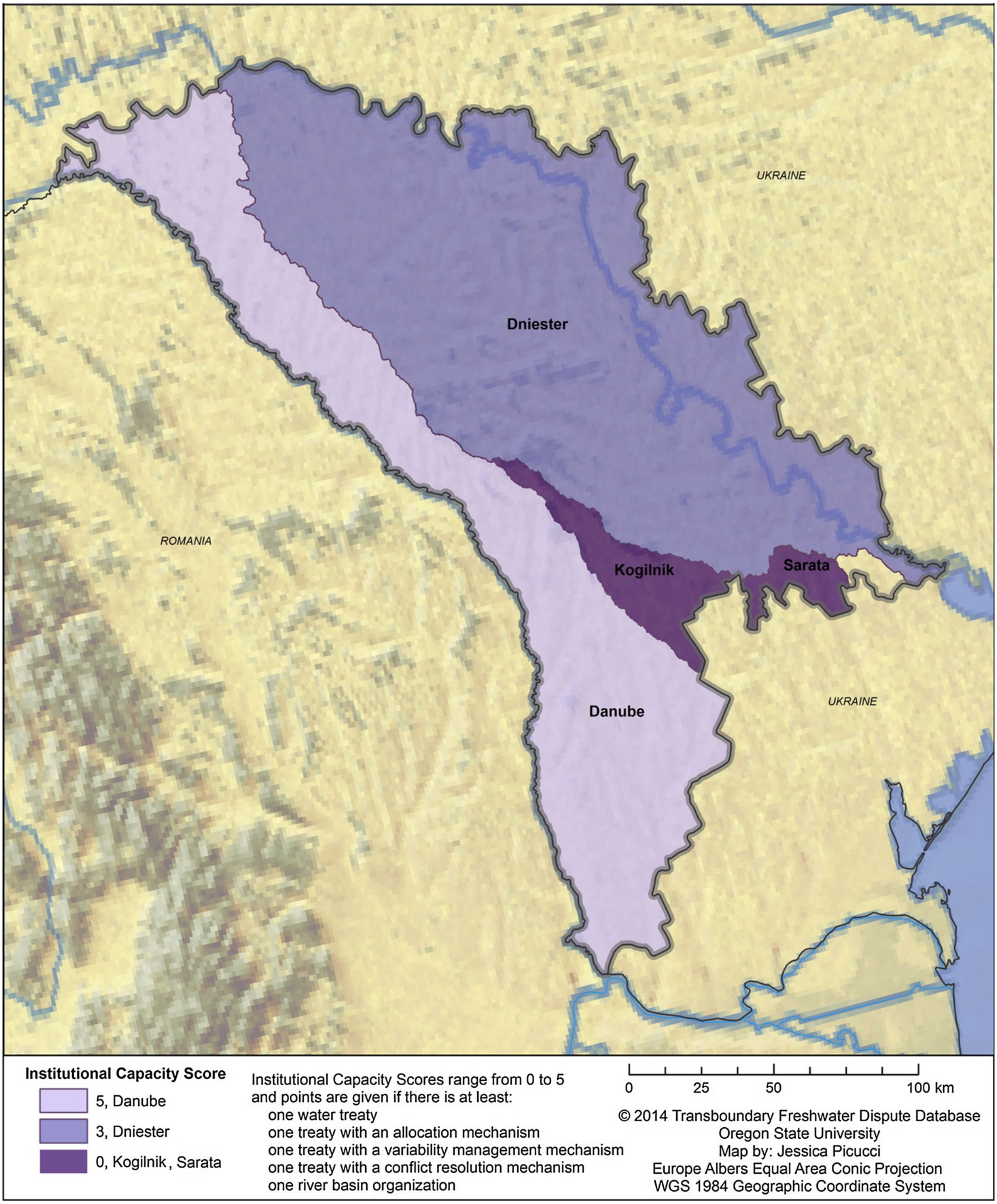

Fig. 27 Moldova's institutional capacity by basin country unit

Fig. 28 Institutional capacity of the extent of Moldova's transboundary basins by basin country unit

the entire transboundary basin scale, including neighboring countries in the region.

Population density

Moldova has about 3.4 million inhabitants with just over 75% identifying as Moldovan as well as minority populations of Romanian, Ukrainian, Gagauz, Russian, and Bulgarian; and about 90% of the population identify as Orthodox Christian (CIA 2017). Moldova is the poorest country in Europe with 40% of the population living below the poverty line (Nauges and Van den Berg 2008). Life expectancy is 71 years and 43% of the population is aged 25–54 years. More than 80% of the country's population have access to improved drinking water and more than 99% of the population is literate (CIA 2017).

The majority of Moldovans live in a shared basin, as almost 100% of the country falls within a shared basin. The Danube basin, shared with approximately 18 upstream countries is not as central to the Moldavian economy and water use as the Dneister basin is, which is shared only with upstream riparian Ukraine. Figures 31 and 32 show population densities by country and international basin scale, including neighboring countries in the region.

Resilience score

As is displayed in Table 6, Moldova ranks low to low/mid-low resilience. This ranking is based on its limited available water resources withdrawn mostly from a transboundary basin, as well as high amount of population found within a shared basin.

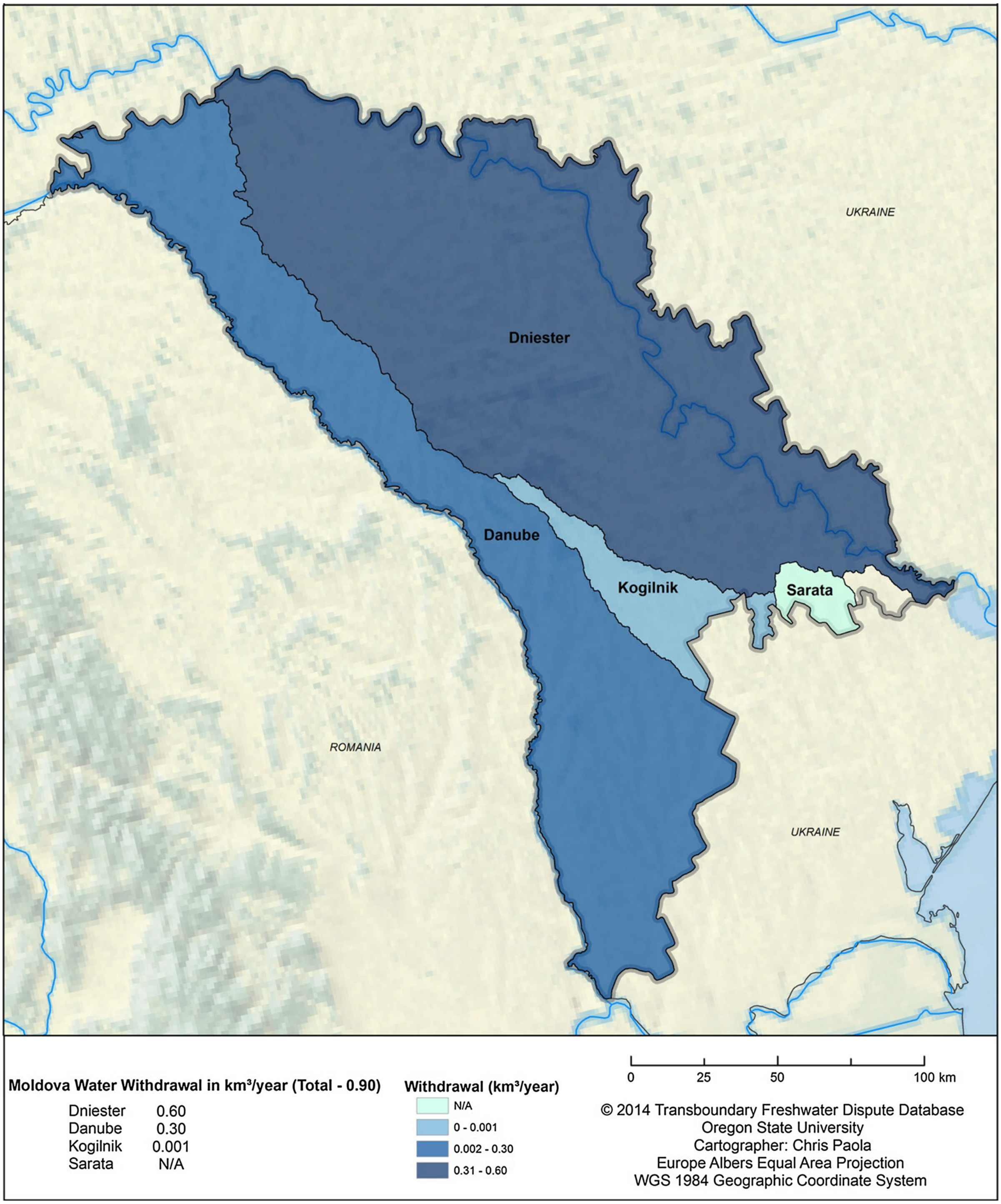

Fig. 29 Moldova's water withdrawal by basin country unit

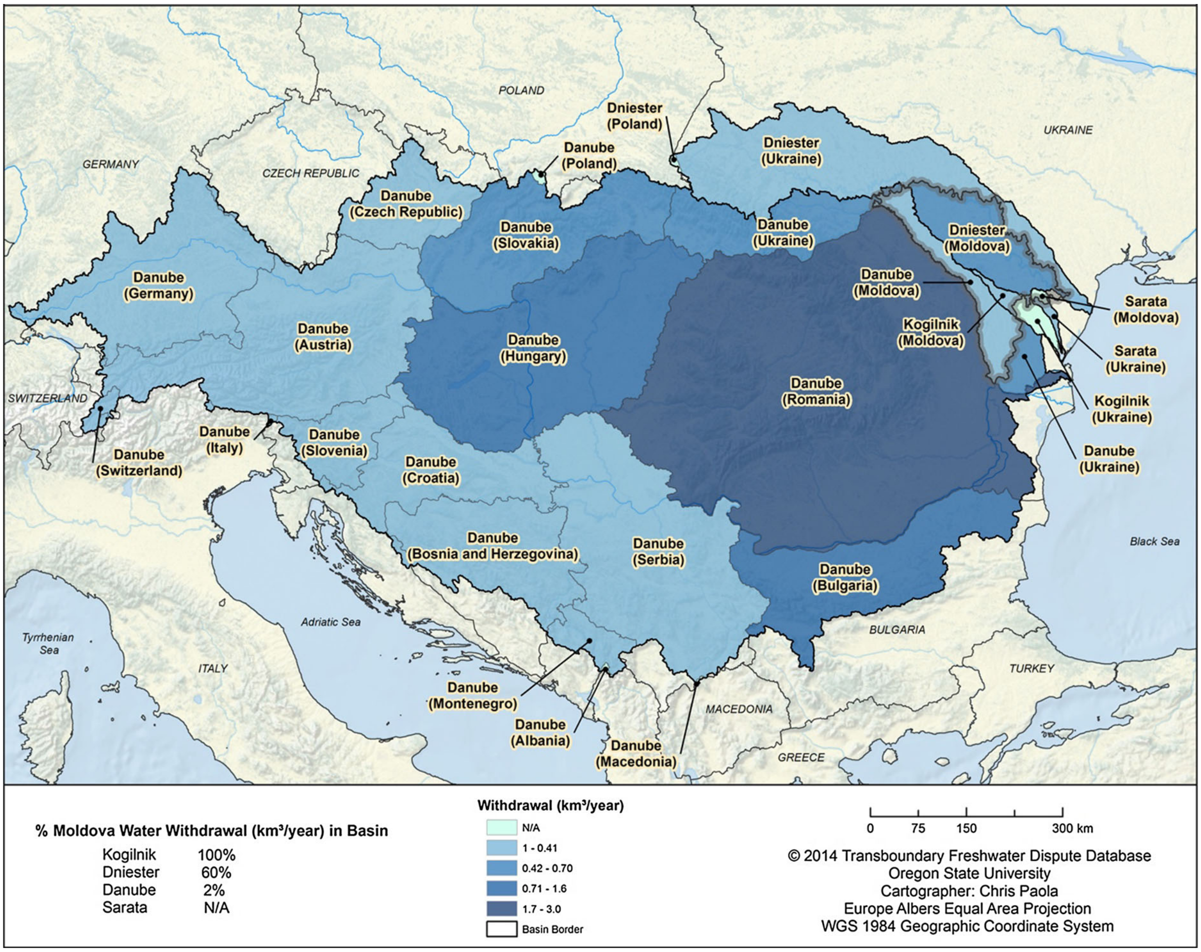

Fig. 30 Water withdrawals by extent of Moldova's transboundary basins by basin country units

Sudan

Sudan, the largest landmass country in Africa, shares five transboundary basins, three of which cover 1% or less of Sudanese territory. These basins are the Nile, Lake Chad, Baraka, Gash (or Mareb), and Congo. Close to 70% of Sudan's territory, or 1,350,616 km^2, falls within the Nile River Basin and 15% of the country's land is found along the river (Ministry of Irrigation and Water Resources 2010). The White and Blue Nile rivers come together in Khartoum to form the main Nile River that continues into Egypt's territory. While the White Nile carries a consistent flow of water year round, the Blue Nile accounts for a higher volume of water, (estimates between 65 and 85%), during the rainy season (FAO 1997). Sudan's only downstream riparian neighbor is Egypt, but it is upstream of Ethiopia on the Blue Nile and of Uganda, Rwanda, Burundi, Kenya, Tanzania, South Sudan on the White Nile. The country relies heavily upon Nile water for agriculture and industry both for domestic and international markets. In fact, the Nile constitutes the main water source for Sudan[6] (Omer 2010). Figures 33 and 34 show Sudan's transboundary basins at the country scale and at the entire transboundary basin scale, including neighboring countries in the region.

Institutional capacity

Sudan has agreements about its shared water use in the Nile River and Gash River basins. Sudan has no

[6] Groundwater constitutes another source of water for Sudan, but less than 1% of available groundwater is being utilized.

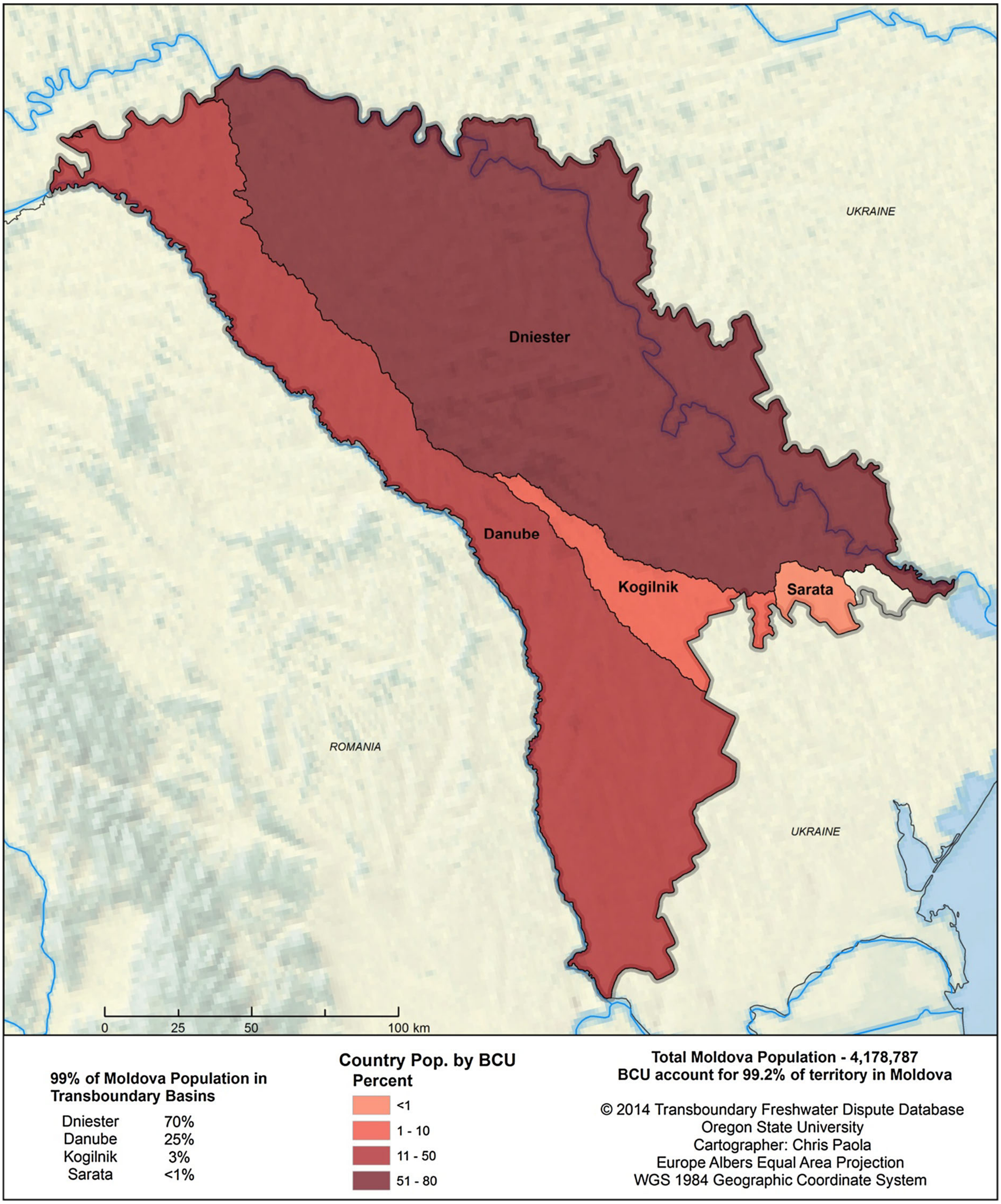

Fig. 31 Moldova's population density by basin country unit

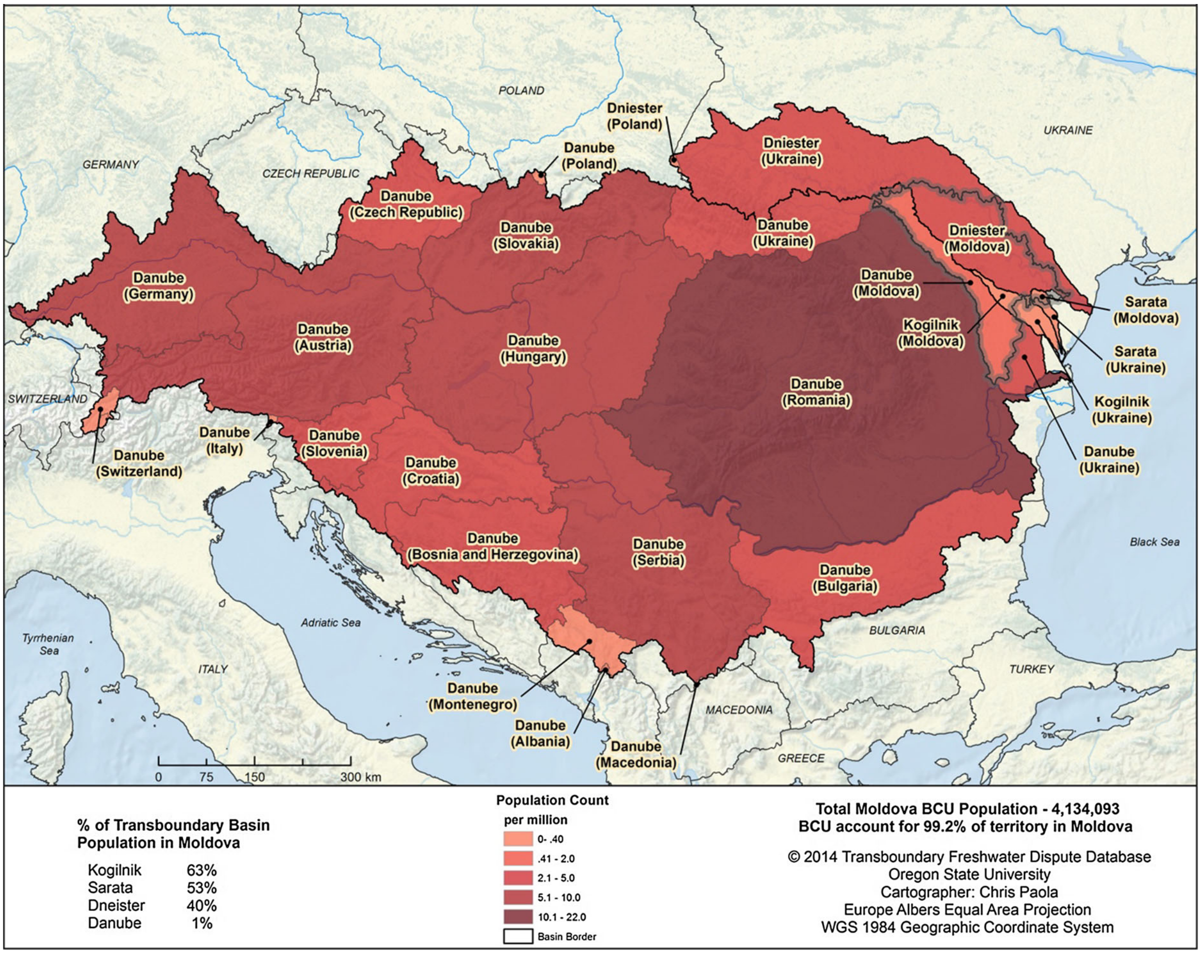

Fig. 32 Population density by extent of Moldova's transboundary basins by basin country units

agreements for Lake Chad, Congo/Zaire or Baraka basins. The 1929 Nile Treaty was first signed during colonial rule and resigned in 1959 between the countries of Egypt and Sudan, excluding the upstream neighbors, allocating the entirety of the 55.5 billion m^3 to Egypt and 18.5 billion m^3 to Sudan (Carlson 2013). Nile water has been central to development of the Sudanese economy used most primarily in agricultural, in the production of oil and gas for export, in the production of hydro-electricity, and as coolant for other power plants. While Sudan is part of the Nile Treaty with Egypt, no official agreement with the other upstream riparian countries exists regarding water development, sharing, or management; though since 1999 attempts at basin-wide coordination have been made. In 1999, the Nile Basin Initiative was formed to include basin member countries to review and suggest revisions to the 1959. Treaty culminating in the Cooperative Framework Agreement and eventually establishing a river basin organization. Egypt and Sudan have stalled these processes and are also central to the ongoing discussions with Ethiopia about cooperation on the Grand Ethiopian Renaissance Dam. Sudan, positioned immediately downstream from the dam, will receive direct benefits in flood control and sediment reduction (Cascão and Nicol 2016). Figures 35 and 36 depict institutional capacity ranking at both the country and international basin scales, including neigboring countries in the region.

Water withdrawals

While exact numbers and salient data about water use in Sudan is not available, general ideas about

Table 6 Moldova's water-related resilience

Moldova Mode = 1 Median = 1.5 Low to Mid-low Resilience				
Low = 1	**Mid-low = 2**	**Medium = 3**	**Mid-high = 4**	**High = 5**
1 main water resource	**2 available water resources**	**3 available water resources**	**4 available water resources**	**5 or more available water resources**
> 75% withdrawal from a shared basin(s)	**75% to 50% of withdrawal from a shared basin(s)**	**50% to 25% of withdrawal from a shared basin(s)**	**<25% of withdrawal from a shared basin**	**0**
Population: >81%	**Population: 61%- 80%**	**Population: 41%- 60%**	**Population: 21%-40%**	**Population: <20%**
No treaties, river basin organizations, or agreements	**One treaty**	**One treaty with mechanism or river basin organization or two treaties**	**One treaty with mechanism and 1 more mechanism or river basin organization or 3 treaties**	**One treaty with 2 or more mechanisms and river basin organization or One treaty with >2 mechanisms or 4 or more treaties**

consumption in Sudan is centered on agriculture, some 97%, as the main economic driver (UN Environment 2017). The world's largest aquifer, the Nubian Aquifer containing nonrenewable or fossil water resources, lies beneath Sudanese territory, but remains largely untapped. The surface water that is used for municipal and irrigation uses experiences seasonal fluctuations. Therefore, five dams used for storage, as well as hydropower and flood control, have been constructed along the Nile waterways (AQUASTAT/FAO 2016). Thirty-two percent of the population is accessing contaminated water, mostly from surface waterways (Reliefweb 2017). Figures 37 and 38 show water withdrawals at the country scale and at the entire transboundary basin scale, including neighboring countries in the region.

Population density

The majority of Sudan's population lives within the Nile River Basin. This is largely due to the desert climate of Sudan and the need for food and water. While Sudanese population growth is estimated at 2.4%, there are challenges to the population from water scarcity, water borne disease, regional ongoing conflict, and malnutrition (UN Environment 2017). The 40 million Sudanese number less than the 90 million estimated citizens in downstream Egypt and upstream Ethiopia, but unlike many other African countries, only about 1/3 of the population are urban, and only an estimated 68% of the population have access to secure water resources (Reliefweb 2017). Figures 39 and 40 show population densities by country and international basin scale, including neighboring countries in the region.

Resilience score

As presented in Table 7, Sudan ranks between low resilience and mid-low resilience. This is due largely to the high amount of withdrawal and population found within the shared Nile basin and that there is no viable alternative to the Nile waters. While the institutional capacity is ranked high, this has little bearing on the overall score.

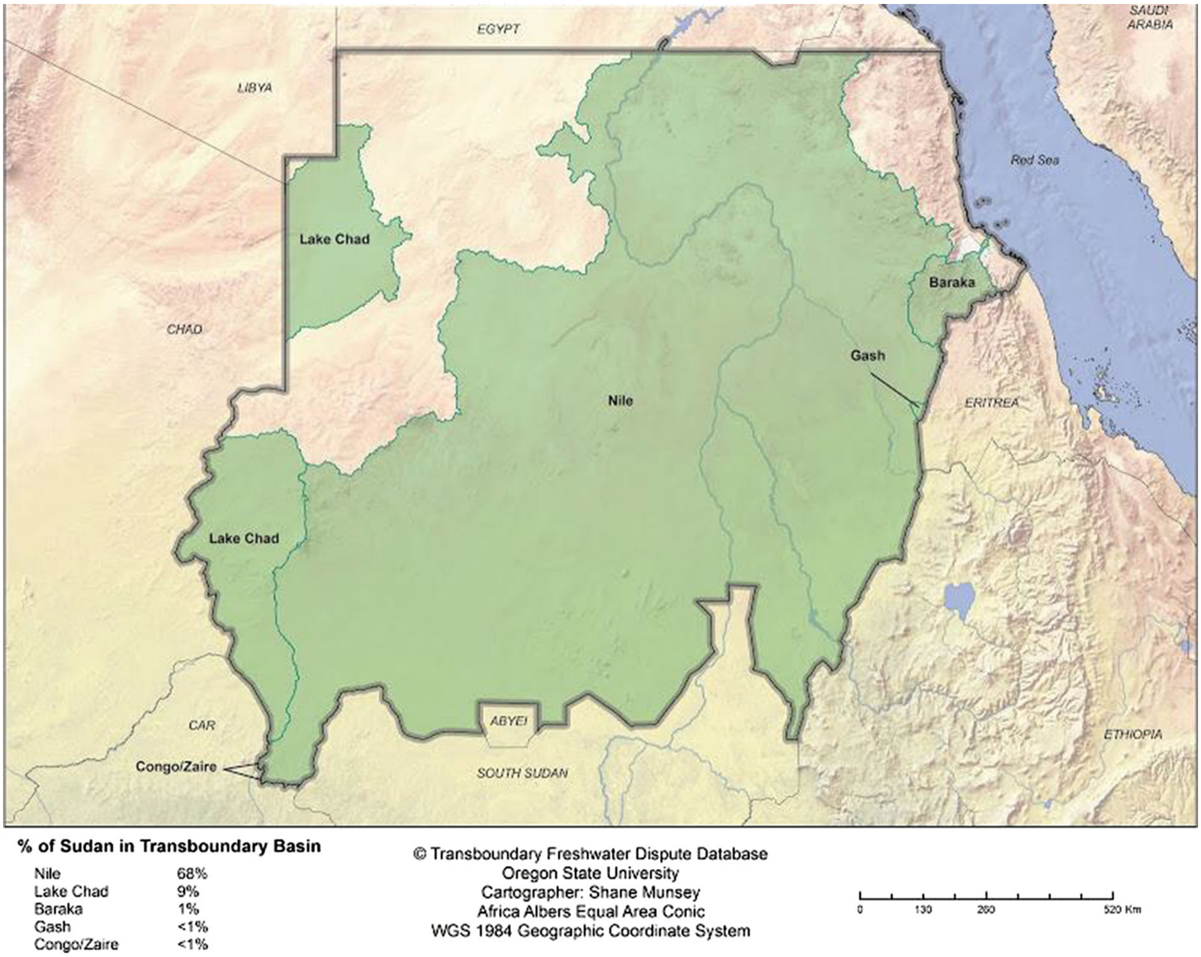

Fig. 33 Sudan's transboundary basins by basin country unit

Fig. 34 Regional extent of Sudan's transboundary basins by basin country unit

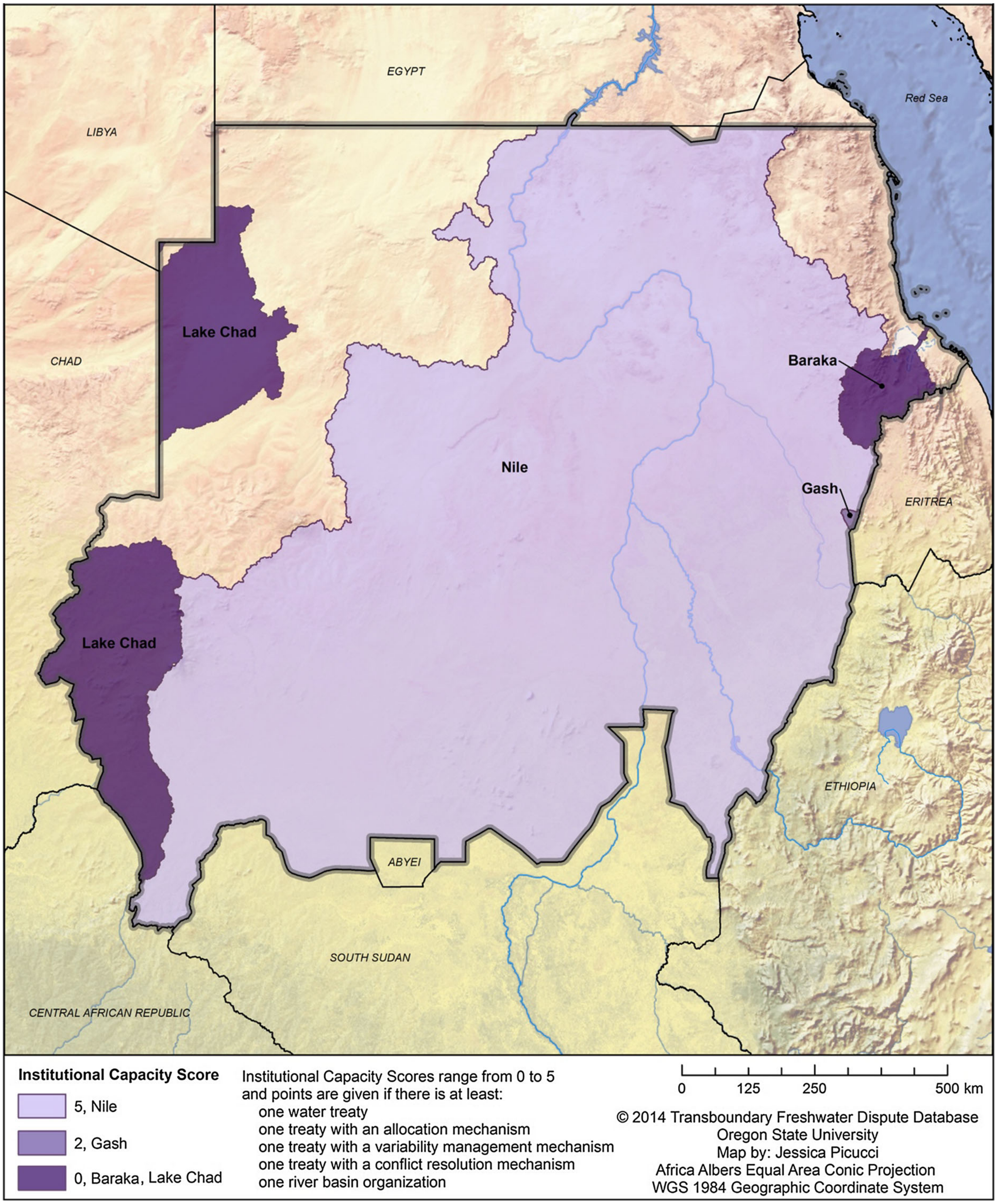

Fig. 35 Sudan's institutional capacity by basin country unit

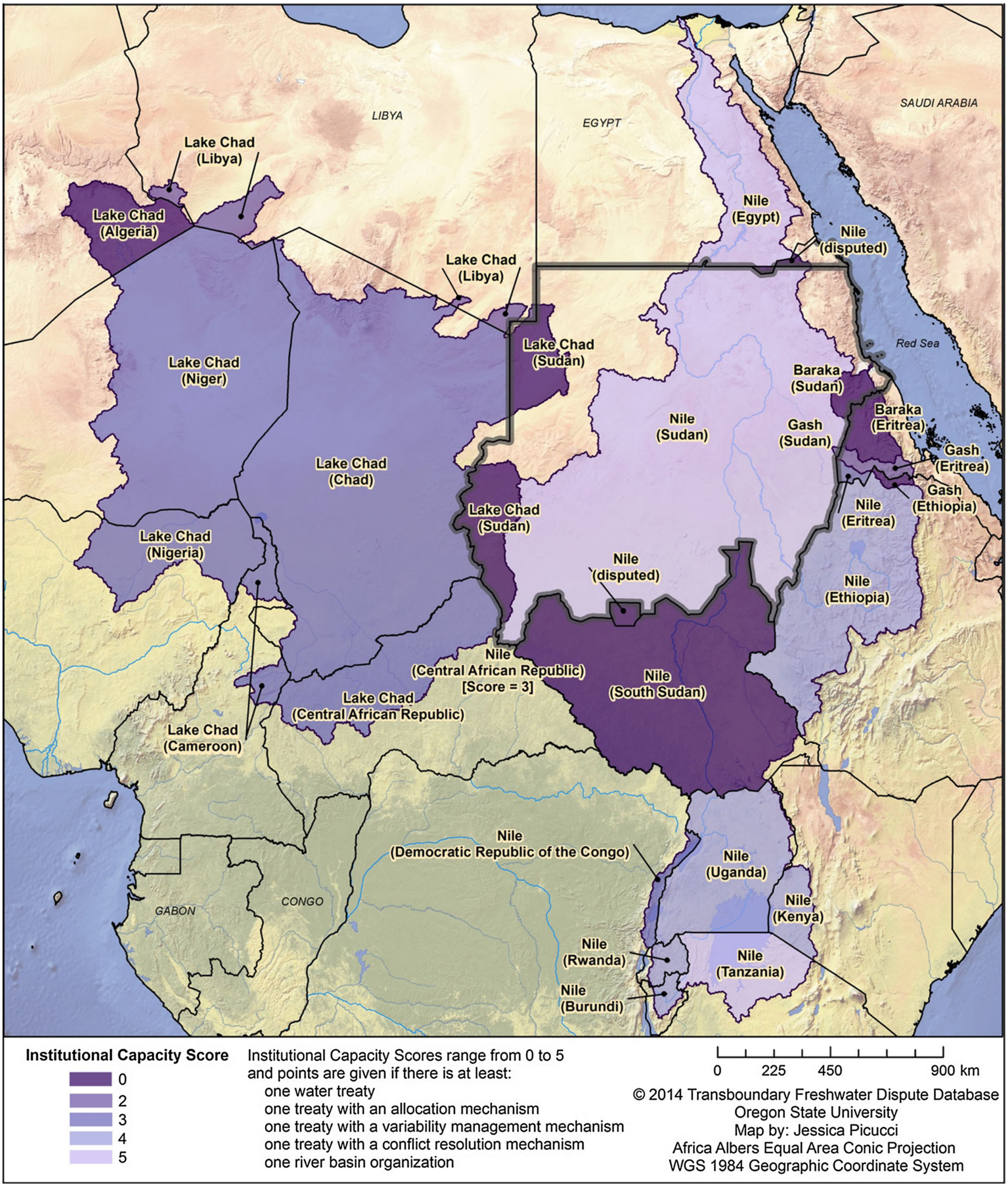

Fig. 36 Institutional capacity of the extent of Sudan's transboundary basins by basin country unit

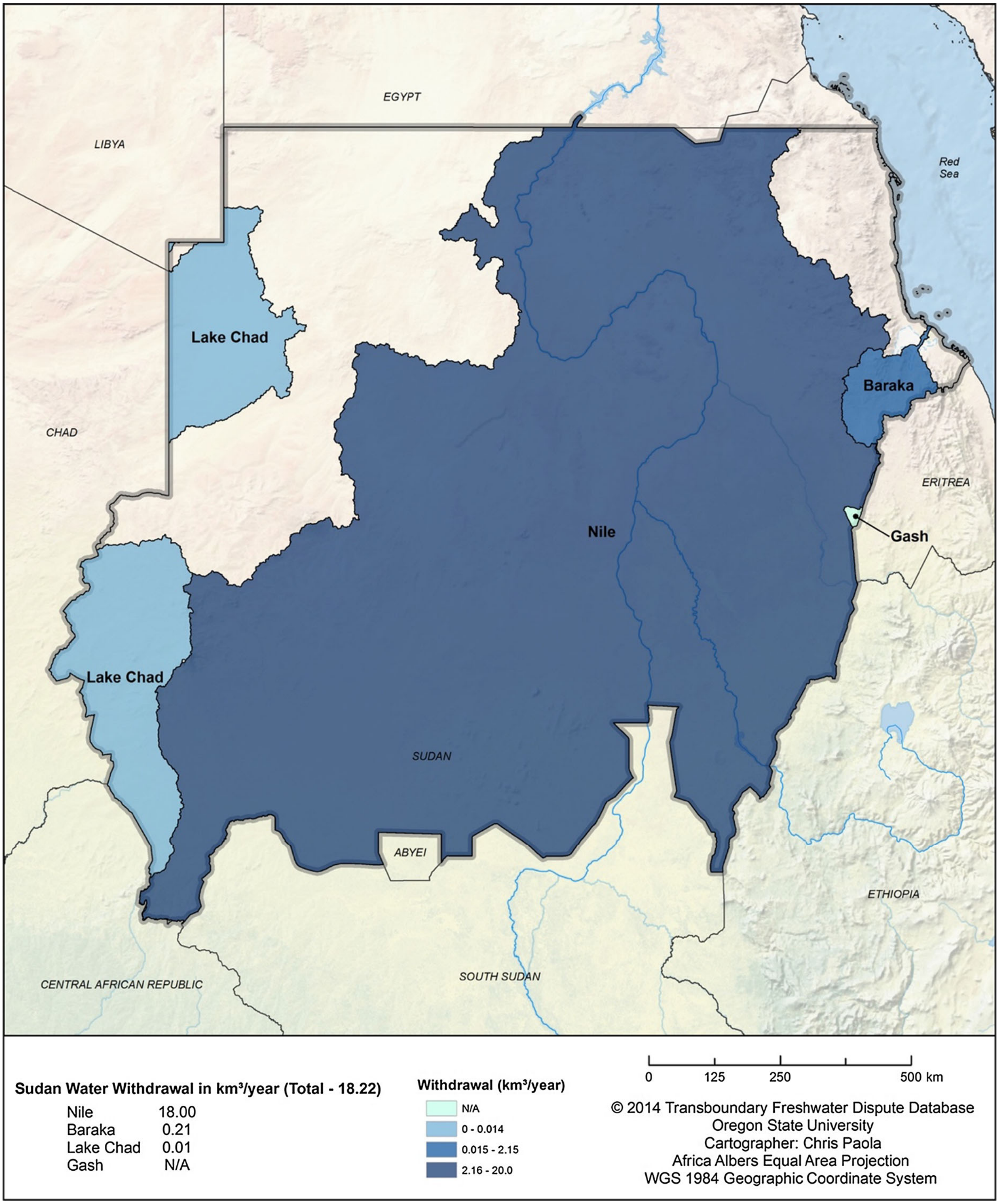

Fig. 37 Sudan's water withdrawal by basin country unit

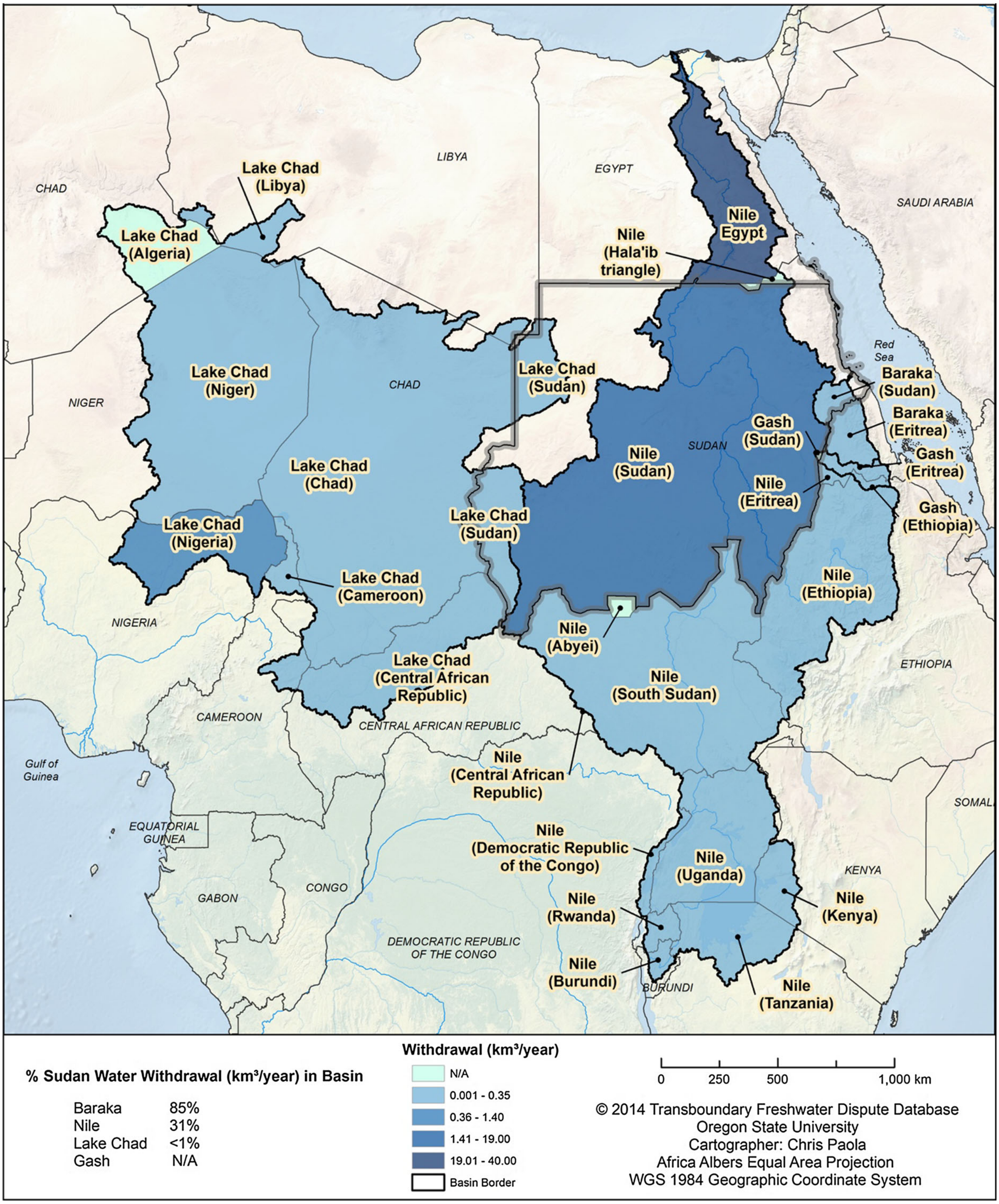

Fig. 38 Water withdrawals by extent of Sudan's transboundary basins by basin country units

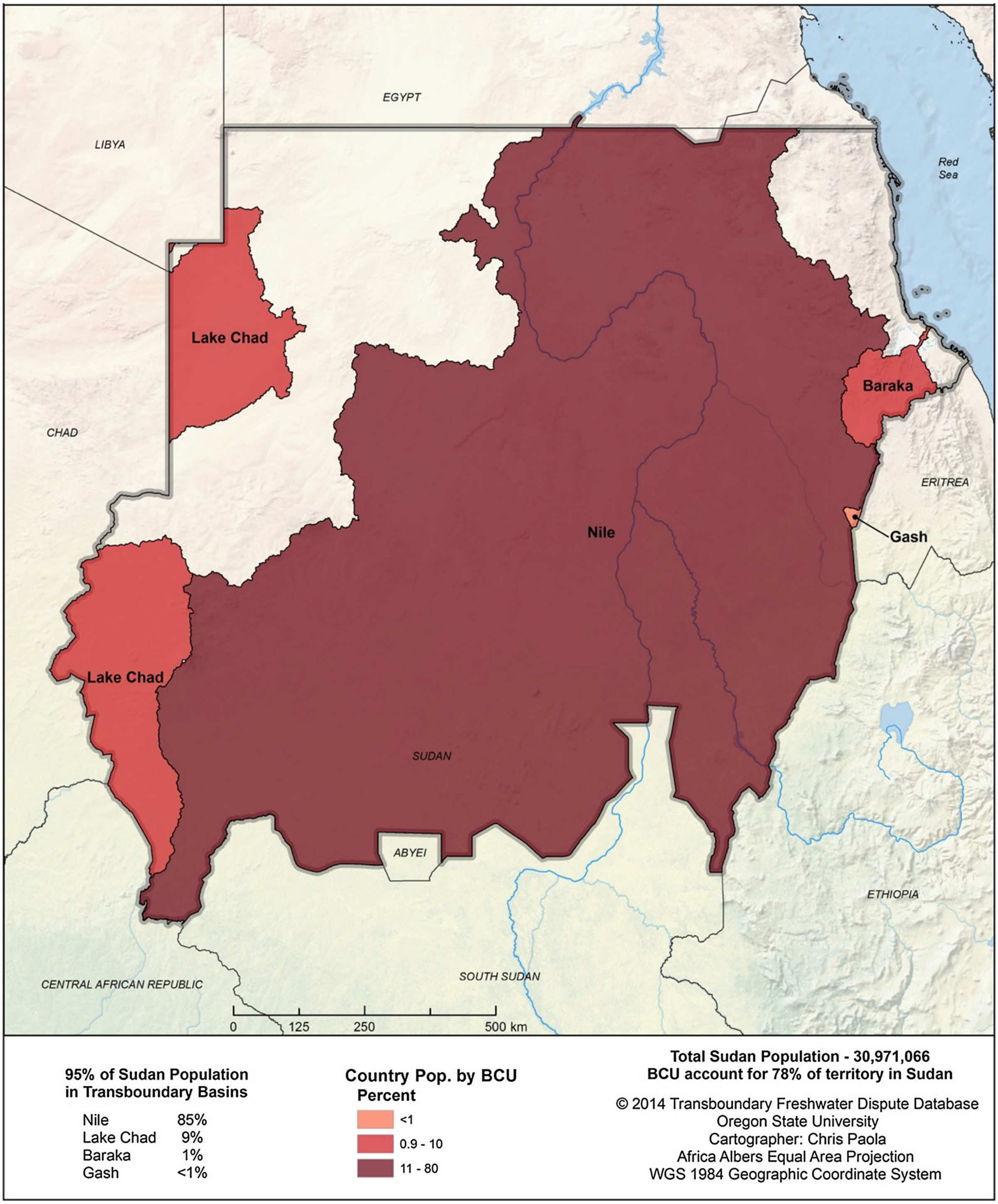

Fig. 39 Sudan's population density by basin country unit

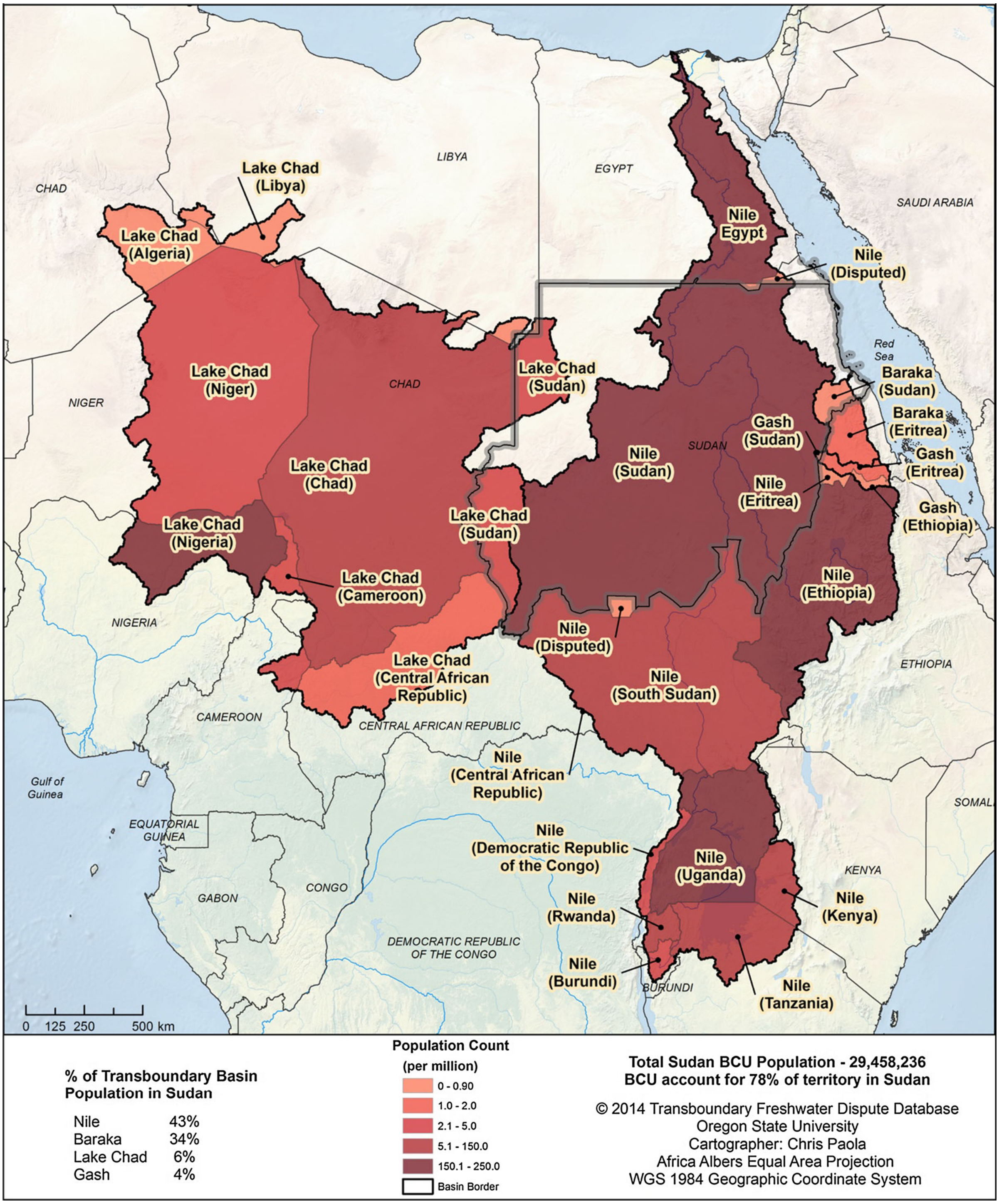

Fig. 40 Population density by extent of Sudan's transboundary basins by basin country units

Table 7 Sudan's water-related resilience

Sudan
Mode = 1
Median = 1.5
Low to Mid-low Resilience

Low = 1	Mid-low = 2	Medium = 3	Mid-high = 4	High = 5
1 main water resource	2 available water resources	3 available water resources	4 available water resources	5 or more available water resources
> 75% withdrawal from a shared basin(s)	75% to 50% of withdrawal from a shared basin(s)	50% to 25% of withdrawal from a shared basin(s)	<25% of withdrawal from a shared basin	0
Population: >81%	Population: 61%- 80%	Population: 41%- 60%	Population: 21%-40%	Population: <20%
No treaties, river basin organizations, or agreements	One treaty	One treaty with mechanism or river basin organization or two treaties	One treaty with mechanism and 1 more mechanism or river basin organization or 3 treaties	One treaty with 2 or more mechanisms and river basin organization or One treaty with >2 mechanisms or 4 or more treaties

Table 8 Resilience score of sample countries

Afghanistan	China	Iraq	Moldova	Sudan
Low to mid-low resilience	High resilience	Low resilience	Low to mid-low resilience	Low to mid-low resilience
Mode: 1	Mode: 5	Mode: 1	Mode: 1	Mode: 1
Median: 2	Median: 5	Median: 1	Median: 1.5	Median: 1.5

Conclusion

This study focuses on countries that share water resources across political borders. We argue that countries with a high percentage of their territory in a shared basin, a high dependency ratio (reliance on neighboring countries for freshwater resources), and/or a high number of shared basins may be more vulnerable than other countries to water-related instability. We test this by conducting a geospatial analysis of social (population), development (water withdrawals), and political (institutional capacity) datasets. We then create a tool to assess a country's resilience. Based on our vulnerability parameters, we selected five countries with different attributes and from different geographies: Afghanistan, China, Iraq, Moldova, and Sudan.

Our results are summarized in Table 8 and suggest that China boasts the highest water-related resilience. This is largely because the population in shared basins is relatively small, as is the associated water withdrawals. China's alternative water resources are concentrated in domestic basins. Interestingly, while China has high institutional capacity, the agreements are limited to its northern rivers while the majority of China's water resources are located in the southern part of the country and agreements don't yet govern those international rivers. Iraq had the lowest resilience score. This is largely because Iraq's population is almost entirely located within a shared basin, as are its associated water withdrawals with no significant existing water alternatives. Iraq does have high institutional capacity in the form of international agreements with upstream countries on its shared basin; however, this is overshadowed by other aforementioned basin impacts. In addition, the agreements that currently govern shared waters have not facilitated nor do they reflect the trilateral coordination necessary for effective basin-wide water management. The other three countries we analyzed scored between low and mid-low water-related resilience. Afghanistan scored at the higher end of this range, followed by Moldova and Sudan. We found that high institutional capacity is overshadowed when the other parameters of water withdrawal, alternative water resources, and population density score low for the resilience score of our case studies.

In summary, this study describes a geospatial analytical approach that can be used to form a resilience assessment of water-related stability of countries with transboundary freshwater resources. This study is likely to give rise to several new research questions that will aid in developing a more nuanced understanding of the role of water resource stressors in a country's stability, such as examining potential hot spots highlighted by this method in specific basin country units.

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