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Global hydrobelts: improved reporting scale for water-related issues?

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Abstract

Questions related to water such as its availability, water needs or stress, or management, are mapped at various resolutions at the global scale. They are reported at many scales, mostly along political or continental boundaries. As such, they ignore the fundamental heterogeneity of the hydroclimate and the natural boundaries of the river basins. Here, we describe the continental landmasses according to eight global-scale hydrobelts strictly limited by river basins, defined at a 30′ (0.5°) resolution. The belts were defined and delineated, based primarily on the annual average temperature (T) and runoff (q), to maximise interbelt differences and minimise intrabelt variability. The belts were further divided into 29 hydroregions based on continental limits.

This new global puzzle defines homogeneous and near-contiguous entities with similar hydrological and thermal regimes, glacial and postglacial basin histories, endorheism distribution and sensitivity to climate variations. The Mid-Latitude, Dry and Subtropical belts have northern and southern analogues and a general symmetry can be observed for T and q between them. The Boreal and Equatorial belts are unique. The hydroregions (median size 4.7 Mkm^2) contrast strongly, with the average q ranging between 6 and 1393 mm yr^{-1} and the average T between −9.7 and +26.3 °C.

Unlike the hydroclimate, the population density between the North and South belts and between the continents varies greatly, resulting in pronounced differences between the belts with analogues in both hemispheres. The population density ranges from 0.7 to 0.8 p km^{-2} for the North American Boreal and some Australian hydroregions to 280 p km^{-2} for the Asian part of the Northern Mid-Latitude belt. The combination of population densities and hydroclimate features results in very specific expressions of water-related characteristics in each of the 29 hydroregions. Our initial tests suggest that hydrobelt and hydroregion divisions are often more appropriate for water-relative global analysis and reporting than conventional continental or political divisions.

1 Introduction

Geographers have been mapping and/or tabulating the world's water balance and addressed global water-related questions, such as its distribution, availability or population needs, for more than a hundred years (Perthes, 1845, 1894). Mapping global water resources was first done for precipitation and runoff; the maps were at a very coarse resolution due to sparsely available data, a lack of global models and a lack of satellite imagery. In 1964, the Soviet Academy of Science in Moscow issued a novel work, the *Physico-geographic Atlas of the World* (Gerasimov, 1964), which presented a similar set of maps for precipitation and runoff, together with relief, geology, climate, vegetation, etc., as vector maps for each continent. The global river network was presented at an unprecedented resolution (1/20 000 000) for each continent and for the Soviet Union. In 1975, two German geographers, Baumgartner and Reichel, published the World Water Balance with detailed maps and tables on precipitation, evaporation and runoff for each continent as well as specific tables for latitudinal zones. Korzoun et al. (1978) established another description of the global water balance for UNESCO, which they presented for each continent and which included dozens of tables. Even though Baumgartner and Reichel (1975) considered drainage basins to oceans, ultimately none of the global-scale analyses took into account the natural hydrographic entities delineated by river basins in their reporting and tabulations.

Global hydrology outputs have changed markedly in the last twenty years due to satellite imagery, global hydrological models and Geographic Information Systems (GIS). Subsequently, these three tools have made it possible (i) to map the components of the hydrological balance at high resolution (Vörösmarty et al., 2000c; Fekete et al., 2002; Alcamo et al., 2003; Oki and Kanae, 2006), (ii) to delineate surficial river networks and/or the boundaries of river basins at a global scale, first at 2° (two arc degrees) (Probst, 1992; Probst et al., 1997) then at 30′ (30 arc minutes or 0.5°) (Vörösmarty et al., 2000a, b; Oki and Kanae, 2006) and finer, and the lakes and wetland distributions (Lehner and Döll, 2004), (iii) to replace paper copies of the world hydrological atlases with digital geospatial maps at various resolutions (Vörösmarty et al., 2000a, b, c; Alcamo et al., 2003; Lehner and Döll, 2004; Oki and Kanae, 2006; van Beek et al., 2011), and (iv) to combine water resources with other numerical maps, particularly population maps, resulting in the analysis of water needs and availability at high resolutions (Vörösmarty et al., 2000c; Viviroli et al., 2007; Kummu et al., 2010; Wada et al., 2011).

Global river water chemistry datasets have also been created for Earth System analysis, particularly to map global river inputs to coastal oceans for carbon and nutrients (e.g. Ludwig and Probst, 1998; Seitzinger et al., 2005, 2010; Dürr et al., 2011). Studies on aggregated river basins have been gradually regionalized, first for rivers discharging water into oceans at different latitudinal bands (Probst, 1992), then for homogeneous coastal zone catchments, termed COSCATs (Meybeck et al., 2006, 2007), specific ocean basins, regional seas and estuarine types (Meybeck and Dürr, 2009; Laruelle et al., 2010; Dürr et al., 2011). Similarly, the regionalisation of water-related issues has been increasingly studied based on more homogenous hydro-climatic, political and/or socioeconomic regions. For instance, Asia has been divided into Eastern Asia, Southern Asia, Northern Asia and the Middle East using country aggregates (e.g. Kummu et al., 2010). Researchers have also recently clustered world river basins into 426 homogeneous ecoregions (Abell et al., 2008), with catchment areas ranging from 23 km^2 to 4.53 Mkm^2 (average 311 000 km^2) on the basis of their fish populations. The largest basins, which are more heterogeneous, are also fragmented, for example into 13 ecoregions for the Amazon River basin (Abell et al., 2008).

The analysis of global water-related issues, needing discrete river basins as the analysis unit, is now commonly performed at 30′ resolution ($n = 60\,000$ cells, $n = 6200$ individual river basins) (Vörösmarty et al., 2000a, b), with higher resolution for regional analysis or specific questions. When multiple issues need to be compared, various spatial delineations and/or reporting formats have been used; this has been done, for instance, for river water management using the following scales: (i) continents (Kulshreshtha, 1998; Vörösmarty et al., 2000c; Rockström et al., 2009; Wada et al., 2011),

(ii) economic and/or political regions (Falkenmark, 1997; Kulshreshtha, 1998; Arnell, 2004; Islam et al., 2007; Kummu et al., 2010), (iii) countries ($n = 100$ to 200 entities) (Sullivan et al., 2003; Falkenmark et al., 2009; World Water Assessment Programme, 2009), (iv) latitudinal bands (Baumgartner and Reichel, 1975; Kummu and Varis, 2011), and (v) climate (Köppen, 1931) and ecosystem bands (Holdridge, 1967). Other river aggregating has been done to assess the impact of damming ($n = 100$ to 1000) (Vörösmarty et al., 1997; Nilsson et al., 2005), as well as the hydro-ecoregions (Abell et al., 2008).

Traditional global-scale reporting, however, faces multiple complications. Aggregating the results at a country level may only smooth out major hydro-physical and social discrepancies for the largest countries, such as China, Russia, the US, Australia, Canada or Brazil. Furthermore, it is difficult to compare studies on different geopolitical entities when the political situation is evolving, such as for the European Union or the former USSR. It is also difficult to analyse a great number of entities just using tables: similarities and/or contrasts are not obvious when more than 50 entities are used, while they are masked if only a very small number of regions (e.g. six continents) are used. Natural hydrological boundaries, which delineate rivers basins, are now often stated to be more appropriate to analyse and manage water-related issues (Millennium Ecosystem Assessment, 2005; World Water Assessment Programme, 2009). Moreover, the hydroclimatic conditions of an area greatly impact a society's water consumption behaviour and its traditional livelihood structure.

We postulate that the analysis and tabulation of multiple water-related issues are better performed when using similarly defined permanent spatial entities, particularly when done on a global scale, rather than traditional reporting scales. We argue that *an analysis of global water issues can be improved and harmonised using a limited and fixed number of spatial entities that are delineated without compromising river basin boundaries*.

We thus propose to delineate the continental landmass to homogenous hydrological regions, the *Hydrobelts*, which are formed with aggregated river basins and decomposed on continents, as *Hydroregions*. The goal is to define hydrobelts at a useable resolution that makes it possible to easily connect them to other databases at the same resolution. We consider less than thirty hydroregions, for which the hydroclimate, vegetation and population characteristics can easily be tabulated and compared. The long-term objective is (i) to facilitate the Earth System Analysis related to riverine fluxes, and (ii) to provide an *integrated analysis of water-related issues*, such as river changes, demographic trajectories and water resources analysis, for fixed spatial entities. The feasibility of delineating hydrobelts and their homogeneity is a major point of our discussion. We focus on the non-glaciated part of continents, excluding Greenland and Antarctica.

2 Hydrobelt delineation principles and datasets used

2.1 Principles of hydrobelt delineation

In order to facilitate mapping, reporting and analysis at a global scale, we defined hydrobelts for crossing the continental borders, forming hydrologically homogenous regions, based on the following criteria:

1. Hydrobelts are delineated by natural hydrological basins, which cannot be segmented (e.g. headwaters are not separated from lowlands).
2. Belts are defined on the basis of their average water balance attributes (the hydroclimate).
3. They are designed to minimize their intra-belt hydroclimate heterogeneity and to maximise their inter-belt discrepancy.
4. Hydroregions correspond to the expression of hydrobelts on the different continents, they are contiguous and take into account continental limits.

The limits of river basins are the basis for the delineation. The *exorheic* drainage of the continents, i.e. the drainage that is connected to the world's ocean, includes 6100 river basins exceeding 400 km^2 at a resolution of 30′ (Vörösmarty et al., 2000a, b). The 47 largest river basins (exceeding 0.5 Mkm^2) correspond to over half of the continental area that drains into oceans or internal (*endorheic*) regions (Meybeck and Ragu, 1995; Vörösmarty et al., 2000a, b; Milliman and Farnsworth, 2011). Therefore, the greatest parts of the belt boundaries correspond to these large basins, among which the Amazon (#1, 6.1 Mkm^2), the Congo (#2, 3.7 Mkm^2), the Ob (#3, 3.0 Mkm^2), the Mississippi (#4, 3.0 Mkm^2) and the Nile (#5, 2.9 Mkm^2) are the largest ones.

Two main hydroclimate indicators were used to delineate the hydrobelts: the annual water runoff (q, $\mathrm{mm\,yr}^{-1}$), derived from the runoff data constructed by Fekete et al. (2002), and the average air temperature (Hijmans et al., 2005). Water runoff data are available at a spatial resolution of 30′ (Vörösmarty et al., 2000c; Alcamo et al., 2003; Oki and Kanae, 2006; van Beek et al., 2011). The temperature data are available at a spatial resolution of 30″ (30 arc s) (Hijmans et al., 2005). Temperature data were aggregated to a spatial resolution of 30′, similar to runoff data. The delineation of hydrobelts takes into account the previous global analysis of the climate and vegetation on different continents done by Köppen (1931) and Holdridge (1967). They show latitudinal variations, marked west-east gradients for the largest continents – the continentality – and a relative symmetry between the Northern and Southern Hemispheres, except for the coldest regions found in noticeable extent only in the Northern Hemisphere. We defined eight hydrobelts based on the average annual temperatures and runoff in the aggregated river basins (see Table 1 for the temperature and runoff targets):

- Boreal belt (BOR), essentially defined by its annual average temperature, below 0 °C, and only found in the Northern Hemisphere,
- North and South Mid-Latitude belts (NML and SML), defined by medium runoff and temperature figures and by their general latitudinal position centred at 45° N and 45° S,

- North and South Subtropical belts (NST and SST), defined by an average temperature exceeding 15 °C, by medium runoff and by their position at 17° N and 17° S,
- North and South Dry belts (NDR and SDR), only defined by their low runoff ($0 < q < 150\,\mathrm{mm\,yr^{-1}}$),
- Equatorial belt (EQT), defined by its high and relatively constant temperature throughout the year (annual average temperature $T > 20\,^{\circ}\mathrm{C}$) and its elevated runoff ($q > 750\,\mathrm{mm\,yr^{-1}}$), and by its position centred near the equator.

All of the belts have been named based on their latitudinal position, except for the Dry belts, which have considerable latitudinal ranges (see further). As Greenland and Antarctica have few flowing rivers, they are only considered in the global tabulation as *glaciated hydrobelts.* Six continents are considered: North and South America, Europe including Anatolia, Asia separated from Europe by the Ural and South Caucasus Mountains and including New Guinea, and finally Australia including New Zealand.

2.2 Datasets used to characterize the hydrobelts and hydroregions

The datasets used to divide and characterize the hydrobelts are detailed in Table 2 and fully tabulated in the Supplement. The climate and hydrological data represent the situation in the latter half of the 20th century (in most cases 1960–1990). For our analysis, the hydrological data (precipitation, runoff) were area-weighted (e.g. total discharge over total area for a given entity, i.e. belt or region).

Arheic areas are operationally defined here by an inter-annual runoff of less than $3\,\mathrm{mm\,yr^{-1}}$ (Vörösmarty et al., 2000a, b), based on the global hydrological model provided by Fekete et al. (2002). This limit between *arheism* (total absence of river flow) and rheism (some river flow, at least one flood event every 10 yr) has been verified for extremely arid regions, such as the Lake Eyre basin in Central Australia (Kotwicki, 1986).

The population data (Klein Goldewijk et al., 2010) is for the year 2005. Average population density is the ratio between the total population and the total area of any belt or region. Full ranges of cell attributes and latitudes correspond to the 5 %–95 % percentiles of their spatial distributions.

3 Delineation of hydrobelts

Delineating the hydrobelts was a stepwise-standardized process. We first characterised the largest exorheic river basins ($n = 200$) based on their dominant hydroclimate. The remaining smaller basins ($n = 6000$) were then clustered using a previous aggregation of world rivers into 156 coastal catchment entities (median size of 0.45 Mkm^2), termed COSCATs (Meybeck et al., 2006). COSCATs were originally designed to harmonise the reporting of river fluxes with oceans at a global scale; they were defined with several constraints, such as the climate homogeneity, regional sea basin limits, ocean floor topography, and continental limits (see detailed presentation of COSCATs in Appendix 1).

Since the *endorheic* drainage of the continents was not studied previously (Meybeck et al., 2006), we consider here 79 additional aggregations of river basins (median size of 0.086 Mkm^2) in these internal regions of continents that are presently not connected to oceans, such as: the Great Basin (USA), the Caspian Sea basin, split between Europe and Asia, the Lake Chad basin, the Rift Valley and the Okavango River basin in Africa, the Aral Sea basin in Asia, the Lake Eyre basin in Australia and many smaller ones in Central Asia, Australia and the Americas.

We needed to make several minor modifications to the original COSCAT division when delineating the hydrobelts. The modifications concerned first islands and archipelagos, which are originally within one COSCAT due to the topography of the ocean floor and were now delineated to different belts or regions due to a wide range of hydrological characteristics within a COSCAT. A second set of adjustments concerned a few COSCATs that originally had mixed climate features, which we now split into two different hydrobelts (see details about these re-attributions in Appendix 1).

The re-aggregation of the world river basins (catchment area ranging from 400 km^2 to 6.1 Mkm^2) results in a definition for 251 hydrological entities; the entities are limited by the natural drainage area limits. An example of how we delineated the COSCATs and their re-aggregation for Central and South-Asia is schematically presented in Fig. 1. For instance, three adjacent cells in Tibet are linked, through river networks, to three receiving cells in, (i) the Indian Ocean through the Indus River, (ii) the Aral Sea and the Amu Darya River, and (iii) the Lop Nor salt lake in China through the Tarim River.

Finally, we clustered these 251 entities into eight belts (see Fig. 2) until the intrabelt hydroclimatic homogeneity and interbelt discrepancy could not progress any more without significantly fragmenting the belts into a number of pieces, thereby violating a major criterion (see Sect. 2.1). This process was iterative and included multiple verifications and decisions regarding the identification and clustering of various hydrological conditions. The Mid-Latitude belt in Asia and the Subtropical belts were the most difficult ones to define (see Sect. 5.1).

The hydroregions correspond to the portion of the hydrobelts present in each continent. In Asia, the very large Boreal (14.5 Mkm^2) and Dry (13.6 Mkm^2) hydroregions present marked temperature differences. They were split into two parts. With these separations, we were able to define 29 major hydroregions (see map in Fig. 2). Once we had delineated the belts and hydroregions, we used existing databases to establish their general attributes based on their cell distribution (median values and percentiles) and their cell-area weighted averages.

4 Characteristics of hydrobelts

In this section, we first present the hydrobelts based on their hydrophysical characteristics and then in terms of climate and vegetation. The population characteristics of each belt are then presented in the general discussion in Sect. 5.2.

4.1 General hydrophysical characteristics of hydrobelts

The general geographic position, size, the current proportions of the endorheic area, permafrost and past glacial cover (maximum Quaternary glacier extent – mostly Late Glacial Maximum LGM) for each belt are presented in Table 3 along with their average temperature, precipitation, runoff and population density (see also Fig. 3). The characteristics of each belt are introduced below along with their major rivers (see Appendix 1 for a full list of river basins), river hydrological and thermal regimes, past Holocene history and sensitivity to climate change. We take into account the classical descriptions made by physical geographers (Gerasimov, 1964; Fairbridge, 1972), particularly for past glacial cover, and by hydrologists (Rodier, 1964; Korzoun et al., 1978; Haines et al., 1988). Our segmentation of eight belts is somewhat similar to the nine ecozones defined by Schultz (2005), but, at the same time, significantly differs from it because we chose to use river basin boundaries; our terminology is also partially identical to his (Boreal, Subtropical and Dry domains). The fish biodiversity description that we provide is adapted from Tedesco et al. (2008) and Abell et al. (2008).

4.1.1 Boreal belt

The *Boreal belt* (surface area: 26 Mkm^2) is the coldest of all the belts. Its annual temperature is largely negative, −6.6 °C on average (range in boreal hydroregions from −12 °C for East Siberia to −1.4 °C for Northern Europe; Table 4, Fig. 4). Its median latitude is 62° N, ranging from 49.7° N to 73.2° N (5 % to 95 % of the cell distribution). It extends throughout the northern parts of Europe, Asia and North America. The average precipitation (P) of this belt is 437 $\mathrm{mm\,yr}^{-1}$ and the evapotranspiration (ETP) is 214 $\mathrm{mm\,yr}^{-1}$, resulting in an average runoff (q) of 223 $\mathrm{mm\,yr}^{-1}$ (Table 3).

Some of the world's greatest river basins are found in this belt; the rivers include the Yukon, Mackenzie, Churchill and Nelson Rivers in North America, the Northern Dvina and Pechora Rivers in Europe, and the Ob, Yenisei, Lena, Indigirka, Kolyma, Anadyr, Penzhina and Amur Rivers in Siberia. All of these rivers have sufficient runoff to reach the Arctic Ocean and regional seas (the Bering Sea and Sea of Okhotsk for the Pacific Ocean, and Hudson Bay and Ungawa Bay for the Atlantic Ocean). The rivers are frozen during several months of the year and are characterised by snowmelt river regimes with marked seasonal variations in runoff. This regime is characterized by a very pronounced late spring or early summer flood pulse, with ice jams that have a huge erosive power on riverbanks (Costard et al., 2007), limiting the aquatic biota.

During at least one of the Quaternary ice ages, 54.3 % of this belt was covered by ice caps (23 % in West Siberia, 34.7 % in East Siberia, 77.7 % in Europe and 88 % in North America; Table 4). Many of the present river networks are, therefore, very recent (Potter and Hamblin, 2006). The last glaciers melted 6000 yr ago, leaving multiple heritages that are still impacting the present morphology, land cover, hydrology and biodiversity of the river basins: (i) the occurrence of major lake provinces – Canadian and Scandinavian shields and Taymir peninsula – and large wetlands provinces (Lehner and Döll, 2004); (ii) the permafrost dominance (from 30 % to 88 % of their area, average 75 %); (iii) the specific coastal topography, such as fjords and archipelagos, associated with a hard, rocky coast (Dürr et al., 2011). The aquatic biota diversity, e.g. the richness of fish species and endemism, is limited in these river basins, which often have a very short history compared to other rivers in the world (Abell et al., 2008).

4.1.2 Mid-Latitude belts

Mid-Latitude belts are characterised by their median runoff, which is close to the world average for exorheic regions, and their average temperature. Former glacial cover has affected them much less than the Boreal hydrobelt, and they have limited endorheic or arheic areas (Table 3). Due to the unbalanced distribution of land area between the Northern and Southern Hemispheres, the corresponding areas of the Mid-Latitude belts are quite unequal (24.2 Mkm^2 for the Northern Hemisphere vs. 4 Mkm^2 for the Southern Hemisphere) and their mean latitudes are somewhat different (43° N and 34° S).

The *Northern Mid-Latitude belt* (24.2 Mkm^2) is quite extensive. It is characterized by a medium positive temperature (mean ranging from +7.2 °C to +12.2 °C between hydroregions, being +9.1 °C on average), precipitation (809 mm yr^{-1}) and runoff (343 mm yr^{-1}), all of which are close to the world's means for the non-glaciated regions and non-endorheic regions (12.9 °C, 869 mm yr^{-1} and 340 mm yr^{-1}, respectively) (Tables 3 and 4; Fig. 3). This belt ranges from a latitude of 26.7° N to a latitude of 58.2° N (median 42.7° N) and also extends throughout half of North America, more than 95 % of the European continent, large parts of Eastern Asia, and parts of Southern Asia. It is important to note that the NML Belt is totally interrupted between Europe and Asia by the Northern Dry Belt (Fig. 2) and fragmented in Asia into two parts, south and east of the Tibet Plateau (Fig. 2).

The river basins of this belt are generally connected to the coastal ocean (exorheic drainage): the Columbia, Mississippi/Missouri and Saint Laurence Rivers for North America; the Rhine, Elbe, Rhone, Danube, Don and Dnieper Rivers for Europe; and, the Indus, Ganga/Brahmaputra, Yang Tse Kiang (Chang Jiang) and Yellow (Huang He) Rivers for Asia. This belt also includes the Western Caspian tributaries from the Volga to the Kura, which are sensu stricto endorheic basins but characterized by medium to high runoff figures: this inclusion results in an endorheism rate of 8.7 % for this belt.

Many of these NML basins were exposed to glacial cover (27.8 % on average), and the legacies of the glaciations can be important. Fourteen per cent of the basin areas in Asia, 25 % of those in Europe and 44 % of those in North America, as well as nearly 100 % for individual basins, such as the Saint Lawrence River basin (attributed to this belt on the basis of its latitudinal position), were exposed to glacial cover. In comparison, the Danube River basin has been much less glaciated. The extent of the present permafrost is also more limited compared to the Boreal belt (6.1 %). Many of these Northern Mid-Latitude rivers have their headwaters in colder climate areas, resulting in marked longitudinal gradients of temperature and hydrological regimes, mixing snow-melt and/or ice-melt in the headwaters of the rivers, and rainfall-evaporation dominance in the lower tributaries. Such contrasts are at their maximum in Asia (see

Sect. 5.1). The river ecology of the Mid-Latitude regions can also be complex and it varies spatially, reflecting the longitudinal variations (e.g. Tedesco et al., 2008). The fish population diversity of the related hydro-ecoregions is intermediate between those of the Boreal rivers and the Subtropical and Equatorial rivers, with the exception of the Asian hydroregion (Abell et al., 2008).

The *Southern Mid-Latitude belt* (4.0 $\mathrm{Mkm^2}$) is different from its northern analogue in many ways. It is six times smaller (4.0 $\mathrm{Mkm^2}$ versus 24.2 $\mathrm{Mkm^2}$) and much warmer (+14.5 °C versus +9.1 °C). Its main hydroclimate characteristics are, nevertheless, similar in terms of precipitation (862 $\mathrm{mm\,yr^{-1}}$ versus 809 $\mathrm{mm\,yr^{-1}}$ for NML) and runoff (292 $\mathrm{mm\,yr^{-1}}$ versus 343 $\mathrm{mm\,yr^{-1}}$) (Table 3; Fig. 3). This belt is essentially exorheic and it can be found on three continents: it covers the westward tip of South America, along the coast of Chile and in central Argentina, it covers a narrow strip of coastal basins in southeast Africa, and it also can be found in Eastern Australia (Murray-Darling River basin) and in New Zealand. As the continental climate is totally absent in this belt (see next section), the thermal and hydrological regimes of these rivers are different from those of the Northern Mid-Latitude belt: the influence of snow melt is very limited, except in parts of New Zealand and Patagonia (Haines et al., 1988).

4.1.3 Dry belts

The Northern and Southern Dry belts are characterized by common hydrological features: (i) high proportions of endorheism (41 % of the total area) and/or arheism (43 %), (ii) allogenic rivers, (iii) variable river regimes, and (iv) a high sensitivity to climate variations that may connect or disconnect the river networks. The proportion of endorheic basins in the Dry hydroregions ranges from 15.1 % in North/Central America to 100 % in Central Asia (Table 4).

Allogenic rivers are quite representative of the Dry belt's basins. They are essentially fed by some headwaters, or *water towers*, located in more humid mountains or plateaux (Viviroli et al., 2007); their medium and lower courses are much drier, without important and/or permanent tributaries. Most allogenic rivers are found in the Dry belt, with the exception of the Indus and Huang He Rivers, which are attributed to the Mid-Latitude belt. When the water balance of the allogenic river basins is positive, they naturally fill the land depressions and reach the coastal ocean. If not, they constitute endorheic basins where the totality of the water generated in the water tower is ultimately evaporated via salt pans (Uyuni, Lop Nor, Kara Bogaz), saline aquifers (Lake Chad) and internal brackish (Caspian Sea, Aral Sea, Balkash Lake) or hyper-saline lakes (Dead Sea, Great Salt Lake). Regular annual hydrographs are only observed for the large allogenic basins fed by the water towers, such as the Nile, and for rivers fed by snow and ice melt (Dukhovny and De Schutter, 2011) (e.g. Shatt el Arab, Amu Darya, Syr Darya, Tarim). Dry regions have generally not been formerly glaciated, except in the hydroregions found in South America (18.8 % of basin areas) and Central Asia (3.7 %) (Table 4).

Other characteristics of the Dry belt rivers are: (i) the wadis, (ii) highly irregular river discharge as a result of flash floods, (iii) marked seasonal dryness, and (iv) large inter-annual variations. In the very dry and/or smallest basins these rivers may not flow at all for a year or more (q between 3 mm yr^{-1} and 30 mm yr^{-1}) (Kotwicki, 1986). During the rare flow events, the specific runoff can exceed 1000 l km^{-2} yr^{-1}, with catastrophic flooding and enormous sediment transports, which are seldom described in the scientific literature (Cruette and Rodier, 1971; Milliman and Farnsworth, 2011).

Both the Northern and Southern Dry belts are very sensitive to climate variations, particularly for precipitation and runoff, as shown by palaeohydrological studies, which still need to be synthesized on a global scale. When the climate becomes dryer, the permanent flows (typically more than 100 mm yr^{-1} runoff) are first turned into highly seasonal flows (30 to 100 mm yr^{-1}), then into non-permanent flows (3 to 30 mm yr^{-1}), resulting in seasonal dryness and river course fragmentation. Finally, the changing climate may lead to permanent dryness or arheism ($<$ 3 mm yr^{-1}) and filling by aeolian deposits. Such a trajectory is the one that has been observed, for example, for the Sahara and Arabia River networks over the last 6000 yr: the lower Nile tributaries were active, Lake Turkana was connected to the White Nile (Nyamweru, 1989), and the Sahara mountain massifs – Hoggar and Tibesti – served as the headwaters for numerous allogenic rivers (Sarnthein et al., 1980; Said, 1993; Petit-Maire and Guo, 1995). Other examples are known from Asia (Caspian, Aral and Balkash lake connections, Kerulen to Amur connection), the Americas (Great Salt Lake to Columbia river basin, Mar Chiquita to Parana) and Central Australia (Fairbridge, 1972; Dukhovny and De Schutter, 2011).

The *Northern Dry belt* (30.2 Mkm^2) has the greatest surface area of all the belts. It corresponds to catchments with very low runoff (average 36 mm yr^{-1}), which is almost ten times lower than the global average for exorheic rivers. It covers a wide latitudinal range, from 6.7° N to 47.7° N (median 29.7° N) (Table 3). This results in marked differences in annual temperatures; they can range from +5 °C to +24 °C between hydroregions (Table 4; Fig. 4). The belt can be found on three continents: (i) in North America (Colorado and Rio Grande/Rio Bravo basins, both exorheic); (ii) in Northern Africa, where it includes the Sahara Desert from the Mauritania coast to the Red Sea plus the endorheic Lake Chad basin; and (iii) in Asia, from the Arabic Peninsula and the East Caspian basins to Mongolia, including only one major exorheic river basin, the Shatt el Arab (or Euphrates/Tigris), and numerous endorheic ones (Ural, Tedzhen, Helmand, Amu and Syr Darya, Tarim, Kerulen) all of which are allogenic.

The *Southern Dry belt* (8.7 Mkm^2) extends from 17.2° S to 44.2° S (median 26.7° S). Due to the landmass distribution, its area is less than one-third that of its northern counterpart. Despite a higher precipitation average (318 mm yr^{-1} versus 253 mm yr^{-1}), the average runoff figures are equivalent (q = 31 mm yr^{-1} in the SDR versus 36 mm yr^{-1} in the NDR) (Table 3; Fig. 3). The Southern Dry belt is also largely characterised by endorheic basins (42.4 %) and arheic areas (56.7 %) basins. It is more fragmented than its northern counterpart. In South America, the belt is split into four parts: the exorheic, but very dry, Peruvian coast, the endorheic Altiplano Plateau (Titicaca Lake basin), the endorheic Mar Chiquita basin and the exorheic Argentinean Pampa, which is fed by numerous allogenic rivers. In Southern Africa, it corresponds to the endorheic basins of Etosha Pan and the Okavango Swamps and to the large Orange allogenic basin. In

Australia, this belt is particularly developed, including the huge endorheic Lake Eyre basin (1.17 Mkm^2) and numerous smaller endorheic and/or arheic basins in Central and Western Australia.

4.1.4 Subtropical belts

The Northern and Southern Subtropical belts also have many hydrological features in common: an even thermal regime with warm conditions throughout the year, with an average annual temperature ranging from 21.3 °C to 26.3 °C, in contrast to marked seasonal variations in the amount of water discharges generated by their specific precipitations regimes, the West Africa and Asia-Australia monsoons. In such a river regime, the ratios of maximum over minimum monthly discharges may largely exceed a factor of ten (Rodier, 1964; Haines et al., 1988). Furthermore, they have a largely positive annual water balance, and have not been influenced much by past glaciations. In such basins, the extension of the floodplain and/or internal wetlands is also highly seasonal, creating some of the world's largest existing river wetlands, such as in the Parana (Pantanal and Lower Parana floodplain), the Niger (Delta Central) and the Mekong (Tonle Sap) Rivers. Holocene river network variations may still be important in the driest basins of these belts. The fish diversity in the subtropical rivers varies from medium to extremely high, as in the Asia subtropical hydroregion (Abell et al., 2008).

The *Northern Subtropical belt* (10.5 Mkm^2) extends from latitude 7.2° N to latitude 25.2° N (median 16.7° N). It is characterized by warm conditions throughout the year (+23.9 °C). In contrast, precipitation (1112 mm yr^{-1} annually on average), generated by the African and Asian monsoons, is seasonal, resulting in a medium amount of runoff (383 mm yr^{-1}) (Table 3; Fig. 3). This belt extends across Central America and the Caribbean Islands, from Florida to the coast of Columbia, across Africa, where it consists of two parts, separated by the Northern Dry belt, West Africa (the Niger basin and the smaller basins of the Gulf of Guinea) and the northern East African Rift. In South Asia the NST belt is also split: the East Deccan dry evergreen forests (Cauwery to Godavari basins) are disjointed from the Southeast Asia basins from the Irrawaddy (Ayeyarwaddy) to the Pearl River (Zhu Jiang).

In Asia and Africa, delineating this belt was a delicate process. The Ethiopian Plateau, a major wet region of east Africa, has been split into the Blue Nile basin, part of the Northern Dry belt, and the Omo and Awash basins (0.37 Mkm^2), attributed here to the NST belt on the basis of their relatively high runoff (q = 200 mm yr^{-1}). In the Southeast Asian basins, the headwaters of the Salween (Nu Jiang) and Mekong (Lancang Jiang) Rivers originate in the Tibet Plateau at altitudes exceeding 4000 m. Their rather limited extent does not, however, affect the subtropical hydrological regimes of the medium and lower courses of these rivers, but it does create heterogeneity in this hydroregion.

The *Southern Subtropical belt* (10.6 Mkm^2) has an area similar to its northern analogue and extends from a latitude of 4.7° S to a latitude of 30.7° S (median 17.7° S). Its water balance (P = 1035 mm yr^{-1}, ETP = 802 mm yr^{-1}, q = 233 mm yr^{-1}) and annual temperature (+21.9 °C) are also similar to those of the NST belt. The belt extends mostly through South America (5.5 Mkm^2) from the Sao Francisco to the Paraná basins and in the coastal basins of Ecuador (Fig. 2), in Southern Africa (4.23 Mkm^2) (Zambezi and Limpopo basins, and Madagascar), and in Northern Australia (Flinders, Mitchell basins).

4.1.5 Equatorial belt

The *Equatorial belt* (16.8 Mkm^2) is unique and lies on both sides of the equator (14.2° S to 8.2° N). When delineated by basin boundaries, its median latitude is slightly shifted to the South (2.7° S). It is very warm (+23.9 °C). The rainfall pattern is much less seasonal and wetter (2124 mm yr^{-1}) than in the Subtropical belts, resulting in the largest belt runoff (960 mm yr^{-1}), despite the maximum belt evapotranspiration (1164 mm yr^{-1}) (Table 3; Fig. 3). The belt is particularly developed in the South America hydroregion, from the Magdalena to the Tocantins Rivers, where it includes two out of three of the world's greatest rivers in terms of discharge: the Amazon (#1, 6590 km^3 yr^{-1}) and the

Orinoco (#3, 1135 km^3 yr^{-1}). The Africa hydroregion includes the Congo River (#2, 1200 km^3 yr^{-1}). These three rivers correspond to 60 % of the Equatorial belt area and their enormous water discharge is responsible for approximately 20 % of the dissolved material inputs to oceans (Meybeck, 1988; Milliman and Farnsworth, 2011). In contrast to these three giant basins, in South and Southeast Asia this belt is very fragmented, corresponding to much smaller basins (< 100 000 km^2) located in narrow coastal strips (West Deccan, Sri Lanka) and on islands (Indonesia and the Philippines). The Fly, Sepik, and Digul Rivers in New Guinea are characterised by some of the world's highest river runoff.

Equatorial river basins have several features in common: (i) a high annual runoff, (ii) thermal and hydrological regimes with limited seasonal variations and (iii) a very pronounced aquatic biodiversity. Their average runoff is 1393 mm yr^{-1} in Asia and 1069 mm yr^{-1} in South America, but only 460 mm yr^{-1} in Africa, due to the Congo River basin, which cannot be fragmented (see the discussion in Sect. 5.1). The river regimes are regular with limited seasonality: their specific discharges at low flow rates are quite high compared to all other regions (Rodier, 1964; Haines et al., 1988). The Amazon and Congo hydrographs are – compared to the other big rivers of the world – very regular with limited seasonal variations (maximum to minimum monthly discharge ratio than three for the Amazon and less than two for the Congo, having the steadiest river regime.

The Amazon, Orinoco and Congo River basins are among the oldest and most stable in the world in contrast to many other great rivers that been either exposed to climate variations (e.g. Central Asia), influenced by active tectonics (South and SE Asia) or exposed to past ice cover (Boreal belt). These three river basins have existed for millions of years (Potter, 1978). The first two have marked altitudinal gradients and combine various biotopes (up to 13 hydro-ecoregions for the Amazon according to Abell et al., 2008). The Congo River basin includes one of the world's biodiversity hotspots, Lake Tanganyika. These features may explain why their fish biodiversity is exceptional, with indicators more than ten times greater (Abell et al., 2008) than those observed for many boreal river basins, in which the present fish communities only began to develop 6000 yr ago.

4.1.6 Discrepancies and similarities between the analogous North and South hydrobelts

This first analysis shows that the eight hydrobelts are well differentiated with regard to their basin hydroclimate (temperature and runoff), their river hydrological or thermal regimes, the way in which they are connected with the oceans of the world (exorheism versus endorheism), their absence of flow (arheism), their past glacial history and their sensitivity to precipitation changes.

Although hydrobelts were designed to present the hydroclimate of continents in a symmetrical way, some important differences between the analogous northern and southern belts remain (Fig. 3 and Table 3). These differences combine (i) the uneven distribution of land masses (NML is, for example, much colder than SML implying also less evaporation and thus 15 % higher runoff) and the lack of a continental land mass south of 55° S, resulting in the absence of a Boreal belt in the Southern Hemisphere, (ii) the occurence of the continental climate only found in the northern belts, and (iii) the orographic discrepancy: Central Asian mountains and high plateaux that have no equivalent in the Southern Hemisphere.

4.2 Climate and vegetation distribution in Hydrobelts

We aimed at maximizing the homogeneity within the hydrobelts and the differences between them. This objective, however, was limited by our first criteria: river basins cannot be fragmented, even when they include multiple climate and/or vegetation zones. This impacts the characteristics of the hydrobelts in many regions: (i) the headwaters of rivers are often located in elevated regions, resulting in marked altitudinal gradients, such as in Central Asian mountain ranges, the Rocky Mountains, the Alps, the Caucasus Mountains and the Andes; (ii) some elongated rivers oriented in a north to south direction cross different climate zones (e.g. the Nile, the Paraná River, many Siberian and Canadian rivers, and many South and Southeast Asian rivers); (iii) West-East gradients of precipitation and/or temperature, amplified by coastal mountain ranges, may induce marked heterogeneity in such basins (e.g. the Niger and Congo Rivers); (iv) spatial climate variability can be quite high in rugged river basins controlled by present-day tectonics, as, for example, in the Ethiopian Rift Valley and in the Himalayas. All these factors may limit the homogeneity within large basins, hence within a given belt.

The analysis of climates and vegetation distribution in hydrobelts, when using the five Köppen climate zones and the seven Holdridge life zones (Fig. 5), is a good example of the limits of hydrobelt homogeneity. Four hydrobelts are well within a single dominant Köppen climate zone, i.e. exceeding 75 % of the belt area, while the other belts are situated within two main climate zones. Holdridge life zones are fragmented more often by hydrobelts and include two or three dominant zones, except for the Equatorial belt, which is found at 81.8 % within the Holdridge Tropical Zone (Fig. 5). This is partly because there are more life zones than climate zones and, thus, the life zones are more fragmented. The Boreal, Equatorial and North and South Dry belts are the most homogeneous belts, with only one clearly dominant type, while the Mid-Latitude and Subtropical belts are the least homogeneous belts, combining two dominant climate types and three vegetation zones.

5 Discussion

Hydrobelts were designed to aggregate contiguous river basins into a limited number of homogeneous entities. This constraint contains some limitations, which we already pointed out for the climate and vegetation (see Sect. 4.2). Some north versus south symmetry of the hydrobelts was also expected. For the hydrophysical attributes, this symmetry is, however, limited by the unbalanced distribution of landmasses into latitudinal zones. For purposes of population distribution, symmetry cannot be expected due to the uneven history of human settlement on the planet. For these reasons, the

29 hydroregions, i.e. the hydrobelt expressions on each continent, are rather individualised and may thus reveal major discrepancies within a given belt, as shown in the following sections.

5.1 Limitations to the hydrobelt definition

Ideally, hydrobelts should be very homogenous, delineated in one piece and very different from one another, as defined in our objectives. In reality, these objectives are subject to limitations, which are directly dependent on the first and fourth criteria (the delineation of river basins and continental boundaries; see Sect. 2.1) and perturbed by a West-East temperature gradient in Asia. These limitations are discussed below in more detail.

5.1.1 Fragmentation of hydrobelts and hydroregions cannot be avoided

The hydrobelts are divided into twenty-nine hydroregions, which are limited by river basins and continental boundaries. We accepted one minor exception to this general rule: between Central America and the northern coast of South America, where two hydroregions overlap with one another (NST-Nam and EQT-Sam, Fig. 2). We decided that it was better to hold out the Northern Subtropical region around the Caribbean Sea basin. Other reasons for the fragmentation of hydroregions include the uneven distribution of relief and hydroclimates on continents (for example in case of African Equatorial belt) and the occurrence of islands (for example in case of Asian Equatorial belt).

5.1.2 Hydroclimate heterogeneity within a given belt cannot be totally reduced

In contrast to one of our major objectives, the level of hydroclimate heterogeneity cannot be totally reduced within a given belt for two reasons: (i) the use of river basin boundaries as a delineation rule, and (ii) the effect of continentality, particularly on temperatures, for the large number of belts oriented in a west-east direction in the

Northern Hemisphere (Boreal, Mid-Latitude, Dry). This point is illustrated by the 5 % to 95 % percentiles ranges over the cells for temperature, precipitation and runoff in each belt (Fig. 3a–c).

In the three northern belts (Boreal, Mid-Latitude and Dry), the inter-belt temperature ranges are greater than the range of average temperatures between all the other belts (Fig. 3a). The five southern belts have an average temperature range of 9.4 °C (14.5 to 23.9 °C), compared to an inter-belt temperature range of 18.5 °C (from −17.2 °C to +1.3 °C) within the Boreal belt, 25.1 °C (from −1.1 to +24.0 °C) within the Northern Mid-Latitude belt and 29.6 °C within the Northern Dry belt (from −2.4 to +27.2 °C). The five belts from the Northern subtropics to the Southern Mid-Latitude in general have narrower temperature ranges, except for the Southern Dry belt (range 19.3 °C; 6.0 °C–25.3 °C) (Fig. 3a). The 25 % to 75 % range of attributes is thus more appropriate for differentiating the hydrobelts, particularly for annual precipitation and runoff figures (Fig. 3b and c, respectively).

In South Asia, the river basins extend from the polar climates to the dry climates (Indus basin; COSCAT #1336) or wet tropics (Ganges-Brahmaputra basin; COSCAT #1332). After a detailed analysis, we considered both COSCATs, Indus and Ganges-Brahmaputra, to be closer to the Northern Mid-Latitude belt, while we attributed the Irrawaddy-Salween basins (COSCAT #1331) and the Mekong-Chao Phraya (COSCAT #1325), with less extended upper valleys, to the Subtropics.

The Congo River basin biases the definition of the Equatorial belt in Africa (Fig. 2). This basin (COSCAT #0014; 3.7 Mkm^2) is actually much more extended than the wet tropics, as defined by Holdridge (circa 1 Mkm^2), and has a much lower runoff (324 $\mathrm{mm\,yr}^{-1}$) than the other parts of the African Equatorial belt ($q = 1450\,\mathrm{mm\,yr}^{-1}$). The African Equatorial hydroregion is, therefore, rather heterogeneous and includes a large amount of dryer steppe tropical regions: its average runoff is only 460 $\mathrm{mm\,yr}^{-1}$, i.e. only half that of the other equatorial regions (Fig. 4b; Table 4).

5.1.3 Split of large hydroregions

In Asia, the very large belts have been split into separate entities due to their marked east-west temperature gradient (Fig. 4a, Table 4). The Asian Boreal region (14.5 Mkm^2) has been split into *West Siberia,* which faces the Arctic Ocean [BOR_Asi(WSb), 6.5 Mkm^2, −4.3 °C on average], and *East Siberia*, which faces the Arctic Ocean, the Bering Sea and the Okhotsk Sea [*BOR_Asi(ESb)*, 8.0 Mkm^2, −9.7 °C on average]. Similarly, the Asian Northern Dry region (13.6 Mkm^2) has been split into the *Middle East* [NDR_Asi(MdE)], which extends from the Jordan basin to the Iranian endorheic regions (5.2 Mkm^2, +21 °C), with only one major river, the Shatt El Arab (or Euphrates/Tigris), and *Central Asia* [NDR_Asi(CAs)] (8.4 Mkm^2, +5.1 °C), which extends from the tributaries of the East Caspian Sea to the Kerulen in Mongolia, including such Afghanistan rivers as the Helmand (Fig. 2). *All the rivers of Central Asia, as defined here, are endorheic* (Table 4), in contrast to the Middle East rivers basins, of which only 23 % are endorheic, although most of the Arabian Peninsula is presently arheic.

5.2 Hydrobelts can facilitate the reporting of global water issues

Water resources indicators have traditionally been reported for entire countries or by using political aggregations, such as the European Union, or regions defined by the United Nations (UN). The use of a continental approach has also been common in many sectors of global geography, such as geochemistry, geopolitics and population dynamics, particularly for Europe, Africa and North and South America. Nowadays, global mapping can be done at high resolution, but the *reporting of results* has still not been harmonised, whether the results are aggregated to a continental scale or at the level of political regions, nor delineated by natural river basin boundaries. Hydrobelts offer a new reporting perspective. Two examples of reporting population distributions using hydrobelts on a global scale are presented here.

5.2.1 Population distribution via hydrobelts

The first application of hydrobelts is presented for the human population based on 2005 estimates (Klein Goldewijk et al., 2010), i.e. for a global population of 6500 million people (Tables 3 and 4; Fig. 3d). As expected, the North and South hydrobelts differentiate the distribution of population at a coarse resolution, but the east-west discrepancies should be addressed at the hydroregion level.

- The *Boreal belt* is the least populated of all the belts, with 123 Mp (million people). Only 1.9 % of the world's population lives in this cold area, which covers 19.8 % of the planet's total area; it has quite low mean population densities, 4.7 p km^{-2}.
- The *Northern Mid Latitude belt* is the most heavily populated belt, with 3300 Mp; this represents 50.8 % of the total world population living on only 18.5 % of the non-glaciated continental landmass. Its average population density is 136.3 p km^{-2}.
- The *Northern Dry belt* holds 11.5 % of the world's population, despite very limited water resources. In these very dry to desert-type areas, which are present across a large temperature range, population densities (average 24.7 p km^{-2}) are still one order of magnitude higher than those found in the Boreal regions.
- The *Northern Subtropical belt* is the second one in terms of total population, with a total of 1247 Mp (19.2 % of global population for 8.0 % of land). The mean population densities are high, 118.1 p km^{-2} on average, i.e. more than twice the average population density for the world.
- The *Equatorial hydrobelt* is presently less populated than the world's average (37.9 p km^{-2} versus 49.6 p km^{-2}), totalling 647 Mp, i.e. 10 % of the world's population living on 12.8 % of the world's land area. The uneven distribution of population per hydroregion is greatest in this belt.

- The *Southern Subtropical belt*, not as extended as its northern counterpart, is four times less populated, with densities of 28.6 p km^{-2} (compared to 118.1 p km^{-2} for the north) and a total population of only 303 Mp.
- The *Southern Dry belt* has the smallest population of all the belts, with only 42 Mp and a very low average density, 4.8 p km^{-2}, which is equivalent to that of the Boreal belt and five times lower than of the Northern Dry belt.
- The *Southern Mid-Latitude belt* supports only 109 Mp, i.e. 30 times less people than its northern analogue. This striking discrepancy is due to its mean population density, 27.3 p km^{-2}, which is eight times lower and similar to that of the Southern Subtropical belt, 28.6 p km^{-2}. It also comprises a much smaller area than its northern analogue.

As a result of these distributions, 81.4 % of the world's population lives in the three northern hydrobelts (North Mid-Latitude, North Dry, North Subtropics), which cover 49.6 % of the non-glaciated continental landmass. The population density is five times greater in the northern belts than in their southern analogues: 136.3 compared to 27.3 p km^{-2} for the Mid-Latitude belts, 24.7 p km^{-2} compared to 4.8 p km^{-2} for the Dry belt and 118.1 p km^{-2} compared to 28.6 p km^{-2} for the Subtropical belts (Table 3; Fig. 3d). Only 16.6 % of the population lives in the Equatorial and Southern belts, which cover 30 % of landmass, whereas 1.9 % of the world's population lives in the Boreal belt, which covers 19.8 % of the planet's land area (Table 3).

According to our findings, it seems that population density is mostly limited by hydroclimatic conditions in the Boreal belt, and less so in the Dry regions. This is supported by the findings of Kummu et al. (2011). The main control factors explaining the North versus South and "Old World" versus "New World" discrepancies are linked to the different histories of human settlement (McNeill and McNeill, 2003; Klein Goldewijk et al., 2010), as detailed in the results of the population distribution by hydroregions (Table 4; Fig. 4c).

In summary, *human population is not distributed on the continents according to the same statistical laws as the hydroclimate attributes* (Fig. 3d). The intrabelt range of population density, as measured by the 5 % to 95 % percentile ranges, is greatest in the Northern Mid-Latitude belt and the Northern Subtropical belt, i.e. in the most populated belts (an average of 136 p km^{-2} and 118 p km^{-2}, respectively). The distribution of population density over the 30′ cells for a given belt is also skewed towards higher densities. This is due to the occurrence, and sometimes the dominance, of urban population hotspots.

5.2.2 Population in spatial entities

Another type of experimental reporting concerns the amount of population living in hydrobelts vs. those living in continents, represented by bubble charts in a temperature versus runoff domain (Fig. 6). The similarity of hydro-physical attributes between the North and South belts is graphically demonstrated, while the differences in total population are highlighted. When using averages for the continental areas, the population living in the coldest conditions ($< 0\,^{\circ}$C) is totally masked and the population living in dry conditions ($q < 150$ mm yr^{-1}) is almost completely masked from the reporting. When using averages for the hydrobelts, these populations are sufficiently taken into account and quantified (Fig. 6). Such differentiation is amplified at the level of the hydroregions: *the status of water resources, therefore their management, is better described at the hydroregion level than when using geopolitical boundaries*.

6 Conclusions and perspectives

In this paper, we presented the hydrobelt concept, designed for the analysis and reporting of water-related issues. Using four criteria, based purely on hydrophysical features (average temperature, precipitation, runoff and basin boundaries), we divided the world into eight hydrobelts, which are hydrologically as homogenous as possible, while the interbelt differences are differentiated to a significant degree. The Mid-Latitude and Subtropical hydrobelts are roughly distributed along similar latitudes and have northern and southern analogues, while the North Boreal and Equatorial hydrobelts are both unique. The hydrobelts sufficiently take into account many important features of the earth system and hydrological concepts such as endorheism/exorheism, arheism and the former glacial cover of river basins.

We further divided the hydrobelts into 29 hydroregions, which were delineated by natural drainage basin limits and continent boundaries. The hydroclimates are relatively similar within a single belt and in the analogues found in the Northern or Southern Hemispheres. In contrast, the global distribution of population in the hydroregions is quite different due to the history of global demography: (i) the belts in the Northern Hemisphere are more heavily populated than their counterparts in the Southern Hemisphere, (ii) the hydroregions of the “Old World” are much more populous than those of the “New World” and (iii) the Australian hydroregions are much less populated than all other similar hydroregions.

When applying hydrobelts and hydroregions to water resource-related issues, the preliminary analysis shows higher differentiations compared to many conventional aggregations, e.g. those done using continents or political entities. This is well illustrated by the distribution of average population density, which varies over two orders of magnitude when analysed at the level of hydroregions.

We argue, therefore, that hydrobelts and hydroregions could be, in many cases, more appropriate for the global scale reporting of water-related issues, as well as for comparing and/or combining their fixed spatial entities, compared to the more conventionally used continents or other non-physical regional aggregations. The belts could also be useful when the spatial analysis would benefit from including the river basin boundaries in the analyses, e.g. climate change impacts, the relationships between basins and population, water management, aquatic biodiversity, river fluxes and basin yields and their alteration by humans. The double reporting level, eight hydrobelts or twenty-nine hydroregions, also offers flexibility when tabulating and reporting the global scale analyses.

Supplementary material related to this article is available online at: http://www.hydrol-earth-syst-sci-discuss.net/9/9119/2012/hessd-9-9119-2012-supplement.pdf.

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References

Abell, R., Thieme, M. L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S. C., Bussing, W., Stiassny, M. L. J., Skelton, P., Allen, G. R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J. V., Heibel, T. J., Wikramanayake, E., Olson, D., López, H. L., Reis, R. E., Lundberg, J. G., Sabaj Pérez, M. H., and Petry, P.: Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation, BioScience, 58, 403–414, doi:10.1641/b580507, 2008.

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., and Siebert, S.: Development and testing of the WaterGAP 2 global model of water use and availability, Hydrolog. Sci. J., 48, 317–338, 2003.

Arnell, N. W.: Climate change and global water resources: SRES emissions and socio-economic scenarios, Global Environ. Change, 14, 31–52, 2004.

Baumgartner, A. and Reichel, E.: The World Water Balance, Elsevier, 179 pp., 1975.

Brown, J., Ferrians Jr., O. J., Heginbottom, J. A., and Melnikov, E. S.: (revised February 2001) Circum-Arctic map of permafrost and ground-ice conditions, National Snow and Ice Data Center/World Data Center for Glaciology, Digital Media, available at: http://rims.unh.edu/data/data.cgi (last access: 29 August 2011), Boulder, CO, 1998.

Costard, F., Gautier, E., Brunstein, D., Hammadi, J., Fedorov, A., Yang, D., and Dupeyrat, L.: Impact of the global warming on the fluvial thermal erosion over the Lena river in Central Siberia, Geophys. Res. Lett., 34, L14501, doi:10.1029/2007GL030212, 2007.

Cruette, J. and Rodier, J. A.: Mesures de débits de l'Oued Zeroud pendant les crues exceptionneles de l'Automne 1969, Cahiers ORSTOM, Série Hydrologie, 13, 33–64, 1971.

Dukhovny, V. A. and De Schutter, J.: Water in Central Asia: Past, Present and Future, CRC Press Inc, 432 pp., 2011.

Dürr, H., Laruelle, G., van Kempen, C., Slomp, C., Meybeck, M., and Middelkoop, H.: Worldwide Typology of Nearshore Coastal Systems: Defining the Estuarine Filter of River Inputs to the Oceans, Estuar. Coast., 34, 441–458, doi:10.1007/s12237-011-9381-y, 2011.

Dürr, H. H., Meybeck, M., and Dürr, S. H.: Lithologic composition of the Earth's continental surfaces derived from a new digital map emphasizing riverine material transfer, Global Biogeochem. Cy., 19, GB4S10, doi:10.1029/2005GB002515, 2005.

Falkenmark, M.: Meeting water requirements of an expanding world population, Philos. T. R. Soc. B, 352, 929–936, doi:10.1098/rstb.1997.0072, 1997.

Falkenmark, M., Rockström, J., and Karlberg, L.: Present and future water requirements for feeding humanity, Food Security, 1, 59–69, doi:10.1007/s12571-008-0003-x, 2009.

Fekete, B. M., Vörösmarty, C. J., and Grabs, W.: High-resolution fields of global runoff combining observed river discharge and simulated water balances, Global Biogeochem. Cy., 16, 1042, doi:1010.1029/1999GB001254, 2002.

Haines, A. T., Finlayson, B. L., and McMahon, T. A.: A global classification of river regimes, Appl. Geogr., 8, 255–272, 1988.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., and Jarvis, A.: Very high resolution interpolated climate surfaces for global land areas, Int. J. Climatol., 25, 1965–1978, 2005.

Holdridge, L. R.: Life Zone Ecology, Tropical Science Center, San José, 1967.

Islam, S., Oki, T., Kanae, S., Hanasaki, N., Agata, Y., and Yoshimura, K.: A grid-based assessment of global water scarcity including virtual water trading, Water Resour. Manag., 21, 19–33, 2007.

Klein Goldewijk, K., Beusen, A., and Janssen, P.: Long-term dynamic modeling of global population and built-up area in a spatially explicit way: HYDE 3.1, The Holocene, 20, 565–573, 2010.

Köppen, W.: Das Geographische System der Klimate, Handbuch der Klimatologie, Berlin, Germany, 1931.

Korzoun, V. I., Sokolov, A. A., Budyko, M. I., Voskresensky, K. P., Kalinin, G. P., Konoplyantsev, A. A., Korotkevich, E. S., and L'vovich, M. I.: Atlas of World Water Balance and Water Resources of the Earth, USSR Committee for the International Hydrological Decade, Studies and Reports in Hydrology 25, Unesco, Paris, 663 pp., Leningrad, 1978.

Kotwicki, V.: Floods of Lake Eyre, Engineering and Water Supply Department, Adelaide, 99 pp., 1986.

Kulshreshtha, S. N.: A Global Outlook for Water Resources to the Year 2025, Water Resour. Manag., 12, 167–184, doi:10.1023/a:1007957229865, 1998.

Kummu, M. and Varis, O.: The World by latitudes: a global analysis of human population, development level and environment across the north-south axis over the past half century, Appl. Geogr., 31, 495–507, doi:10.1016/j.apgeog.2010.10.009, 2011.

Kummu, M., Ward, P. J., de Moel, H., and Varis, O.: Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia, Environ. Res. Lett., 5, 034006, doi:10.1088/1748-9326/5/3/034006, 2010.

Kummu, M., de Moel, H., Ward, P. J., and Varis, O.: How close do we live to water? A global analysis of population distance to freshwater bodies, PLoS ONE, 6, e20578, doi:10.1371/journal.pone.0020578, 2011.

Laruelle, G. G., Dürr, H. H., Slomp, C. P., and Borges, A. V.: Evaluation of sinks and sources of CO2 in the global coastal ocean using a spatially-explicit typology of estuaries and continental shelves, Geophys. Res. Lett., 37, L15607, doi:10.1029/2010gl043691, 2010.

Leemans, R.: Global Holdridge Life Zone Classifications, in: Global Ecosystems Database Version 2.0, NOAA National Geophysical Data Center, Boulder, Colorado, USA, 1992.

Lehner, B. and Döll, P.: Development and validation of a global database of lakes, reservoirs and wetlands, J. Hydrol., 296, 1–22, 2004.

Ludwig, W. and Probst, J.-L.: River sediment discharge to the oceans: present-day controls and global budgets, Am. J. Sci., 298, 265–295, 1998.

McNeill, J. R. and McNeill, W. H.: The Human Web: A Bird's-Eye View of World History, W. W. Norton & Company, 368 pp., 2003.

Meybeck, M.: How to establish and use world budgets of riverine materials, in: Physical and chemical weathering in geochemical cycles, edited by: Lerman, A. and Meybeck, M., Kluwer Academic Publishers, Dordrecht, 247–272, 1988.

Meybeck, M. and Dürr, H. H.: Cascading Filters of River Material from Headwaters to Regional Seas: The European Example, in: Watersheds, Bays, and Bounded Seas – The Science and Management of Semi-Enclosed Marine Systems, edited by: Urban, E. R. J., Sundby, B., Malanotte-Rizzoli, P., and Melillo, J. M., SCOPE Series, Island Press, Washington, 115–139, 2009.

Meybeck, M. and Ragu, A.: GEMS/Water Contribution to the Global Register of River Inputs (GLORI), Provisional Final Report, UNEP/WHO/UNESCO, Geneva, 245 pp., 1995.

Meybeck, M., Dürr, H. H., and Vörösmarty, C. J.: Global coastal segmentation and its river catchment contributors: a new look at land-ocean linkage, Global Biogeochem. Cy., 20, GB1S90, doi:10.1029/2005GB002540, 2006.

Meybeck, M., Dürr, H. H., Roussennac, S., and Ludwig, W.: Regional Seas and their interception of riverine fluxes to oceans, Mar. Chem., 106 (Wollast Memorial Special Issue), 301–325, 2007.

Millennium Ecosystem Assessment: Ecosystems and Human Well-being: Synthesis, Island Press, Washington, DC, 155 pp., 2005.

Milliman, J. D. and Farnsworth, K. L.: River Discharge to the Coastal Ocean – A Global Synthesis, Cambridge University Press, New York, 2011.

Nilsson, C., Reidy, C. A., Dynesius, M., and Revenga, C.: Fragmentation and flow regulation of the world's large river systems, Science, 308, 405–408, 2005.

Nyamweru, C.: New evidence for the former extent of the Nile drainage system, Geogr. J., 155, 179–188, 1989.

Oki, T. and Kanae, S.: Global Hydrological Cycles and World Water Resources, Science, 313, 1068–1072, doi:10.1126/science.1128845, 2006.

Perthes, J.: Taschen-Atlas über alle Theile der Erde, Gotha, 1845.

Perthes, J.: Sea Atlas, Gotha, 1894.

Petit-Maire, N. and Guo, Z. T.: Mid-Holocene climatic change and man in the present-day Sahara desert, Quaternary Deserts and Climatic Change, Al Ain/United Arab Emirates, 351–356, 1995.

Potter, P. E.: Petrology and chemistry of modern big river sands, J. Geol., 86, 423–449, 1978.

Potter, P. E. and Hamblin, W. K.: Big Rivers Worldwide, Brigham Young University, Geology Studies, Provo,Utah, 78 pp., 2006.

Probst, J.-L.: Géochimie et Hydrochimie de l' érosion continentale. Mécanismes, bilan global actuel et fluctuations au cours des 500 derniers millions d'années, Sciences Géologiques Mémoires 94, Strasbourg, 161 pp., 1992.

Probst, J. L., Ludwig, W., and Amiotte Suchet, P.: Global modelling of CO_2 uptake by continental erosion and of carbon river transport to the oceans, Science Geological Bulletin, 50, 131–156, 1997.

Rockström, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S., and Gerten, D.: Future water availability for global food production: The potential of green water for increasing resilience to global change, Water Resour. Res., 45, W00A12, doi:10.1029/2007WR006767, 2009.

Rodier, J. A.: Régimes hydrologiques de l'Afrique Noire à l'ouest du Congo, Mém, Orstom, Paris, 137 pp., 1964.

Rubel, F. and Kottek, M.: Observed and projected climate shifts 1901–2100 depicted by world maps of the Köppen-Geiger climate classification, Meteorol. Z., 19, 135–141, 2010.

Said, R.: The River Nile – Geology, Hydrology and Utilisation, 1st Edn., Pergamon Press, Oxford, New York, Seoul, Tokyo, 320 pp., 1993.

Schultz, J.: The ecozones of the World, Springer, 252 pp., 2005.

Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H. W., and Bouwman, A. F.: Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: an overview of Global Nutrient Export from Watersheds (NEWS) models and their application, Global Biogeochem. Cy., 19, GB4S01, doi:10.1029/2005GB002606, 2005.

Seitzinger, S. P., Mayorga, E., Bouwman, A. F., Kroeze, C., Beusen, A. H. W., Billen, G., Drecht, G. V., Dumont, E., Fekete, B. M., Garnier, J., and Harrison, J. A.: Global river nutrient export: A scenario analysis of past and future trends, Global Biogeochem. Cy., 24, GB0A08, doi:10.1029/2009GB003587, 2010.

Sullivan, C. A., Meigh, J. R., Giacomello, A. M., Fediw, T., Lawrence, P., Samad, M., Mlote, S., Hutton, C., Allan, J. A., Schulze, R. E., Dlamini, D. J. M., Cosgrove, W., Priscoli, J. D., Gleick, P., Smout, I., Cobbing, J., Calow, R., Hunt, C., Hussain, A., Acreman, M. C., King, J., Malomo, S., Tate, E. L., O'Regan, D., Milner, S., and Steyl, I.: The Water Poverty Index: Development and application at the community scale, Nat. Resour. Forum, 27, 189–199, 2003.

Tedesco, P. A., Hugueny, B., Oberdorff, T., Dürr, H. H., Mérigoux, S., and de Mérona, B.: River hydrological seasonality influences life history strategies of tropical riverine fishes, Oecologia, 156, 691–702, doi:10.1007/s00442-008-1021-2, 2008.

van Beek, L. P. H., Wada, Y., and Bierkens, M. F. P.: Global monthly water stress: 1. Water balance and water availability, Water Resour. Res., 47, W07517, doi:10.1029/2010wr009791, 2011.

Viviroli, D., Dürr, H. H., Messerli, B., Meybeck, M., and Weingartner, R.: Mountains of the world – water towers for humanity: typology, mapping and global significance, Water Resour. Res., 43, W07447, doi:10.1029/2006WR005653, 2007.

Vörösmarty, C. J., Sharma, K., Fekete, B., Copeland, A. H., Holden, J., Marble, J., and Lough, J. A.: The storage and aging of continental runoff in large reservoir systems of the world, Ambio, 26, 210–219, 1997.

Vörösmarty, C. J., Fekete, B. M., Meybeck, M., and Lammers, R. B.: The global system of rivers: its role in organizing continental land mass and defining land-to-ocean linkages, Global Biogeochem. Cy., 14, 599–621, 2000a.

Vörösmarty, C. J., Fekete, B. M., Meybeck, M., and Lammers, R. B.: Geomorphometric attributes of the global system of rivers at 30-minute spatial resolution, J. Hydrol., 237, 17–39, 2000b.

Vörösmarty, C. J., Green, P., Salisbury, J., and Lammers, R. B.: Global Water Resources: Vulnerability from Climate Change and Population Growth, Science, 289, 284–288, 2000c.

Wada, Y., Beek, L. P. H. v., Viviroli, D., Dürr, H. H., Weingartner, R., and Bierkens, M. F. P.: Global monthly water stress: 2. Water demand and severity of water stress, Water Resour. Res., 47, W07518, doi:10.1029/2010WR009792, 2011.

World Water Assessment Programme: The United Nations World Water Development Report 3: Water in a Changing World, Paris: UNESCO, and London: Earthscan, 2009.

Table 1. Target limits of annual average temperature (T) and runoff (q) for aggregated river basins defining hydrobelts.

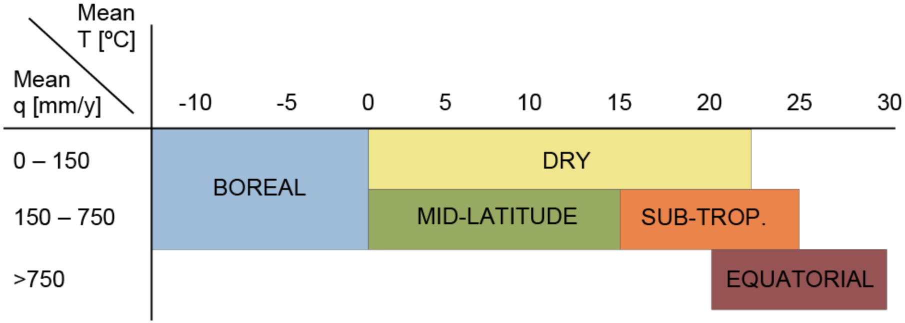

Table 2. Datasets used for the hydrobelt delineation and analysis.

Indicator/ Index	Year	Source	Data format	Notes
COSCAT	~ 1960–1990	Meybeck et al. (2006)	Gridded Polygon	Global spatial data with 30′ resolution (~ 60 km at the equator)
Temperature	1960–1990	WorldClim v1.4 (Hijmans et al., 2005)	Raster	Global spatial data with 30″ resolution (~ 1 km at the equator)
Runoff	~ 1960–1990	Fekete et al. (2002)	Raster	Global spatial data with 30′ resolution (~ 60 km at the equator)
Precipitation	1960–1990	WorldClim v1.4 (Hijmans et al., 2005)	Raster	Global spatial data with 30″ resolution (~ 1 km at the equator)
Exorheism/ endorheism	~ 1960–1990	Vörösmarty et al. (2000a,b)	Gridded Polygon	Global spatial data with 30′ resolution (~ 60 km at the equator)
Permafrost	~ 1960–1990	Brown et al. (1998)	Raster	Spatial data with 30′ resolution (~ 60 km at the equator); Northern Hemisphere only (very minor occurrences in Southern Hemisphere)
Glacier cover	Quaternary	Dürr et al. (2005)	Polygon	Global data; Maximum ice extent throughout one of the Quaternary ice ages (mostly Late Glacial Maximum but not necessarily)
Holdridge life-zones	1990	Leemans (1992)	Grid	Global spatial data with 5′ resolution (~ 10 km at the equator)
Climate regions	1975–2005	Rubel and Kottek (2010)	Polygon	The average Köppen-Geiger climate c lassification for the year 1975–2005.
Population density	2005	HYDE (Klein Goldewijk et al., 2010)	Raster	Global spatial data with 5′ resolution (~ 10 km at the equator)

Table 3. General average characteristics of Hydrobelts (cell averages, weighted averages and totals). BOR = Boreal, NML = Northern Mid Latitude, NDR = Northern Dry, NST = Northern Sub Tropical, EQT = Equatorial belts and SML, SDR, SST their Southern analogues (see Fig. 2 for their spatial distributions and Table 2 for data sources of the used datasets).

Name	Mean	Area	Of which belongs to				Temp	Prec	Runoff	p_{dens}	Pop.
	lat. [°]	[10^3 km^2]	Endorheic	Arheism	Permafr.	Glaciat.	[°C]	[mm]	[mm]	[p km^{-2}]	[10^6 p]
BOR	62	25,983	–	0.4 %	74.8 %	54.3 %	−6.6	437	223	4.7	123
NML	43	24,209	8.7 %	1.0 %	6.1 %	27.8 %	9.1	809	343	136.4	3300
NDR	29	30,258	41.2 %	38.8 %	6.1 %	4.0 %	17.2	253	36	24.5	740
NST	17	10 559	3.5 %	0.7 %	1.7 %	1.7 %	23.9	1112	383	118.4	1252
EQT	−3	16 826	–	0.2 %	–	–	23.9	2,124	960	37.9	638
SST	−17	10 599	0.6 %	3.9 %	–	0.4 %	21.9	1035	233	28.6	303
SDR	−27	8677	42.4 %	56.7 %	–	4.0 %	18.3	318	31	4.8	42
SML	−34	4008	–	4.7 %	–	10.7 %	14.5	872	292	27.3	109
TOTAL[a]	31	131 119	14.3 %	13.5 %	17.6 %	17.7 %	12.7	789	277	49.6	6509
Glaciated[b]	NA	15,430				100 %					0.1

[a] Total of non-glaciated land; [b] throughout one of the Quaternary ice ages.

Table 4. General average characteristics of Hydroregions (weighted averages and totals) presented in three North-South profiles. BOR = Boreal, NML = Northern Mid Latitude, NDR = Northern Dry, NST = Northern Sub Tropical, EQT = Equatorial belts and SML, SDR, SST their Southern analogues; North America (NAm), South America (SAm), Europe (Eur), Africa (Afr), Asia (Asi) and Australia (Aus) (see Fig. 2 for their spatial distributions). For other abbreviations see Table 2.

Name	Mean	Area	Of which belongs to				Temp	Prec	Runoff	p_{dens}	Pop.
	lat. [°]	[10^3 km^2]	Endorheic	Arheism	Permafr.	Glaciat.	[°C]	[mm]	[10^6]	[p km^{-2}]	[10^6 p]
BOR_Nam	60.6	9383	–	1.1 %	80.6 %	87.7 %	−6.7	426	224	0.8	7.4
NML_Nam	42.1	7667	–	1.2 %	6.4 %	44.2 %	8.0	874	345	39.7	304
NDR_Nam	31.2	2835	15.1 %	12.5 %	1.3 %	2.3 %	14.5	424	37	25.4	72
NST_Nam	19.7	1634	–	1.7 %	–	–	21.8	1440	439	104.5	171
EQT_Sam	−3.8	9183	–	0.1 %	–	–	24.1	2171	1069	10.9	100
SST_Sam	−18.4	5054	–	0.2 %	–	0.7 %	21.5	1126	235	33.4	169
SDR_Sam	−31.5	1835	29.3 %	22.3 %	–	18.8 %	10.3	290	111	12.1	22
SML_Sam	−35.1	1696	–	0.3 %	–	23.4 %	12.9	1031	462	39.1	66
BOR_Eur	65.2	2069	–	–	30.4 %	77.3 %	−1.4	615	370	4.7	10
NML_Eur	49.1	8632	24.4 %	0.5 %	2.2 %	25.5 %	7.2	658	250	90.1	778
NDR_Afr	18.7	13 825	17.9 %	51.6 %	–	–	23.6	290	35	27.6	382
NST_Afr	12.8	4704	7.8 %	0.8 %	–	–	26.3	735	165	55.2	260
EQT_Afr	−1.5	4620	–	–	–	–	23.2	1630	460	24.1	111
SST_Afr	−15.1	4230	1.6 %	2.4 %	–	–	21.3	966	254	31.6	134
SDR_Afr	−23.8	2150	39.9 %	16.1 %	–	–	18.6	390	18	7.4	16
SML_Afr	−31.0	387	–	34.3 %	–	–	15.9	616	56	48.3	19
BOR_Asi(WSb)	58.7	6529	–	0.0 %	64.5 %	23.0 %	−4.3	432	199	5.8	38
BOR_Asi(ESb)	60.6	8014	–	0.1 %	87.9 %	34.7 %	−9.7	409	206	8.5	68
NML_Asi	32.1	7900	–	1.4 %	10.1 %	14.4 %	12.2	909	440	280.8	2218
NDR_Asi(MdE)	27.0	5189	22.7 %	35.5 %	–	–	21.0	154	35	33.7	175
NDR_Asi(CAs)	41.6	8386	100.0 %	17.5 %	21.5 %	13.7 %	5.1	192	36	13.3	112
NST_Asi	19.9	4241	–	0.2 %	4.2 %	4.2 %	21.9	1403	606	193.8	822
EQT_Asi	−0.1	3023	–	0.5 %	–	–	24.3	2738	1393	141.2	427
SST_Aus	−16.9	1314	–	22.7 %	–	–	25.1	908	157	0.7	0.9
SDR_Aus	−25.6	4692	48.6 %	88.6 %	–	–	21.3	296	6	0.8	3.9
SML_Aus	−32.7	1925	–	2.6 %	–	1.7 %	15.6	784	188	12.7	24
TOTAL	31	131 119	14.1 %	13.5 %	17.6 %	17.7 %	12.7	789	277	49.6	6509

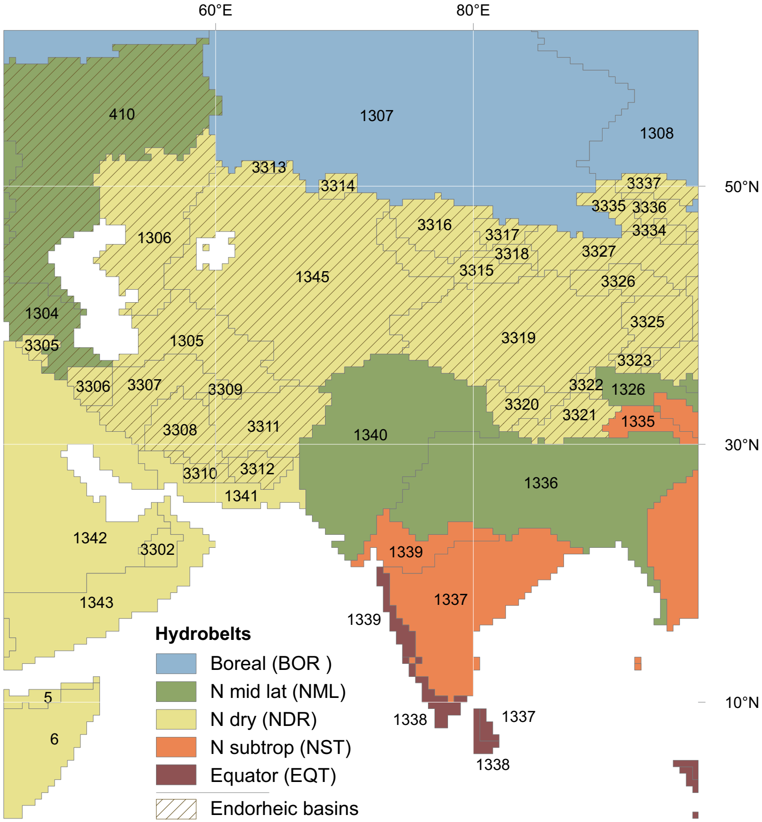

Fig. 1. Delineation of coastal catchment (COSCATs), exorheic and endorheic river basins and their aggregation into hydrobelts: example of Central and South Asia. COSCATs coding (except endorheic regions) from Meybeck et al. (2006) (see the Supplement for tabulated information and coding of the endorheic COSCATs).

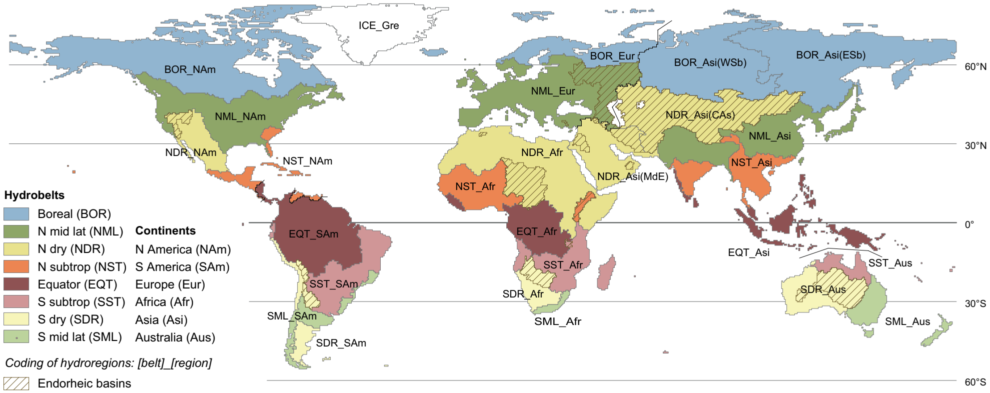

Fig. 2. Limits and coding of global hydrobelts and hydroregions.

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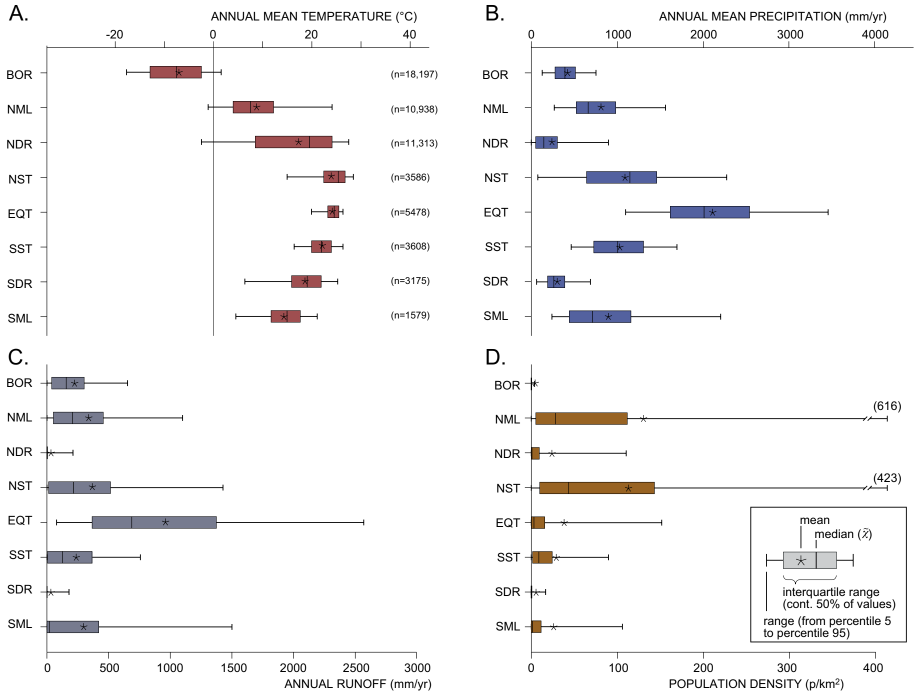

Fig. 3. Distribution of average annual cell characteristics in hydrobelts presented with box plot graphs. **(A)** annual mean temperature; **(B)** annual mean precipitation; **(C)** annual runoff; and **(D)** population density. BOR = Boreal, NML = Northern Mid Latitude, NDR = Northern Dry, NST = Northern Sub Tropical, EQT = Equatorial belts and SML, SDR, SST their Southern analogues (see Fig. 2 for their spatial distributions). Ranges correspond to the 5–95 percentile distribution. Note: outliers are not plotted.

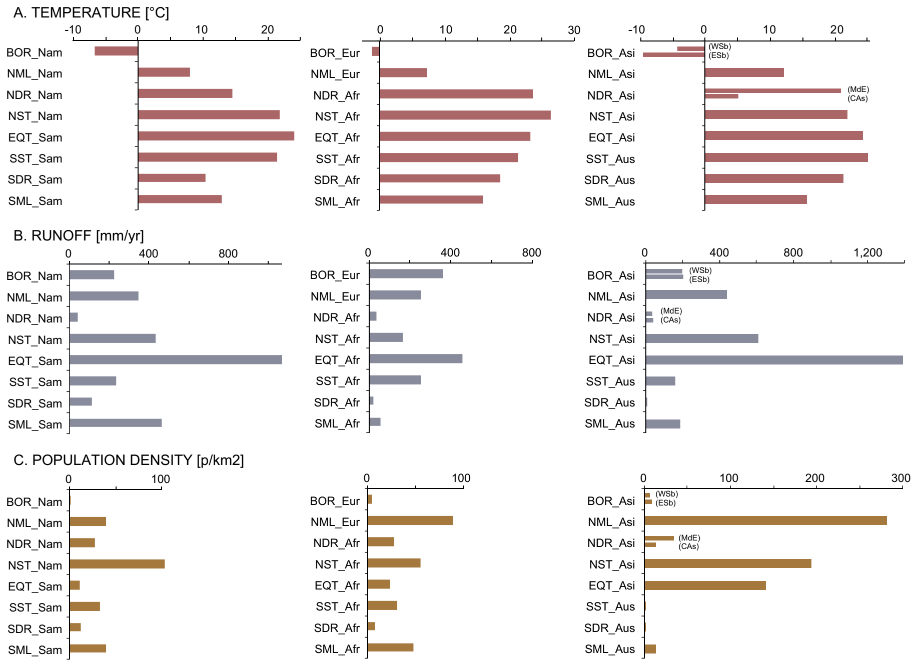

Fig. 4. North to South distributions for the 29 individual hydroregions on each continent along three North-South profiles: (1) North America (NAm) and South America (SAm), (2) Europe (Eur) and Africa (Afr), (3) Asia (Asi) and Australia (Aus). **(A)** average temperatures; **(B)** runoff; and **(C)** population density. BOR = Boreal, NML = Northern Mid Latitude, NDR = Northern Dry, NST = Northern Sub Tropical, EQT = Equatorial belts and SML, SDR, SST their Southern analogues (see Fig. 2 for their spatial distributions).

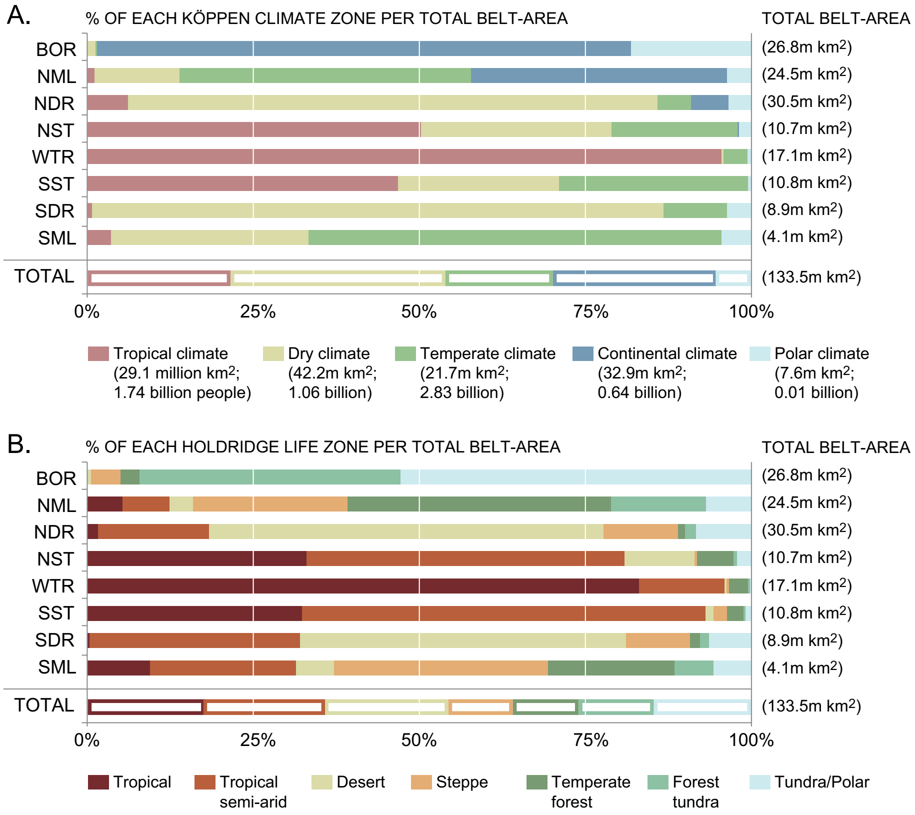

Fig. 5. Distribution of the proportions of Köppen Climate zones **(A)** and of Holdridge life zones **(B)** in hydrobelts, in % of total for a given belt.

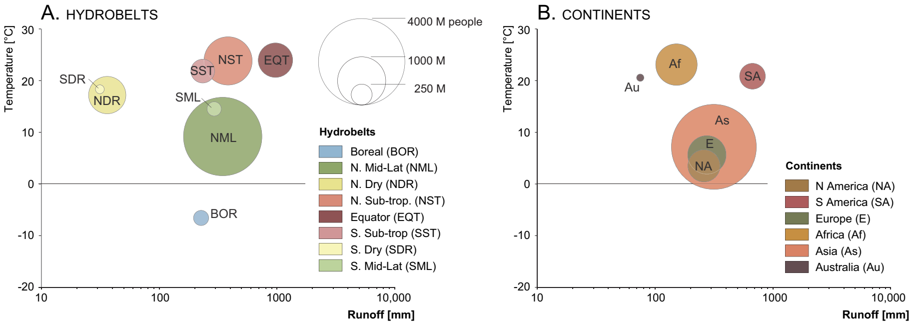

Fig. 6. Bubble chart of populations represented in a runoff vs. temperature domain. **(A)** reporting using hydrobelts, and, **(B)** reporting using continents ($30'$ cell averages of annual figures for temperatures and runoff).