What defines a "Reasonable Utilization" of an International River? With Application to the Niger Basin and Nile Basin

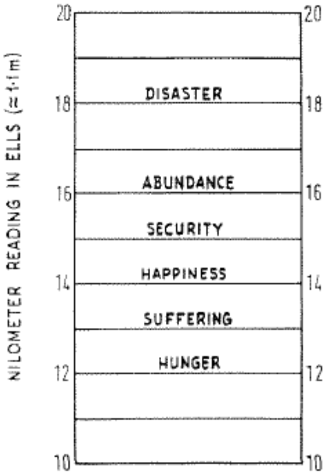

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*Illustration from Dooge (1988).

What defines a “Reasonable Utilization” of an International River? With Application to the Niger Basin and Nile Basin

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ABSTRACT

The general principles of the UN Convention on the Law of the Non-navigational Uses of International Watercourses include “*Equitable and reasonable utilization and participation”*. Here, we address the question of what defines a “reasonable utilization” of an international river?

While “equitable” utilization can be defined using tools of social sciences, we assume that “reasonable” utilization is a concept that has to be grounded, at least partly, in principles of physical sciences. We emphasize two main “hydrologic” services of rivers: (i) to offer natural drainage for some sub-basins, and (ii) to offer natural irrigation in other sub-basins. Which of these services dominate would depend on “climate” and “hydrology” of the sub-basin under consideration. We use the hydrologic theory of Budyko to link hydrology and climate, and to develop a criterion for objective determination of the dominant regime in a river sub-basin and the associated hydrologic service. We interpret “reasonable utilization” concept in light of these two hydrologic services offered by the river. Identification of these services enable objective definition of the water resources to be utilized and shared. Without defining these resources, their “utilization” cannot be “reasoned” objectively. The theory, and examples from the Niger basin and the Nile basin, offered in this report illustrate that determination of the hydrologic service that is provided by an international river is a necessary step before applying the principles of the water convention. Without determination of which of these services dominate (drainage vs irrigation), no “reasonable” utilization of the resources offered by the river can be reached.

Judges, politicians, and social scientists attempting to define “equitable” utilization of the resources and services offered by an international river basin, need to start by defining the “natural character” of the river. Different rivers have different “natural characters”. These differences manifest themselves in the nature of hydrologic services they offer (drainage vs irrigation), and in the spatial distribution of these services. Without identification and recognition of these objective differences, the dialogue about “cooperation” and “equitable” utilization, which is encouraged by the water convention, would be hampered by “confusion” and hence is not likely to produce lasting agreements.

Introduction:

The UN Convention on the Law of the Non-navigational Uses of International Watercourses, UN (1997), defines a “watercourse” to mean “a system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus”. Here, we focus on surface waters, or rivers. The general principles of this convention are spelled in Articles 5-10, summarized by the headings below:

5. *Equitable and reasonable utilization and participation;*
6. *Factors relevant to equitable and reasonable utilization;*
7. *Obligation not to cause significant harm;*
8. *General obligation to cooperate;*
9. *Regular exchange of data and information;*
10. *Relationship between different kinds of uses*.

The question addressed in this report is what defines a “reasonable utilization” with reference to this convention? And how that interpretation can be applied in practice. We use the Niger basin and the Nile basin as examples for illustrating the theoretical concepts introduced in this report.

General Theory:

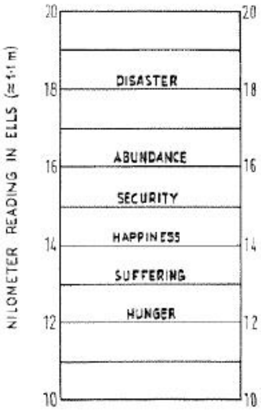
While equitable utilization and participation can be interpreted and defined using tools of social sciences, we assume that “reasonable” utilization is a concept that has to be grounded, at least partly, in principles of physical sciences. For any concept or agreement to be reasonable, that concept has to be consistent with scientific knowledge, specially what we know about nature and how it works. As such, arguments and agreements can then be reasoned and justified on solid objective foundations. Under “reasonable utilization”, the convention stipulates that rivers “be used and developed by watercourse states with a view to attaining optimal and sustainable utilization....”. The factors relevant to equitable and reasonable utilization, specified by the convention, include “geographic, hydrographic, hydrological, climatic, ecological and other factors of a natural character”. There is a clear emphasis on sustainability, natural character of rivers, and explicit reference to the sciences of hydrology, climate and ecology.

The science of hydrology is about the natural behavior of water, including flow in rivers. For millennia, naturalists such as Pliny the Elder documented the important role of water in people life, and how natural variability is the norm defining hydrology of rivers. Too much water causes flooding and disasters, and too little water causes suffering and hunger (Figure 1). Natural rivers work to drain regions overwhelmed by water surplus and flooding, and elsewhere rivers work to irrigate lands suffering from deficits and droughts. For examples, rivers in Britain and Ireland drain the wet soils and discharge the excess water to the ocean making land cultivation possible. Similarly, rivers in the American Midwest such as the Illinois river drain the soils, enabling one of the most productive agricultural systems. Agricultural drainage of soils using subsurface tile and surface drainage ditches has been practiced in the upper Midwest of the United States (e.g. Iowa) for more than a century (Franz et al (2014)). On the other hand, rivers like the main Nile and the lower Tigris and Euphrates supply water to dry soils in arid regions which makes irrigation and agriculture possible. Natural irrigation due to seasonal flooding of the river banks supported irrigation in these arid regions for millennia.

The term “natural irrigation” is defined in this report as the natural process through which the river discharge declines as water travels downstream due to either infiltration through the wetted perimeter of the river, or infiltration through the wetted land area of the valley as the river seasonally floods the surroundings. This term is not used to mean the” man-made irrigation” practiced by forcibly removing water from the river using man-made infrastructure such as dams and canals.

Two important “hydrologic” services of rivers are to drain soils where rainfall is excessive, and to supply and irrigate lands where rainfall is too little. The 20th century hydrologist Budyko developed a theory that links hydrology to climate. He proposed a universal relationship between two indices, one describing climate and the other describing hydrology (Budyko’s theory is well described by Donohue et al. (2007)). The climate index (dryness index) is defined by the ratio of atmospheric demand for evaporation (potential evaporation (PET)) to the actual atmospheric supply of water (precipitation (P)). The hydrology index (evaporative index) is defined by the ratio of actual evaporation (AET) to the actual atmospheric supply of water (P). Budyko postulates that the relationship between the two indices is universal described by the black line

Pliny the Elder (AD 23- AD 79)



Dooge (1988)

Figure 1: Pliny the Elder, and his description of hydrologic conditions in Egypt as illustrated by Jim Dooge, Dooge (1988)

(Budyko curve) in Figure 2. Observations from many different regions support the theory of Budyko. For examples please see Donohue et al. (2007).

From the perspective of evaporation physics, the Budyko curve of Figure 2 defines two regimes: a regime where evaporation is smaller than precipitation and the rate of evaporation is limited by the availability of energy to vaporize water, and a regime where evaporation consumes all the water availed by precipitation and hence the lack of additional water limits the rate of evaporation. Climate as characterized by the dryness index of Figure 2 dictates which regime dominates the river basin (or sub-basin): an energy limited regime, or a water limited regime.

The physics of runoff tell a story similar to that of evaporation, since runoff and evaporation are the two complementary components of precipitation. Under the energy limited regime, runoff is produced at the hillslopes, as the difference between precipitation and evaporation, and rivers assume the responsibility of transporting that water away, driven by the force of gravity. In absence of the river channel network and associated gradients, the generated runoff piles up on the hillslopes leading to flooding and swampy conditions. The main hydrologic service of the river network, under these conditions, is to transport the water generated by runoff away, draining the soils, enabling growth of natural vegetation and cultivation of crops. Some major rivers such as the Amazon and the Congo travel across vast basins falling under the energy limited regime, and transport downstream an increasing load of water and sediment, eventually discharging into the oceans. However, other rivers such as the Nile, the Tigris, and Euphrates transport water from sub-basins where energy is limiting into sub-basins where water is limiting. Under the water limited regime, no runoff is generated and all the precipitation is consumed by evaporation. Further, some of the river flowing into sub-basins dominated by this regime may naturally flood the surrounding valley and naturally irrigate the soils.

Here, we emphasize that two important “hydrologic” services of rivers are to offer natural drainage for some sub-basins, and to offer natural flooding and irrigation in other sub-basins. Which of these services dominate would depend on the “climate” and “hydrology” of the basin considered (Please see Figure 2). Hence, in discussing the water convention, we need to interpret the “reasonable utilization” concept in light of these two hydrologic services offered by the river.

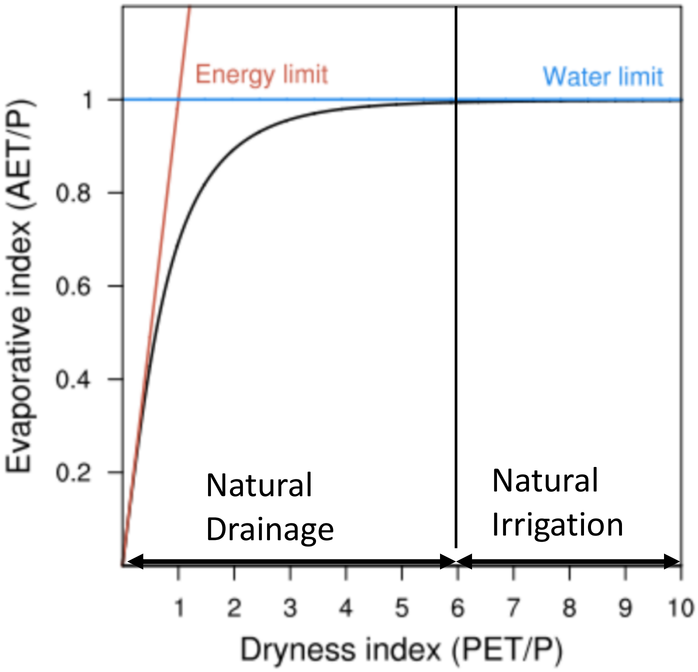


Figure 2: Budyko Curve

The rationale behind this statement stems from the fact that these hydrologic services objectively define the nature and scale of the resources to be utilized. Without defining these resources, their “utilization” cannot be “reasoned” objectively. The discussion of “reasonable utilization” would then reflect subjective assumptions about the nature and the scale of the resources that are subject to “equitable and reasonable utilization”.

The hydrologic services, grounded in the sciences of “climate” and “hydrology”, define the “natural character” of the river. Respecting this “natural character” and insuring the continuity of these services for communities living in the sub-basins is the defining theme for “sustainable” utilization. Ignoring the “natural character” of an international river, and how different sub-basins of the river provide different types of hydrologic services, cannot form the bases for “reasonable utilization”, consistent with the convention. Acknowledging these services and their benefits to society is the starting point in any rational dialogue about sharing the benefits of the river. Some countries may benefit from the natural drainage service offered by the river, and this hydrologic service cannot be denied by building dams downstream that would result in flooding of vast lands upstream. That would not be a “reasonable utilization”. Other countries may have benefited for millennia from the natural flooding by the river and associated irrigation, bringing needed water to their arid land. This hydrologic service cannot be suddenly denied due to changes in social conditions upstream. That would similarly not constitute “reasonable utilization”. However, some limited adjustments to these services can be mutually agreed to by upstream and downstream countries, consistent with other principles of the convention.

There are two categories of international rivers: rivers that provide spatially uniform hydrologic service draining the soils, and eventually discharging excess water to the ocean, such as the Amazon and the Congo; and rivers that provide a mix of hydrologic services: draining the soils in upstream sub-basins, followed by irrigation of soils in downstream sub-basins, such as the Tigris, Euphrates, and the Nile.

Rivers around the world have been offering their hydrologic services before emergence of human societies. The early history of human civilizations describes societies that either benefited from rain falling directly over naturally drained soils, or involved settlements along the bank of rivers benefiting from natural irrigation service offered by the river.

Application to the Niger Basin:

In applying the general theory presented in the previous section, we focus first on the Niger river Basin, defined here as the main river flowing from the highlands in Guinea northward though Mali, and then bending clockwise through Niger, and finally towards the south through Nigeria discharging into the Atlantic Ocean (Figure (3)). As the distribution of precipitation shown in Figure 3 indicates, Guinea and southern Nigeria enjoy plenty of rainfall, Mali receives limited rainfall amounts, located in the transition zone between the hydroclimatic extremes of Guinea and Niger at the border with the Sahara Desert.

The stretch of the Niger basin shown in Figure 3 is an example of an international river shared by 4 countries. Based on climate data from the Climate Research Unit (CRU), Figure 3 presents the variation of precipitation, actual evaporation, and potential evaporation, along the river valley. The dryness index during the rainy season is shown in Figure 4. During the rainy season defined here as (June-July-August), in the first 1000 kilometers downstream from the source and the last 1000 kilometers upstream from the ocean, the dryness index (PET/PR) is less than 1, and as a result the Budyko index is less than 1, indicating dominance of the natural drainage regime. In Northern Mali at the border of the Sahara Desert, the dryness index exceeds about 5, and the Budyko index reaches 1, indicating dominance of the natural irrigation regime, according to Figure 2.

During the rainy season defined here as precipitation exceeds actual evaporation over most of the basin, but with significantly large differences between evaporation and precipitation in Guinea and Southern Nigeria. The sub-basins of the Niger basin in Guinea and Southern Nigeria are the areas where natural drainage is the dominant hydrologic service of the river. Downstream from Guinea in Northern Mali and Niger, the natural irrigation regime dominates. This is especially true if we consider hydrologic fluxes at annual time scales.

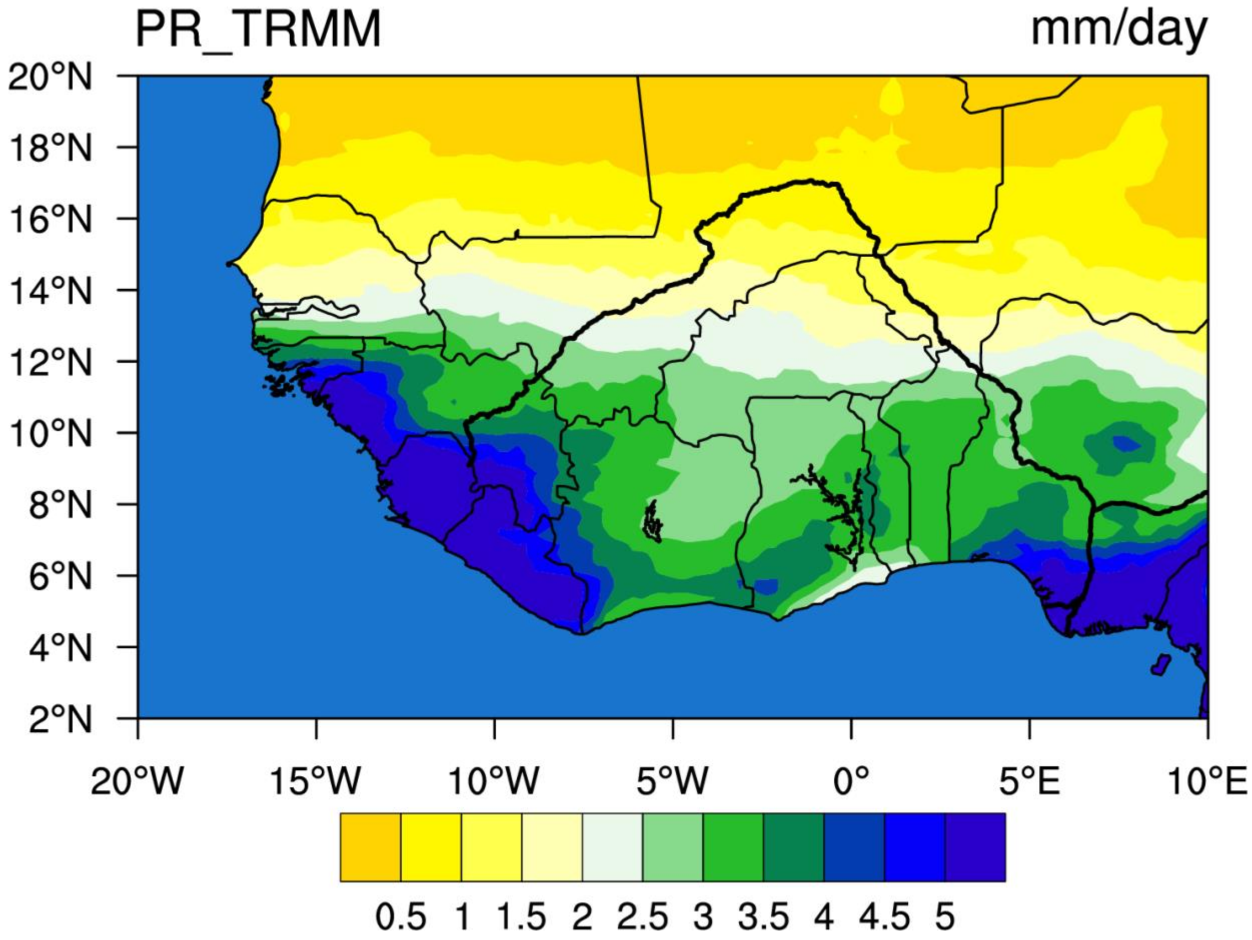


Figure 3: Distribution of annual precipitation in the Niger Basin, in mm/day, based on observations from the Tropical Rainfall Measuring Mission (TRMM)

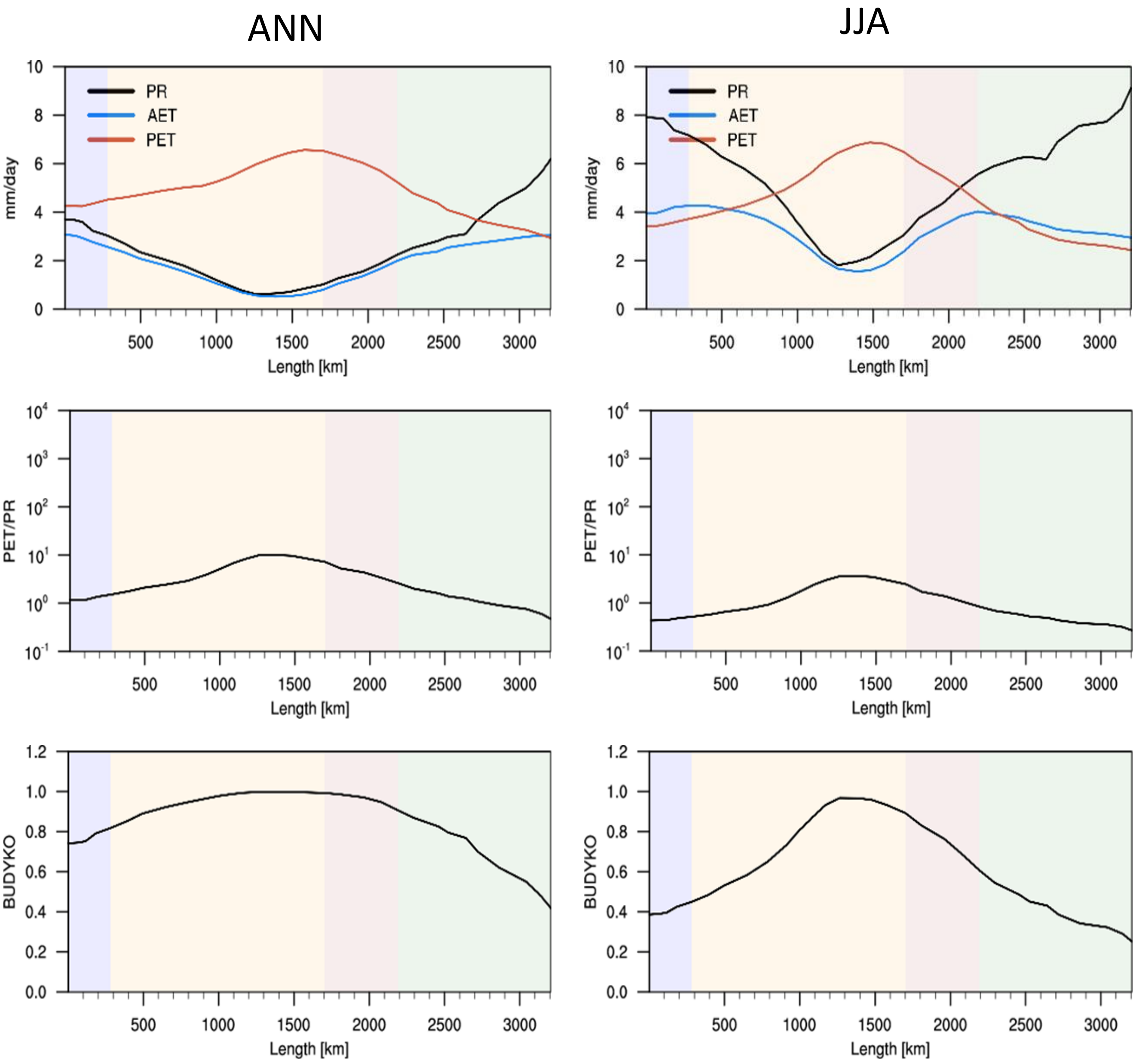


Figure 4: Application of the theory in the Niger basin.
Walking down the river from Guinea to Nigeria (ANN is annual; JJA is June, July, August)
PR: precipitation; AET: Actual evapotranspiration; PET: Potential evapotranspiration;
Blue: Guinea, Yellow: Mali, red: Niger, Green: Nigeria

The stretch of the river from Niger to Southern Nigeria presents an interesting and unique case where the river transports water from the desert border into the humid topics of Africa! In discussing “reasonable utilization” of the Niger river, this natural character of the river is an important background information. This unique setting provides an excellent example for the need to consider the diversity of natural characters at different segments of any river in the analysis of what constitutes a “reasonable” utilization of an international river.

In applying the principles of the water convention in any analysis on how to share the Niger river water between riparian countries, recognition of these different natural regimes and the different hydrologic services identified above should be the starting point towards “reasonable” utilization of the river and its resources.

Application to the Eastern Nile Basin:

In a second application of the general theory, we focus on a segment of the Eastern Nile Basin, defined here as the valley surrounding Abay river in Ethiopia, the Blue Nile in Sudan, and the Nile in Sudan and Egypt (Figure (5)) (a broader definition of the Eastern Nile includes Eritrea and South Sudan). As the distribution of precipitation shown in Figure 5 indicates, Ethiopia enjoys plenty of rainfall, Egypt receives very little, and Sudan is the transition zone between these two hydroclimatic extremes.

The Eastern Nile basin is an example of an international river shared by 3 countries. Based on data from the Climate Research Unit (CRU), Figure 6 presents, for the rainy season as well as annual time scale, the variation of precipitation, actual evaporation, and potential evaporation, along the river valley downstream from lake Tana. The region where precipitation exceeds actual evaporation includes the Abay river in Ethiopia and about 400 km stretch of the Blue Nile in Sudan. This sub-basin of the Eastern Nile is where natural drainage is the dominant hydrologic service of the river. Downstream along the Blue Nile in Sudan and along the Nile in Sudan and Egypt, the natural irrigation regime dominates.

The dryness index (PET/PR) increases persistently downstream as shown in Figure 6. In the first 1200 kilometers downstream from lake Tana, the dryness index is close to 1 (see Figure 5), and the Budyko index is less than 1, indicating dominance of the natural drainage regime. A few

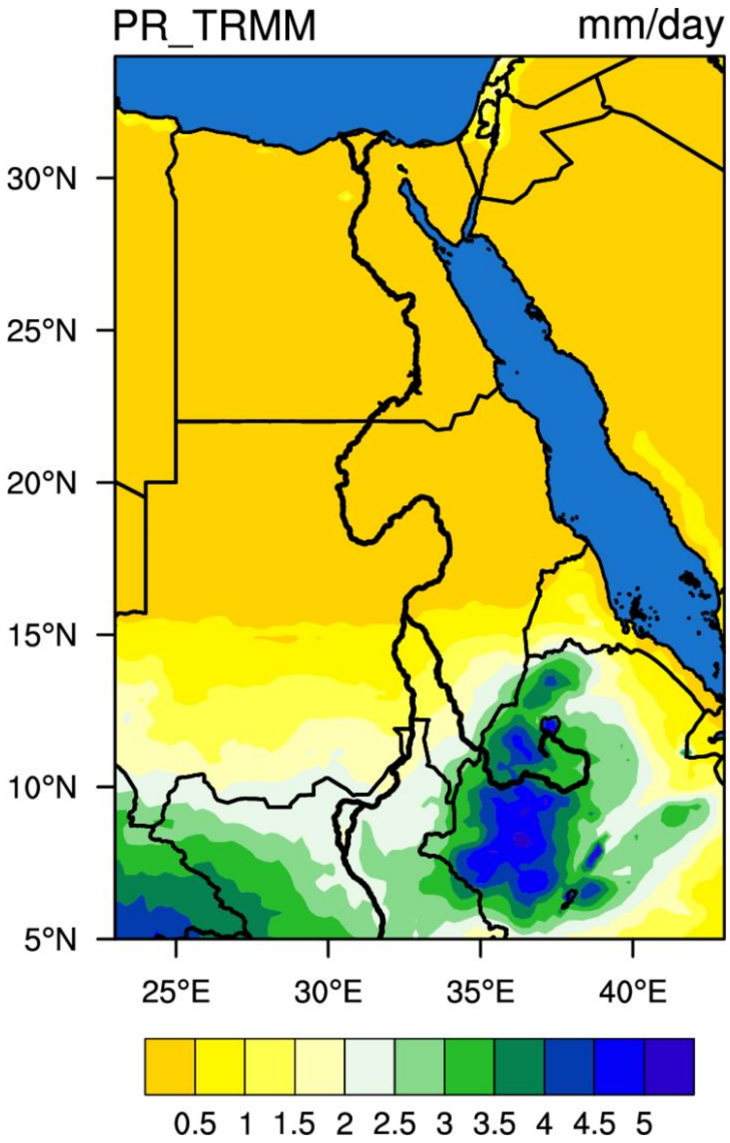


Figure 5: Distribution of annual precipitation in the Eastern Nile Basin, in mm/day, based on observations from the Tropical Rainfall Measuring Mission (TRMM)

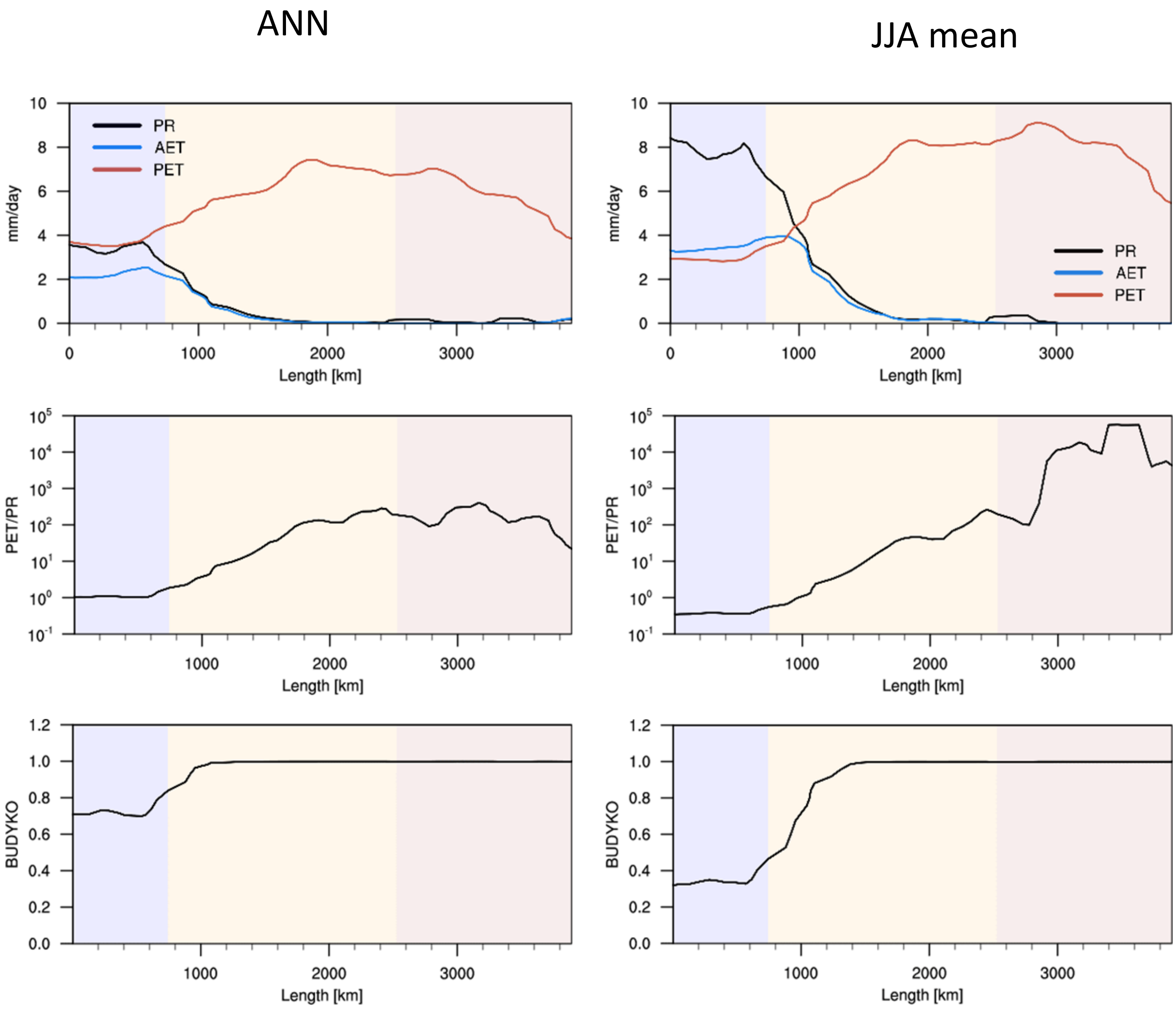


Figure 6: Application of the theory in the Nile basin.
Walking down the river from Lake Tana to Mediterranean (ANN is annual; JJA is June, July, August)
PR: precipitation; AET: Actual evapotranspiration; PET: Potential evapotranspiration;
Blue: Ethiopia, Yellow: Sudan, red: Egypt

hundreds of kilometers into Sudan, the dryness index exceeds about 6, and the Budyko index reaches 1 (Figure 4), indicating dominance of the natural irrigation regime, according to Figure 2. These findings are more evident during the rainy season than at the annual time scale.

In applying the principles of the water convention to the controversial issue of how to share the Eastern Nile water between Sudan, Egypt, and Ethiopia, recognition of these two regimes and the two different hydrologic services identified above should be the natural starting point towards "reasonable" utilization of the river and its resources. The water resources offered by the river are intimately linked to these services.

Comparing Examples from Across the Nile Basin:

Application of theoretical concepts developed above to the entire Nile basin reveals a rich range of natural conditions across the basin. In Figure 7, against the background of the Budyko curve, we describe three different sub-basins: the Abay river basin in Ethiopia, the main Nile in Sudan and Egypt, and the White Nile in South Sudan.

Efficiency of natural drainage is often a limiting factor for agriculture in Ethiopia. The recent study by Yang et al (2020) investigated agricultural yield in Ethiopia. Figure 7d taken from their report presents the correlation between agricultural yield and precipitation. Within the Abay river basin, the correlation is negative indicating that excessive precipitation and associated reduction in solar radiation act to reduce cereal yield. Yang et al. (2020) conclude that "more precipitation is likely to harm crop yield in lake Tana basin", which is part of the Abay river basin. Additional evidence for how adding water to the soils, by irrigation, in the Abay river basin may impact agriculture negatively can be found in the review of waterlogging in Ethiopian irrigated agriculture by Gebrehiwot (2017). He suggests that "Ethiopia's agricultural production has been challenged by severe waterlogging and salinity problems which has resulted in substantially lower yields than the potential. Waterlogging is the main drainage problem in the small-scale irrigation schemes in the vertisols dominated highland areas". In another study, (Keneni et al. 2002) demonstrate how the potential of Ethiopian soils for crop production is constrained due to waterlogging. As discussed in several studies, (Erkossa et al. 2004; Kebede and Bekelle 2008), waterlogging during the rainy season, reduces length of the growing season, and hence reduces crop yield.

The capacity of the Abay river to drain the Ethiopian highlands is strained due to four different processes. First, the basin suffers from seasonal waterlogging, especially the clayey soils that cover significant areas within the basin, as documented in the studies referenced above. These natural processes may limit the efficiency of the river in draining Ethiopian highlands. Second, significant changes in land-use and land-cover have been documented for the Abay river sub-basin (Rientjes et al. (2011); Gebrehiwot et al. (2010); and Bewket (2002)). These anthropogenic processes tend to enhance runoff at the expense of evaporation, and as a result cause significant increases in river flow adding additional demand on the natural drainage service offered by the Abay river. An increase in river flow, consistent with the changes in land cover, was documented based on empirical observations of river flow near the border between Ethiopia and Sudan (Siam and Eltahir (2017)). Third, climate change may have resulted in more rainfall over the Ethiopian highlands and increased flow in the Abay river flow. Future climate change is projected to increase rainfall significantly over the Ethiopian highlands (Siam and Eltahir (2017)), adding more water that will likely strain the drainage services of the river further. Fourth, the Ethiopian water plan includes new irrigation projects that are needed for supporting dry season agricultural activities. Any irrigated agriculture suffers from drainage problems which can only be avoided by careful design of drainage systems. All these factors combined suggest that “reasonable utilization” of the Abay river basin should focus primarily on enhancing sustainability of the natural drainage service offered by this river.

Adequacy of irrigation is often a limiting factor for agriculture in Sudan and Egypt. This is the second example highlighted in Figure 7. Conditions on the valley of the main Nile sub-basin where any precipitation or enhanced river flow translates directly into larger potential for agricultural production, and solar radiation is never a limiting factor for crop yield represent the exact opposite to the corresponding conditions in the Abay river, in terms of the relationship between water availability and yield. This contrast stems from the dominance of the two different regimes discussed in the previous section, natural drainage and natural irrigation, in the two different sub-basins of the Eastern Nile. However, Egypt and Sudan need to recognize the

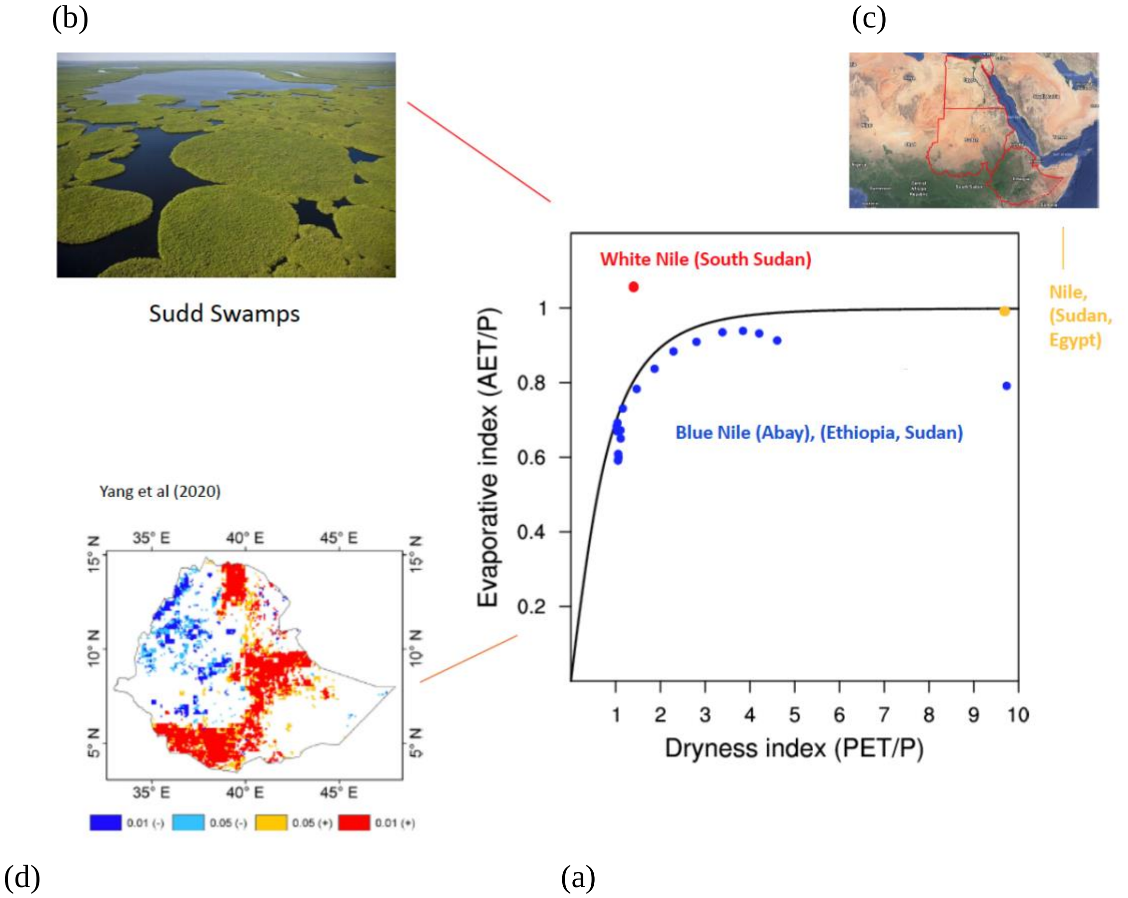


Figure 7: Examples from the Sub-basins in the Nile basin: (a) Budyko framework; (b) Sudd swamps; (c) Main Nile; (d) Abay river basin, correlation between precipitation and crop yield estimated by Yang et al (2020)

limited nature of the water supply in the Nile, and seek to aggressively mange the demand on water (population control, and efficient water use) so that the Nile may continue to offer its irrigation services in a sustainable fashion.

The third example from the Sudd region in South Sudan illustrates what happens when rivers fail in providing their hydrologic service of natural drainage. After the White Nile enters into South Sudan the channel gradient becomes so small to the extent that river flow ceases, flooding the surroundings, and creating the Sudd swamps shown in the picture. Under such conditions, the actual evaporation exceeds the local precipitation, and assumptions of Budyko's theory are no longer valid since the river flooding supplies additional water and sustains evaporation rates beyond what local precipitation may offer. Obviously, under swampy conditions agricultural production for most crops is reduced significantly. The example of these swamps illustrates the critical role of the hydrologic service offered by rivers in the form of natural drainage. However, we acknowledge the important ecological significance of the swamps as important natural systems with rich diversity of flora and fauna.

Conclusion:

The theory and examples offered in this report illustrate that determination of the nature of the hydrologic services that are naturally provided by an international river is a critical step in applying the principles of the UN water convention. Without such determination, no "reasonable" utilization of the resources offered by the river can be reached. Before judges, politicians, and social scientists attempt to define "equitable" utilization of the resources and services offered by an international river basin, they need to first define the "natural character" of the river, identify the hydrologic service offered by the river, and determine the nature and scale of the resources to be utilized. Different segments of the Niger river basin exhibit different "natural character" and offer different hydrologic services. Within the Nile basin, the Abay is different from the White Nile, and both are different from the main Nile. These differences manifest themselves in what hydrologic services they offer, and in how they function according to the principles of physical sciences. Without recognizing these objective differences, the political dialogue about cooperation and equitable utilization, which is encouraged by the water convention, would be hampered “confusion”, which does not offer a solid foundation for any sustainable progress of human societies.

The ideas and concepts presented in this report are offered to invite open intellectual engagements among physical scientists that over time could lead to some level of consensus among scientists about how approaches of physical sciences may inform negotiations leading to resolution of transboundary water conflicts (Choudhury and Islam (2018).

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