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A river basin as a common-pool resource: a case study for the Jaguaribe basin in the semi-arid Northeast of Brazil

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ABSTRACT
This paper applies 'common-pool resource' concepts to analyse to which extent the physical characteristics of a river basin facilitate or impede good management of water in different parts of a river basin. In addition, we compare the apparent manageability of water in the different parts of the basin with the actual agricultural performance in each area. As a case study we have analysed the Jaguaribe basin in the semi-arid Northeast of Brazil. To characterize a certain location within a river basin, the term 'downstreamness' is introduced and quantitatively defined. Depending on its 'downstreamness' each municipal district in the basin is categorized in one of three topographical zones: upstream, midstream or downstream. Per topographical zone, we evaluate to which extent five specific 'conditions for good manageability' are met. These five conditions have been taken from the literature on common pool resources. It appears that three conditions are increasingly met if we go from upstream to downstream, while the other two conditions are better met if we go in upstream direction. Factors that make water better manageable downstream are the better possibilities for water storage, better predictability of water flows and the lower level of mobility of water resources. Factors that make it easier to manage upstream water resources are the small spatial extent of the allocation problem and the clearly defined boundaries of the system. In the case of the Jaguaribe basin, the net result appears to be most favourable in the midstream zone, where the advantages and disadvantages for good water management are in the best balance. As a result, the agricultural performance, measured in terms of productivity and stability of production, is best in the midstream zone of the basin.

Keywords: Common-pool resources; river basin; water resources management; agricultural performance; Brazil.

1 Introduction

This paper applies concepts from the theory on common-pool resources (CPRs) to analyse to which extent the physical characteristics of a river basin facilitate or impede good management of water in different parts of a river basin. In addition, we compare the apparent manageability for the different parts of the basin with the actual agricultural performance in each area. CPR theory is grounded in game theory and has been applied in a wide variety of case studies, mostly on the local level (Ostrom, 1990; Ostrom *et al.*, 1994, 2002). With respect to water resources management, CPR theory has been applied in the case of competition over water resources in irrigation systems (Baland and Platteau, 1999; Bardhan and Dayton-Johnson, 2002; Lam, 1998; Tang, 1992). The surface or groundwater reservoir from which farmers get their irrigation water is regarded in those studies as a 'common-pool resource'. The characteristics of a 'common-pool resource' is that there is competition over the resource and that there is no private ownership; various users have access to the resource at the same time. Beyond the scale of a water reservoir for irrigation, one can also regard the water within a catchment or river basin as a whole as a common-pool resource. The scale is larger, but the characteristics are similar: many users have access to the water in a basin and compete for it. To date, however CPR studies have typically focussed on local resources (Agrawal, 2002), rather than on large resource systems like river basins.

In a river basin, in which many water reservoirs are situated, one cannot speak of a single resource stock as is the case for an irrigation scheme with one central water reservoir. A river basin with multiple reservoirs is therefore principally different from a canal-irrigation system and should rather be regarded as a system of nested or connected CPRs. In this study, we regard a river basin as one large water system that consists of a network of connected smaller water systems. Each smaller water system – characterised by a variable water stock – can be regarded as a 'local common-pool resource'. The local common-pool resources are connected through water flows from one to another. As a result, we expect two different sorts of competition: local competition over the water *within* each smaller water system and competition over water *between* the smaller water systems, notably between upstream and downstream users.

In CPR terminology we can say that a river basin as a whole is an asymmetrical CPR. In symmetric CPRs externalities between users are mutual whereas in asymmetrical CPR systems, like river basins in which water flows from up- to downstream, externalities may become unidirectional. Unidirectional externalities

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in river basins are, to some extent, comparable to the ones experienced in canal-irrigation systems. In such systems, the disadvantaged users are the ones located at the downstream tail of the system, most distant from the resource stock (Bardhan and Dayton-Johnson, 2002).

The obvious advantage of upstream water users in a river basin is that they are 'first in use'. However, the advantage of downstream water users is that in downstream direction there is naturally more water, because water in a basin collects at the downstream outflow point of a basin. This 'funnel effect' can potentially counterbalance the negative effects of upstream use. Users in downstream parts benefit from the accumulation of water, making them less sensitive to spatial variations of rainfall, in comparison to users located near small streams more upstream.

In the terminology of the literature on common-pool resources, CPRs are goods characterized by 'low excludability' and 'high subtractability' (Ostrom, 1990). Low excludability refers to the fact that it is difficult or costly to exclude users from using the resource. High subtractability means that the consumption by one user ('appropriator' in CPR-terminology) subtracts from the possible use ('appropriation') by others. The major concern with common-pool resources is that they easily get overexploited because there is a conflict between individual and group rationality. As Hardin (1968) argued, the tragedy of common-pool resources is that from the point of view of the individual user it is attractive to use more than what would be best from a group perspective, often leading to overexploitation of the resource. Therefore, many studies on CPRs analyse under which conditions cooperation among users does or does not occur (Ostrom, 1999; Ostrom *et al.*, 2002) or under what conditions common-pool resource management can be sustainable (Agrawal, 2002). Agrawal synthesized findings of a large body of empirical work on common property and the commons, including the work of Ostrom (1990) and Blomquist *et al.* (1994). Among the factors influencing the manageability of CPRs, the following resource system conditions are associated with good manageability:

- Small spatial extent
- Well-defined boundaries
- Possibilities of storage
- Predictability of resource flows
- Low levels of mobility of the resource

Based on topography and water storage capacity in the various parts of a river basin we describe to which extent in the various parts of the basin the conditions that are associated with good manageability are met. As a case study we have analysed the Jaguaribe basin in the semi-arid Northeast of Brazil.

2 Study area

The Jaguaribe basin is located within the institutional borders of the state of Ceará in the semi-arid Northeast of Brazil (Figure 1). The basin covers approximately 74,000 km^2 (COGERH, 2003a). Average yearly precipitation ranges from 400 to 2,000 mm. Temporal rainfall variability is highly significant on a suite of scales: inter-annual variability, seasonal variability and variability at the time scale of a week (Enfield *et al.*, 1999; Gaiser *et al.*, 2003; Smith and Sardeshmukh, 2000; Uvo *et al.*, 1998). In Ceará the combination of impermeable crystalline rocks in the soil and high temperatures produces high rates of evapotranspiration and little groundwater storage. Groundwater resources are considered to be of limited importance in most areas of the basin (Johnsson and Kemper, 2005). Seventy-five percent of the basin's reservoir capacity is provided by three surface reservoirs which have transformed about 470 kilometres of the rivers in the middle and lower part of the basin into perennial waterways.

On average, around 45% of the irrigation area in the downstream valleys is used for rice production, consuming an

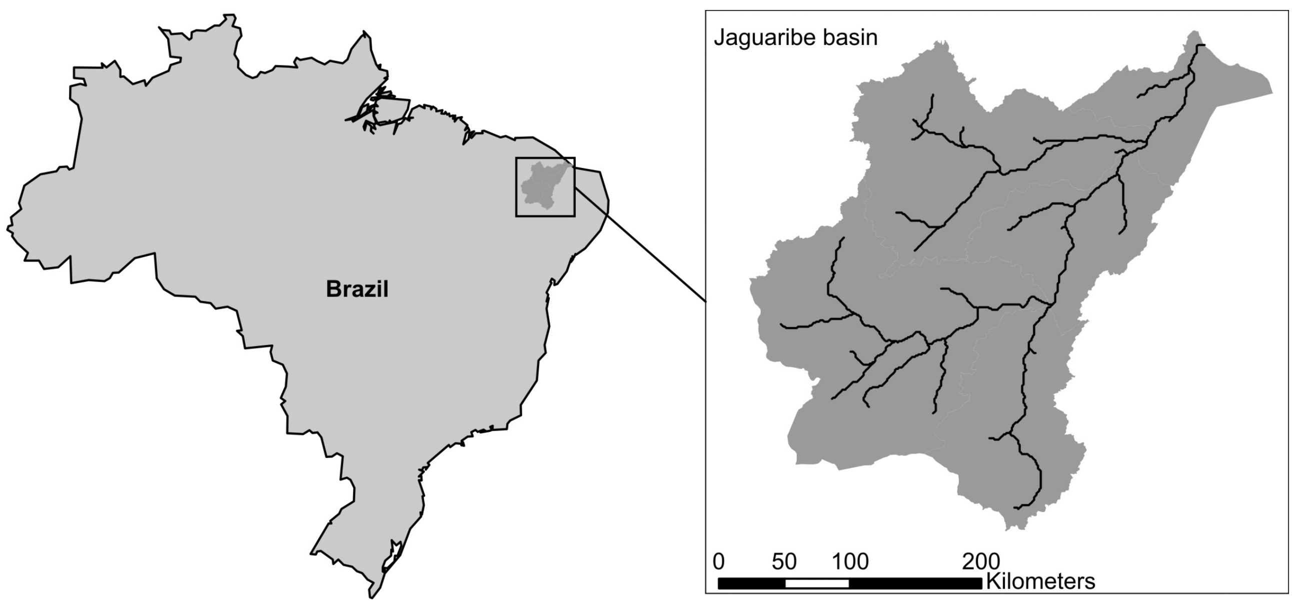

Figure 1 The Jaguaribe basin.

estimated average of 60% of the water destined for irrigation (Lemos and de Oliveira, 2004). Rice is cultivated in both upstream and downstream areas. Irrigation for rice production is an intensively discussed practice in Ceará because of its high pressure on water reserves in strategic reservoirs (COGERH, 2001; COGERH, 2003a; Johnsson and Kemper, 2005).

Water management in Ceará is a combination of state level management with decision-making at smaller territorial scales than the river basin, such as sub-basins, regulated river valleys, and reservoirs (Johnsson and Kemper, 2005; Lemos and de Oliveira, 2004). For many local water reservoirs in the Jaguaribe basin, user commissions decide on the allocation of water resources from the reservoirs without having an official mandate (Lemos and de Oliveira, 2004).

3 Method

In four subsequent steps we analyse: (1) the topography of the basin, (2) the observed water resources distribution, (3) the extent to which the physical characteristics of water resources in different parts of the river basin facilitate or impede good management of the water, and (4) the spatial distribution of observed agricultural performance in the basin.

Step 1: Description of topography

Topography determines the direction of resource flow. Actual flows are influenced by rainfall rates, water use, evapotranspiration and storage. Every location x in a river basin can be characterized by the size of its upstream catchment area. If the upstream area (A_{up}) is divided by the total catchment area of the river basin (A_{tot}), a fraction is determined which we call 'downstreamness' (D_x):

$$D_x = \frac{A_{up}}{A_{tot}} \times 100\%$$

Water flows accumulate from up- to downstream. The direction of flow accumulation is determined using a 90 m resolution digital elevation model of the river basin (EMBRAPA, 2006). Based on the outcome, every municipal district within the Jaguaribe basin is categorized into one of three topographical zones: upstream, midstream or downstream.

Step 2: Analysis of water resources distribution

We analyse the water resources distribution in the basin over space and time. Water resources distribution is evaluated by analysing stability of resource flows and storage in the basin. We analyse inter-annual stability of flow at eight measurement stations in three upstream sub-basins in the Jaguaribe basin (Figure 2). For each of the sub-basins up- and downstream flow characteristics have been compared for the period 1990–2003.

Intra-annual stability is determined by dividing monthly dry season flow ($\text{Nov}_{(t-1)}$–$\text{Jun}_{(t)}$) by monthly wet season flow ($\text{Jul}_{(t)}$–$\text{Oct}_{(t)}$) for the period 1990–2003. We evaluate the differences over space.

For analysing storage capacity in the river basin we have considered the 58 largest reservoirs. All these reservoirs are public reservoirs, of which construction was initiated by the national or state government. The 'downstreamness' of the total storage capacity in the river basin (D_{SC}) was determined as follows:

$$D_{SC} = \frac{\sum_{x=1}^{n} SC_x D_x}{\sum_{x=1}^{n} SC_x},$$

where D_x represents the downstreamness of reservoir x and SC_x the storage capacity of reservoir x.

The stored volumes for the 58 largest reservoirs in the basin reservoir volumes are evaluated for the period 1996–2003. The weighted average downstreamness of the total stored water volume in the basin (D_{SV}) at the end of the rainy season was

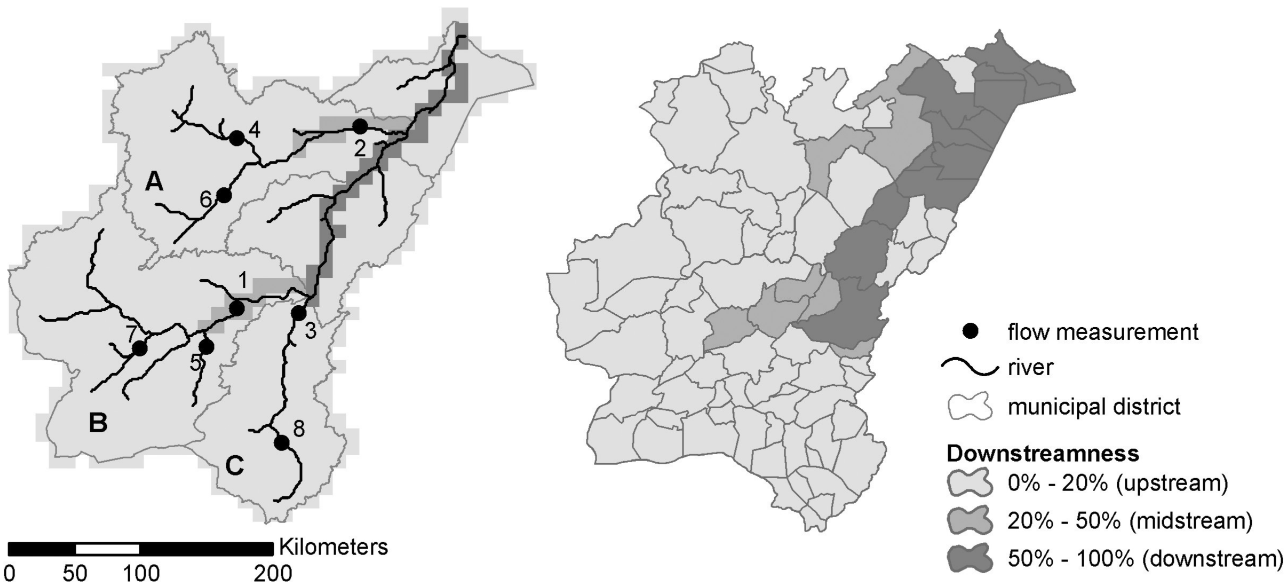

Figure 2 The 'downstreamness' per grid cell (left) and per district (right). In the left map, three sub-basins are shown: Banabuiú (A), Alto Jaguaribe (B) and Salgado (C). In the right map, all 80 districts in the basin have been categorized as either up-, mid- or downstream.

determined as follows:

$$D_{SV} = \frac{\sum_{x=1}^{n} SV_x D_x}{\sum_{x=1}^{n} SV_x},$$

where D_x represents the downstreamness of reservoir x and SV_x is the stored volume in reservoir x. The downstreamness of the total stored water volume in the basin (D_{SV}) at the end of the rainy season was then compared to the downstreamness of the storage capacity in the basin (D_{SC}).

Step 3: Evaluation of the five conditions for good manageability per topographical zone

The rainfall variability and topography (step 1) and the distribution of the water storage capacity in the basin (step 2) determine to which extent the conditions for good management of the water in the various parts of the basin are met. In this step we use the subdivision of the basin into three topographical zones as made in the first step: upstream, midstream en downstream. Per topographical zone we evaluate to which extent the five conditions for good manageability as mentioned in the introduction are met: small spatial extent, well-defined boundaries, possibilities of water storage, predictability of water flows, and low levels of mobility of the water. We expect that relative good manageability of water in a certain topographical zone results in a relatively good agricultural performance, which is evaluated in the last step.

Step 4: Assessment of agricultural performance

To measure agricultural performance in the basin three indicators are used following Conway (1987). This is done for all 80 municipal districts in the river basin. The three indicators of agricultural performance are:

- *Productivity*: the average yearly value generated per hectare in a district. To unify the output of various agricultural products, their monetary value is used. This value is based on average prices per agricultural product for the period 1994–2004 (IBGE, 2006).
- *Stability (S)* of production: the variation of production over time (1990–2004). Use is made of the coefficient of variance (*CV*) for agricultural production. Stability is defined as: $S = 1/CV$.
- *Equitability (E)* of productivity and stability over space. Use is made of the Gini coefficient (Gini, 1912) for which the agricultural incomes from seasonal crops of the 80 municipal districts in the basin are taken into account. Equitability is defined as: $E = 1 - Gini$, with $0 \leq Gini \leq 1$.

The focus of the agricultural performance analysis is on the main seasonal crops cultivated in the basin (rice, maize and beans). This choice has been made because decision-making with respect to cultivating these crops is done on a seasonal basis, so inter-annual dependencies for land use are limited.

Use is made of agricultural production data (IBGE, 2006), rainfall data (FUNCEME, 2006), a digital elevation model (EMBRAPA, 2006), a database on reservoir volumes and releases from the Brazilian National Department of Works Against Droughts (DNOCS) and the Ceará state department for water resources management (COGERH, 2003b) and river flow data from the Brazilian National Water Agency (ANA, 2006).

4 Results

4.1 Topography

The ‘downstreamness’ of locations within the river basin is shown in Figure 2, first on grid level (left figure) and then on district level (right figure). The downstreamness has been classified into three topographical zones: upstream, midstream and downstream. The downstreamness of a district as a whole is measured at its most downstream point.

4.2 Water resources distribution

Given unchanged hydrological conditions, higher yearly rainfall rates yield higher yearly discharges at the outlet of a sub-basin. Deviances from this trend are explained by inter-annual effects, largely related to storage. The 1993 drought seriously affected discharges in 1994 in all three sub-basins. The amount of rain in 1994 would have resulted in a higher discharge if it wasn’t for the 1993 drought. Most probably, saturation of natural and artificial storage bodies upstream of the measurement stations took up a large part of the 1994 rains.

In sub-basins A, B and C inter-annual stability of river discharge increases in the downstream direction (Figure 3). This holds most strongly for sub-basin A, where a large strategic reservoir is operated to serve the downstream community, including many farmers using the river for irrigation.

Reservoir management in sub-basin A is much more successful in stabilizing river flow in comparison to the other sub-basins. The average flow is however considerably lower than in the other two sub-basins. The characteristics of flow for the three sub-basins are summarized in Table 1.

State authorities and local communities adapt to rainfall variability by constructing dams. In the Jaguaribe basin this process of adaptation is ongoing (Figure 4). It decreases mobility of water resources at local scales. The installation of new reservoirs brings

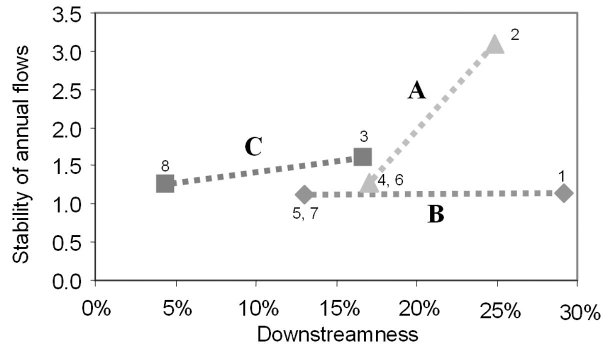

Figure 3 Stability of annual flows (1/coefficient of variance) in three upstream sub-basins: A = Banabuiú sub-basin; B = Alto Jaguaribe sub-basin; C = Salgado sub-basin. The numbers refer to flow measurement station(s). In case of two numbers, averages for two stations have been used.

Table 1 Discharge characteristics of three upstream sub-basins.

Variable	Unit	A*	B*	C*
Catchment size	km^2	17 900	21 000	12 000
Reservoir capacity	10^3 m^3/km^2	154	16	37
$\frac{Q(\text{dry season})}{Q(\text{rainy season})}$	–	0.86	0.01	0.03
Annual variance of discharge	Coefficient of variance	0.32	0.88	0.62
Average downstream discharge	10^6 m^3/year	257	312	410
Average rainfall	mm/year	752	703	862

A = Banabuiú sub-basin; B = Alto Jaguaribe sub-basin; C = Salgado sub-basin.

along the potential for creating externalities for downstream users. The capacity-weighted downstreamness of the basin's storage capacity (D_{SC}) has shown a decreasing trend after the installation a large reservoir in 1961 (Figure 4). This trend continued until the installation of the large Castanhão reservoir in 2003 (COGERH, 2003b).

The basin's storage capacity slightly increased in the period between 1996 and 2003, while total stored volume decreased (Figure 5). In Figure 6 the average capacity-weighted downstreamness of storage capacity (D_{SC}) and the average volume-weighted downstreamness of stored volume (D_{SV}) are shown.

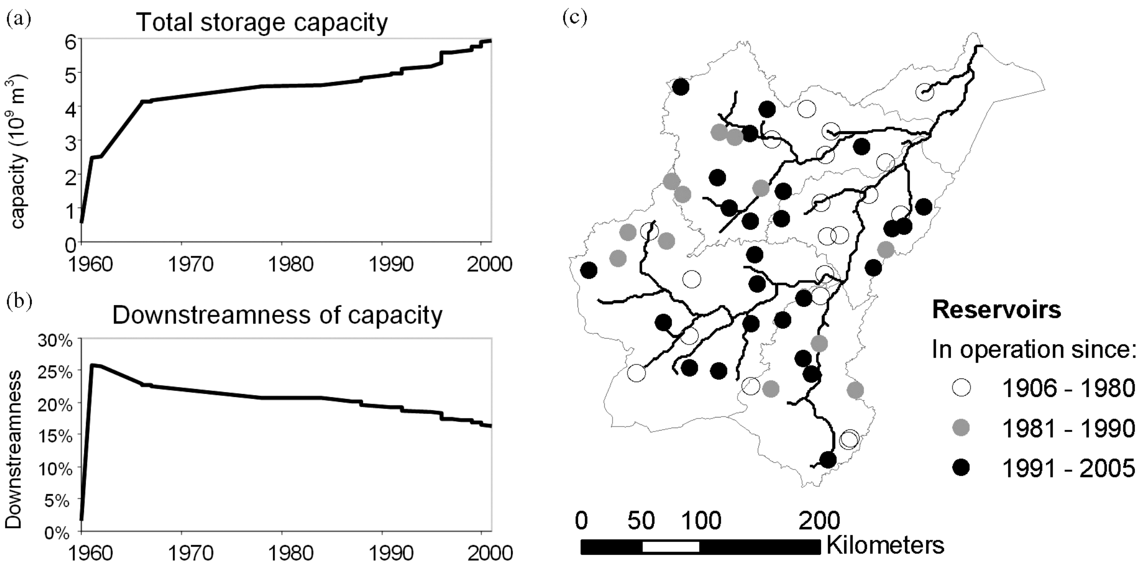

Figure 4 (a) Total strategic storage capacity in the Jaguaribe basin increases in time; (b) Downstreamness (D_{SC}) of storage capacity decreases in time; and (c) Locations of constructed public reservoirs in the Jaguaribe basin since 1906.

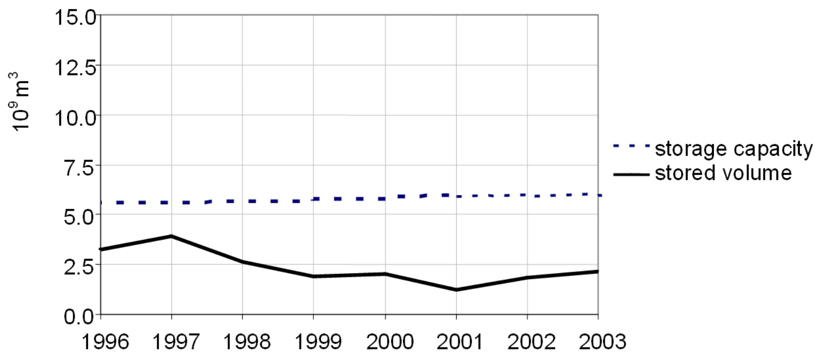

Figure 5 Storage capacity and stored volume in the Jaguaribe river basin.

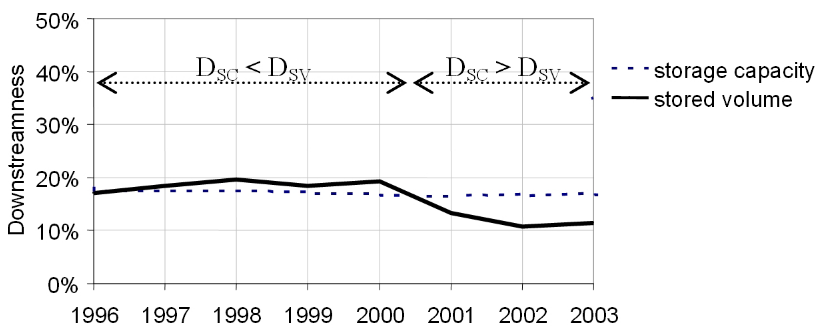

Figure 6 Downstreamness of total storage capacity (D_{SC}) and stored volume (D_{SV}) (July 1st).

In the dry year of 1998, total stored volume dropped, while the downstreamness of stored volume (D_{SV}) increased. This can be explained by the fact that inter-annual storage is more easily achieved in relative downstream parts of the river basin. However, in the dry year of 2001, downstream stored volumes decreased faster than upstream stored volumes. In the years following 2001, total stored volume rose again while the downstreamness of stored volume (D_{SV}) decreased further and consequently the situation with $D_{SC} > D_{SV}$ remained. For a period of three years (2001–2003) a situation with upstream above-proportional storage (and subsequent use) was observed. This is explained by the low saturation level of the reservoir network in this period. With an increasing share of storage capacity left unsaturated following a drought, the downstreamness of stored volume (D_{SV}) moves up, provided that rainfall rates are not extremely high. This implies that upstream storage recovers faster after a drought than downstream storage. The sequence of rainfall events is very important for the spatial allocation of water quantities. Responsible for the effects of the sequence of rainfall events are what we call the 'funnel effect' and the 'storage effect' (Table 2). The 'funnel effect' refers to the accumulation of flow in the downstream direction. The 'storage effect' refers to the storage of water in reservoirs and favours the water users that are first in line, i.e. the upstream users. The extent of their effect depends greatly on the spatial distribution of reservoir capacity, the extraction of water resources, rainfall quantities and the sequence of rainfall events over time.

4.3 Evaluation of the five conditions for good manageability per topographical zone

Table 3 shows the differences between the three topographical zones in the Jaguaribe river basin with respect to the five conditions for good manageability as listed in the introduction. For the Jaguaribe basin, high downstreamness of a local CPR should generally be associated with a large spatial extent, an ill defined boundary, good possibilities for water storage, high predictability of flows and a low level of mobility. On the other hand, low downstreamness associates with a small spatial extent, well-defined boundaries, modest possibilities for water storage, low predictability of flows and high mobility. So, for neither upstream nor downstream, the physical characteristics univocally associate or dissociate with good manageability.

A river basin can be divided into an infinite number of sub-basins, since every geographical location in a basin has its own unique catchment area. A low downstreamness of a geographical location in the river basin is associated with a relatively small spatial extent of the relevant resource system, whereas a high downstreamness of a geographical location is associated with a relatively large spatial extent of the relevant resource system due to the size of their respective catchment areas.

A low downstreamness of a geographical location in the river basin is associated with well-defined boundaries, because the amount of storage in the upstream catchment area is relatively low. For a geographical location with a high downstreamness it is less clear to what extent stored resources in the upstream catchment are available for use at that location. The inter-annual sequence of rainfall events is of critical importance for distribution of water availability over the upstream catchment of that location. During drought, upstream reservoir capacity remains unsaturated. Following a meteorological drought, a relatively large share of rainfall volumes is stored upstream in order to saturate upstream reservoir capacity. This process facilitates for above-average use in locations with a relatively low downstreamness. Nested upstream sub-basins can be regarded as external to

Table 2 The influence of the 'funnel effect' and the 'storage effect' over time.

Process	Effect on users	Wet following wet year	Wet following dry year	Dry following wet year	Dry following dry year
Funnel effect	Outlet-advantage for downstream water users	+ + ++	+ + +	++	+
Storage effect	First-in-line-advantage for upstream water users	+	++	+ + +	+ + ++

A '+' indicates the extent of occurrence of the effect. Both effects occur every year. However, the Funnel effect is relatively large in a wet year following a wet year and the Storage effect is relatively large in a dry year following a dry year.

Table 3 The extent to which the five conditions for good manageability are met, per topographical zone.

Topographical zone	Conditions for good manageability of the resource system				
	Small spatial extent	Well-defined boundaries	Possibilities of storage	Predictability of flows	Low levels of mobility
Upstream	+	+	−	−	−
Midstream	±	±	±	±	±
Downstream	−	−	+	+	+

+ means that the condition for good manageability is met;
± means that the condition is moderately met;
− means that the condition is not met.

the catchment of that geographical location, either temporarily or even permanently.

As supported by the results presented in Section 4.2, users at geographical locations with a relatively high downstreamness have the advantage of being located downstream of a larger storage capacity in the upstream catchment area than users at locations with a lower downstreamness. Therefore, this condition is increasingly met with increasing downstreamness.

Due to the greater possibilities of storage in downstream locations and the merging of streams from different subbasins, the mobility and predictability of flows are relatively large in downstream locations. Water resources can be released from storage reservoirs at a moment of choice. The observed increase of stability with increasing downstreamness (Figure 3) relates to these factors. Therefore, these conditions are increasingly met with increasing downstreamness.

The storage capacity and geographical location of reservoirs together with the extent to which the reservoir capacity is saturated play an important role in the propagation of externalities. An increase in reservoir capacity due to the construction of additional reservoirs in upstream parts of the river basin increases basin closure (Molden, 2007) and therewith the potential for producing negative externalities towards downstream.

4.4 *Agricultural performance*

The agricultural productivity and stability of production in each of the three topographical zones in the Jaguaribe basin is shown in Table 4. Both for productivity and stability of production the same pattern has been encountered. Districts in the midstream zone appear to have the highest productivity and the most stable production. Users in the midstream part have taken advantage of their relative downstream position in comparison to the districts in the upstream zone. This is of great importance in order to cope with short-term intra-season rainfall variability and to be productive in the dry season. In dry periods, users in the midstream zone experience the advantage over downstream users of first access to water from large reservoirs.

Equitability of agricultural productivity in the basin is influenced by both physical processes and human activities. The spatial distribution of agricultural production over the river basin becomes clear when the Gini-coefficient of seasonal crop value for all 80 districts is compared to the actual locations in the river basin where the agricultural production is established. The average yearly rainfall in the river basin has a (95%) significant linear

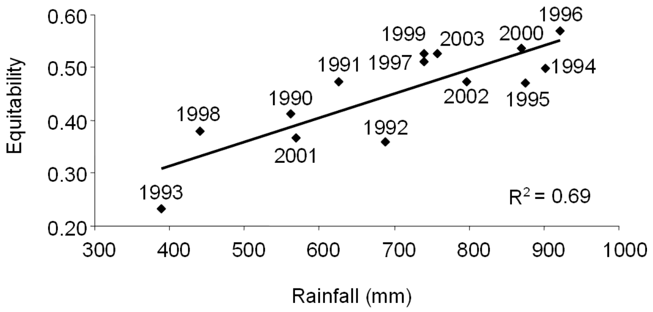

Figure 7 Equitability (1 – Gini-coefficient) of production value in the Jaguaribe basin as a function of average rainfall.

Table 5 The agricultural performance per topographical zone in the Jaguaribe river basin.

Location	Observed agricultural performance	
	High productivity	High stability
Upstream	−	−
Midstream	+	+
Downstream	±	±

A '+' indicates strong correspondence between the characteristic and the location, '±' indicates moderate correspondence between the characteristic and the location and a '−' indicates weak correspondence between the characteristic and the location.

positive relation with equitability (Figure 7). Decreasing equitability comes with a more downstream-centred total production value.

As we pointed out earlier, two counter effective processes influence spatial heterogeneity of water availability in a river basin: storage of water (natural or artificial) favours upstream water users, whereas accumulation of flow in the downstream direction favours downstream users. The result of these two processes is a relatively good agricultural performance in the midstream part of the Jaguaribe river basin. This is shown in Table 5, which is a qualitative interpretation of the data shown in Table 4. The relative good agricultural performance in the midstream zone is achieved while all conditions for good manageability of water are moderately met (Table 3). As we saw in Table 3, some of the conditions are not met in the upstream zone, while other conditions are not met in the downstream zone. This may play a role in the relative worse agricultural performance in those zones.

Table 4 Productivity and stability of production of seasonal crops (rice, beans, maize) for the period 1990–2003.

Topographical zone	Productivity (Real/ha)	Stability of production (1/coefficient of variance)
Downstream	370	2.9
Midstream	520	4.0
Upstream	200	1.9
Basin total	240	2.4

5 Discussion

The asymmetry of a river basin resource system does not fully obstruct cooperation that is beneficiary for both up- and downstream users. Users in downstream areas are situated downstream of storage facilities. This can make upstream users dependent on downstream production in times of meteorological drought. Governmental organizations could respond by supporting virtual water trade (Allan, 1998). Such trade can include both virtual-water flows from downstream to upstream areas inside the basin and virtual-water flows from outside the basin into upstream areas inside the basin.

Although not explicitly taken into account here, attributes of users are very important for sustainable governance (Agrawal, 2002). Among these attributes are users' dependency on the resource, their autonomy, organizational experience and income heterogeneity. Income heterogeneity is likely, based on the observations in Table 4. In the literature on CPRs, equality of income is used to explain the success or failure of CPR management (Jones, 2004). Either very high or very low levels of inequality are argued to facilitate for successful resource management. Changing inequality redistributes incentives and has therefore an ambiguous effect on the ability of users to take steps toward conserving their resources and even toward setting up the required mechanisms (Baland and Platteau, 1999). In the case of the Jaguaribe basin income inequality can vary considerably over space and time. The results show that agricultural performance relates to both rainfall variability and stored water resources. This makes it very difficult to determine the influence of income inequality on governance of water resources and vice versa.

Data availability somewhat limited the scale of analysis. Firstly, the spatial resolution of analysed data is too coarse for detailed analysis of most of the local CPRs. Finer resolutions can be achieved by using remotely sensed imagery classification methods. Secondly, the temporal resolution of one year does not allow for the consideration of seasonal differences for use of water resources. Variations around the average agricultural calendar are possibly important for understanding the process of propagation of externalities between local CPRs in the downstream direction. Thirdly, the temporal extent of the analysis is limited. This limits the meteorological extremes taken into account as well as the combinations of sequential meteorological events that are considered to be very important, since externalities occur at an inter-annual scale.

6 Conclusion

The physical characteristics of local freshwater CPRs vary, depending on their location in a basin. For neither location all five conditions for good manageability are favourable at the same time. The more a local CPR is located towards downstream, the more it should be associated with a large spatial extent, ill defined boundaries, good possibilities of storage, high predictability of resource availability and low levels of resource mobility.

The sequence of rainfall events over time and the spatial distribution of reservoir capacity in a river basin influence the extent to which the merging of rivers and streams towards downstream can compensate for externalities due to upstream water abstractions. This principle is an addition to the concept of head-end/tail-end problems encountered in irrigation schemes (Bardhan and Dayton-Johnson, 2002) for the river basin scale. The concept of downstreamness proved useful in explaining how the five conditions for good manageability improve or worsen from up- to downstream.

From a river basin perspective, storage in local CPRs in upstream parts of a basin should be associated with 'first capture' or 'use it or lose it' strategies (Blomquist *et al.*, 1994; Schlager *et al.*, 1994), since storage in local upstream CPRs is meant to serve local use. Storage in local upstream CPRs in semi-arid river basins, such as the Jaguaribe basin, should therefore be regarded as appropriation from the 'river basin scale common-pool resource'.

Acknowledgements

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