Towards an Atlas of Lakes and Reservoirs in Burkina Faso

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Scope: questions/ challenges the tool addresses

One of the key attributes of small reservoirs in many locations in the world is the unreliability (or the absence) of up-to-date inventories. The evaluation of their potential at national or regional scales, and the strategic planning of future infrastructure in selected areas, are dependant on accurate information. It is important to have at disposition a synoptic perspective highlighting "*where reservoirs are*".

Burkina Faso is probably the West African country with the highest density of small reservoirs. As elsewhere, the demand for the creation of new reservoirs remains constant. Neither the actual distribution of small reservoirs nor the spatial dynamics associated with the construction of new devices are available. Basic information regarding the status of small reservoirs i.e. their locations and size remain to be gathered and shared.

Small reservoirs are artificially created aquatic ecosystems. Intrinsic factors such as size (depth) determine their potential (e.g. capacity, biological productivity). But external driving pressures, hereafter called *contexts*, ultimately control their effective properties (Cecchi 2007). Growing populations and intensive use of watersheds may exert severe pressures that e.g. modify runoff or stimulate eutrophication. Conversely the value of small reservoirs isolated in an area devoid of people is questionable. Contexts, including human behavior, modulate their potential. It is useful to locate reservoirs in response to the key drivers exerted by their environment.

A 'pilot' Atlas of Lakes and Reservoirs of Burkina Faso, called FasoMAB, has been developed to fulfill these needs. Earlier versions of the atlas were developed to help to profile specific interventions of the SRP in Burkina Faso, and first of all determine "*where to work*". It was decided to focus scientific activities in areas simultaneously characterized by high densities of populations and high densities of reservoirs (*hot spots*). Administrative limits were first used to select these areas, with departments (N=351) as finest grain (Fig. 1). Further refinements provided alternative geographical perceptions of these hot spots. Using the grid of the Climatic Research Unit to pixelize the country allowed a neutral identification of *clusters of reservoirs*; the use of a Digital Elevation Model furnished a hydrographic perspective and allowed the identification of *target basins*.

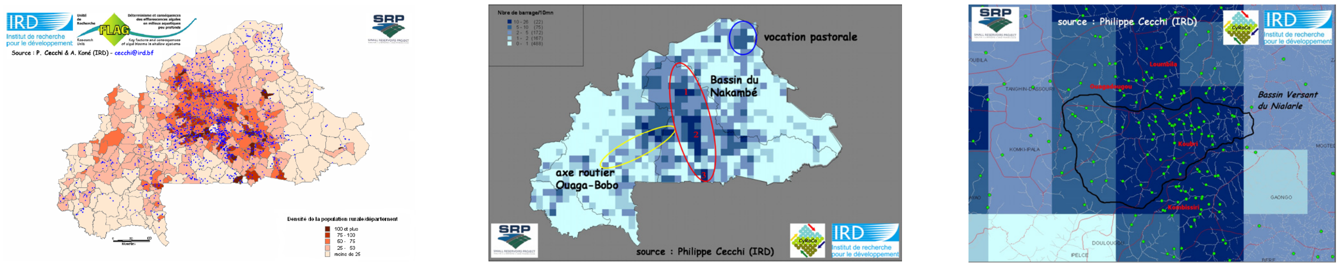


Figure 1: Examples of tools used to the selection of hot spots, clusters of reservoirs and target basins for the implementation of SRP activities in Burkina Faso.

The tool has been developed using only the most recent available secondary databases, provided by official sources (to insure the fingerprinting of data). Merging and interconnecting these heterogeneous data was problematic. We homogenized this disparate information in a metadata base, and created a tailor made GIS to combine all of the data, and generate maps.

Subsequently we realized that this project intended solely to focus the work of the SRP (i.e. to select study areas), could also be a valuable by-product of the SRP project.

The FasoMAB atlas has been developed to share this information, through a limited series of maps and commentaries that present some of the main characteristics of lakes and reservoirs in Burkina Faso. The ambition is not to provide a definitive description. Daily reservoirs are built or destroyed. This atlas could nevertheless contribute to a better assessment of reservoirs, and maybe could stimulate further initiatives. From a very pragmatic point of view, the atlas allows immediate visualizations ("*the power of maps*") of reservoirs and thus illustrates their role and importance. This tool highlights some of these insights, as displayed by the FasoMAB atlas.

Target group of the tool

The target groups for this tool are those concerned with small reservoirs in Burkina Faso and those who may see the utility in creating a similar atlas in their region of interest. The FasoMAB atlas has been developed to share small reservoir information with the National Water Management Directorate (DGRE), an institutional partner of SRP in Burkina Faso. FasoMAB is accessible online via the DGRE and IRD web sites.

Requirements for tool application

Because we used secondary databases provided by different institutions (see Table. 1), which sometimes have very different geographical attributes, cross-validation was required. The GIS specialists organized the data in a unique and efficient meta-system. It required the meticulous and time-consuming comparison and validation of the different sources to create the atlas.

Different categories of data were used:

- Registers and inventories (reservoirs, populations, etc.) developed by national institutions such as DGRE and the National Institute for Statistics and Demography (INSD). Although various attributes and descriptors are included within these data bases, the information is usually not systematically georeferenced. An exception, new DGRE database, PEM: Modern Watering-Places, 2006, provides both watering locations and population data with georeferenced attributes for the first time for the entire country. We used this data base. However, it needed cleaning and preparation (see limits in Table 1).
- Thematic maps (administrative limits, hydrographic networks basins, and geomorphology, etc.), sometimes redundantly provided by different sources had to be corrected and merged, for

example the DGRE and National Geographic Institute (IGB) maps of the hydrographic network. In that case, the data are often georeferenced, but sometimes using different projection systems. The DGRE uses a geographical reference system incompatible to currently accepted geographical format. The use of an alternative resource (Digital Terrain Model SRTM90, NASA) allowed a clarification of the hydrographic network. Other thematic data, not georeferenced, were provided as polygons.

- Remote sensing information was provided by IGB, which corresponds to a Landsat TM-based description of land use at the national scale from two different periods (1992 and 2002). We'll see below the important limitations associated to these data resources (see limits in the table 1). Regarding surface water, and whatever the limitations encountered, this data base remains up to now unique, in providing a national and synoptic perspective. Thematic maps and remotely sensed information provide details on extent and distribution of water masses, but have limitations when individual attributes (e.g. age) are of interest.

The FasoMAB pilot Atlas has been developed in combining information from these different sources with the aim of presenting the status of surface waters in Burkina Faso within their human and biophysical environment.

FasoMAB is a small "pilot" project. The ultimate version of this kind of tool should be developed by national or basin level agencies, and ideally regularly updated using a uniform format shared by all of the agencies providing data. It should be public good accessible to all users.

Tool: description and application

Thematic data

The data used in the creation the FasoMAB Atlas are listed in Table 1. A brief description of the treatments used follows.

Verification, treatment, and modification

The data have been systematically verified (quality, mode of acquisition, comparison of sources...) and treated (reformatting and organization). Whenever necessary, records have also been modified (localized, substituted, deleted, or extended). Finally they have been validated, a step which consisted of defining quantitative limits and a few subjective standards. Missing or inadequate data were recreated if they could not be found in other available data sets.

Projection system

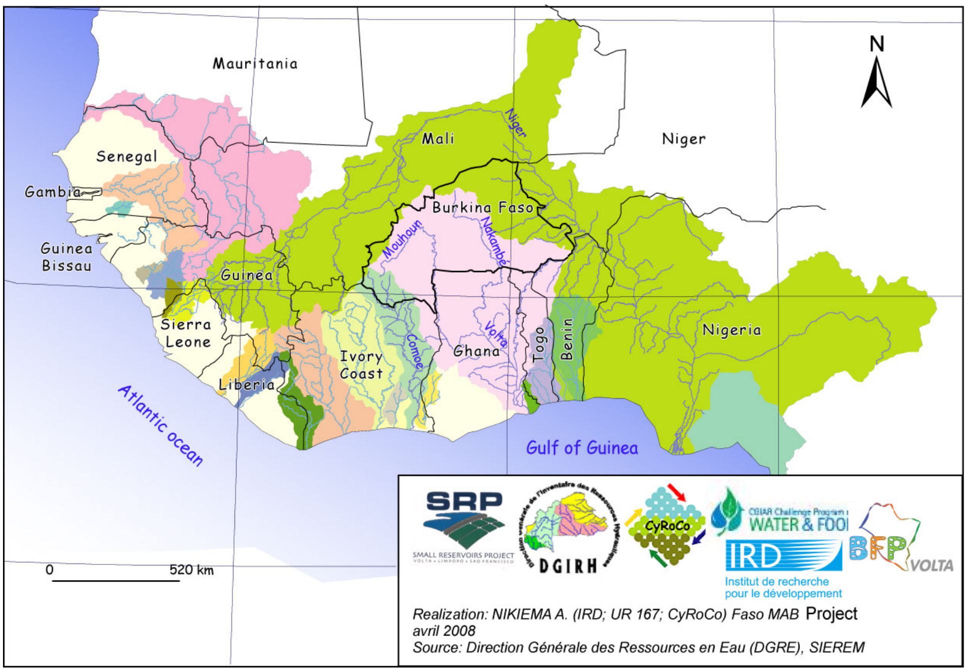
ArcGIS has been used to incorporate all collected information and to generate maps. ArcGIS uses the first northern UTM zone (zone 30N) projection, based on the WGS 84 datum. Our data are most densely concentrated in this zone, and WGS 84 is the datum used by the global positioning system (GPS). Thus, this choice facilitates the importation of eventual new data without excessive treatment.

Type	Name	Source	Treatment
Administrative	Departments	**BNDT** (National database on places and territories) from IGB (Geographic Institute of Burkina Faso)	Verification and modification of polygons. Projection and creation of identifiers.
	National boarders, Provinces, Regions	**BNDT**	Verification of boarders (different versions depending on date and eventual local conflicts).
	Villages	**BNDT** **PEM 2006** (Modern Water Resources) database from DGRE (General Direction of Water Resources) **RGPH 1996** (National Population Census) from INSD 2005 (National Institute for Statistics and Demography)	There are 2 tables for villages in the PEM database. For the first (10,307 records), populations (from RGPH 1996) are available in 76% of records. The second (8,909 **georeferenced** records) provides information regarding habitat and activities. These two tables have been merged and verified: comparison with "paper" census of 1996, verification of localizations with BNDT 2002 and eventual relocalization, etc. Finally, 8,302 georeferenced villages (among the 8,909) are available with their populations. It has to be mentioned that all the information provided by the second database has been completely modified (data extraction, codification, format, etc.) to be exploitable (toward Access requests).
		limits :	*After several verifications and confrontations of the different available date resources, the majority of villages appeared correctly georeferenced. However a fraction (724) of these villages remained localized out of their administrative department where their populations are nevertheless aggregated. Only 80 of them are localized at more than 5 km from their administrative department. We hypothesize that, owing to the augmentation of the number of departments in 1996 (from 301 to 350), some villages are still today administratively attached to their "older" department, inducing the observed discrepancies.*
Groundwater	Public fountains (BF), Watering Places (PEM), Distribution network (SD)	**PEM 2006**	Creation of identifiers; verification of localization (in the PEM database, watering-places are identified by the village's code: it's possible to measure the distances between infrastructures and villages, and to eventually correct their localization); modification (extraction and codage) of data.
Surface water	Lakes and reservoirs	**PEM 2006** from DGRE (725 reservoirs), **PPB/BAD 2001** (Small Reservoirs Project of African Bank for Development) from DGRE (1450 water masses)	These two bases have been compared and merged. The important discrepancies between the information they provide and the field's realities are discussed hereafter.
Access to water	Domestic water providing	**RGPH 1996** from INSD 2000	Departments are the finest available grain.
Hydrography	National and international basins		Created in using the DTM (Digital Terrain Model) SRTM90 from NASA: existing data appear either false, or insufficiently precise, or provided in unknown projection system. Creation of identifiers, ordering and classification.
	Hydrographic network (2 versions)	*version for representation*	verification, adaptation and modification of the hydrographic network provided by the BNDT 2002.
		version for eventual further modelizations	created following the DTM (Digital Terrain Model) SRTM90 from NASA.
Topography		**DTM SRTM90** from NASA	
Land and land use	Geomorphology, Land use in 1992 and 2002	**BDOT 2002** (Land Use National Database) from IGB, **Geomorpho 2002** from IGB	Simplification of classes (20 intially and 9 finally), rasterization.
		limits :	*The results of the diachronic approach (differences in land use at the national scale between 1992 and 2002) where intriguing. After a meeting and discussions with the responsible of the BDOT project at IGB, we decided to invalidate all the 1992 data base, except water, owing to important biases associated to the (visual) discrimination of land use classes for the 1992 coverage (see text hereafter). It was a deception not to be able to realize such a diachronic approach, even at short time scale (ten years).*
Meteorology		**CRU 2006** (Climatic Resarch Unit), 10' x 10'	

Table 1: Types, names, sources and treatments of data used for the implementation of the FasoMAB' GIS.

Illustration of results

Burkina Faso is a small (274,000 km^2) land locked West African country. It is enclosed in the large northward swing of the Niger River: a third (30.5 %) of the national territory, mainly in his northern and eastern parts, is in the Niger basin (Map 1). Most of the country (63.1 %) is in the upper end of the Volta Basin. The remaining (6.5 %), bordering Mali and Ivory Coast, drains into the major rivers that constitute the Comoé basin. In Burkina Faso, the Volta basin is mainly constituted by two large watersheds, the Mouhoun (former Black Volta, 53 % of the Volta basin' area in Burkina Faso) and the Nakambé (ex-White Volta, 47%).



Map 1: Localization of Burkina Faso (West Africa)

Owing to their different characteristics (size, latitude, etc.), these basins carry very different quantities of water across Burkina Faso's boarders. With more than 5 km^3 yearly flowing towards Ghana via the Nakambé and Mouhoun rivers (Tab. 2), the Volta basin appears as the most important transboundary watershed of Burkina Faso (Andreini et al. 2002): its importance is crucial to the hydrologic budget of the Volta Lake in Ghana.

Basin	Annual Flow at Boarder (km^3)	Population (inh./km^2)	relative anthropogenic pressure
Comoé	1.55	19.6	0.52
Niger	0.87	23.3	0.62
Mouhoun	2.64	40.6	1.08
Nakambé	2.44	52.9	1.40
Burkina Faso	**7.50**	**37.6**	***1.00***

Table 2: The transboundary basins of Burkina Faso (data: populations, INSD 2000; hydraulic features, DGRE 2001).

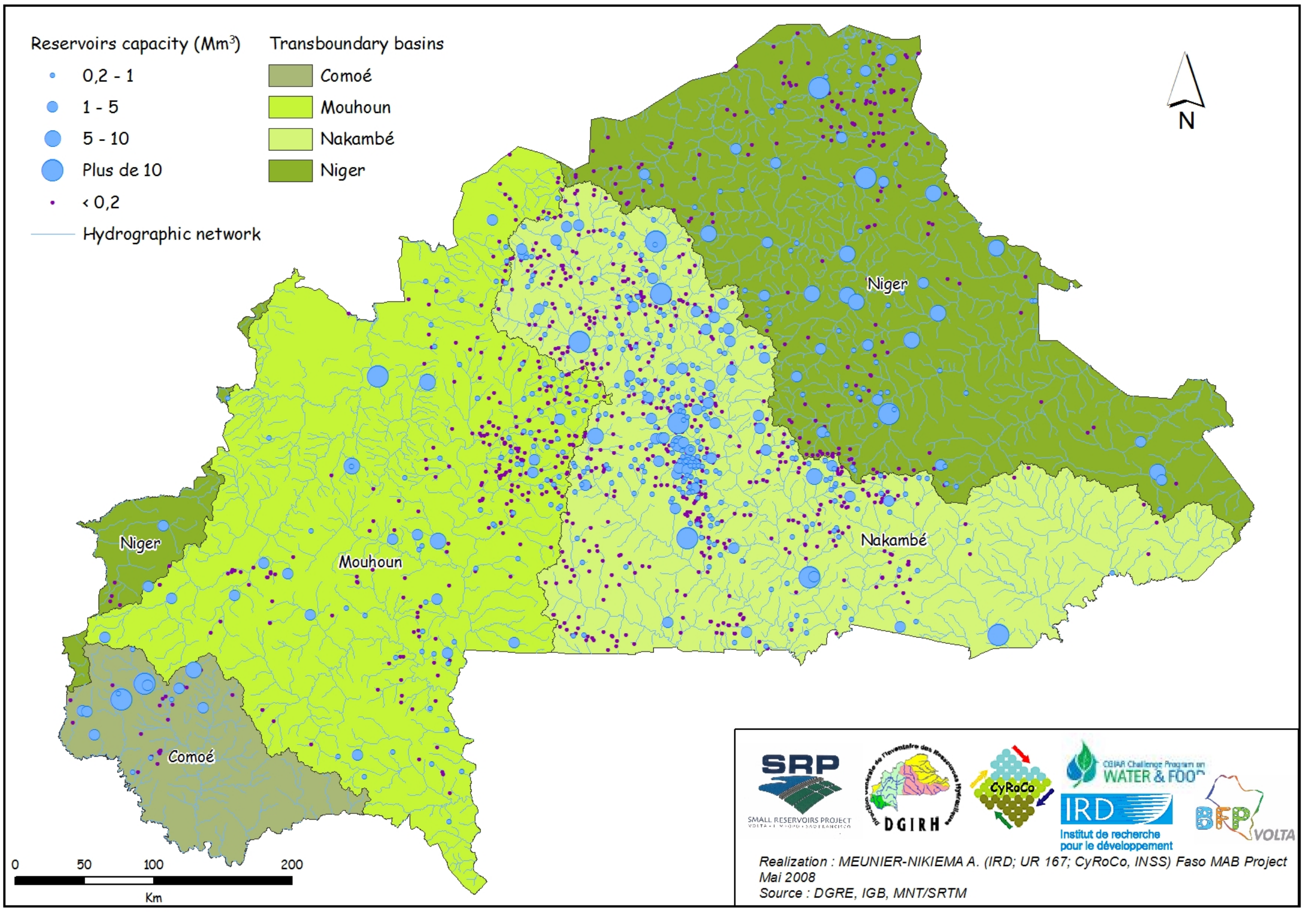
A large fraction of the national population resides in the Volta: densities are elevated, particularly for the Nakambé basin (see Table. 2). Anthropogenic pressures exerted on resources (ratio of population's densities used here as proxy) are expected to be there 2 to 3 times those in the Comoé and Niger basins.

Lakes and reservoirs in Burkina Faso

Information regarding the lakes and reservoirs of Burkina Faso are available from two main sources: the official inventories provided by DGRE (locked in 2001) and the remote sensing data on water masses > 5 hectares, as described by the Land Use National Database (BDOT, IGB) in 2002 (see Table 1).

DGRE database

The DGRE data are presented as a series of attributes (location, administrative features, technical characteristics, date of construction, type and dimensions of dikes, heights and volumes, etc.), theoretically provided for 1453 records (Map 2).



Map 2: Localization of the 1453 lakes and reservoirs in Burkina Faso (DGRE records). The class < 0.2 Mm^3 includes also reservoirs without capacity-related information.

Apart from location and administrative features, that could be confirmed from other sources of information (location by BDOT; administrative features by BNDT, e.g. national topographic database); none of these characteristics is verifiable. Moreover, only a fraction of records are complete.

Age of reservoirs, as example, is an important parameter: 1053 records (72.5 %) are available (Fig. 2). The oldest reservoirs are over a century old: it's a record in West Africa! Today, this water constitutes a normal component of landscape: uses and users have evolved together. Half of registered reservoirs were built between 1974 and 1987, during a dramatic drought that affected all West Africa. The construction of dams was chosen as a measure to secure water for people and their livestock. Building reservoirs as a form of insurance against drought continues today. We observe new construction daily in field and in local newspaper reports. New reservoirs will continue to be a reality in rural Burkina Faso for the foreseeable future.

The census of DGRE indicates that 335 reservoirs were built in the 14 years between 1988 and 2001, approximately 24 per year. Following this same pattern, 143 reservoirs were built in six years between 2002 and 2007. Assuming this trend continues, 198 reservoirs should have been built recently, bringing the total number of reservoirs in Burkina Faso to about 1650

Where are they? What are their sizes?

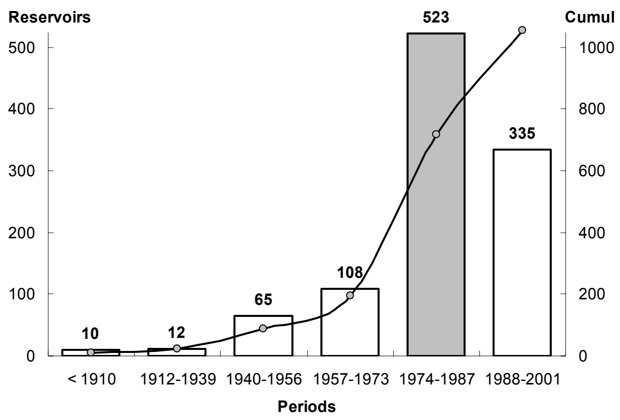


Figure 2: Age of reservoirs in Burkina Faso (N = 1053). The drought period (1974-1987) is indicated in grey.

Capacities of reservoirs

Volume is registered for 1015 reservoirs (70 % of the records) in the DGRE census (Fig. 3).

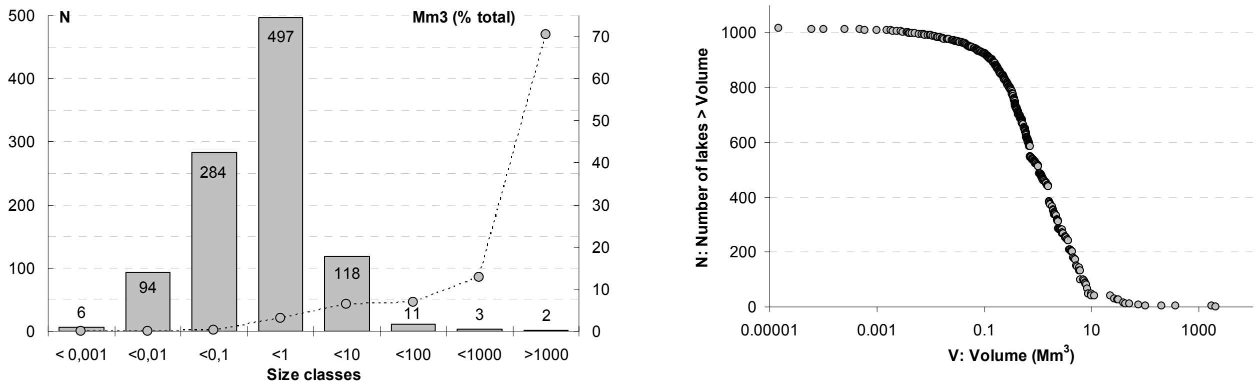


Figure 3: Size distribution (volumes) of reservoirs in Burkina Faso (DGRE database).

Two large reservoirs (Bagré and Kompienga, 1.7 and 2 km^3 respectively), both in the Southern part of the Nakambé basin (see Map 3) account for more than 60 % of the national capacity (Fig. 3). Conversely, the contribution of the numerous small reservoirs (capacity < 1 Mm^3: N = 881, 86.8% of the total number of reservoirs) represents less than 3.3 % of the national capacity.

The number and size of the reservoirs are strongly dependant on the morphology and their location in the drainage network. A general expectation is that there should be an inverse relationship between their size and their number: *smaller they are, more numerous they are*. Both the histogram and the size distribution frequency of registered volumes indicate a truncation of the observed distribution, reflecting the fact that small-size infrastructures are always poorly represented in official data bases (Meybeck 1995, Lehner & Döll 2004).

Thus, we postulated a significant underestimation in the census of smallest reservoirs in the DGRE database. It should to be added however that doubling the number of the smallest reservoirs registered (e.g. < 1 Mm^3) wouldn't change significantly the global contribution of the different capacities'classes, as largest reservoirs will continue to represent more than 93 % of the national storage.

The Volta basin is again particularly important (Tab. 3): 85% of the national storage capacity is in reservoirs located on the Nakambé or its tributaries, confirming the strategic role played by this basin in Burkina Faso.

	Classes (Mm^3)					Capacity		
Basins	<0.2[	[0.2-1]	]1-5]	]5-10]	]>10	**Total**	**Stocked**	**%**
Comoé	0	3	17	6	89	0.11	0.06	49.0
Niger	6	28	42	74	83	0.23	0.10	42.2
Mouhoun	9	28	36	20	370	0.46	0.29	61.6
Nakambé	18	88	116	30	4182	4.43	2.24	50.5
Total	33	146	211	130	4724	**5.24**	**2.68**	**51.1**

Table 3: Reservoirs' capacities in Burkina Faso. The stocked capacity corresponds to the mean interannual volume stocked within reservoirs as estimated by DGRE (2001).

Around fifty percent of the total storage capacity is replenished annually (DGRE 2001): the yearly filling of reservoirs is not systematic; a large fraction of stored water is immediately used, mainly for hydropower, irrigation and tap water. For the Nakambé river and its tributaries, the amount of water yearly stored within reservoirs corresponds to quite the annual inflow of the river (2.24 Mm^3 stocked and 2.44 Mm^3 as annual inflow, see Table 2): an increasing in the storage' capacity if the Nakambé basin will obligatorily affect the annual inflow, highlighting the potential tensions between Ghana and Burkina Faso regarding transboundary water sharing.

BDOT

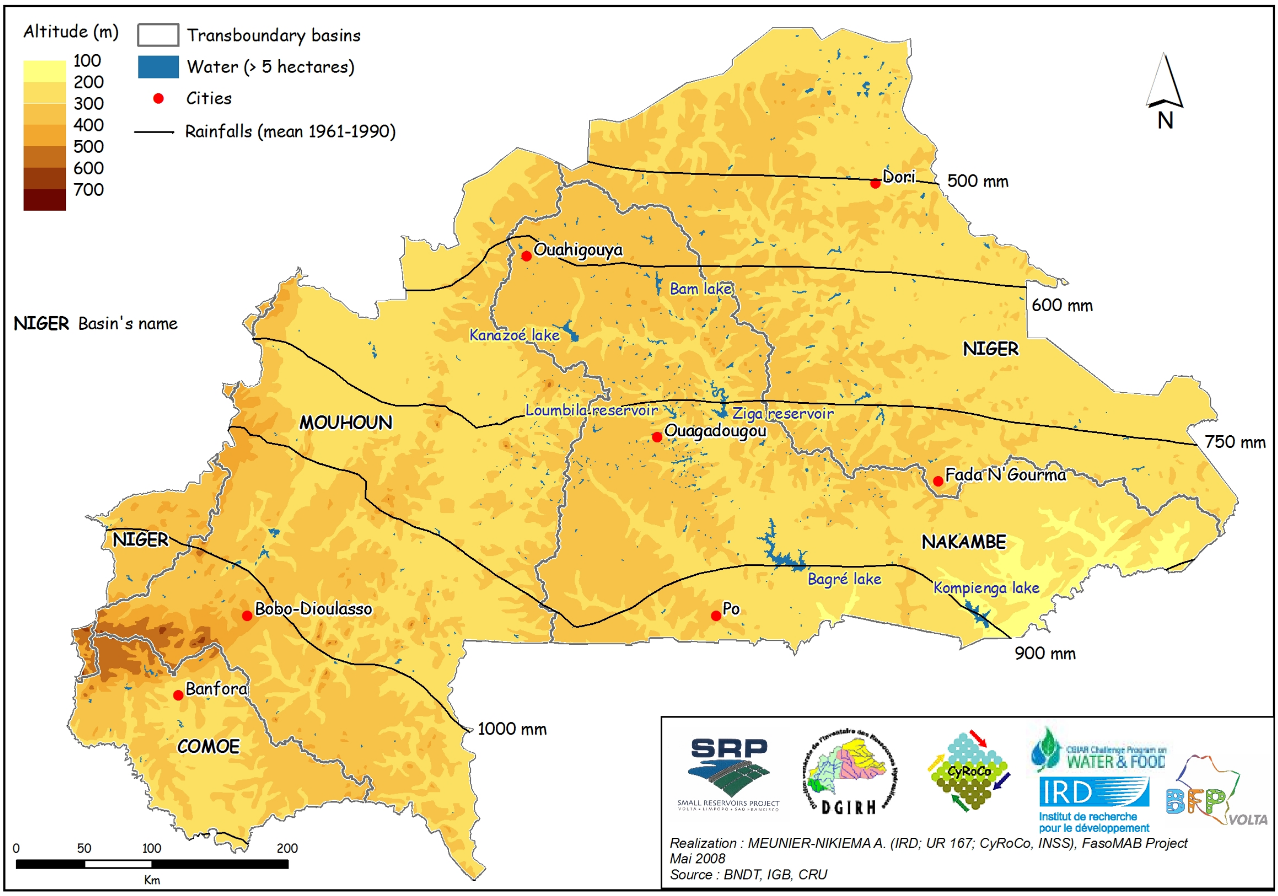
The classification procedure applied by IGB for the land use characterization (BDOT) allows for the description of all water bodies with areas > 5 hectares. It provides synoptic information, at the national scale, that includes both location and size. Unluckily, no clear indication regarding season and thus hydrologic status, e.g. high versus low water, with all infinite intermediary options is really available. We made two major assumptions to use the information provided by BDOT.

- The addition of all water bodies identified by the automatic classification procedure used by IGB for the treatment of the 2002 remote sensing sources (Landsat TM; see § limitations of the tools) provides a minimal value. We assume that the water bodies (> 5 hectares) identified were *effectively* present: if for seasonal reason (e.g. low versus high levels), areas are undervalued, or if some reservoirs have not been sensed remotely because they are too small or dry, the following estimates should be considered as explicitly underestimated.
- The spatially heterogeneous visual treatment used for the establishment of the BDOT 1992 data made unrealistic an analysis of land use evolution from 1992 and 2002 (see § limitations of the tools). Nevertheless, we consider that owing to the unambiguous, even though visual, detection of surface water > 5 hectares on Landsat TM colored compositions (> 50 pixels 30m x 30m), the values indicated for 1992 will also (e.g. as for 2002) constitute a minimum. Seasonal reasons (e.g. low levels) as accuracy of treatments (more or less convincing) could minimize, but not major, the observed situations, and particularly the differences hereafter discussed between the two periods.

Spatial distribution of lakes and reservoirs

Around 1,050 km^2 of water (0.4 % of the national territory, 274,000 km^2) have been automatically identified by IGB using a standardized procedure for the classification of 2002 remote sensed information (Map 2). They found 620 lakes and reservoirs > 5 hectares. Their distribution covers all the country. There is no simple relationship between the rainfall pattern (here represented by the CRU data, see New et al. 2002) and the distribution of reservoirs. Most of them are concentrated in the central part of the country and along the Nakambé corridor. Burkina Faso is a relatively flat country without any significant relief. The majority of water bodies are located at altitudes between

200 and 400 m; there does not appear to be relationship linking their size and their altitude, mostly because of the coarse grain used for elevation' delineation (100 m). The deepest reservoir of the country, Kompienga, lies under the 200 m isoclines.



Map 2: Lakes and reservoirs > 5 hectares in Burkina Faso.

Fourteen hundred and fifty reservoirs were inventoried in the 2001 DGRE database. An unknown fraction of them is temporary. Six hundred and twenty water masses were identified by BDOT in 2002: the discrepancy is significant! Seasonal reasons have first to be suspected. A complete Landsat TM coverage of the country for landuse characterization may reasonably be found during the dry season, when cloud cover is supposed to be minimal, and also when contrasts between classes are said to be maximal. For the four largest reservoirs in the country (Kompienga, Bagré, Ziga and Yako), their observed sizes in 2002 corresponded to around 70% of their maxima. It's reasonable to assume that the BDOT classifications were made with dry season pictures. It implies that the smaller water bodies may be too small to be depixelized, or even dry, justifying some of the observed discrepancy.

The DGRE database indicated that some 24 reservoirs were built yearly between 1988 and 2001 and 240 reservoirs were probably built between 1992 and 2002. The BDOT indicates an increase of only 79 between the two periods. Owing to the previous discussion, we argue that they correspond to large enough (e.g. perennial) systems, highlighting again the poor representation of smallest aquatic ecosystems, including small reservoirs.

Despite these limitations, approximately 1,000 km^2 of water were identified in 2002. They constitute an important resource, hereafter illustrated by considering solely their value to local fisheries.

West African inland fisheries are estimated to produce 50-75 kg/hectare. The FAO database on fisheries indicates a mean value of 60 kg/hectare for the largest reservoirs of the Burkina Faso (see http://www.fao.org/fishery/countrysector/FI-CP_BF/fr), whereas Villanueva et al. (2006) reported a yield of about 80 kg/hectare for the Bagré reservoir in its early stages of filling. It corresponds to the activity of 2 to 5 fishermen/km^2. Applying the smallest of these numbers (e.g. 50 kg/hectare) to 2002 values (Tab. 4) indicates an annual productivity of 5,280 tons, involving 2,000 to 5,000 fishermen. With a (voluntary low) price of 250 FCFA/kg (0.38 €/kg), it corresponds to an annual market of 1.3 billions of FCFA (2 M€). It's far from nothing! From 1992 to 2002, surface of lakes and reservoirs increased by a third (Tab. 4). Using these figures (see Table 4) it can be estimated that annual yield of fish increased by 1,310 tons providing work for 500 to 1300 new fishermen, and generating additional income of approximately 327 MFCFA (0.5 M€) per year. Reservoirs clearly contribute by their productivity to the food security and livelihoods of many people in Burkina Faso.

BDOT	N	A (km^2)	P (km)
1992	541	794	3237
2002	620	1056	4043
Dif.	79	262	806
Dif. (%)	*+ 14.6*	*+ 33.0*	*+ 24.9*

Table 4: Water surfaces associated to reservoirs as discriminated by BDOT in 1992 and 2002: N, number; A, area; P, perimeter.

In 2002, BDOT also reported that the length of the shoreline associated to these water bodies, was approximately 4,000 km. Applying the mean national population' density (see table 2) to a buffer zone of 3 km along this shoreline indicates that about half a million of inhabitants are in close contact with water (Keiser et al. 2005 used a distance of 2 km away from the shoreline of reservoirs to delineate the potential biting area of mosquitoes; 3 km is much less than the distance traveled daily by rural people to use water from reservoirs). This population could be considered at risk regarding water borne diseases (McCartney et al. 2007). The shoreline is the contact area between users and water bodies: it's a place of labor, for domestic purposes or for small scale production; it's also a place for leisure, particularly for childrens. The shoreline is the principal hot spot associated the transmission of water borne diseases and contamination. From 1992 to 2002, the creation of 800 km of new shoreline may have benefited approximately 90 000 (maybe new) people, using the different goods and services associated to the close availability of water, and conversely exposed them to a potential new burden of threats.

These different estimations are in all probability low. The areas and shoreline lengths are intermediate if not minimal values owing to seasonal fluctuations in the dry season and we assume also a huge underestimate for both areas and shorelines due to the pixel size (11 pixels/hectare with Landsat TM). In addition the number of (small) reservoirs is obviously underestimated.

How to deal with this last point?

Size distribution of reservoirs

Size (surface) distribution of water masses in 1992 and 2002 reveal close characteristics: the most striking features is its linearity when drawn on a double logarithmic scale (Fig. 4). This indicates that the lake size distribution follows a power law in the form $N = xA^y$; an observation made already by various authors (Wetzel 1990, Meybeck 1995). If $y = -1$, the relationship becomes scale invariant, implying that the distribution of lakes and their sizes is fractal in form (Lehner & Döll 2004), as observed for small reservoirs in the Upper East of Ghana (Liebe 2002).

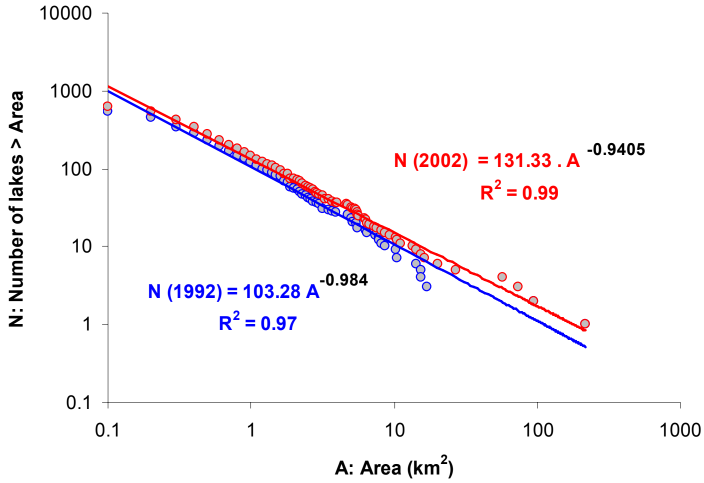


Figure 4: Size distributions of the lakes and reservoirs distinguished by the BDOT in 1992 (N=541) and in 2002 (N = 620).

The application of these power laws allows the calculation of (theoretical) N values that will perfectly fit the observed regressions in 1992 and in 2002 (Tab. 5).

Area (km^2)	N cumul 92	N calc. 92	N obs. 92	Δ 92	N cumul 02	N calc. 02	N obs. 02	Δ 02
0.05	1969	973	86	887	2198	1053	86	967
0.1	995	892	343	**549**	1145	1014	402	**612**
1	103	93	102	-9	131	116	119	-3
10	11	10	9	1	15	13	12	1
100	1	1	1	0	2	2	1	1
	Total 92	*1969*	*541*	***1428***	***Total 02***	*2198*	*620*	***1578***

Table 5: Calculated size distribution of reservoirs in 1992 and 2002

These calculated numbers have to be considered with precautions: these are brutal estimations! However, several interesting points are highlighted:

- Regressions are strongly influenced by large systems, which are the less abundant. The addition of 4 large identifiable reservoirs (surfaces between 10 and 100 km^2) between 1992 and 2002 significantly improve the quality of the regression (Fig. 4).
- Differences between calculated and observed numbers show that discrepancy increase with the diminution in size of water masses (Tab. 5).
    - A same value is indicated in BDOT 1992 and BDOT 2002 for the smallest size' classe, [0.05 – 0.1[km2: N = 86, whereas all other classes have increased during the same period. It's not by chance: it's a bias, probably associated to the visual treatment realized on BDOT 1992. Assemblages of pixels are too small for a global and efficient "on-screen" discrimination. This class is also the most sensitive to seasonal variations and shall be the most underestimated by BDOT, owing to the remote sensing period used.
    - More interesting are the results associated to the size'classe [0.1 – 1[km^2: results indicate that in 1992 as in 2002, less than half of the theoretical number of water masses have been discriminated by the treatments applied to remote sensed information. The smallest reservoirs in concern, 100 hectares, will appear in their majority too large to dry: if present, they shall have been discriminated, *a minima* with the automatic procedure applied by IGB in 2002. We may conclude that even if there is an underestimation of the exact number of reservoirs included in this size' classe, this underestimation shouldn't be as important as the regression suggests it could be. The DGRE census inventoried 1450 reservoirs in 2001: we already advocated that the discrepancy between this number and

the 620 water masses depicted by BDOT in 2002 is for a significant part attributable to very small reservoirs. We may confirm that medium size' reservoirs (e.g. [0.1 – 1[km2) wouldn't be so in concern. This observation may perhaps also sustain the idea that all "theoretical" places eligible for reservoirs' construction are far from being saturated.

- o Following the DGRE database information, we forecasted that 240 reservoirs may have been edified between 1992 and 2002: BDOT indicates that only 79 have been effectively created. We may further consider that the difference (240 - 79 = 161) could be attributable to smallest reservoirs (< 0.1 km^2), which number didn't change between 1992 and 2002 in BDOT (N = 86 for both periods). So far, we'll consider that in 2002 this class corresponded to an effective of (86 + 161) 247 reservoirs, growing their total number towards 781 in 2002.

From 1992 to 2002, 526 new km^2 of water have been identified by BDOT. Among them, 262 km^2 (Tab. 4) have been attributed to reservoirs: 264 km^2 (50 % of this augmentation) have to explained.

We postulated that BDOT underestimated the number of small reservoirs, and have modified the number of systems < 0.1 km^2 from 86 to 247. This enhancement (+ 161 reservoirs) may however correspond to a maximum increase of 16 km^2 in surface. Even in increasing by a factor 10 this number (e.g. + 1600 reservoirs < 0.1 km^2 between 1992 and 2002), the associated surface wouldn't exceed 160 km^2. Around 100 km^2 remained still to be justified. We may conclude that apart from the artificial evolution of the water surface associated to the edification of new reservoirs, other factor(s) may interplay: a seasonal lag between the two seasons of remote sensed information acquisition could first be suggested as, independently of the presence (and number) of reservoirs at these two periods, there were more water (≈ + 38%) in 1992 than in 2002 [(264 – 160)/264 km^2].

It follows that areas and shorelines described for 2002 correspond to minimal values that are clearly associated to large enough ecosystems to occupy significant surfaces "late" in the dry season. The 620 water masses identified in 2002 may thus be associated to perennial water masses.

Assembling BDOT and DGRE census

Among the 1453 records in the DGRE lakes and reservoirs census, 419 only are available to compare their indicated characteristics, namely their volume, and their surface as estimated by the BDOT classification (for surface > 5 hectares). Even if it corresponds to a drastic reduction, this shortened database could be useful to explore eventual relationships between these two parameters.

As previously discussed, BDOT 2002 provides areas and shorelines: there is (logically) a perfect allometric relationship between both (Fig. 5). Such a relationship validates the quality of data obtained from the BDOT. It indicates also a clear homogeneity in the form of reservoirs.

A compactness coefficient (equivalent to the Gravelius coefficient for watershed), called Shoreline Development Index (D_L, Hutchinson 1957) has been calculated: $D_L = 0,282 * P * A^{-1/2}$ with P, the shoreline length (km) and A, the Area (km^2) of the water masses: D_L is the ratio of the length of the shore line to the length of the circumference of a circle of area equal to that of the water system in concern. Only a few lakes, such as crater lakes approach the circular shape, i.e., $D_L = 1$ (circular). This coefficient is always greater than 1: more it is low, more the water masses in concern have a regular form. D_L is strongly dependant on the size of water masses (Fig. 6), indicating first that smaller they are, the more simple their morphology is. It reveals also the global homogeneity of reservoirs both within (relatively small and non recovering standard deviations) and between the different classes (regression). That sounds logical regarding their spatial distribution (Nakambé corridor mainly) and their dispersion within the low margins of the basin (between the 200 m and 400 m isoclines).

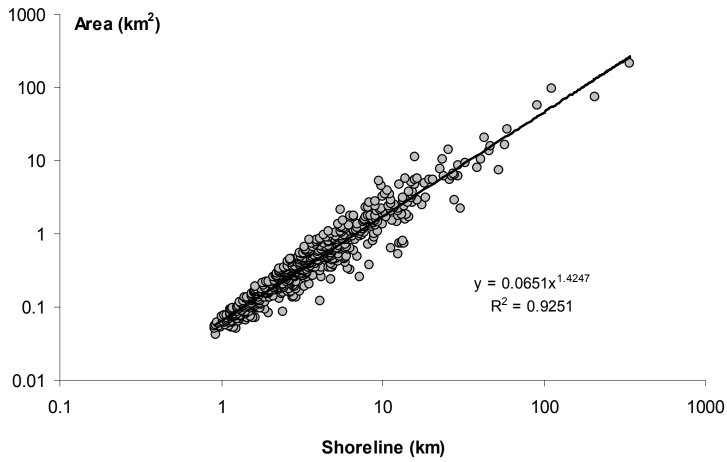


Figure 5: Allometric relationship between areas and shorelines, as provided by the BDOT 2002, for the 620 water masses detected.

What is known about reservoirs in Burkina Faso is their low mean and maximum depths. Apart from the Kompienga reservoir, the deepest of the country, which benefits from an undulated landscape, and from some rare medium systems located within the high course of Comoé River (e.g. Moussodougou, Douna), maximal depths rarely exceed 10 to 15 m. For perennial reservoirs, areas may vary from, say, 1 to 1000 km^2, whereas in the same time, the maximum depths will remain proportionally quite constant in varying, say, between 5 to 15 m: a factor 1000 for areas, a factor 3 for depths. It means that reservoirs in Burkina Faso are mostly shallow lakes, their relative shallowness increasing with their size.

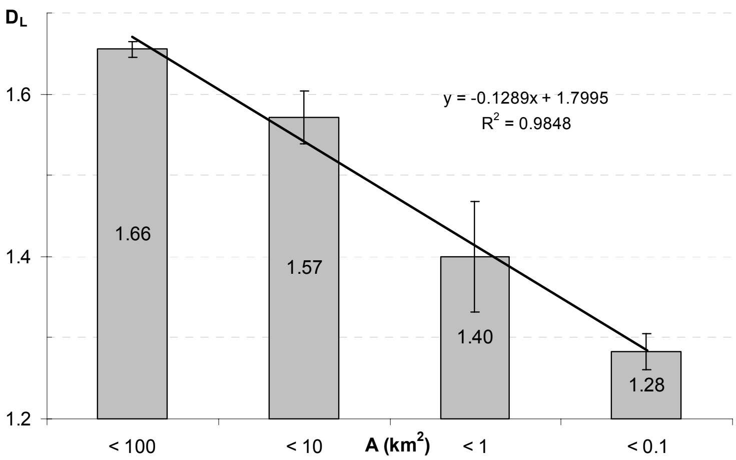


Figure 6: Shoreline Development Index (D_L) by size classes (N = 620, BDOT 2002).

This echoes with the previous observation regarding morphology of reservoirs: when increasing the area, the shoreline will proportionally increase faster for large systems than for small one, but in involving very shallow areas. In other words, to increase by one unit the volume of large systems will require proportionally far more surface than what is required for small ones.

The same ensemble of objects, namely the lakes and reservoirs from Burkina Faso, could be described towards two different and completely independent data sources: on the one hand, the DGRE census and, on the other hand, the BDOT classification. The census, locked in 2001, and the BDOT 2002 are supposed to be contemporaneous, and thus comparable. The superposition of both distributions suggests a certain amount of redundancy (Fig. 7).

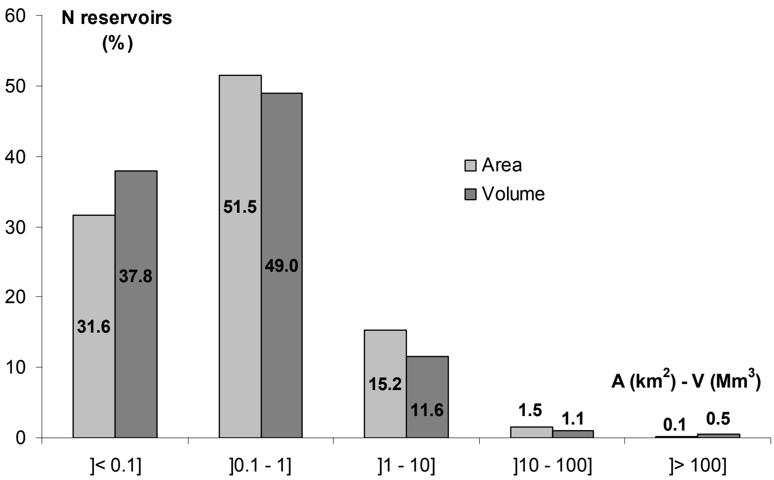


Figure 7: Size's distribution (% per classes) of lakes and reservoirs. Volume, V (Mm^3): DGRE census, N=1015; Surface, A (km^2): BDOT 2002 modified to take into account the smallest reservoirs, N=781.

Both distributions apply to the same ensemble of objects: the relative contribution of the different size classes reveals a coherent pattern, in volume as in surface, indicating again the predominance of small (< 1 km^2 / 1 Mm^3) even very small (< 10 hectares / 100 000 m^3) water masses. Unluckily, no information is provided by that way regarding the existence of eventual relationship linking volumes and surfaces.

Volumes provided by the DGRE census and areas from the BDOT 2002 are available for 419 water masses. A significant tendency links these morphological traits (Fig. 8).

The two larger reservoirs (Bagré and Kompienga) were eliminated. Three small size outliers have been (graphically) identified and were simply discarded because of evident error for their volumes. For the larger systems (grey dots on Fig. 8), two apparent outliers have also been identified and obvious typographic mistakes corrected. But it's by evidence impossible to proceed identically for the whole data base, first owing to the absence of any external reference allowing the validation of the information provided. Huge tendencies only can be proposed.

We first estimated for each record its theoretical volume by applying the regression (Fig. 8), and compared the estimations to the registered values provided by the DGRE census. We eliminated all records whose volume was over- or underestimated by more than 75 %: 277 records remained available to recreate another regression, **V (x 1000 m^3) = 1,612 x A (km^2), R^2= 0.95**.

Applying this second regression to the 618 records < 100 km^2 provided by BDOT indicates first that 1.2 km^3 were stored within these perennial water masses during the 2002 dry season. We previously observed that an underestimation evaluated to 38 % characterized the BDOT 2002 classification, when compared to the 1992 classification. We also indicated that the surfaces provided by BDOT 2002 for the larger reservoirs of the country were underestimated by around 30 %.

It seems thus admissible to apply such a coefficient to the estimated volumes and thus to propose a stored capacity of (1.2 km^3 + 30 %) = 1.56 km^3. Adding the cumulated capacities of Bagré and Kompienga indicates that 5.26 km^3 were stored in 2002: it corresponds to values provided by the DGRE census (Tab. 3) but without taking in account the numerous < 0.1 km^2 reservoirs (30 to 35 % of the total, Fig. 7). We already observed that their storage contribution remains weak, whatever their number.

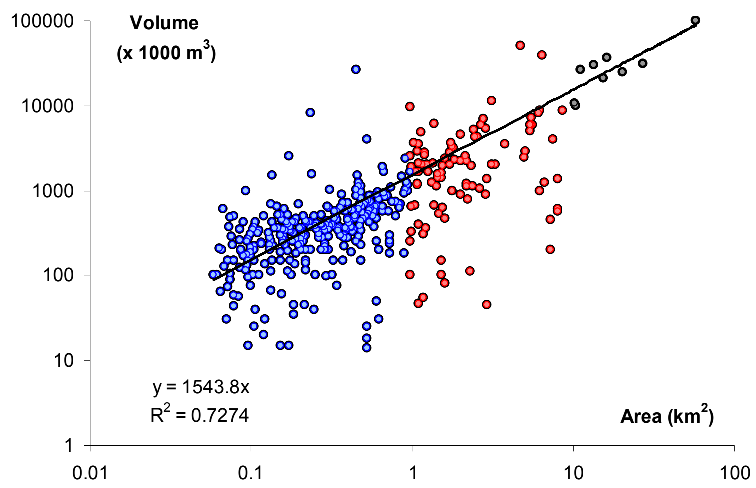


Figure 8: Allometric relationship linking volume (V) and areas (A) for 414 lakes and reservoirs < 100 km^2 from Burkina Faso. Blue dots: < 1 km^2, red dots: [1 – 10] km^2, grey dots: > 10 km^2.

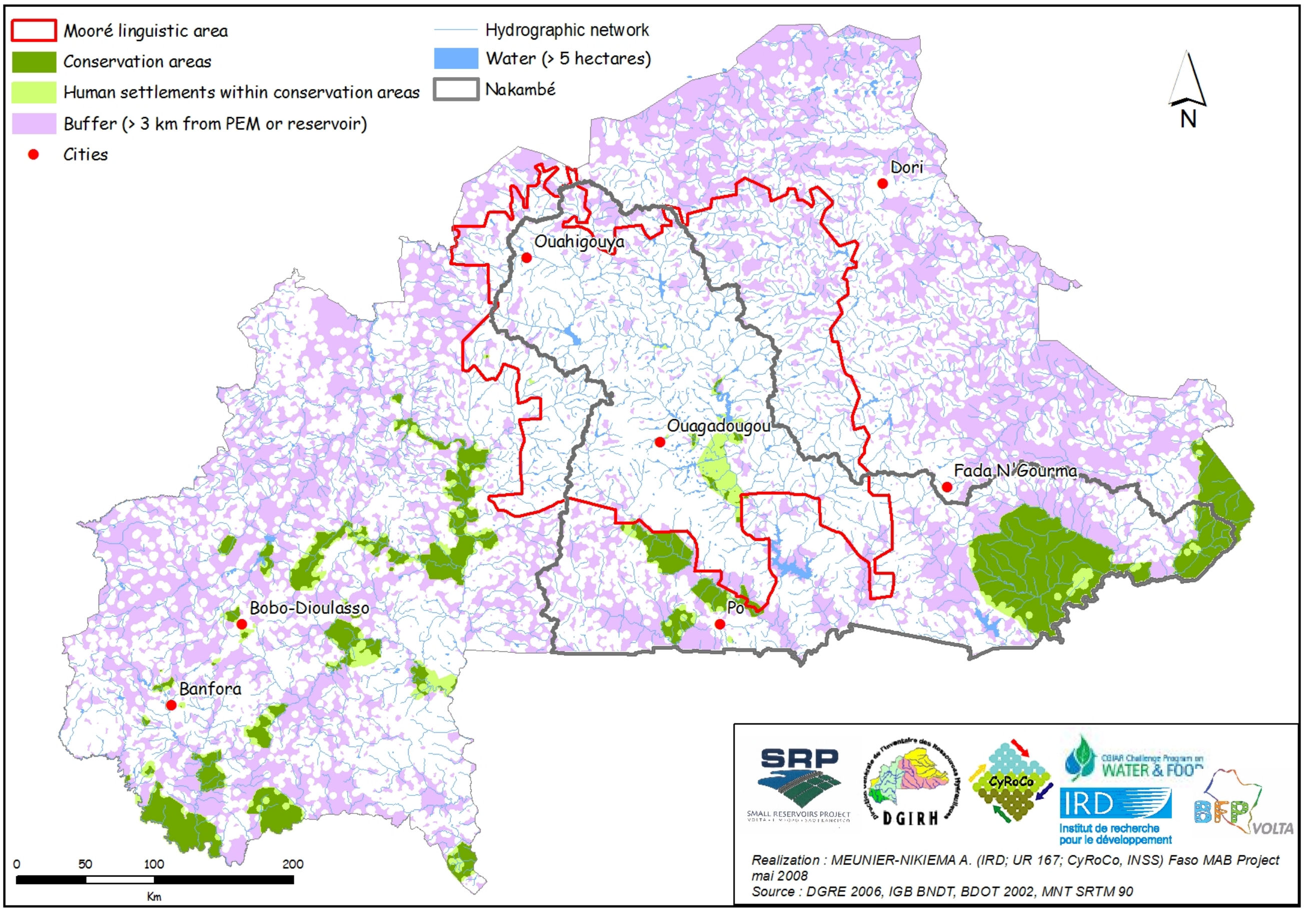
If this assertion could be acceptable at a global scale, as discussed here in terms of hydrologic budget, its pertinence becomes doubtful at local scales. Water storage facilities are a resource, particularly in arid country, and as such contribute to the water poverty alleviation, first in terms of water availability.

About water resources and availability in Burkina Faso

Map 3 provides an illustration of a more sophisticated treatment allowed by the FasoMAB project. The PEM database (DGRE 2006) indicates the localization of all groundwater distribution devices implemented in Burkina Faso. We added all reservoirs as inventoried by the DGRE (2001) database, and projected both categories of water resources on a map clothed with the hydrographic network (a combination of BDOT 2002 and those that has been created with the SRTM numerical model). A 3 km radius buffer has thus been created around each of the georeferenced point indicating the presence of a water providing device. Any point of the territory that is located out of this buffer is declared as "*water scare area*" and appears with a pink color on Map 3. For WHO (Howard & Bartram 2003), a distance > 1 km is defined as a "no access" situation, always inducing severe health damages. We increase this distance to 3 km to minor local heterogeneities and illustrate more clearly large infra- and inter-regional discrepancies. Water devices are defined here as points. For lakes and reservoirs, polygons should have been used: their shorelines are indeed systematically used by their riverines. Pink areas around the Bagré and Kompienga lakes (in the southern part of the Nakambé basin) are thus abusive. It remains that the observed distribution of water scarce areas is firstly characterized by its extreme patchiness.

An important fraction of the country appears in water scarce conditions as defined here, and large pockets without infrastructures are apparent. These areas may constitute target areas in terms of future equipments.

These "water scarce" zones are welting the central part of the country which constitutes a dramatic exception. The concentration of water providing devices within the Nakambé basin (dark line on Map 3) is obvious: surface water as groundwater are intensively exploited. We already have mentioned that this area corresponds to the densest zone of the country: there is an evident link between both as investments are logically concentrated in the most populated areas.



Map 3: Water scarcity in Burkina Faso. The mooré linguistic area delineation provided by BNDT corresponds to the extension of the "Moogo" kingdom at the end of the 19th century, as indicated by Izard (2004, p. 114).

The delineation of the linguistic area shared by the Mossi folk (red line on Map 3) provides another perception of this concentration, probably highlighting the resilience of a traditional but still powerful Establishment that continues to drain within its own influential area a large fraction of development project.

Conservation areas, free of human settlements are also of interest: most of them (dark green on Map 3) are not equipped with water harvesting devices, as there is theoretically nobody to use them. The Nakambé corridor, East of Ouagadougou, constitutes a noticeable exception. All clear green zones correspond to area theoretically free of populations that appear either pressured on their borders (as particularly apparent in the western part of the country, along the Mouhoun River and its tributaries), or quite completely invaded (see the two conservation areas located east of Bobo Dioulasso). In this particular last case, the resettlement of refugees populations recently drawn aside of Côte d'Ivoire has to be directly involved (Courtin 2007).

These two last points introduce a fundamental dimension: the historical perspective.
The map illustrates the location of all georeferenced watering places in Burkina Faso: their obvious concentration in the central part of the country has historical foundations. The delineation of the mooré linguistic area on Map 3 corresponds also and for a long time to the delineation of a degraded area (Izard 2004). With a mean population density of 15 inb/km^2 at the end of the 19th century, with important disparities (desertion of inland valleys, large scattering of settlements and concentrations in focal places), the "Moogo" kingdom early appeared as a very populated area. It's seems

paradoxical regarding the unfavourable pedological context and the constitutive soils poverty of this area: overpressure on the natural resources and land degradation seemed a process installed since (and maybe for) a long time.

The situation observed in the periphery of conservation areas points out the existence of another scale of change, related to contemporaneous dynamics. If in some place the resettlement of refugees – it was at that time a priority – explains the erosion of protected areas, in many others, it's the human densification within the bordering buffer zones that is in concern. It highlights the sometimes very focal but local demographic dynamics that may often induce, accordingly to the human densification, also focal and local overpressures and degradations.

The definition of contexts of small reservoirs, first goal of our tool, has to encompass these two historical dimensions. The Nakambé basin will be again explicitly in concern in our tool kit, regarding in particular cyanobacterial communities that develop preferentially and massively within its reservoirs, and their eventual relationship with the intensification of agricultural practices around the reservoirs. It is hypothesized that huge driving pressures are exerted by watersheds on the global metabolism of reservoirs, including the determinism of the structure of the living communities that develop inside. The influence of contemporaneous landuse is now clearly established (Burford et al. 2007) and the consideration of diachronic insights has proven its importance (Harding et al. 1998). It creates however a very complex situation, as the identification of pertinent proxies including both the actual and the historical conditions, will require (1) adequate data to effectively document the situations, (2) at a pertinent scale. It couldn't be the case with a global perspective. This constitutes one of the main limitations of our tool.

Limitations of the tool

Reservoirs themselves

It is well known that even for large systems, the reservoir' census provided by DGRE is not exhaustive: Ziga, recently constructed to provide drinking water to the capital, with a capacity of 200 Mm^3, was not included, nor was the 75 Mm^3 Kanazoe Dam. Both are in the top 10 of largest reservoirs of the country; both lie on the Nakambé River. By definition it is difficult to quantify the error for small reservoirs. We estimated in comparing our data to maps provided by the RESO Project (a regional inventory of water resources) that in some places (along the southern portion of the Mouhoun River, particularly) the official reservoir's database includes fewer than 70% of the dams effectively present. This error may not be the same at national level: numerous recently (after 2001) constructed dams may not be included in the DGRE database. Furthermore, although there has been a general augmentation of the number of dams, new construction is not necessarily occurring at the same rate throughout the country. Their contribution remains largely insignificant in terms of water budget but their local influence is most often of great importance.

Land Use

The BDOT (Base de Données d'Occupation des Terres, "Land Use Data Base") provided information on land occupation over the whole country. This came out of a project sponsored by Burkina Faso's Projet National de Gestion des Terroirs (PNGT; "National Land Management Project") and realized by IGN-France International in partnership with the Geographic Institute of Burkina (IGB). BDOT uses the hierarchical nomenclature standardized by CORINE LAND COVER, which was initially developed for the European Union and later validated for tropical zones. The land use is described using pixels whose size can range between 5 and 25 hectares according to land use classes.

The current BDOT database consists of three elements: data collected in 1992 and 2002, and a field named "changes" which summarizes all the differences in land use values between the two periods. It has a resolution of 5 hectares and can thus be considered as a dynamic view of the changes that occurred during the decade. This database, however, unfortunately turned out to be truncated. The 2002 database remains completely valid, as it was created automatically by a standard procedure: it provides local data at the national scale. The 1992 database, on the other hand, was constructed manually by superposing the BDOT 2002 data and a classification of Landsat images taken in 1992. Changes in soil occupation were detected by examining the two images on the screen. To accomplish this, the country was partitioned into 200,000 square tiles; these were then assigned to various IGB operators for processing.

The noticeable heterogeneity of the "changes" data (Fig. 9) thus reflects the relative skill, precision, and even patience of these operators. The central part of the country contains the greatest number of reservoirs and a very large population, and is therefore crucial to any mobilization of water resources. Yet, quite obviously, this strategic region is far from being the best documented area. Is this absence of visible change really attributable to very weak evolution in an area where population density has indeed been elevated for a long time and where recent local changes appear too small (< 5 hectares) to be detected on screen? Or does this zone's apparent stability simply reflect the operator's lack of fitness in treating the data? In the end, the 1992 BDOT and the "changes" database were not used in our analysis. We only conserve the water surfaces estimations provided by BDOT 1992, as it is assumed that even a visual discrimination allows a minimal detection, at least for medium size' reservoirs.

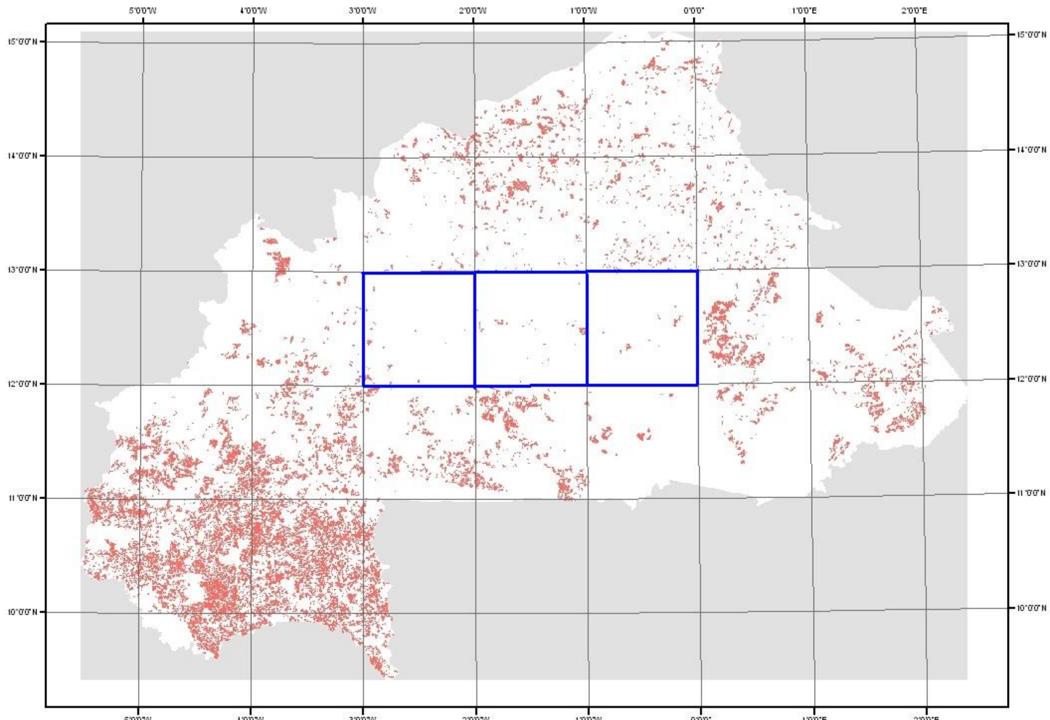


Figure 9: The BDOT "changes" database.

Population

Today 650,000 people, or about 5% of the national population, are not correctly geo-referenced. If one supposes that this population is uniformly scattered at the national level, then no bias should be introduced on this scale. This assertion becomes less valid when zooming in on smaller areas. The "villages" database (N>8000) that we have constituted represents the elementary unit of the GIS. Its coherence is assumed on the scale of *departements* (N=350) or basins of several thousand square kilometers. This coherence will have to be validated on a case-by-case basis for any geographic units of smaller size (notably for basins covering tens to hundreds of square kilometers). On the scale of the Nariarle River[1], for example, specific validation reduces the uncertainty to about 2% of the basin's 150,000 inhabitants.

Lessons learned and perspectives

By combining different sources of information, it has been possible to develop a tool that allowed, if not a renewal, but a synthetic description of lakes and reservoirs in Burkina Faso. Their number, obviously underestimated by the official census, may clearly be majored by ten % *a minima*. To correct the database for large systems is not problematic. More complex even impossible is to rectify information for small systems owing to the absence of external reference. Remote sensed information revealed its limits, first for seasonal reasons. It permitted however to show that both sources (DGRE census and BDOT classifications) provided redundant information: the same objects (e.g. reservoirs) are focused. The very elevated numeric contribution of small even very small systems is highlighted. However, owing to their small size, even a doubling of their number wouldn't erode the dramatic dominance of a small number of (large) reservoirs in the constitution of the national capacity yearly stored in Burkina Faso.

The populated Nakambé basin is particularly in concern: the annual flow is yearly retained within principally 4 reservoirs, all 4 in the top five of the largest systems of the country. Simultaneously, this basin concentrated most of small reservoirs, constituting a very dense network of scattered water resources.

A relative morphological unity characterizes these reservoirs: very shallow, largely open owing to the flatness of the landscape, they need important areas to accumulate significant volumes in developing elongated shorelines. They offer large surfaces for evaporation.

A very minimal estimation is to consider that around half a million of persons is living less than 3 km from a perennial reservoir, mostly again within the Nakambé corridor. Historical reasons justify the concentration of reservoirs within this basin where both long time tendencies (degradation and overexploitation of watersheds) and recent dynamics (agricultural intensification around reservoirs) may exert strong influences on the functioning and properties of water masses.

The combination of data provided by DGRE and BDOT allow ultimately the establishment of a coarse relationship linking areas and volumes of reservoirs at the national scale. The results provided are coherent.

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[1] As of today, this basin contains the highest known density of reservoirs in West Africa: more than 50 in a region of about 1500 km^2.

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