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Evaluation of Flows in Poorly Gauged for the Improvement of the Hydraulicity of Lake Chad

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ABSTRACT
The exploitation of Digital Terrain Models in order to aggregate the mobilized flows in a poorly gauged catchment area has been used to study the water potential of the Chari and Logone basins. On the basis of water transfer projects from the Congo Basin to Lake Chad, our study has set itself the objective of evaluating the existence of the necessary volume of water in the Chadian basin without causing water stress in the basin Congo. From the three identified study areas, physical characteristics of the related watershed were extracted. They were used with the Model of the NRCS (National Resources Conservation Service) to determine the flows of our work. Our results were conclusive proving the usefulness of our study model.
Keywords - Climate change, Digital Terrain Model (DTM), Watershed, Rain, Flow, Discharge, Direction of water flow

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I. INTRODUCTION

Climate change is severely affecting the ecosystems of the Sahel region and those of the Congo Basin, including Lake Chad and its tributaries. The area of this inland sea is drastically reduced by 25000 km^2 to 4000 km^2 and potentially exposes it to drying out. The unique idea to date is the transfer of water from the Congo and Oubangui-chari rivers for its bailout. This mega project, with an initial objective of transferring 100 km^3/year of water [1], it was reduced twenty years later to 3, 8 km^3/year [2]. The populations bordering the Lake Chad basin suffer durably.

However, the losses by infiltration are accentuated in addition to the piezometric depressions which direct the piezometric gradients of the shores of Lake Chad towards the interior of the land without seasonal inversion [3]. The crown of granite basement (Aïr, Hoggar, Tibesti Ennedi, Ouaddaï, Adamaoua, Jos) does not favor underground supply [4]. In addition, the average temperature will increase considerably throughout the Congo basin by the end of the century. This is in contrast to the no major change in annual rainfall with a forecast of longer and more frequent dry seasons in the northern regions of the Congo basin [5]. The slight slopes of the Chari and Logone rivers, the main tributaries, combined with significant land transport, contribute to the constitution of the sills to their hydraulicity and then to that of Lake Chad [6, 7].

By virtue of the various hydraulic models, taking into account the effect of climate change and anthropogenic actions on the rivers [8] and their fields of application, we consider in the case of our study the specific models whose parameters are applicable to the rural basins and that of Lake Chad.

Some authors have given indications and steps that can allow the development of an empirical hydrological model based on the rainfall-flow relationship – using Digital Terrain Models [9, 10]. Others have proposed approaches for estimating water levels in floodplains based on statistics [11] and flows in watersheds using satellite images [12].

In a weakly gauged watershed, the aim of our study is to evaluate on the basis of digital models of mobilizable land to contribute to a sustainable bailout of Lake Chad. We will use our transfer function, flow aggregation and iteration activation. For us, it is a question of verifying the water potential of the Chari and Logone basins in order to drain the flow sought by the water transfer project from the Congo basin to Lake Chad.

II. MATERIAL AND METHODS

II.1. Study areas

The study areas (Fig. 1) covered two watersheds including that of the Chari and Logone rivers, both, tributaries of Lake Chad. Their similarities lay in natural discharge and spreading of runoff water in the winter period from the start of soil saturation and the overflow of their bed.

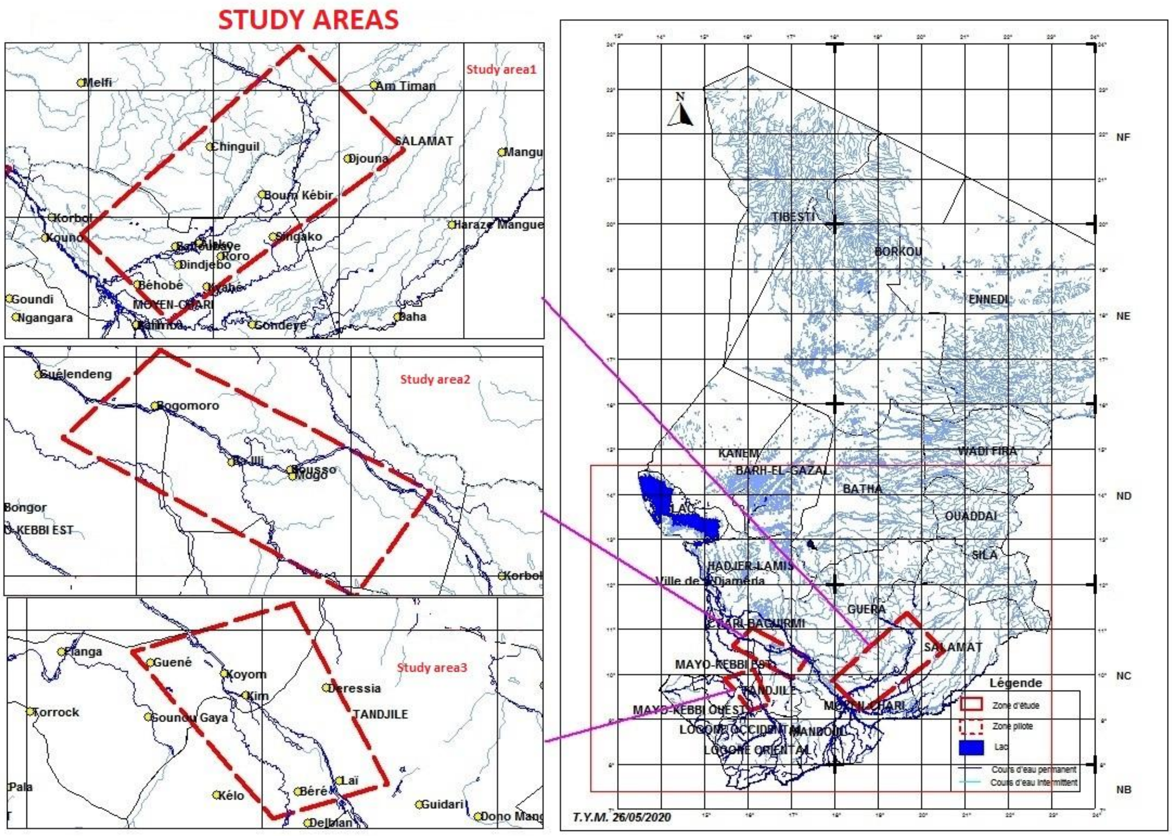

Figure 1: Study areas

In the study areas, two (2) seasons alternated almost equidistantly with a rainy season which extended from May to October (6 months) and a dry season from November to April. The average rainfall was 891 mm for the areas of Dobo (Study area1) and Absorto (Study area2) and 1000 mm for the zone of Bomou (Study area3).

II.1.1. DOBO (Study area 1) and ABSORTO (Study area 2)

Its hydrographic network is made up of rivers [13] including Bahr Keita, Salamat, Aouk, Lake Iro and ponds (Haraze). These streams flowed from the North-East to the South-West and flowed into the Chari River through the Barh Salamat and Barh Aouk channels. The Chari River meanwhile presented spills, during floods, on some of its sections and others were parallel to the Chari along axis Migna-Kouin-Korbol-Banker-Absorto-Laïri and the flood plains of Massenya.

The dominant vegetation was the clear Sudano-Guinean Forest tree Savannah. However, herbaceous vegetation typical of floodplains dominated the area in the flooded parts.

The flows of the Chari River according to the characteristics of the related watersheds [14] are presented in table 1 and table 2.

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Table 1: Chari River flow at Sarh – Year 1990 to 2010

Latitude = 9.15 - Longitude = 18.416666 Watershed area =193000 km²												
Mean monthly two-decadal flow values (m3/**s)**												
Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average flow	123	74	46	30	24	28	51	221	477	542	399	238
Min flow	32	16	11	7	9	7	19	65	190	182	114	74
Max flow	257	152	100	60	50	65	103	374	706	730	582	470

Table 2: Chari River flow at Mailao – Year 1990 to 2010

Latitude = 11.6 - Longitude = 15.283333 Watershed area= 500.000 km												
Mean monthly two-decadal flow values (m3/**s)**												
Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average flow	77	41	16	6	5	6	21	115	376	534	356	158
Min flow	23	8	5	3	3	3	5	17	92	111	90	59
Max flow	182	92	39	13	8	15	57	303	981	1357	1069	411

II.1.2 BOUMO (Study area 3)

The zone covered the floodplains of Tandjilé and Mayo Kébbi East. The hydrographic network was essentially covered by the Logone River. The spills traveled along the Laï-Kim-Djoumane-Bongor axis the water flowed partly into the Yaérés. The zone was sparsely treed but there were herbaceous plants specific to flooded areas. The flows of the Logone River according to the characteristics of the related watersheds [14] are presented in table 3 and table 4.

Table 3: Logone River flow at Laï – Year 1990 to 2010

Latitude = 9.4 - Longitude = 16.3 Watershed area = 60.320 km²												
Mean monthly two-decadal flow values (m3/s)												
Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average flow	102	72	38	32	55	107	341	1023	1480	981	364	147
Min flow	50	31	17	14	26	35	197	613	922	520	176	84
Max flow	459	403	62	57	102	166	575	1572	2189	1838	656	319

Table 4: Logone River flow at Bongor – Year 1990 to 2010

Latitude = 10.266666 - Longitude = 15.41666 Watershed area = 73.700 km²												
Mean monthly two-decadal flow values (m3/s)												
Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average flow	96	71	55	39	66	114	338	891	1578	1152	458	181
Min flow	53	40	31	24	33	62	190	542	914	563	172	80
Max flow	194	135	105	85	107	161	548	1533	2599	2192	999	388

II.2. Methodology

We proceeded to the definition of the transfer function. It consisted in the determination of the pilot watersheds of the study and acquisition of their Digital Terrain Models by the extraction of satellite data using the technique of interferometry [15]. This process made it possible to obtain physical characteristics of watersheds (altitudes, slopes, areas, etc.) and hydrological processes. It induced the identification of the grids of the directions of flows and accumulations of rainwater (Fig. 2) then the areas of production, transfer and storage. The direction of water flow was by coding and varied according to the approaches of theoretical convention [16]. However, the water could drain in one direction, North, West, South or East depending on the lowest altitude [17].

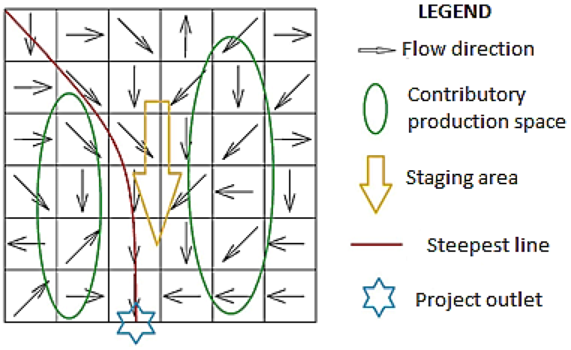

Figure 2: Flow Direction Models

In the case of our study, we noted a low altimetry of the so-called flat zones posing a problem of discontinuity of the flows followed by the stagnation of the waters in depressions. The following treatments had to be followed including (i) the reversal of the hydrographic path, (ii) the digging of the neck of depression and (iii) the filling of the depressions.

In our weakly gauged study areas, the NRCS Model (National Resources Conservation Service) for its reliability [18, 19], was adopted and allowed us to obtain the average decadal flows for each pilot area, over two consecutive decades. The interpolation and consolidation of missing rainfall data contributed to the evaluation of flows and contributions by pilot basin (Chari and Logone).

The discharge aggregation function led to collection of all the discharges from the sub-basins along the line of greatest slope. From this function was deduced the hydrological balance of our study with iterative parameters. These parameters depended on local anthropological requirement. They involved the activation function which served as a triggering factor for drainage of flows towards Lake Chad.

III. RESULTS

We presented the quality of the Digital Terrain Models (DTM), the interpolations of the missing rainfall data, the flows, the losses and the hydrological balance of our study.

III.1. The quality of the Digital Terrain Models

The Digital Terrain Model (DTM) of the pilot study zones obtained in 3D format is presented in Fig. 3.

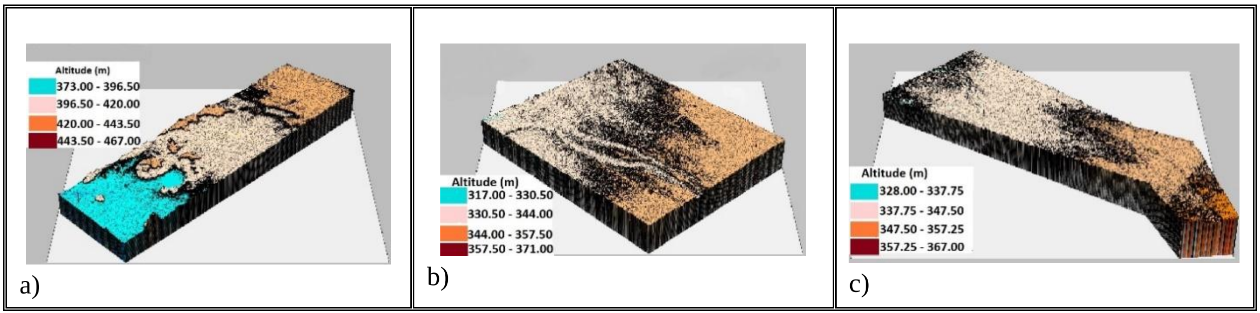

Figure 3: a) Dobo area (Bahr Azoum floodplains) – b) Absorto area (floodplains overflowing on Massenya) – c) Boumo area (Lai floodplains to Kim).

Following the projection « *ETRSTM Zone 33, Northern Hemisphere (ETRS89) / p 3045* » from the DTM Digital Terrain Models) with an accuracy of 30 m, we obtained the information presented in table 5.

Table 5: Information obtained from DTM

N°	Study areas	Lower boundary coordinates	Upper boundary coordinates	Min average altitude (m)	Max average altitude (m)	Surface (km^2)	Perimeter (km)
1	ABSORTO	X : 698320.0098 Y : 1118332.6759	X : 797380.0098 Y : 11216222.6759	317	371	4732	277.1
2	BOUMO	X : 569544.1279 Y : 1028646.1912	X : 649044.1279 Y : 1104696.1912	328	367	1977	231.3
3	DOBO	X : 919543.1480 Y : 1065410.5238	X : 1105123.1480 Y : 1252880.5238	373	467	11700	519.7

From these data, precise information characterizing the watersheds is extracted, in particular the area, the elevation, the slopes and the fairly precise delimitation of the flood zones and the dry zones. They clearly showed areas of spillage, return runoff and irregularities in stream beds (Fig 4).

III.2 The flow

The ten-year average flows for each pilot zone, over two consecutive decades are presented in table 6 and table 7.

Table 6: Ten-year average flow estimate – year 1995 to 2004

N°	ZONE	CN	S (mm)	P (mm)	A (km^2)	Q ($m^3.s^{-1}$)
1	ABSORTO	86	41	798	4732	750
2	BOUMO	77	76	949	1977	864
3	DOBO	86	41	1023	11700	977
	TOTAL			2770		2591

Explanations : A - area ; CN - parameter ; P - precipitation; Q - flow; S - basin's retention volume

Table 7: Ten-year average flow estimate – year 2005 to 2014

N°	ZONE	CN	S (mm)	P (mm)	A (km^2)	Q ($m^3.s^{-1}$)
1	ABSSORTO	86	41	798	4732	361
2	BOUMO	86	41	949	1977	1043
3	DOBO	86	41	1023	11700	992
	TOTAL			2770		2396

Explanations : A - area ; CN - parameter ; P - precipitation; Q - flow; S - basin's retention volume

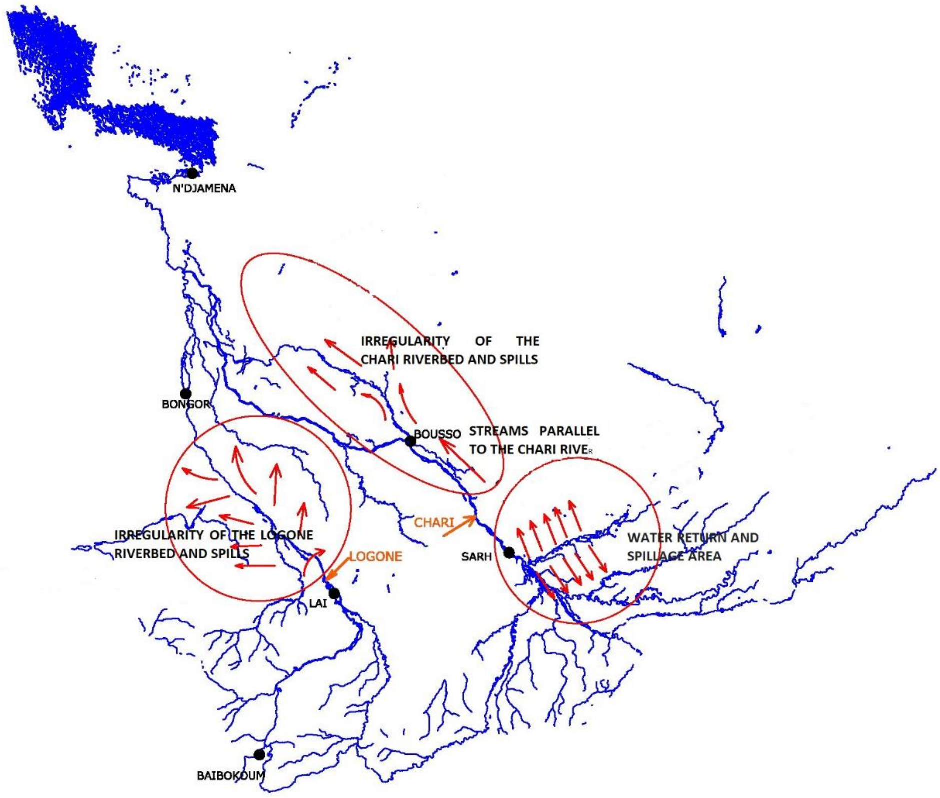

Figure 4: Irregularity of the beds of the Chari and Logone rivers

III.3 Losses

From the ten-year average flows obtained, we also checked the flow departing from Sarh and their transit point of Mailao (Fig. 5).

The median rate of loss from the Chari River wad around 30% without the high, uncontrollable production in the Dobo pilot area and for the Logone River in Laï (Fig. 6).

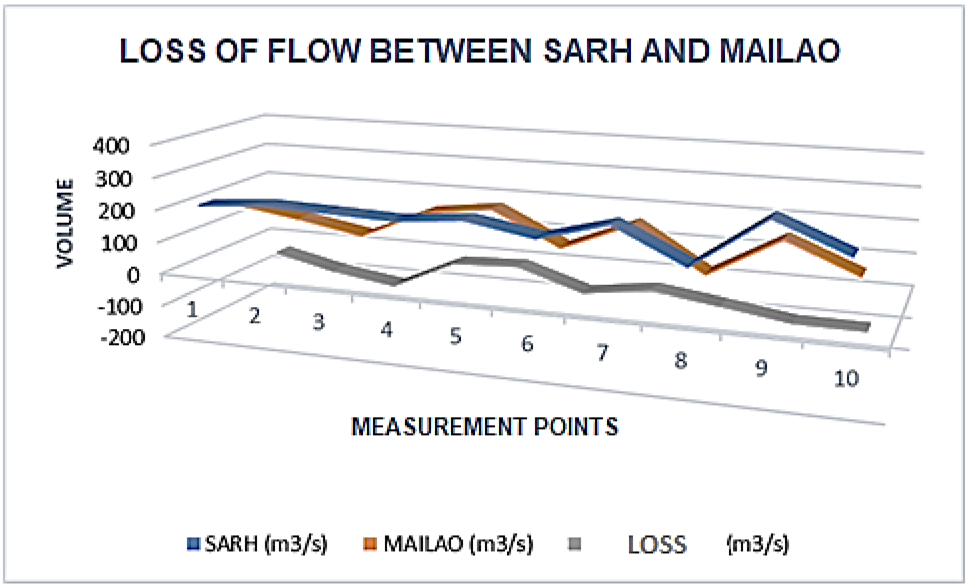

Figure 5: Loss of flow between Sarh and Mailao

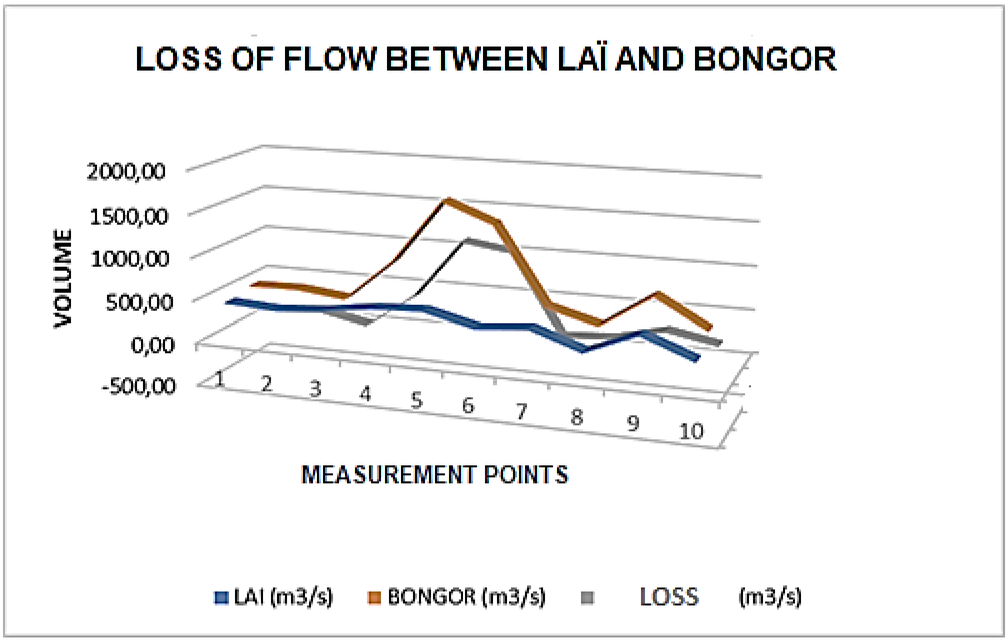

Figure 6: Loss of flow between Laï and Bongor

All of our results led to the statement of the hydrological balance of our study project for the sustainable refloating of Lake Chad. It took into account a global and sustainable balance between hydrodynamic and climatic parameters. It was written as follows:

$$Q_j + \Omega Q_j + P_j + \frac{\zeta H_{lj}}{S_{lj}} \geq E_{li} + ETP_{li} + I_{li} + \frac{\psi H_{li}}{S_{li}}$$

With the notations below:

Q_j: initial contributions from tributaries ($Km^3.an^{-1}$);

ΩQ_j: cumulative contributions from production areas ($Km^3.an^{-1}$);

P_j : local rainfall over Lake Chad (mm) ;

$\frac{\zeta H_{lj}}{S_{lj}}$: relative stock of stability relative to time ($Km^3.an^{-1}$);

E_{li}: direct evaporation on Lake Chad ($Km^3.an^{-1}$) ;

ETP_{li}: evapotranspiration taking into account the ecosystems of Lake Chad ($Km^3.an^{-1}$);

I_{li}: direct infiltration from Lake Chad ($Km^3.an^{-1}$);

$\frac{\psi H_{li}}{S_{li}}$: relative volume sought over time ($Km^3.an^{-1}$);

S_{li}: surface of Lake Chad before the project (Km^2) ;

S_{lj}: surface of Lake Chad of the project (Km^2) ;

ψH_{li}: water level prior to the project ($m.an^{-1}$) ;

ζH_{lj}: stable water level of the project ($m.an^{-1}$).

IV. DISCUSSIONS

We had set our hypothesis to verify the water potential of the Chari and Logone basins in order to drain the flow sought by the project to transfer rainwater from the Congo basin to Lake Chad. The results were conclusive regarding the water potential of the Chari and Logone basins. Our discussion focused on our two pilot study areas of Dobo and Absorto in connection with the entry point of the waters of the various transfer projects [1, 2].

Regional transfer function were valid in an ungauged context [20]. We had proceeded to the interpolation of the missing pluviometric data in addition to the uniformity of the rains in the watersheds of the study areas and the surface runoff with a supposedly soil. For the pilot zone of Dobo, the average flow was of the order of 900 $m^3.s^{-1}$ over two (02) consecutive decades over an area of 11700 km^2, without neglecting all the losses due to infiltration phenomena and evapotranspiration.

The water Stream was not flowing efficiently to the Chari River. Beds of parallel watercourses that skirted the Chari captured runoff water and drained it to the flood-prone areas of Massenya. In addition, significant returns have been observed towards the areas of Kyabé and Sarh.

Also, irregularities of the beds are observed in the pilot zone of Absorto around the town of Bousso where a significant quantity of ten-year average flows of the number of 500 $m^3.s^{-1}$ is mobilized over an area of 4732 km^2. It is noticed that these waters are drained towards the vast flood plains of Massenya. An analysis of the loss of flow from the Chari River confirmed this through the consolidated results obtained on the Mailao site.

The results obtained, through our work, were similar to those from the work of Billon [21] following which the maximum observable flood over twelve years in the Bahr Azoum (Am-timan) watershed is 324 m3.s^{-1}. While the median flood is 250 m^3.s^{-1}. In addition, in the Barh Keita (Kyabé) over a catchment area of 14.000 km^2, the maximum flow was 547 m^3.s^{-1} over ten (10) consecutive observations. The maximum annual flow of median frequency is around 260 m^3.s^{-1}.

However, the two-decade average flow taking losses into account was of the order of Qtx1 $_{(Dobo)}$ ≈ 650 m^3.s^{-1}. It amounted to saying the following :

- ✓ For the LCBC (Lake Chad Basin Commission) Transfer Project at the entrance to the Chari River, the objectives were set as follows :
  - $108\ m^3.s^{-1} \leq Q_{Mcblt} \leq 300\ m^3.s^{-1}$.
  - $3\,000\ km^2 \leq S_{Mcblt} \leq 5\,500\ km^2$
  - $0{,}50\ m \leq H_{Mcblt} \leq 1\ m$
- ✓ Our work has produced a two-decade average flow :
  - $Q_{tx1(Dobo)} \approx 650\ m^3.s^{-1}$

While the Chari River represented the largest provider of inputs without the mobilizable flows of our study, we had estimated not to fix from the start the important parameters such as the height of water and the surface to be reached in order to avoid the shock of brutal handing-over of return of the waters.

We have stated, in addition to balancing the input and output elements of our water balance, two activation functions $\{\psi H_i, \zeta H_j\}$. They are dynamic, iterative and progressively adjusted. The adaptability of the populations to the sustainable replenishment of Lake Chad and in relation to its area S_i and S_j were the keys to the activation of our hydrological balance. Our results showed the importance of spill and flood control. They could help avoid stressing the ecosystems of the Congo Basin.

V. CONCLUSION

Our work has made it possible to highlight the advantage of the use of Digital Terrain Models (DTM) in line with hydrological studies in an ungauged to weakly gauged watershed for the processing of data reduced to the torque rain-flow.

Our research model revealed the water power available in Chadian territory and the mobilizable recharge stock capacity of surface water in the Chari and Logone basins.

In perspective, we would like the processing of uncertainties and errors associated with the control of water abstraction control in Cameroon and Nigeria. The recalibration of part of the bed of the Chari and Logone rivers then their confluence in Ndjamena (Chad) will contribute to optimizing the control of spills and limiting flooding in order to sustainably supply Lake Chad.

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