Spatio-Temporal Dynamics And Gaps In The Distribution Of Surface Water Points In The Biosphere Reserve Of Pendjari (Benin, West Africa)

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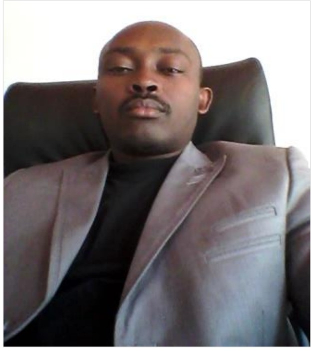

Agronomist from Benin (West Africa), Méryas D. KOUTON was Director of Pendjari National Park and is currently conducting his doctoral research works on the development of water points in the Biosphere Reserve of Pendjari and wildlife - water point relationships. He is co-author of several articles on the vegetation of the reserve and the book "Habitat and Plant Species of the Biosphere Reserve of Pendjari" published in 2016.

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ABSTRACT

As water is the most important resource that justifies the presence and the development of wildlife, the management of surface water has always been a major concern of Reserves managers. In the Biosphere Reserve of Pendjari, located in the Sudanian zone in Benin, the spatio-temporal water availability was studied. The results showed that at the beginning of the dry season, there were 103 water points and that density would be sufficient to satisfy the needs of fauna. That potential was reduced by 64% before rainy season. The density hides an aggregative distribution and concentration of water points along Pendjari River all the dry season, especially at the end of the dry season. Water stress on wildlife is highest in March and April when the distance between water points was four times greater. Such aggregative distribution of water points gathers a high concentration of wildlife around few permanent water points with increase predation and damage on the vegetation. The analysis of the gap based on the regular quadrat of 10 km and 100 km² buffers suggested creating and / or rehabilitating 23 ponds to improve the density and the distribution pattern that must be regular mostly in the dry season.

Keywords: Surface water, Distribution, temporal change, Seasonality, Wildlife, Pendjari Reserve

1. INTRODUCTION

The management of the wildlife reserves whatever the forms (game ranch, national park, hunting area, refuges, etc.) in arid and semi-arid zones always depended on the control of water availability and distribution (Western, 1975). There is a worldwide agreement on the fact that spatio-temporal dynamic of surface water has an influence on large herbivore distribution patterns in arid and semi-arid ecosystems (Heezik van, Khairy & Seddon, 2003; Fensham & Fairfax, 2008). There is no doubt that surface-water provision especially in the dry season may be an important management option available to manipulate the densities and distribution patterns of certain herbivores in arid and semi-arid conservation areas (Redfern, 2002; Chamaillé-Jammes, Valeix & Fritz, 2007; Chamaillé-Jammes, Fritz & Murindagomo, 2007). An important part of the management relies on the interactions between the water points and the distribution of the herbivores. The availability and distribution of surface water in wildlife reserves were known to be extremely important factors in the distribution of wildlife (Fryxell & Sinclair, 1988; Bergstrom & Skarpe, 1999; Smit, Grant & Devereux, 2007; Loarie, Vannaarde & Pimm, 2009). Several studies in the arid zones of the United States of America, in Spain and the savannahs of East and South Africa highlighted the importance of surface water for wildlife in relation to Birds, herbivores and carnivores, sometimes in relation to climate change (Gleick, 1989; Broyles & Cutler, 1999; Murdoch, Baron & Miller, 2000; Kasiringa, 2010; Lacasa *et al.*, 2010; Davis & Hirji, 2014) and even confirm the importance of integrating water for Wildlife in national water management plan (Frederick, Major & Stakhiv, 1997). It has even been shown that the irregularity in surface water availability in semi-arid savannah affects the distribution of large mammals and forage availability (McNaughton & Georgiadis, 1986; Skarpe & Bergstrom, 1986). Other researches showed the negative effects of that way to provide water by highlighting increased mortality for some herbivorous around artificial water points (Walker, Matthews & Dye, 1986; Walker, 1987), consequence of increasing predation around (Smuts, 1978; Harrington *et al.*, 1999; de Boer *et al.*, 2010), which may even contribute to the decline of rare antelopes (Harrington *et al*. 1999). Most of this research has focused on East and southern African savannas, with little emphasis placed on savannas in West Africa. In fact, empirical data for West African surface water distribution is generally lacking (Schuette *et al.*, 1998; Kassa, Libois & Sinsin, 2008), giving the obvious value of resolving spatio-temporal change in surface water availability for the wildlife, and the unique climatic and habitat conditions of West African savannas (Odoulami *et al*., 2017), a comparative study at seasonal scale is warranted.

Despite, the high number of research on the dynamic of surface water worldwide, our knowledge of surface water resources in the West Africa savanna has been based on maps of perennial water bodies, maximum extents of wetlands, well-known rivers and potential drainage networks and on fragmentary knowledge of temporary surface water (Agbossou & Okoundé, 2000). Especially in these regions, where a high inter- and intra-annual variability of surface water resources can be observed, temporary water bodies can be missed in mapping due to their short and erratic appearance. After a couple of experiences in Nazinga, Burkina Faso, Lungren (1997) proposed a density of 1 surface water point for 100 km² as acceptable water availability condition for an open ranch.

However, information about the spatio-temporal dynamics of surface water resources is particularly important for several reasons among which knowledge on the behavior of animals to drought and the development of a water management plan in wildlife reserves. Additionally, several parks in West Africa such as the Biosphere Reserve of Pendjari (BRP) in Benin, known for its large diversity and tourist attraction, apparently experienced a lack in water supply for wildlife, especially during the dry season. This first exploratory work aims (i) to determine spatial and temporal variations of abundance and repartition and compare the density to theoretical value; (ii) to characterize their distribution patterns and; (iii) to identify gaps to be filled if applicable.

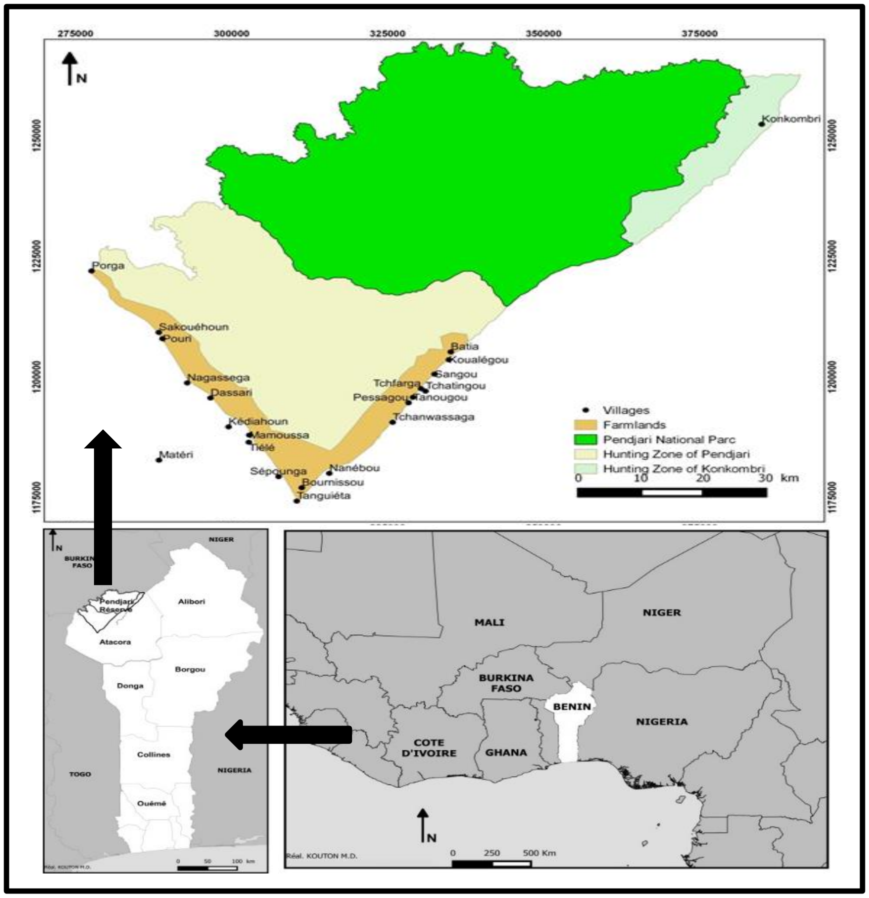
2. MATERIAL AND METHODS

2.1. STUDY AREA

The Biosphere Reserve of Pendjari (BRP) is located in the North-West of the Republic of Benin, West Africa; it is fully located in Sudanian zone, between 10°30'N and 11°30'N, 0°50'E and 2°00'E (Figure 1). It is part of the W-Arly-Pendjari (WAP) landscape, the largest transboundary protected areas in West Africa. The BRP covers 4711.4 km², of which 2660.4 km² are occupied by the Pendjari National Park (CENAGREF, 2016) and the others composed Pendjari and Konkombri Hunting Zones (PHZ and KHZ).

Due to its geographical position, it generally has a dry season from October to April and a rainy season from April to October. Annual precipitation ranges from 900 to 1200 mm. The average monthly humidity is below 10% during the dry season. The average temperature is around 25°C with maxima of more than 48°C between January and March. The Pendjari River (300 km) is the only one permanent water course in the BRP. In the dry season, the river runs dry in several places, leaving some water points in and nearby its main stream.

Figure 1*: Location and zones of the Biosphere Reserve of Pendjari.*



The fauna of the BRP is typical for this region of West Africa. There are 11 different species of antelopes (Buffalo, Kobe, Bohor Reed buck, Waterbuck, Roan Antelope, Hartebeest, Topy, Bushbuck, Common Duiker, Red-flanked Duiker, Oribi) as well as species already extinct or threatened in much region, such as cheetah, elephant, lion and African wild dog. Three of the "Big Five" can be easily seen in the Park: the lion, the elephant and the buffalo, which ranks the reserve in the average of african parks. The leopard is also present.

Three hundred and seventy eight bird species have been identified (163 migrators, 63 from Palearctic zone). Sixty two fish species and 100 reptile species (Grell, 2002) have been countered.

2.2. DATA COLLECTION

Water point concept

Surface water points are geographical spaces in watersheds where the local geomorphology gives the soil a shape of a basin that stores quiet water a time after the surrounding spaces have been completely excavated. It includes natural and artificial pools and water sources which retention basin.

Data collection on water points

Before the field phase, the documentation (Agbossou & Okoundé, 2000), the satellite images and vegetation map of the BRP were used to identify the water points in the Reserve. This tentative list has been analyzed with the rangers. Only water points regularly established each year since at least 15 years were considered. The data collected on the water points included:

- GPS coordinates
- Name of the pool (if any)
- The presence or not of water
- The dimensions: this has been done by classifying the ponds as "large", "medium" and "small" at the beginning of the dry season.

All points recorded at the end of the rainy season were revisited monthly until the establishment of the following rainy season, from 2014 to 2016.

2.3. DATA ANALYSIS

Density of water points and its variation

The variation of the number of water points over time was established. The number of perennial water points corresponds to the number of water points at the end of the dry season, just before the first major rains. A monthly decrease rate per period was calculated using the formula:

$$\Delta n = (n_{t+1} - n_t)/100$$

Where n is the number of water points at t.

The total density in water points and the density per zone were calculated to compare to the empirical density of the water points to reach for the minimum needs of the fauna.

For a given area (Pendjari Hunting Zone, Konkombri Hunting Zone and Pendjari National Park) the density formula is as follows:

$D_{ij} = N_{ij} / S_i$ with

D_i: Density in water point of zone i for period j

N_i: number of water points in zone i for period j

S_i: Area of zone i determined by QGIS

i is the area considered

j is variable between all months of the dry season.

For the Pendjari Hunting Zone, the area used is the hunting territories of Porga and Batia; the surrounding farmlands were excluded because of human activities influence on the occurrence of the wildlife. The calculation of the density per zone does not mean that the compartments are partitioned. The wildlife exploits the whole area of the reserve. But the management modes are different, if there is a gap, it is wise to know the need by zone.

Mapping of water points

Under QGIS, the geo-referenced database lead to elaborate for each period of two months the distribution map of the pools in BRP showing zones and hydrography. If there is a gap, the altitude layer is used for positioning suggested pools to be created or rehabilitated.

Study of water point distribution pattern

In order to characterize the spatial distribution of water points in the reserve its variations throughout the dry season, the same database was subjected to statistical software R (R Core Team 2016) with the Spatstat package and its dependencies. The Maptools package allowed the use of shape files in R software. The null hypothesis of a random distribution was tested with the 99 simulations of Monte Carlo (Baddeley & Turner, 2005; Baddeley, Rubak & Turner, 2015). The estimator used was L function which is a modified form of Rippley's K function (Rippley, 1977; Rippley, 1981; Diggle, 1983).

$$\hat{L}_{12}(r) = \sqrt{\frac{\hat{K}_{12}(r)}{\pi}} - r.$$

In which $\hat{K}_{12}(r)$ is the estimator of K_{12} (r) with r the radius, i.e. the distance between the water points.

The estimated L(r) quantifies the degree and type of spatial association (distribution) between the water points by considering the distances between them in a radius r for 99 simulations. An envelope was thus elaborated with the values confirming the null hypothesis at the center. The empirical distribution represented by a curve was qualified as random when it was within the envelope interval. Above, we have an aggregative distribution and a repulsive distribution or regular distribution below.

From this analysis, we also got for each period the distribution of distances between two neighboring water points (Nearest Neighbor Distance "NNDIST"). This parameter, supplemented with its dispersion, gave information on the stress experienced by the animals in accessing water in the dry season, in addition to the density of the water points.

Gap analysis

The density at the end of the dry season was analyzed in relation to the experimentally standards for the savanna of West Africa, in the Nazinga ranch, Burkina Faso (Lungren, 1997; Lungren & Bouché, 2008) and Amboseli ecosystem, Rift Valley in Kenya (Western, 1975): 1 water point per 100 km² i.e. one pool every 10 km on average. This theoretical comparison was applied to a grid system of the BRP under QGIS with grids of 10 km of side completed by buffers system (circle of 5.64 km) around water points to visualize the deficient zones and to position if applicable, new pools.

3. RESULTS

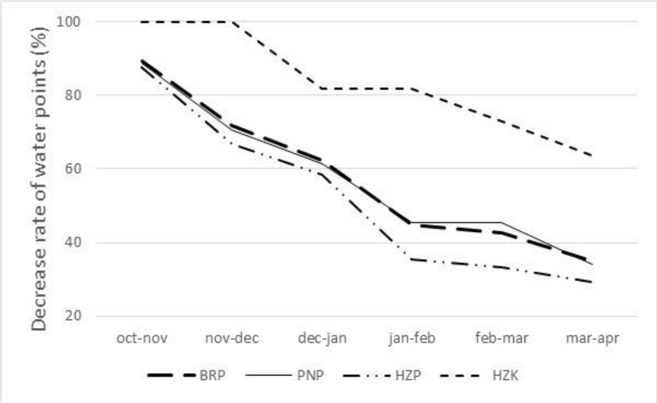
3.1. ABUNDANCE, DENSITY AND DISTRIBUTION OF WATER POINTS AT THE BEGINNING OF DRY SEASON

A total of 103 surface water points were recorded, including 06 artificial pools, 03 natural water sources and 94 natural pools at the end of the rainy season, corresponding at the beginning of the dry season. This corresponds to a density of 0.0235 water point / km² for the reserve. Although the majority (47%) of these water points was observed in the PHZ, the highest density was observed in the KHZ (0.04 water points/km²). More than 80% of the listed water points are close to permanent watercourses including the Pendjari River and its most persistent tributaries (Podiega, Yapiti and Magou).

3.2. WATER POINT CHANGE ACCORDING TO THE ZONING SYSTEM AT TIME SCALE

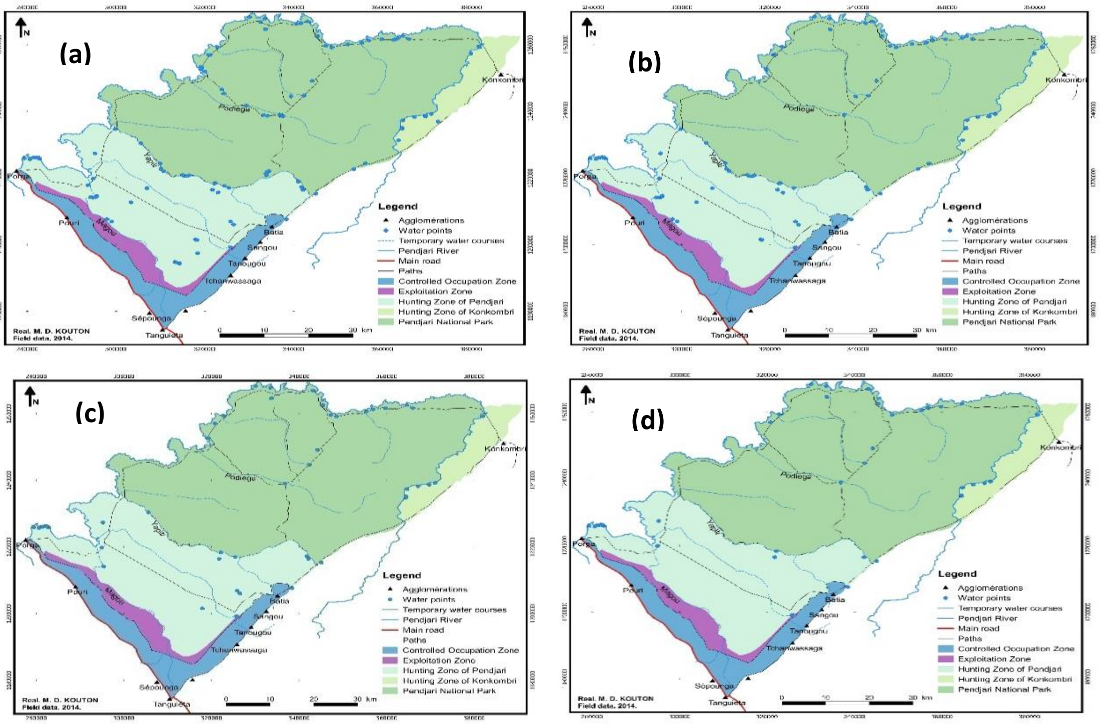
The 103 water points recorded at the beginning of the dry season gradually decreased along the dry season. Their number varied from one zone to another, leaving only 36 water points at the end of the dry season. Those 36 water points are considered as perennials. The reserve then loses 64% of its water points during the dry season. There are only 15 water points left for the PNP, 14 for the PHZ and 7 water points for the KHZ. The period from February to April is accoutered thee highest decrease rate for PNP water points when December to February is the most critical for PHZ (figure 2).

***Figure 2**: Decrease rate in water point's number through the dry season*



The decline in the potential surface water points was almost identical for PNP and PHZ and for the entire reserve. On other hand, the KHZ loosed only 36.3% of its water points. The densities consequently decreased to 0.008; 0.005; 0.010 and 0.027 water points per km² respectively for BRP, PNP, PHZ and KHZ. Figure 3 present the spatio-temporal dynamic of water points in the different components of the BRP.

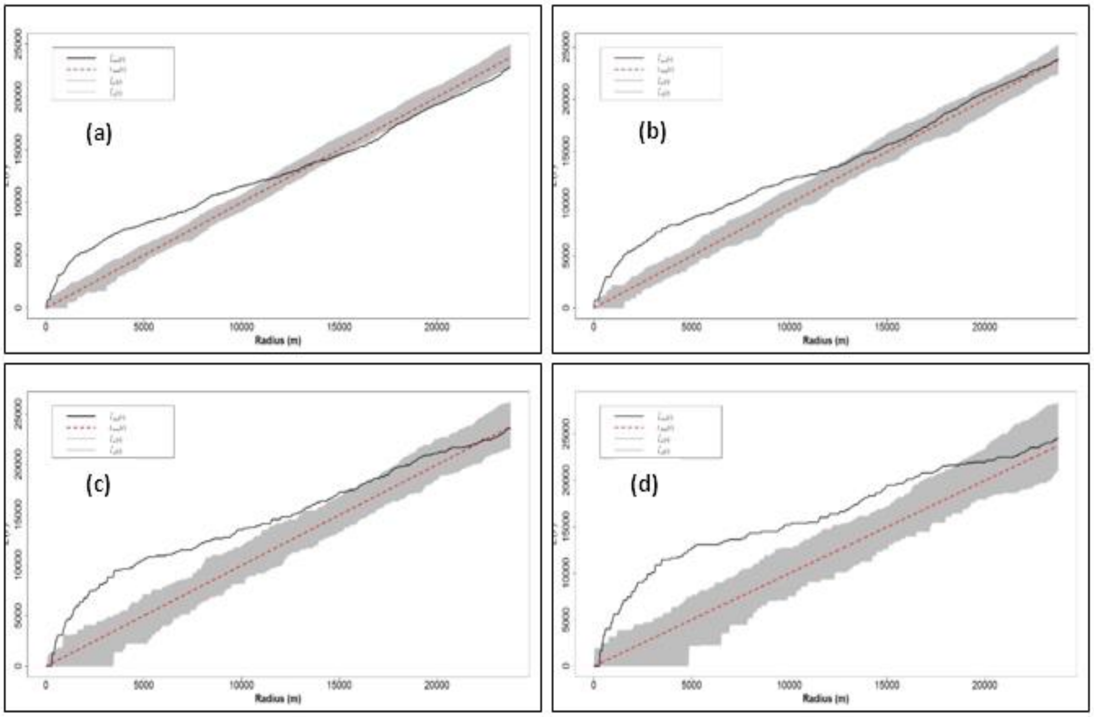
***Figure 3**: Distribution of surface water points in BRP at October (a), December (b), February (c), April (d)*



3.3. SPATIAL DISTRIBUTION OF WATER POINTS AND ITS EVOLUTION IN THE RBP

Figure 4 shows the spatial distribution of water points in the BRP in October, December, February and April. The water points have an aggregative distribution over the first kilometers. Thus, at the end of the rainy season (early dry season), for a radius of less than 11 km, the water points are aggregated. For the distance between 11 and 20 km they present a random distribution and are regular over 20 km radius. In December, February and April, i.e. for the rest of the dry season, the distribution is aggregative over the first 11, 16 and 19 kilometers respectively and remains random afterwards over the entire extent of the Reserve. In the dry season, the average distance to the nearest neighbor increases four times from 1.6 km ± 1.7 in October to 5.6 km ± 4.9 at the end of April, comparing to rain season.

***Figure 4**: Spatial distribution pattern of surface water points in the BRP at October (a), December (b), February (c), April (d).*



3.4. GAP ANALYSIS

Comparison of density

Figure 5 shows the variation of the density of water in the Reserve and its different zones compared to the standard of 0.01 water point / km². It is noted that a lack of water begin from January for the hole reserve. KHZ is saved from that situation. The theoretical densities of 0.01 water point per km² correspond to one water point for a square of 100 km² (10 km x 10 km). The grid of the BRP presents the density of the water points per quadrat. Although at the beginning of the dry season the assessment based on the reference density presents a comfortable situation for the reserve and its areas, there are still many quadrats without any water point. In October, there are 14 quadrats without water point in the BRP, which reach 27 at the end of the dry season (figure 5).

Figure 5: *gap analysis based on quadrats and buffers*

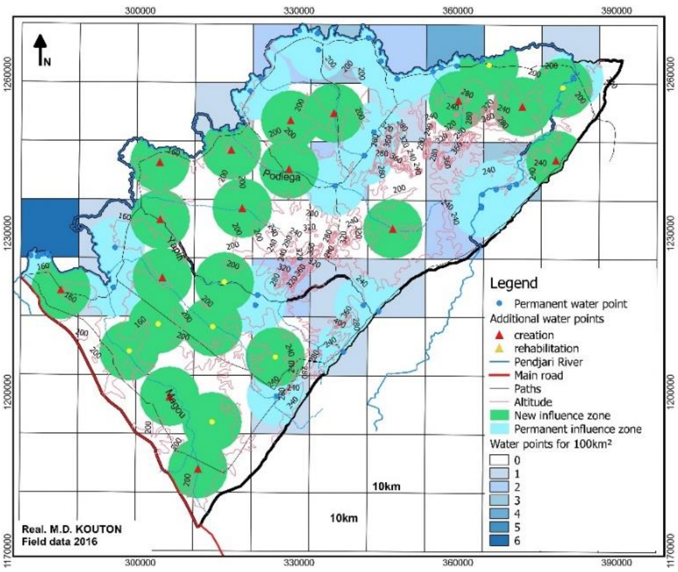


Table 1 shows the evolution of the cumulated number of quadrats dried per zone and per period. The period from February to April is the most severe period in the BRP with the drying off of 64% of water points. This is then the period of maximum stress for wildlife.

Table 1: *Drying evolution from October to April*

	October	December	February	April
BRP	14	15	19	25
	Variation	1	4	6
PNP	11	12	12	14
	Variation	1	0	2
PHZ	3	3	6	8
	Variation	0	3	2
KHZ	0	0	1	1
	Variation	0	1	0

Source: Field works 2014 - 2016

The buffering of permanent water points and superposition with quadrats method revealed the zones of water unavailability at the end of dry season. It then emerges that 23 perennial water points must be made in the BRP to fill the gap and make a comfortable distribution of water for wildlife at the end of the dry season. The representation at Figure 5 shows a normal pattern of repartition when we take account of altitude (mountains) and water courses in the reserve. It revealed that all the 23 water points are not to be created. Some of them are confounded with temporary water point existing and then, will need rehabilitation to perpetuate them.

4. DISCUSSIONS

The BRP has 103 surface water points at the beginning of the dry season. This corresponds to a sufficient density for that period; therefore it has sufficient potential water points for wildlife. This potential is identical for the three zones of the reserve and would allow at first sight to conclude that until March, there is enough water in the reserve for the fauna although from January the PNP begins an important deficit. In April, the end of the dry season, there are only 36 water points remaining for the whole reserve, which is insufficient considering the reference of 0.01 water point per km² (Western, 1975; Lungren, 1997). That evolution of the density of water points over time partly explains the degree of stress on wildlife in terms of water availability (Western, 1975; Fryxell & Sinclair, 1988; Bergstrom & Skarpe, 1999; Chamaillé-Jammes *et al.*, 2007; Smith *et al.*, 2007; Loarie *et al.*, 2009). At that time, density became four times lower than what it had been at rainy season. In this situation, the KHZ maintains a potential far above the reference: there is a small hunting territory with a very elongated form bordered by the Pendjari River and its pools and escarpments. Therefore, it is not surprising that the KHZ is a zone of high concentration, the most densely populated by the fauna in the reserve (CENAGREF; 2014).

Paradoxically, the study of the distribution of water points considering the distances between then, presents an aggregate distribution on 11, 16 and 19 km when we advanced in the dry season, before becoming random beyond 20 km. Is it the ideal distribution for water needs for wildlife? An aggregate distribution hides the water deficit in a territory (Western, 1975). The small distance between water points in this case creates a concentration of fauna on a portion of the territory while the necessary forage is not locally sufficient. Animals, irrespective of the habits of some species to travel daily from medium to large distances, must have sufficient water and forage in their habitat (Owen-Smith, 1996; Brawata & Neeman, 2011) and it is not possible with a high aggregative pattern around closer water points. Aggregative distribution is synonymous with strong forage competition, and thus greater predation due to the concentration of herbivores (Redfern, 2002; Redfern *et al.*, 2005; Kasiringa, 2010). It is because of this fact that several authors have for a long time feared the closely multiplication of water points in the fauna reserves, accusing this activity of source of reduction of the population of some herbivores, the disappearance of some others due to the proliferation of carnivores (Smuts, 1978; Harrington *et al.*, 1999). But as these two results showed, water points density alone does not show how to assess surface water availability for wildlife, but a more equitable distribution, ideally regular in wildlife habitats, would offer consequently welfare for the fauna and a more balanced use of the forage available in ecological niches (de Leeuw *et al.*, 2001; Redfern *et al.*, 2003; Todd, 2006; Shannon *et al.*, 2009).

For the period from March to April, a regular (repulsive) distribution was reached beyond 22 km radius between water points when the average distance between water points at that period is approximatively 5 km. It means that water points are highly aggregated within radius of 5 km. The obvious consequence is that locally, for this peak period of the dry season, the animals will gather around the water points and the distance to the next very high would not allow movements between water points (Epaphras *et al.*, 2008). It is under these conditions that predation is established (Brawata & Neeman, 2011), and scenes in favor of lions become frequent at the Bali pool (center of the Reserve), Fogou, Diwouni, Sacrée, Yanguali … and artificial pools with water supplies.

The period from February to April is the period of greatest stress for BRP fauna. Both the density in water point is low, as the little available water points is badly distributed over the whole reserve. From February to April, BRP is confronted to the greatest drainage, both in number of water points disappeared and in area (quadrats or buffers) of the reserve becoming deprived of water point. This period obviously corresponds to high temperatures (mean of 30°C) with regular maximums reaching 39°C to 40°C, almost zero rainfall (0-5 mm on average) and a daily insolation time of more than 12 hours, all conditions combined for a strong evaporation of the surface waters and a strong evapotranspiration of the aquatic plant species which in this case turns into a pump to evaporate the water from the pools (Flaschka, Stockton & Boggess, 1987). It is obviously Onagraceae of the genus Ludwigia (witch work as water pumps) present in more than half of the pools of the reserve. Limnological studies carried out by ORSTOM on dams in the Kopienga basin just at north of the Pendjari basin in Burkina Faso showed that the lowest levels of surface water were recorded in March, April and May (Brunel & Bouron, 1992). If the present results show that in the Pendjari basin, little further at south compare to Kopienga, this dry period begins in February since 2014, it is only due to the effect of the climatic changes that induce the descending sahelization towards low latitudes increasing the drought.

Water stress on the fauna is therefore present in the BRP firstly because of the unequal distribution of surface water points and secondarily because of their low density towards the end of the dry season. This is, of course, what accounts for the movement of elephants, large consumers and "water-dependent species" (Western, 1975; Valeix, Chamaillé-Jammes & Fritz, 2007) off-reserve and following the course of the river to the downstream, facing so many risks from poachers.

The gap analysis by the mapping of the quadrats and buffers shows that to have a watering point about every 10 km, it will be necessary to fill 25 quadrats, or to realize 25 perennial water points for the whole reserve.

It would not be about the creation of all new water shape for the reserve, but rather, rehabilitating in a precise way certain surface temporary water points that dry up sooner and make them more permanent. Considering the distribution by quadrat and altitudes shape files as well as the situation of the water points at the beginning of the dry season, figure 5 is realized to propose to the manager the possible water points to be rehabilitated or create in order to answer to:

- achieve standards of 0.01 water point / km² at the end of the dry season,

- have an average distance of 10 km between the water points

- have water points where other resources are already guaranteed (Owen-Smith, 1996; Brawata & Neeman, 2011).

This last condition then leads to subtract the quadrats little inhabited by the great fauna, in particular the mountain areas and then get a total of 23 water points among what 8 existing and suitable for a rehabilitation.

Research works have a great implication when managers will decide to fill that gap. It will concern first the determination of all other native resources on the area which will receive new water points. Geophysical parameters (soil nature, depth of non-permeable substratum, slope…) must also be studied to confirm new positions.

5. CONCLUSION

The spatial pattern the water points and their evolution over time explains more the stress that the fauna suffers when we advance in the dry season. The BRP has 103 water points at the beginning of the dry season, which is reduced by 64% under the effect of evaporation, infiltration, evapotranspiration and consumption by wildlife. To increase the loyalty of the Pendjari fauna in the dry season, increase their density and better guarantee the use of plant resources by wildlife on all its grazed areas, the creation of 15 pools and the rehabilitation of 8 are necessary. The 8 pools which must be rehabilitated are largely in the PNP. This would allow for a good potential of at least 1 water point every 10 km in the reserve and a fairly regular distribution, which is needed to better accommodate the visitors and avoid a very high concentration of wildlife, sometimes devastating plant resources along the Pendjari River.

This study was carried out independently of the ethology of water-dependent species and their relation to water, which are significant factors in determining pools frequentation.

The density of the water points alone is not a parameter justifying water availability for wildlife in BRP. Before any intervention to improve water availability, managers must consider the target animal species, the water-using species in the ecosystems and the protection of the species regarding the predators.

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