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RESEARCH ARTICLE

APPLICATION OF THE STATISTICAL APPROACH TO ESTIMATION EXTREME WIND SPEEDS FOR EFFICIENT STRUCTURAL DESIGN OF CIVIL ENGINEERING STRUCTURES IN CONGO-BRAZZAVILLE

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ABSTRACT

Extreme values of climatic variables (winds) present challenges in terms of the stability of built structures and environmental risks. In fact, estimating the recurrence of extreme wind speeds and basic natural speeds provides essential information for the design of certain civil engineering structures, such as buildings, bridges and others, with a view to ensuring their self-stability and, ultimately, the protection of the population and their environment. The aim of this work is to estimate the extreme speeds and basic gentle speeds of the winds in order to prevent the risks associated with the collapse and instability of certain built structures. The data used in our work cover a period from 1981 to 2020 and were obtained from meteorological observations at 09 stations across the country. The distribution law used in this work is Gumbel's law. The maximum annual wind speeds were adjusted to this law, and the parameters were estimated using an appropriate methodology. Based on Gumbel's law, it produced interesting results for all the weather stations considered. All these calculations show that the area most sensitive to wind is Kouilou Pointe-Noire (Vnb = 4.75m/s and Ve = 8.29m/s), and the least sensitive is Brazzaville (Vnb = 1.75m/s and Ve = 3.07m/s). These data are essential for calculating the basic and extreme dynamic pressures with a view to sizing civil engineering structures.

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INTRODUCTION

Since time immemorial, man has sought to protect himself against the elements by building shelters of all kinds using different types of materials (eco-materials or modern materials). We also build bridges to make it easier to move from one point to another. However, while all constructions dating back to the primary era were built intuitively, contemporary sustainable constructions have to take into account not only the physical-mechanical aspects of the materials to be used, but also the stability of the building as a whole by highlighting other types of stress, in this case the effect of the wind, in relation to its immediate environment. Wind is a highly complex aerodynamic phenomenon. As a result of the variability of the many parameters that govern it, its instantaneous horizontal speed has a fluctuating spatio-temporal character that justifies spectral considerations [1]. Similarly, extreme winds are currently attracting the attention of construction professionals and meteorologists, as they can cause damage to buildings and civil and industrial structures, especially in view of the climate changes observed recently [2]. Now, a building or any type of civil engineering structure must withstand the stresses to which it is likely to be subjected during its operation or lifetime, for reasons of stability. Thus, this article highlights the determination of extreme wind speeds to be considered in the design of civil and industrial structures. The raw data is processed using a statistical approach inspired by GUMBEL's law. For this purpose, annual data was collected from the National Civil Aviation Agency, based in Congo-Brazzaville. In fact, in the lower layers of the atmosphere, wind is considered to be a turbulent airflow that induces a fluctuating field of forces on the load-bearing structures of the buildings or structures it encounters. This field then causes random vibrations, which can develop excessively until they reach the limit load and lead to the ruin of the structures if no action is taken to ensure predictability [3]. Estimating the recurrence of extreme wind speeds therefore provides essential information for the design and construction of infrastructures such as buildings, bridges and other engineering structures, with the aim of ensuring their self-stability and the safety of users and their property [4]. In reality, wind has a devastating and significant effect on built structures. It has an enormous influence on the stability of built structures. However, in the context of this work, the statistical modelling of extreme **speeds**values was carried out using the gross maximum speeds of annual winds because they are easy to use statistically [5], using Gumbel's law. In fact, this law is used by most official meteorological services to determine extreme climatic values; winds, rainfall, etc. [6]; [7]; [8]. Several studies have also shown the robustness of Gumbel's law in estimating extreme values [9]. The consistency of this Gumbel's law comes from its breadth in the application of computational elements and the geometric configuration of the plot on the linear probability scale [4]. The aim of this work is to estimate extreme wind speeds in order to predict the risks associated with instability, collapse and destabilization of built structures in Congo-Brazzaville.

Presentation of the Study Area

The study was carried out over the entire study area, taking into account the various weather stations installed in the different departments.

Geographical Location

The Republic of Congo is a country in Central Africa that straddles the equator. It covers an area of 342,000 km2 and has a 170 km coastline on the Atlantic Ocean. It is bordered by Gabon to the west, Cameroon to the north-north-west, the Central African Republic to the north-north-east, the Democratic Republic of Congo to the north-east, south-east and south, and Cabinda (Angola) to the south-west. The country stretches 1,500km from north to south and 425km from east to west [10;11].

Figure 1. Administrative mapof Congo, (geographical division - archives department, Ministry of Foreign Affairs, 2004)

Topography

The relief of the Congo is moderate overall, with relatively low altitudes. It is essentially made up of three features: plains, Plateaux, hills and medium mountains. The Congo is located in the sedimentary basin of the Congo River and on the ancient granite rocks of the old African basement that come to the surface in the south-west. The plains are presented in the coastal plain, the Niari valley and the Congolese Cuvette. The coastal plain lies between the Atlantic Ocean and the Mayombe, is 50km to 60km wide and 170km long. It is a sedimentary basin with altitudes varying between 200 and 300 metres. The soil of this coastal plain is largely sandy. The Niari valley, on the other hand, is a depression between the Mayombe and the Chaillu massif. The altitude in this area is around 320 metres. The Congolese Cuvette is located in the north of the country. It is the western part of this great Central African basin. It forms a large, gently sloping Amphitheatre, rising towards the west. It is also an alluvial and sedimentary plain, some of which is flooded. Its altitudes range from 200 metres to 380 metres, [12]. The Ubangi Plateaux separate the Congolese Cuvette from the Chad Basin in the far north, [13]. To the north-west, the Western Sangha plateaux are eroded and hilly. They are dominated by Mount Nabemba, the highest peak in the Congo at 1,000 metres. In the centre, a sandy area of Plateaux and hills is dominated by four plateaux, including Bakukuya (450 km2), Djambala (1,250 km2), Ngo-Nsah (300 km2) and Mbé (6,500 km2),[14]. In the south, Pool has sandy-sandstone Plateaux dominated by the Plateau waterfalls, the Bembé Plateau and the Dondo Plateau. These are all located in the south-west of the country and are the Chaillu massif and the Mayombe. The Chaillu massif, located between the Téké Plateaux and the Niari valley (which includes part of south-east Gabon), is a powerful granite and gneiss massif 850 metres above sea level. Its highest point in the Congo is Mount Birougou at 900 metres. The Mayombe lies between the coastal plain and the Niari valley. Its highest points are Mount Bamba (850 metres) and Mount Mvoungouti (930 metres), [15]. The relief (altitude) favours the circulation of the various air masses approaching the area.

Climate

The Congo lies entirely within the hot, humid intertropical zone between the 4th parallel north and the 5th parallel south. Air masses are subordinate to anticyclones. The two anticyclones, the Saharan and South African, produce masses of hot, dry air that flow westwards, while the St Helena anticyclone directs hot, humid air eastwards and north-eastwards, penetrating the interior of the country. In the south-west of the country, the relief units run parallel to each other and from north-west to south-east. In the north and center, the west is elevated and the east is a low-lying area. This allows good air and precipitation circulation. The vegetation, made up of forests and savannahs, ensures high relative humidity, [16; 17; 18].

Climate characteristics

The Congo has an average temperature of 25°C. Temperature variations are small, fluctuating between 2°C and 5°C. The air is always humid. Rainfall is around 1,600 mm per year, with peaks in March-April and October-November.

Types of Climates

Recent work by Samba and Nganga (2011) has shown that long series of climatic data subdivide the Congo into two types of climates: the equatorial climate in the north and the humid tropical climate in the south.

The Equatorial Climate

The equatorial climate is hot and humid in the north of the country, particularly in the departments of Likouala, Sangha, the north of west Cuvette and Cuvette central. The average temperature is 26°C, with abundant rainfall all year round, ranging from 1,800 mm to 2,000 mm per year. The dry season is virtually non-existent. The temperature range is 2°C.

The Humid Tropical Climate

The humid tropical climate affects the south of the country from the Atlantic coast to Brazzaville, as well as the north of the Pool and part of the Plateaux department. The average temperature is 25°C, with rainfall ranging from 1,200 mm to 1,600 mm per year. The climate is predominantly influenced by intertropical low pressure from October to May and southern subtropical high pressure from June to September. Cloud cover is all the more important, and almost permanent, as the activity of the Intertropical Convergence Zone (ITCZ) is reversed, directly influencing solar radiation and insolation. It is also characterized by an alternation of two seasons: a rainy, hot season from November to April and a cool season from June to September. On the other hand, the months of October and May mark the transition into and out of the dry season [17 ;18;19].

MATERIALS AND METHODS

MATERIALS

The climatic data used in our study were obtained from the Civile National de Aviation Agency (ANAC) via the Direction of National Meteorology. The data consisted of wind speed data collected from nine (09) meteorological stations. These data cover a period from 1981 to 2020. Data processing for this study required the use of Excel RStudio software for statistical calculations and the expression of related graphs.

METHODS

Average wind speeds were measured using an anemometer at the nine (9) weather stations. The stations considered in the various stations are located in the following localities: Brazzaville, Pointe-Noire, Impfondo, Dolisie, Ouesso, Makoua, Djambala, Sibiti and Mouyondzi. Their geographical coordinates and number of years of observation are given in the table below.

Table 1. Geographical coordinates and number of years of observations at weather stations in Congo Brazzaville

Meteorological stations	Localization		Altitude (m)	Years of observation	Observation periods
	latitude	longitude			
Brazzaville	4.25°S	15.25°E	319	1981-2020	40 ans
Pointe-Noire	4.82°S	11.90°E	17	1981-2020	40 ans
Impfondo	1.62°N	18.07°E	335	1981-2020	40 ans
Dolisie	-4.2°N	12.7°E	390	1981-2020	40 ans
Ouesso	1.62°N	16.05°E	352	1981-2020	40 ans
Makoua	0.02°S	15.58°E	394	1981-2020	40 ans
Djambala	-2.53°S	14.76°E	791	1981-2020	40 ans
Sibiti	3.68°S	13.35°E	530	1981-2020	40 ans
Mouyondzi	3.98°S	13.92°E	509	1981-2020	40 ans

Similarly, average hourly wind speeds are analyzed using the Canadian standard (CNB), which is a method based on the analysis of maxima of average hourly wind speeds [20;21;22;23;24;25]. Thus, from the reference wind speeds, we identified the maximum annual speeds for each meteorological station. Before analyzing wind speeds qualitatively and quantitatively, the rules recommend that they should first be standardized at a height of 10 m above ground level, hence the expression:

$$\frac{V_H}{V_{10}} = \left(\frac{H}{10}\right)^{\frac{1}{7}} (1)$$

With :

- VH (m/s) is the wind speed measured on the anemometer at height H above ground level;
- V10 (m/s), the reference wind speed measured at the reference height H0;
- H (m/s) height at each weather station.

Exploratory analysis of data from different stations

In this section, the exploratory analysis of data from nine (09) weather stations was carried out in: Brazzaville, Pointe-Noire, Impfondo, Dolisie, Ouesso, Makoua, Djambala, Sibiti, Mouyondzi. For this statistical modelling, we considered the maximum wind speeds for each year over the period studied. This analysis revealed a number of shortcomings in certain meteorological stations with missing data. These have been logically supplemented, either by taking the median or the average of the series. This analysis enabled us to understand the distribution of the data, to detect outliers, to obtain histograms and QQ diagrams, and to plot significant whisker boxes for each weather station.

Modelling of the distribution used

Justification

The statistical modelling of extreme values was carried out using gross maximum annual wind speeds because of their applicability and statistical efficiency, using Gumbel's law [9].

Presentation and modelling of Gumbel's law

This is a law with exponential decay. For durations of 1 hour to a few days, it adjusts for maxima of 10 to 15 days, monthly maxima, seasonal maxima or annual maxima. Its advantage is that it stretches the distribution scale to a probability above 0.90. It is also a doubly exponential function; whose distribution function is:

$$F(x) = exp\left[-exp\left(-\frac{x-a}{b}\right)\right] (2)$$

Where a and b are the position and scale parameters respectively.

So, let's put it this way $U = \frac{x-a}{b} (3)$

U is the reduced Gumbel variable.

From (1) et (2), we have:

$$F(x) = exp[-exp(-U)] (4)$$

$$-\exp(-U) = \ln[F(x)] \ (5)$$

$$U = -\ln[-\ln(F(x))] \ (6)$$

The return time is given by the relation:

$$T_r = \frac{1}{1-F(x)} (7)$$

Hence, the distribution function given by :

$$F(x) = \frac{1}{1-T_r} \ (8)$$

From formulae (2), (5) and (7), we obtain:

$$\frac{x-a}{b} = -\ln\left[-\ln\left(\frac{1}{1-T_r}\right)\right] \ (9)$$

$$x = a - b\ln\left[-\ln\left(\frac{1}{1-T_r}\right)\right] (10)$$

X represents the velocity calculated using Gumbel's law, which is the reference velocity (Vr).

a, and b are calculated using the method of moments, which consists of equating samples with theoretical moments of the law. Using this method, the Gumbel parameters are calculated using the following formulae:

$$\begin{cases} \hat{a} = \mu - \hat{b}\gamma & (11) \\ \hat{b} = \dfrac{\sqrt{6}}{\pi}\sigma & (12) \end{cases}$$

With $\mu = \frac{\sum_i^n x_i}{n}$(13)

$\sigma = \sqrt{\frac{\sum_i^n (x_i - \mu)^2}{N}}$ (14)

$\hat{a}$=position parameter estimated by the method of moments
$\hat{b}$= scaling parameter estimated by the method of moments
μ= the average
σ= Standard deviation
γ= 0.5772 (Euler's constant)
The burst speed is given by the relationship:

$V_o = \sqrt{2}V_r$(15)

With:
V_r (m/s) the reference wind, calculated using Gumbel's law
Vo (m/s) is the gust or base speed.
According to the NV65 rules, the extreme wind speed is given by the following formula:

$V_e = 1.75V_{nb}$(16)

With:

V_n (m/s) the normal wind.
The basic normal speed or gust speed is by definition that which is reached or exceeded only 3 times out of 1000 over a period of 25 years. It is therefore the 3‰ frequency wind that is sought.

Let be:

- n_{ij}, the number of observations of $i^{ème}$wind speed of $j^{ème}$ year of observation.
- n_j, the total number of observations of the $j^{ème}$ year of observation.

The number of observations in thousandths, called the observation frequency, is given by:

$f_{ij} = 1000\frac{nij}{nj}$ (17)

The total number of observations n, of the $i^{ème}$ wind speed over the entire observation period considered is given by:

$ni = \sum_j nij$(18)

The frequency fi associated with ni is given by:

$f_i = 1000\frac{ni}{n}$(19)

With :
n, the total number of observations for the period under consideration for all the years in the station.

Once the Gumbel law had been chosen, the data were adjusted to assess and verify its robustness. Fig. 2 shows that at the Brazzaville weather station, the data fit the law well.

RESULTS AND DISCUSSION

Interpretation of Results

The exploratory analysis and processing of the data revealed outliers in certain localities, which are represented in the whisker boxes shown in the figures below and which give an overview of the variation in wind at each station studied. Figures 1.a; figure 1.b; figure 1.c; figure 1.d; figure 1.e; figure 1.f; figure 1.g; figure 1.h; figure 1.i show that at the Brazzaville weather station, wind speeds vary from 1.9 m/s to 3.1 m/s, with two outliers. At the Pointe-Noire weather station, wind speeds ranged from 2.1 m/s to 3.9 m/s, with no outliers. At the Impfondo, Sibiti, Ouesso and Djambala weather stations, wind speeds varied respectively from 0.4 m/s to 8.1 m/s with three (03) outliers; from 0.3 m/s to 2.8 with no outliers; from 0.7 m/s to 1.8 with two (02) outliers and from 0.8 m/s to 3.4 m/s with one (01) outlier. Similarly, wind speeds varied from 0.9 m/s to 8 m/s at the Dolisie weather station, with one (01) outlier, and from 0.6 m/s to 3.4 m/s at the Makoua weather station, with one (01) outlier. At the Mouyondzi weather station, wind speeds varied from 0.6 m/s to 2.5 m/s. (Figure 1.i).

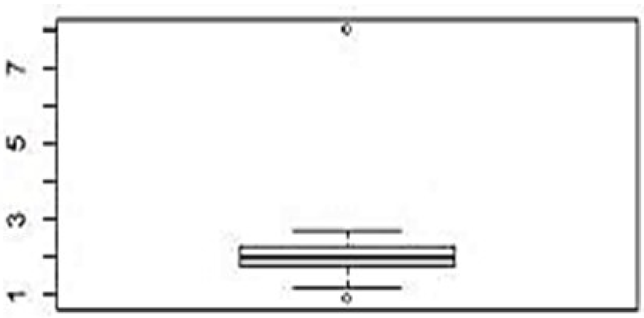

Figure 1 a. Variability of wind speeds in Brazzaville

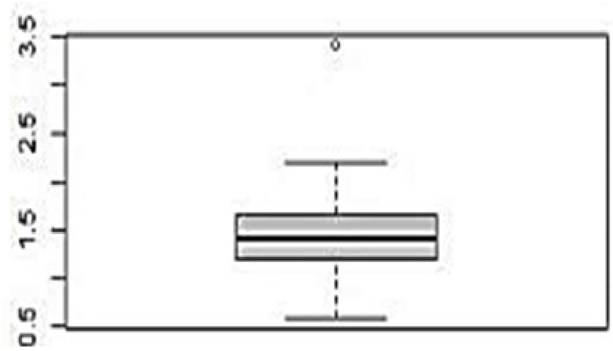

Figure 1 b. Variability of wind speeds in Pointe-Noire

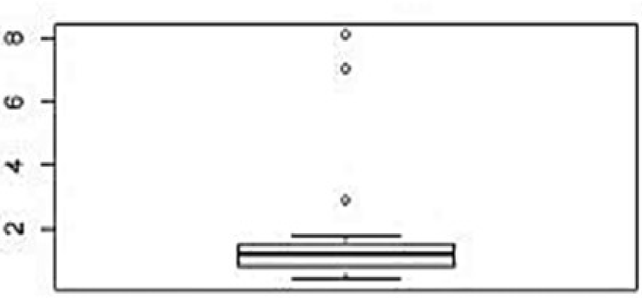

Figure 1 c. Variability of wind speeds in Impfondo

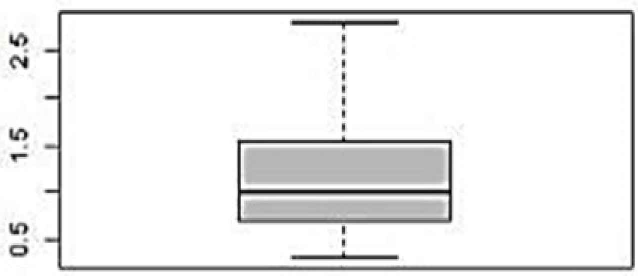

Figure 1 d. Variability of wind speeds in Sibiti

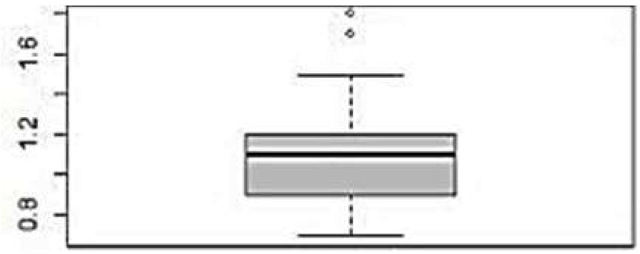

Figure 1 e. Variability of wind speeds in Ouesso

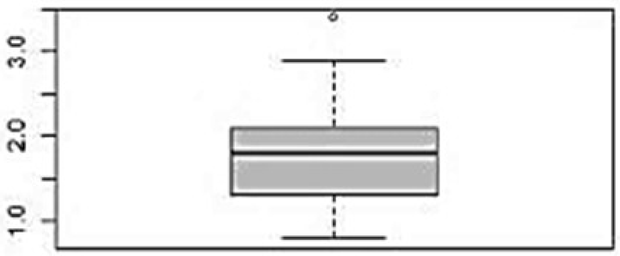

Figure 1 f. Variability of wind speeds in Djambala

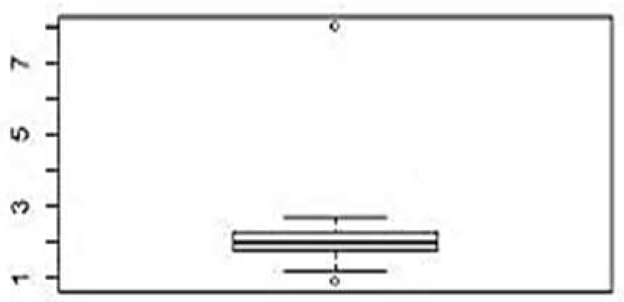

Figure 1 g. Variability of wind speeds in Dolisie

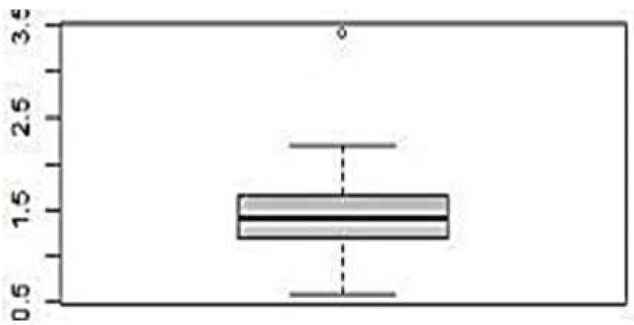

Figure 1 h. Variability of wind speeds in Makoua

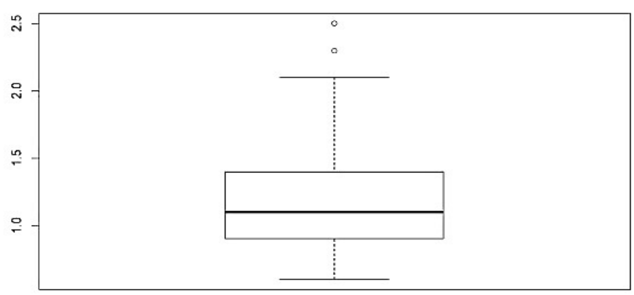

Figure 1 i. Variability of wind speeds in Mouyondzii

Figures 2, 3, 4, 5, 6, 7, 8 and 9 provide informations on the fit of the data in relation to the coefficient of determination. The more precise the coefficient, the better the fit in relation to the robustness of the law. At the Brazzaville station, the coefficient of determination is also significant, i.e. R2= 0.9183, which testifies to the robustness of the law in relation to the data, with a straight line of equation Y= 0.1984x+2.3894, where these two values represent the scale (b) and position (a) parameters respectively (Figure 2). Figure 3 shows the fit of the data to the Gumbel distribution at the Pointe-Noire weather station, with a large coefficient of determination R2=0.9069 and a straight line with equation Y=0.3528x+2.8664, where 0.3528 is the scale parameter and 2.8664 is the position parameter. As for Figures 4 and 5, they respectivelyshow, at the Impfondo weather station, a coefficient of safety R2= 0.9279 with a straight line of equation Y=0.351x+0.9794, where the scale parameter is equal to 0.351 and the position parameter 0.9794; and the Sibiti weather station has a coefficient of determination R2=0.9719, a straight line of equation Y=0.5042x+0.8526 with 0.5042 as the scale parameter and 0.8526 as the position parameter. Figures 6 and 7 show, respectively, the fit of the maximum annual wind speeds to the law at the Ouesso meteorological station with a coefficient of determination R2= 0.9791, a straight line with equation Y=0.1929x+0.9843 with the scale parameter equal to 0. 1929 and the position parameter 0.984, and at the Djambala weather station, a coefficient of determination R2= 0.9791 with a straight-line equation Y=0.4528x+1.5069 where 0.4528 represents the scale parameter and 1.5069 represents the position parameter.Figure 8 shows the fit of maximum annual wind speeds to the law, Dolisie meteorological station, which has a coefficient of determination R2= 0.8832 with a straight-line equation Y=0.307x+1.789, with a scale parameter equal to 0.307 and 1.789 as the position parameter. Figures 9 and 10 show, respectively, the fit of the maximum annual wind speeds to the law at the Makoua meteorological station, which has a coefficient of determination R2= 0.9197, a straight line with equation Y=0.358x+1.2484 with a scale parameter equal to 0. 358 and a position parameter equal to 1.2484, and at the Mouyondzi weather station, a coefficient of determination R2= 0.978 and a straight line with equation Y=0.3542x+1.0231, with a scale parameter equal to 0.3542 and 1.0231 as the position parameter.

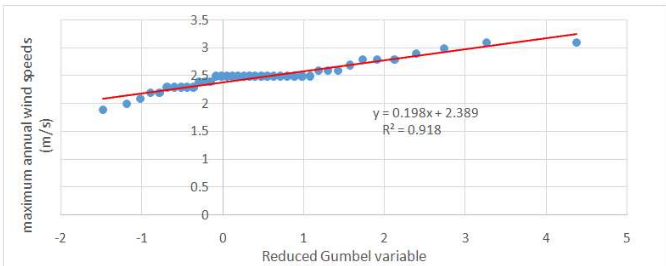

Figure 2. Adjustment of maximum annual wind speeds to Gumbel's law at Brazzaville meteorological station

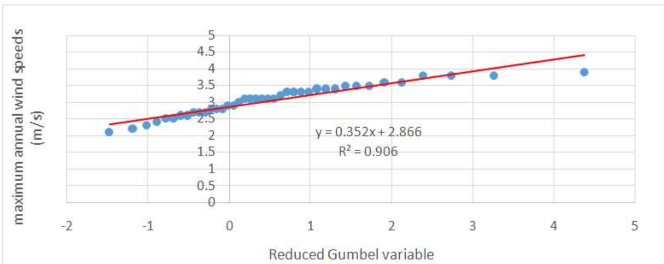

Figure 3. Adjustment of maximum annual wind speeds to Gumbel's law at Pointe-Noire meteorological station

The Gumbel parameters (the scale parameter and the position parameter) were also estimated using the method of moments. The values obtained by this method are very similar to the values estimated by the graphical method. Table 2 gives the values of all these parameters.

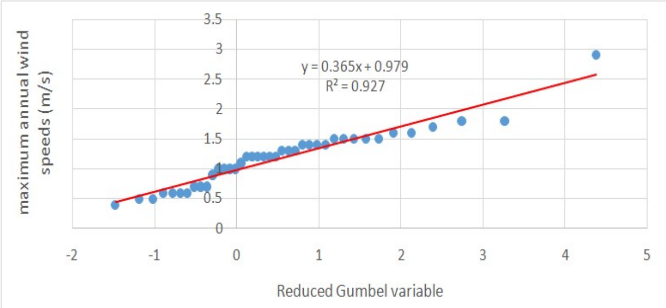

Figure 4. Adjustment of maximum annual wind speeds to Gumbel's law at Impfondo meteorological station

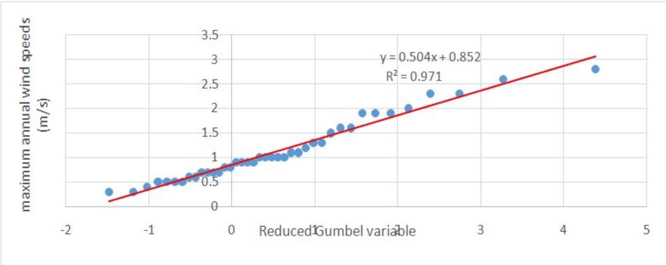

Figure 5. Adjustment of maximum annual wind speeds to Gumbel's law at Sibiti meteorological station

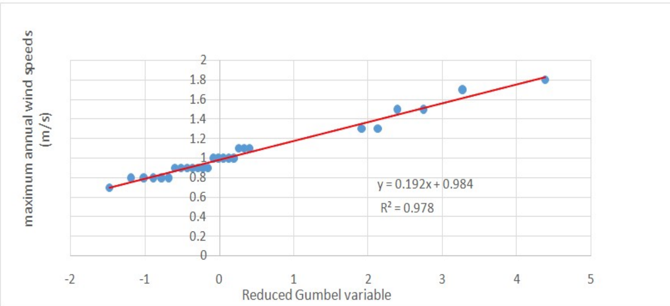

Figure 6. Adjustment of maximum annual wind speeds to Gumbel's law at Ouesso meteorological station

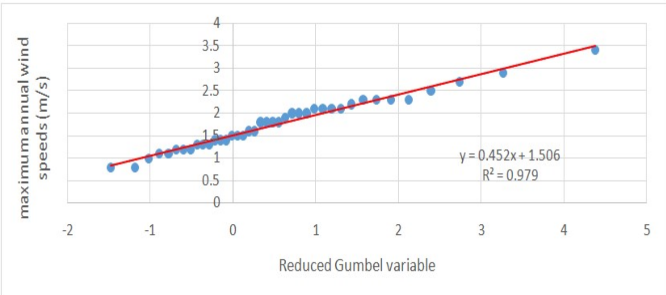

Figure 7. Adjustment of maximum annual wind speeds to Gumbel's law at Djambala meteorological station

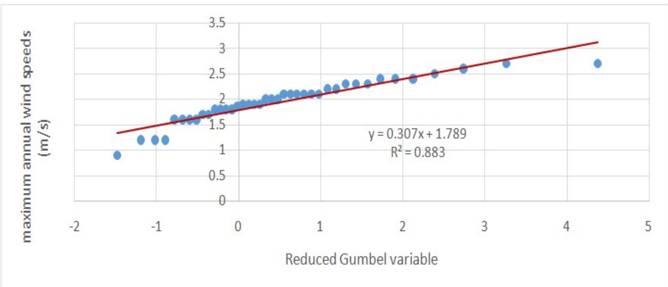

Figure 8. Adjustment of maximum annual wind speeds to Gumbel's law at Dolisie meteorological station

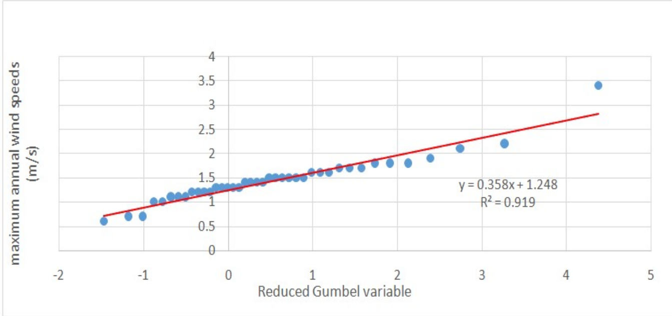

Figure 9. Adjustment of maximum annual wind speeds to Gumbel's law at Makoua meteorological station

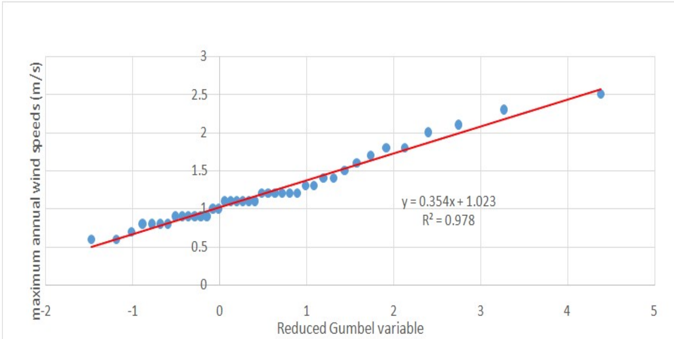

Figure 10. Adjustment of maximum annual wind speeds to Gumbel's law at Mouyondzi meteorological station

Table 2: Gumbel parameter values estimated by the graphical method and the method of moments

	Position parameters (a)		Scale parameter (b)	
Meteorological stations	Graphical method	Moments method	Graphical method	Moments method
Brazzaville	2.3894	2.389	0.1984	0.203
Pointe-Noire	2.866	2.857	0.353	0.364
Impfondo	0.9794	0.9725	0.3651	0.3723
Ouesso	0.9843	0.984	0.1929	0.193
Dolisie	1.789	1.789	0.307	0.307
Djambala	1.5069	1.507	0.4528	0.453
Sibiti	0.8526	0.853	0.504	0.504
Mouyondzi	1.0231	1.023	0.3542	0.352
Makoua	1.2484	1.248	0.358	0.367

Based on the determination of the Gumbel parameters and the modelling of this law, we calculated the reference velocities for each meteorological station with a recurrence time of 100 years at 10-year intervals. These speeds are shown in the table below. All these values enabled us to calculate extreme wind speeds and basic normal speeds or gust speeds. Table 4 shows the results obtained for each weather station with a return time of 100 years, at regular 10-year intervals. For reasons of hardness, the snow and wind rules (NV 66) recommend working with a return time of 50 years. Figure 11 shows the values of normal base or gust speeds at all the weather stations, with a 50-year return time. It shows that the wind speed is much higher at Pointe-Noire with a value of 4.75 m/s, followed by Dolisie with 3.87 m/s, Brazzaville with 3.76 m/s, Impfondo with 3.39 m/s, Djambala with 2.98 m/s, Makoua with 2.46 m/s, Sibiti with 2.16 m/s and Mouyondzi with a value of 2.12 m/s. Figure 12 shows the extreme wind speeds obtained at each weather station with a 50-year return period. It can be clearly seen that at Pointe-Noire, the extreme wind speed is higher than at other weather stations, with a value of 6.27 m/s, 5.13 m/s at Dolisie, 4.98 m/s at Brazzaville, 4.49 m/s at Impfondo, 3.95 m/s at Djambala, 3.26 m/s at Makoua, 2.86 m/s and a value of 2.81 m/s at Mouyondzi, [20;21;22;23;24;25;26;27;28].

Table 3. Speeds calculated using Gumbel's law

		Meteorological stations							
Year of observation 1981-2020	Brazzaville	Pointe-Noire	Impfondo	Ouesso	Dolisie	Djambala	Sibiti	Mouyondzi	Makoua
Year of observation	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020
Period of observation	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans
Return time	Speeds calculated using Gumbel's law								
10	2,54	3,14	1,75	1,13	2,28	1,86	1,24	1,30	1,53
20	2,60	3,25	2,08	1,19	2,52	1,99	1,39	1,40	1,63
30	2,63	3,30	2,24	1,21	2,62	2,05	1,46	1,45	1,68
40	2,65	3,33	2,33	1,23	2,69	2,09	1,50	1,48	1,71
50	2,66	3,35	2,40	1,24	2,74	2,11	1,53	1,50	1,74
60	2,67	3,37	2,45	1,25	2,78	2,13	1,55	1,51	1,75
70	2,68	3,38	2,50	1,26	2,81	2,15	1,57	1,53	1,77
80	2,68	3,39	2,53	1,26	2,83	2,16	1,59	1,54	1,78
90	2,69	3,40	2,56	1,27	2,85	2,18	1,60	1,55	1,79
100	2,69	3,41	2,59	1,27	2,87	2,19	1,61	1,55	1,80

Table 4. Extreme speeds and basic normal speeds as a function of time at each weather station

			Meteorological stations								
			Brazzaville	Pointe-Noire	Impfondo	Ouesso	Dolisie	Djambala	Sibiti	Mouyondzi	Makoua
Year of observation			1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020	1981-2020
Period of observation			40 ans	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans	40 ans
Return time	10	V_{nb}	3.59	4.44	2.48	1.61	3.22	2.63	1.75	1.84	2.16
		V_e	6.29	7.77	4.33	2.81	5.64	4.60	3.07	3.22	3.79
	20	V_{nb}	3.68	4.60	2.94	1.68	3.56	2.81	1.97	1.98	2.31
		V_e	6.44	8.04	5.15	2.95	6.24	4.92	3.44	3.46	4.03
	30	V_{nb}	3.72	4.66	3.17	1.71	3.71	2.91	2.06	2.05	2.38
		V_e	6.51	8.17	5.54	2.99	6.48	5.07	3.61	3.59	4.16
	40	V_{nb}	3.75	4.71	3.30	1.74	3.80	2.96	2.12	2.09	2.42
		V_e	6.56	8.24	5.77	3.04	6.66	5.17	3.71	3.66	4.23
	50	V_{nb}	3.76	4.74	3.39	1.75	3.87	2.98	2.16	2.12	2.46
		V_e	6.58	8.29	5.94	3.07	6.78	5.22	3.79	3.71	4.31
	60	V_{nb}	3.78	4.77	4.46	1.77	3.93	3.01	2.19	2.14	2.47
		V_e	6.61	8.34	6.03	3.09	6.88	5.27	3.84	3.74	4.33
	70	V_{nb}	3.79	4.78	3.54	1.78	3.97	3.04	2.22	2.16	2.50
		V_e	6.63	8.37	6.19	3.12	6.95	5.32	3.89	3.79	4.38
	80	V_{nb}	3.79	4.79	3.58	1.78	4.00	3.05	2.25	2.18	2.52
		V_e	6.63	8.39	6.26	3.12	7.00	5.35	3.94	3.81	4.41
	90	V_{nb}	3.80	4.81	3.62	1.81	4.03	3.08	2.26	2.19	2.53
		V_e	6.66	8.41	6.34	3.14	7.05	5.41	3.96	3.84	4.43
	100	V_{nb}	3.80	4.82	3.66	1.81	4.06	3.11	2.28	2.19	2.55
		V_e	6.66	8.44	6.41	3.14	7.10	5.42	3.98	3.84	4.45

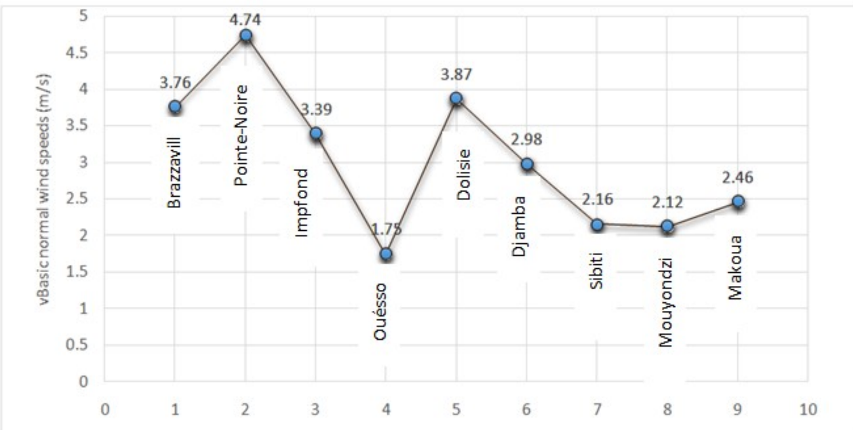

Figure 11. Basic normal wind speeds with a 50-year return period

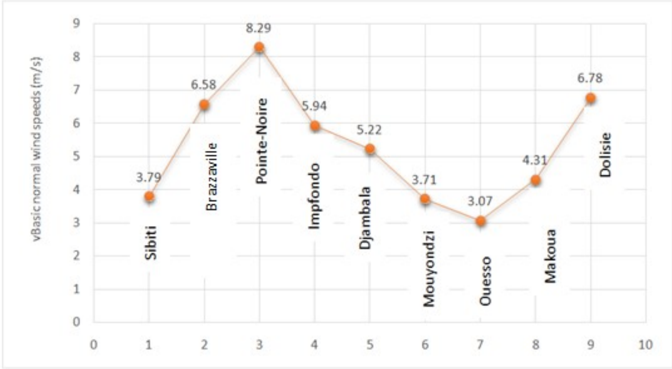

Figure 12. Extreme wind speeds with a 50-year return period

It goes out from annexes 1 and 2 show that wind speeds at Pointe-Noire are higher than at other weather stations. This is because Pointe-Noire is close to the sea and exposed to marine winds. We also note that the wind speed values at the Ouesso weather station are very low, because the town is characterized by the presence of many trees, which disrupt the wind flow. With regard to the results obtained at the various localized stations, the values permitted by the graphic representation of the wind influence zones (appendix 1) as well as that of the consolidated map (appendix 2) suggest a distribution into four influence zones of extreme wind speeds and basic normal speeds, [20;21;22;23;24;25;26;27;28;29]. In short, there are periods of high wind speeds and periods of relatively low wind speeds (Figure 11 and Figure 12).

DISCUSSION

Congo-Brazzaville is characterized by significant wind variability. However, the difference between the maximum values for the Kouilou Pointe-Noire wind data; (Vnb = 4.74m/s and Ve = 8.29m/s) considered as maximum values and the Sangha - Ouesso zone (Vnb = 1.75m/s and Ve = 3.07m/s) as minimum values is justified by their geographical location, climate, relief and vegetation. On the other hand, the preponderance of wind speeds in the Kouilou-Pointe-Noire area is essentially explained by the quasi-permanent establishment of a sea breeze regime, which is reflected in the fact that low relative pressure at ground level is frequent, in this case due to the warm air observed (Sbai et al, 1994; Fallot and Hertig, 2008), Several research projects have already been carried out to determine wind speeds with a view to adapting aerodynamic conditions in certain countries around the world (Zhou, 2010; Noha, 2011; Pobocikova et al, 2017, Sbai et al, 1994, Nsonandèle et al, 2016, Fallot and Hertig, 2008; Fiton, 1988, and many other authors. However, in Africa, with the exception of the Maghreb countries (North Africa), little work has been done in Sub-Saharan Africa (Gbaguidi et al 2010), [20;21;22;23;24;25;26;27;28]. The virtual non-existence of wind data means that all wind calculations for civil engineering structures are based on the French regulations, which are used by most construction professionals. This undoubtedly poses problems of optimization and oversizing of structures. Nevertheless, wind speeds are highly dependent on climatic factors, the environment and the relief of each area. The results concerning the estimation and static modelling of wind speeds within the framework of this work are consistent with those obtained in the research worksin [2;19;20;21;22;23;24;25;26;27;28;29]. Nevertheless, the currents (surface and its Gabon-Congo current) of the continental shelf in front of the town of Pointe-Noire have a major influence on wind speeds in this zone. [Fiton, 1988]. We note, however, that in view of the geographical situation of the Congo, the results of the wind data given in the French regulations (NV, 1965, 1999)[31], or in the Maghreb countries appear to be clearly superior to those obtained in this workfor Congo Brazzaville.

CONCLUSION

The interest of this work has been to find a model capable of analyzing maximum annual wind speeds and determining basic normal values and extreme values. These values will be used to determine the dynamic pressures that are useful in the design of civil engineering structures. All in all, these results show that the area's most sensitive to wind are those of Kouilou Pointe-Noire with values (Vnb = 4.74m/s and Ve = 8.29m/s) followed by the Brazzaville and Pool area (Vnb = 3.76m/s and Ve = 6.58m/s) and the Impfondo area (Vnb = 3.39m/s and Ve = 5.94m/s) in Congo Brazzaville. However, the least sensitive area is the Sangha Ouésso (Vnb = 1.75m/s, Ve = 3.07 m/s). The results obtained augur well for the future of civil engineering and confirm the theory that speed is random and that, in reality, the speed (wind speed) obtained in any one place is valid only in that place. In the future, these velocity values will be used to determine extreme and basic dynamic pressures, with a view to drawing up a definite wind map of the Congo.

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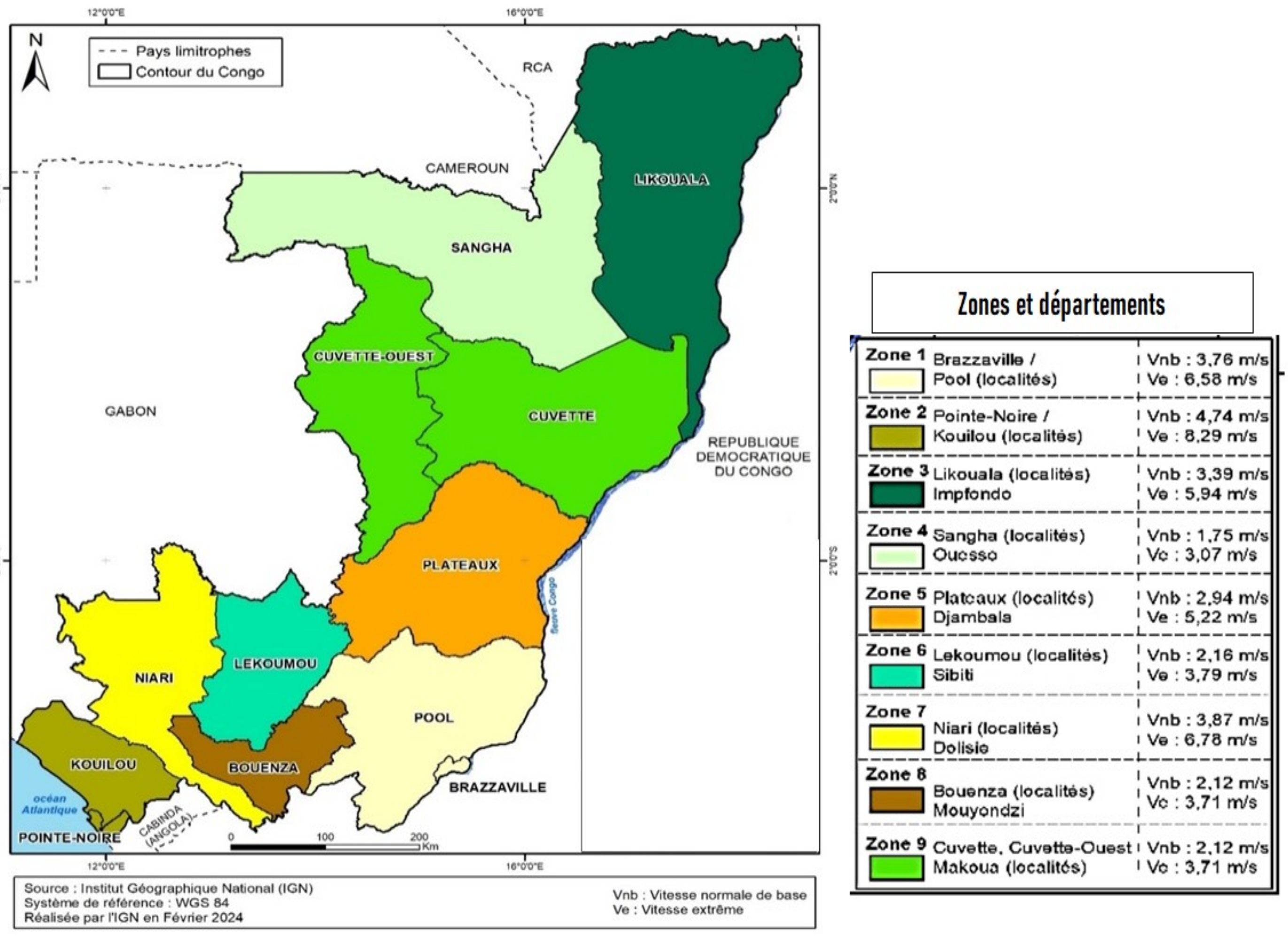
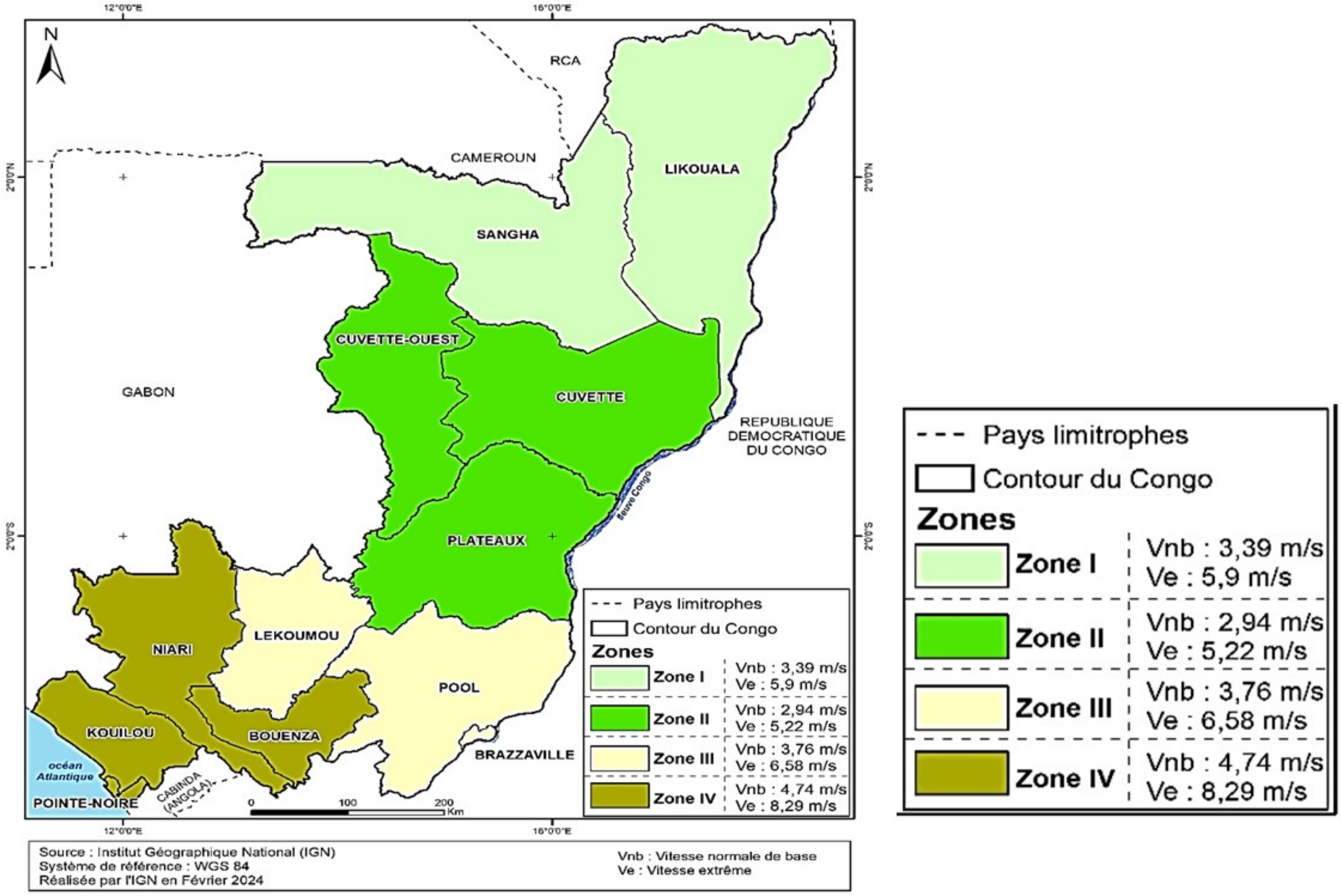


Annex 1. Map of areas where base normal velocities Vnb and extreme velocities Ve are expressed



Annex 2: Grouping of zones of influence and consolidation map of normal speeds

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