Distribution of Prevalence and Impact Factors of Cardiovascular Diseases in Benin*

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Abstract

Cardiovascular diseases (CVDs) are among the leading causes of mortality worldwide, with an increasing prevalence in low- and middle-income countries, particularly in sub-Saharan Africa. This article, part of an ongoing study, utilizes artificial intelligence (AI) in predicting distribution of CVDs, evaluating their impact factors, and proposing strategies for mitigating the prevalence of CVDs.

Aims and objectives: This part of the work focused only on understanding the contexts and impact factors of the different regional factors by answering the related research questions and finally testing the hypothesis on the statistical relationship between the prevalence and level and quality of medical equipment available in the care units as well as the level of access to early detection and prevention of CVDs in each region of the country.

Research methodology: A mixed methods approach was used to collect data (QUAN+QUAL) in a cross-sectional field study. Studies and reports published between 2012, and the beginning of 2024 were searched in academic databases and libraries of the Beninese Ministry of Health (MoH). Studies and reports on the prevalence of CVDs worldwide, particularly in Benin, and reports on CVD (pre)-screening and prevention in Benin were identified. Furthermore, quantitative data were collected through a survey (using a semi-structured questionnaire) conducted at the National Program for the Prevention of Communicable Diseases (PNLMT). The study involved 466 participants sampled from different regions and 36 care units across the country.

Results: People living in rural regions are more severely affected by these diseases. Erdely people (50+ years) are at risk of developing the disease, mostly in rural regions. The research hypotheses were supported by cross-sectional field research across different regions of Benin. The level of CVD incidence in Benin differs from region to region and is correlated with the level and quality of medical equipment in regional healthcare units and the extent to which early detection and prevention programs are implemented. However, analyzing the factors impacting the regional prevalence of CVDs from the computer sciences point of view reveals that awareness raising and early detection programs are poorly implemented. could be supported by digital campaigns (remote care) to raise awareness about cardiovascular diseases.

Keywords

Prevalence of disease, Artificial Intelligence, noncommunicable disease, cardiovascular diseases, Gamification, digital campaign

1. Introduction

Cardiovascular diseases (CVDs) encompass a range of heart and blood vessel disorders, including coronary artery disease, stroke, and hypertension. These conditions are a significant public health concern, especially in sub-Saharan Africa, where the burden is exacerbated by inadequate healthcare infrastructure, low awareness, and socio-economic challenges. Investigating the prevalence and distribution of CVDs in this region is critical for developing targeted interventions.

Noncommunicable diseases (NCDs) are among the leading causes of many deaths worldwide. NCDs kill 41 million people every year, accounting for 71% of all

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deaths worldwide. Every year, more than 15 million people die from NCDs between the ages of 30 and 69;

85% of these "premature" deaths occur in low- and middle-income countries [1], [2].

Worldwide, cardiovascular diseases, such as NCDs, are bearing a high burden of morbidity and mortality. Approximately 30–45% of adults worldwide are suffering from hypertension, the prevalence of which is increasing [3], [4], [5]. In Benin, a low-income country, the most common cardiovascular diseases (CVDs) are hypertension, obliteration of the arteries of the lower limbs (AOMI), cerebrovascular accidents (CVA) and heart failure (HF). Blood pressure (BP) was never measured in approximately 68.2% of Beninese individuals, and more than half of those with elevated BP were unaware of their status [6]. Despite the availability of low-cost antihypertensive drugs in Benin, less than half of known hypertensive patients are treated, and less than one-third achieve blood pressure control at currently recommended targets [7]. Late diagnosis of hypertension and poor BP control increase the frequency of hypertensive complications.

Access to stroke exploration tools remains a real problem, with high social inequalities and health insurance mainly benefiting wealthy people. In Benin, it is estimated that among patients, 109 (29.3%) have suffered from stroke without knowing it, 121 (32.5%) were diagnosed and had an electrocardiogram, and 31 (8.3%) benefited from a cardio ultrasound and 34 ultrasound scans of the neck vessels (9.1%) [8], [9]. This undoubtedly affects the prognosis of patients who do not receive optimal, specific treatment. Differences in the level of healthcare accessibility are a consequence of the medical structure of sub-Saharan African countries and weak health infrastructure. Figure 1 shows the pyramidal structure of the country public health system, where health units at low levels are poorly equipped with medical infrastructure [10].

Access to healthcare in general, particularly to cardiological care, is one of the main problems and challenges facing the public healthcare system in Benin, a sub-Saharan country, due to its public health structure and infrastructure [11]. Medical facilities are often far from residential areas. Most rural populations live in areas devoid of municipal infrastructure, such as streets and power supply systems. Access to healthcare is therefore dependent on the availability of local medical resources. Access to healthcare therefore depends on where one lives. Therefore, compared with urban populations, rural populations face poor access to healthcare [11]. In addition to poor medical infrastructure and equipment, individuals' financial and economic situations play an important role in their poor access to healthcare services and pharmaceutical care [12]. In Benin, 51% of women live relatively close to a hospital, over 13% of women live at least 30 kilometers from a hospital or comparable facility, and the rest have little or no access to medical care [13], [14]. Many regions in Benin have a low capacity to offer cardiovascular disease prevention, early detection, early diagnosis, and management services (SARA survey1 - 2018-).

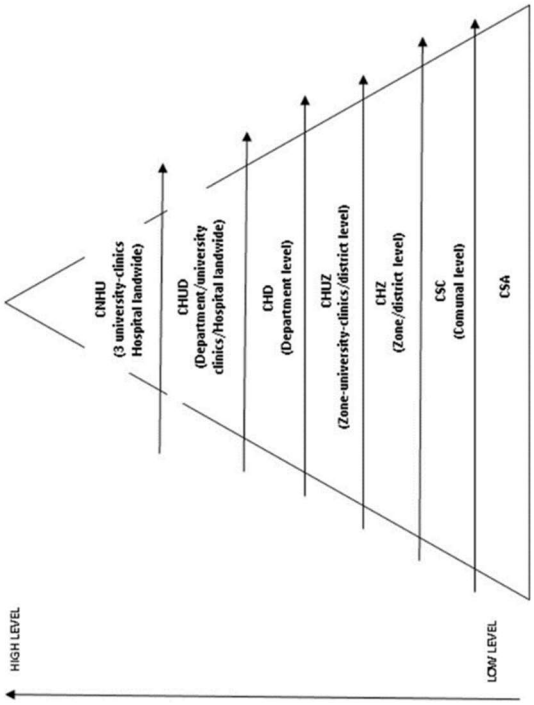

Figure 1: Beninese public health system structure. Source [*[15]* Figure 1 updated]. The country has only a few university hospitals. The majority of the population is living relatively close to an medical primary care unit

The lack of diagnostic and treatment services for cardiac arrhythmias is common in most sub-Saharan African countries, leading to suboptimal care and a heavy burden of premature cardiac death[16]. This fact might be correlated with the prevalence of CVDs across the country since early disease detection and prevention require various strategies and technological support, such as prescreening for diseases [17], eHealth and remote care infrastructures such as pervasive infrastructure [18], medical equipment such as ECGs

[1] https://www.afro.who.int/sites/default/files/2018-08/The%20 Work%20of%20 WHO%20in%20the%20African%20Region%20%20-%20Report%20of%20the%20Regional%20Director%20-%202017-2018%20-%20%20web%20version.pdf

[19], [20] and other medical tools. The lack of medical equipment might obstruct access to cardiac care provision.

Telehealth care, in general, increases access to health care providers [21] and enables care provision in the case of limited physical contact, for example, during the COVID-19 crisis [22], [23], [24]. Remote cardiac care, as a discipline of telehealth care, extends access to cardiologic care, including patient monitoring and education. Although the concept of telehealth care was coined in 1948 in Chester, where physicians started sending radiology images over the telephone and having remote consultation with other physicians2, telehealth is a relatively new topic in medicine and has gained more significance during the last COVID-19 pandemic. Remote patient monitoring started in 1961, and in 1967, ECGs were sent via telephone.

The overall objective of this ongoing study is using artificial intelligence to investigate the distribution of the prevalence of cardiac diseases across the country and their impact factors, to assist in the design of novel technology-based solutions to overcome poor medical equipment and poor access to CVD care services, implement digital campaigns and enable them to sustainably mitigate the prevalence of CVDs across the country. Early detection and management of cardiac diseases, particularly in regions with poor medical resources, can help public health system providers reduce the disease prevalence. The present study, therefore, specifically aimed to investigate the distribution and causes of disease prevalence in each region of the country using AI.

Artificial intelligence (AI) has emerged as a powerful tool in healthcare, offering advanced capabilities in data analysis, predictive modeling, and decision-making support. By leveraging AI, researchers and healthcare providers can gain deeper insights into the distribution of CVDs, identify key impact factors, and design more effective strategies to reduce the burden of these diseases. This article examines the potential of AI in this context and discusses the role of information technology in enhancing these efforts.

The goal of investigating the distribution of cardiac disease incidence is, on the one hand, regarding the structure of the Beninese public health structure to assess the relation between medical equipment (un)availability in cardiac care services and disease prevalence in each region and, on the other hand, factors to be technologically addressed to reduce the prevalence.

2. Theoretical and practical background, motivation, objectives, and hypotheses

2.1. Background

Cardiovascular diseases are among the leading noncommunicable diseases worldwide. Prior studies investigating the prevalence of cardiovascular diseases (CVDs) in Benin have focused mostly on the national prevalence of the disease or on hospitals in certain contexts and/or cases. It is therefore difficult to provide adequate and sustainable solutions to mitigate poor access to CVD care services through early detection. Prevention awareness-raising programs.

This section presents the outcomes of the literature review on the prevalence of CVDs worldwide, particularly in Benin, and early detection, prevention, and awareness-raising programs in the country.

2.1.1. Prevalence of Cardiovascular Diseases

The incidence of cardiac diseases in sub-African countries is high[4]; in particular, blood pressure is approximately 27% in sub-Saharan Africa[5].

Many research studies have addressed the prevalence of CVDs with a focus on cases such as the prevalence of CVDs among certain population groups and inpatients suffering from certain diseases. These studies have focused on determining CVD risk factors in selected populations. Witchakorn et al. investigated the incidence of CVDs among HIV patients in Asia-Pacific regions. A high prevalence of CVDs was found among HIV patients compared with non-HIV patients. Despite this result, the study concluded that a gap exists in HIV/CVD research [25]. According to this study, HIV seems to be a factor impacting the incidence of CVD. Similarly, Huynh Van Minh et al. investigated the prevalence of hypertension in a population of people aged ≥ 18 years in Vietnam [7], and Jérôme Boombhi et al. investigated the prevalence of CVDs and factors associated with blood pressure (BP) in a population of hypertensive black patients in two hospitals in Cameroon and found that an alarming prevalence of CVDs and a sedentary lifestyle in the population in Cameroon were the main CVD risk factors [4]. Camille Lassale et al. investigated the prevalence among people using traditional medicine (TM) in 12 African countries. The study revealed that the proportion of people with high BP using TM matches the incidence of CVDs in sub-Saharan Africa reported in the literature [5].

[2] https://blog.prevounce.com/history-of-remote-patient-monitoring-how-it-began-and-where-its-going

In Benin, the prevalence of blood pressure was 25% in 2015 (Houehanou et al., 2022a).. Many previous studies have investigated the prevalence of CVDs such as blood pressure in Benin, with a focus on nationwide cardiac disease incidence [26], geographical region [3], [27], or cardiac disease in certain population groups [8].

The distribution of CVD incidence in geographical regions in Benin has been less investigated. In 2011, D.S. Houinato et al. investigated the prevalence of CVDs and associated risk factors. The study revealed that department (region) and profession are not associated with the prevalence of hypertension (HT) while age and obesity are significantly associated to HT [9]. Similarly, Michael Ekholuenetale et al. investigated heart diseases among women in Benin and reported a high prevalence of heart and lung diseases in rich environments, unlike Houinato et al., who reported that geographical regions are associated with heart and lung diseases among women of reproductive age [8]. To the best of our knowledge, this study is the only one that has investigated the prevalence of heart disease in geographical regions. However, only women and heart diseases were considered among CVD patients. This fact makes our study novel.

The prevalence of CVDs in Benin is estimated to be 27.5% for hypertension, 3.9% for lower limb artery obligation, 4.6% for stroke, and 1.0% for heart failure3. Hypertension affects 25.9% of Beninese adults according to a national survey conducted in 2015 by the Ministry of Health using stepwise methodology from the World Health Organization [26], [28]; different risk and impact factors were investigated. However, we found no studies that investigated the impact of the level of medical equipment in healthcare units and disease awareness among the population.

2.1.2. Early detection and prevention of cardiovascular diseases

According to the information collected in the latest SARA survey4 (2018), some regions in Benin have a low capacity to offer cardiovascular disease prevention, earlier detection, diagnosis, and management services.

Disease prevention requires knowledge about the disease (health literacy) [17]. Most of the reviewed articles reported an average level of CVD awareness among the studied populations; in [26], awareness was slightly greater than half. The TAHES study (Desormais et al., 2019),, which was conducted in Benin, revealed similar awareness ratios and revealed differences between men and women in terms of disease awareness. It was also reported in [8] that approximately 50% of people involved in a study of four sub-Saharan African countries were not aware of their hypertension; in [9], 77.5% of the study participants were unaware of their state. In [4], the authors state that the subjects are not aware of risk factors such as obesity and others. Based on these findings, it is worth investigating the extent to which disease awareness-raising campaigns or programs are implemented in Benin.

The national implementation of the WHO PACKAGE OF ESSENTIAL NONCOMMUNICABLE (PEN) DISEASE INTERVENTIONS (WHOPEN) strategy is still sporadic. However, in 2023, the WHO founded an information campaign on cardiovascular and diabetes prevention in three departments, namely, Attacora, Donga, and Mono. Many other awareness-raising campaigns and early detection programs were conducted in the same year (2023). However, all these campaigns were addressed to some employees of some national institutions. According to Amidou A. Salmane, the MoH is working on a strategy for public awareness campaigns and early detection programs that could benefit the entire population.

Despite the adoption of WHOPEN, the country lacks a sustainable implementation of early disease detection and prevention programs.

To the best of our knowledge, and according to the literature review on early detection and cardiological disease prevention programs in Benin, no program exists. However, according to Amidou A. Salmane5, the Ministry of Health (MoH) has adopted the WHO package of essential noncommunicable (PEN) disease interventions for primary health care (WHOPEN), a strategy for primary disease prevention and early detection defined by the World Health Organization (WHO).

Educating people in Benin on risk factors for all cardiac diseases, detecting cardiac diseases early and developing better strategies to manage cardiac diseases might assist in reducing the risk of developing and reducing the prevalence of cardiac diseases[29], which is obviously caused by poor access to cardiac screening for early detection, diagnosis, and treatment. However, the Beninese public health structure is facing infrastructural challenges[11] that could challenge the

[3] https://benin.un.org/fr/298-oms-r%C3%A9duire-la-pr%C3%A9valence-des-maladies-non-transmissibles-au-benin

[4] https://www.afro.who.int/sites/default/files/2018-08/The%20 Work%20of%20 WHO%20in%20the%20African%20Region%20%20-%20Report%20of%20the%20Regional%20Director%20-%202017-2018%20-%20%20web%20version.pdf

[5] PNLMNT: National Program for the Prevention of Communicable Diseases

efficiency of initiatives to reduce the prevalence of cardiac diseases in Benin.

2.2. Research Motivation, Objectives, Questions, and Hypotheses

2.2.1. Motivation

This section discusses the research motivation or gap.

Most prior research on the prevalence of CVDs in Benin has focused on the following:

1. Determining the prevalence of certain CVDS, such as hypertension, in a certain group of individuals revealed that individuals suffering from CVD are unaware of the disease [3], [8], [9], [27]
2. CVD risk factors such as obesity and comorbidities[25], [30]
3. Predicting the regional prevalence of CVDs based on collected historical data (risk factors, technical platform level, access to diseases prevention programs, etc.,)

It is well known in the literature that individuals' disease awareness, also called health literacy, can be improved by educating them on disease risk factors and pre-symptoms. Knowing the risks of disease could drive individuals to prevent the disease [31], [32] by following their health and lifestyle. We found in previous studies [33], [34] that health or medical education might impact individual health outcomes. It is, therefore, trivial that knowing and having a good lifestyle may impact the prevalence of the disease in a region.

Early detection of a disease requires access to care services, whereas medical equipment is needed. It is well known in the literature that access to care services is not sufficient to impact individual health outcomes. The quality-of-care services is another factor that amplifies health outcomes. Therefore, it is worth investigating the role that the level and quality of medical equipment could play in the prevalence and/or incidence of diseases. All prior studies are limited in this regard.

To the best of our knowledge, no previous study has assessed the impact of medical equipment, early disease detection and prevention, and the implementation of disease awareness campaigns on the prevalence of CVDs in geographical regions of the country. Therefore, this study was motivated by this research gap and aimed to answer the question of *"to what extent factors such as the level and quality of medical equipment, early disease detection and prevention, and disease awareness raising campaigns could impact the level of geographical prevalence"*.

2.2.2. Research objectives, questions, and hypotheses

The primary objective of this ongoing study is to investigate to what extent information technology could assist in mitigating (reduce) the incidence of CVDs in the country's geographical regions. Therefore, our steps toward this goal are to determine the causes underlying the prevalence and analyze them in the computer sciences.

This part of the research, therefore, aims to do the following:

1. The prevalence of disease and impacting factors in geographical regions of the country were assessed.
2. The number and quality of medical equipment cardiologic units in the districts were assessed.
3. Districts were classified according to their scores (prevalence and equipment level as well as prediction and prevention programs), and the prevalence of districts with similar medical equipment levels, screening, and control programs was compared.
4. Collected data were used to predict the regional prevalence of the CVDs

Regarding the identified research gap, we define the research hypothesis as follows:

H1. The level of prevalence in geographical regions is statistically related to the level of population accessibility to early disease detection (prescreening), prevention programs and the number and quality of existing cardiology equipment in regional care units.

3. Methodology and Study Design

3.1. Study methodologies

This study used quantitative and qualitative mixed-method research to collect data from several targets spread throughout Benin to identify and explain why certain regions are facing a higher incidence and incidence of cardiovascular disease than others.

A total of 398 studies published between 2012 and the beginning of 2024 were identified in dedicated academic databases (PubMed, ScienceDirect, Web of Science, CINAHL, Google Scholar, Scopus). Studies on the incidence of cardiac diseases in Benin were identified and included in the study to assess the prevalence and impact factors of cardiac diseases.

Reports from the Beninese Ministry of Health were also reviewed.

Random forest was used on the collected data (rate of risk factors in each, medical equipment level,

prevention programs, etc.) for predicting the regional prevalence by classification.

3.2. Sampling

The country is divided into 12 departments called "prefectures" and 77 districts called "communes". Representative districts were selected in each department following our selection criteria. The selection criterion for each region was at least a university hospital if it existed and/or was a well-visited healthcare unit with at least a minimum level of cardiovascular medical equipment and cardiologists. On the other hand, care units in rural areas have CVD medical equipment, such as ECG devices.

The participants (cardiologic patients living in large cities and rural regions) and cardiac care units were sampled to investigate the distribution of CVD across Benin and to highlight the regions where there is a need for infrastructure, medical equipment, and staff acquisition.

- A total of 466 participants (patients) participated in the survey from the start to the finish of the survey. Of these, 192 were women, 54.2% lived in rural areas and 44.3% lived in urban areas. It should be noted, however, that 1.6% of these women did not specify their living environment.
- Similarly, there were 265 men, 66.4% of whom lived in rural areas and 32.5% in urban areas, while 1.1% did not specify their living environment. In addition, 09 people who participated in the survey did not specify their gender.
- Participant Care Unit (N = 36), which provides cardiological care, was selected according to predefined criteria. The most visited care units in the department were selected.

3.3. Data sources, collection, and extraction

To explain the reasons underpinning the discrepancy in cardiological care service provision across the country, mixed-method research (quantitative followed by qualitative data collection to explain the outcomes of the quantitative study) and a qualitative survey were conducted.

The kobotoolbox tool was used to develop an online data collection form. Participants can answer questions about discrepancies in CVD medical care services across the country.

Online questionnaires, telephone interviews and face-to-face interviews with open-ended questions (qualitative research, generally subjective) and closed-ended questions (quantitative research) were used to assess the level of perception, prevalence, and involvement in the management of CVD in Benin. The overall survey period runs from February 2023 to November 2023.

The survey used a web-based information-gathering form distributed via social networks to healthcare professionals, facility users, friends, and relatives throughout Benin.

Illiterate people, on the other hand, were helped to complete the questionnaire.

A further qualitative survey consisting of open-ended questions with a focus group of healthcare professionals, including cardiology specialists, was conducted to analyze the outcomes of the mixed-methods study. This involved discussions during a workshop with professionals from each department, including a cardiologist (if possible), a general practitioner and a health center manager (nurse or midwife).

The aim of this workshop is to analyze the quantitative results obtained after presenting the results of the quantitative mixed-method study and to explain, from care professionals' perspectives, the difference in prevalence between regions with the same level of CVD medical equipment.

The following questions were addressed during the discussions:

1. What are the difficulties faced in caring for patients in general and those suffering from cardiovascular disease in particular?
2. How do you explain the difference in the level prevalence of cardiovascular disease in regions where there are no treatment facilities?
3. How do you explain the difference in the level prevalence of cardiovascular disease in regions where treatment facilities are available?
4. What can be done to achieve the same level of care in all regions of Benin?

3.3.1. Mixed Methods Research Questions for Descriptive Research Designs

- **Prevalence of cardiac disease and people's perceptions**

After assessing disease prevalence, people in the selected regions were asked about their disease awareness, blood pressure control and participation in screening programs.

3.3.2. Mixed Methods Research Questions for Causal-Comparative Research Designs

1. Prevalence of cardiac disease and healthcare professional perceptions

Health professionals were asked about factors related to the level of disease prevalence in their regions. Furthermore, they were asked about the adherence of the population to medical control for early detection and treatment.

2. Challenges and Issues Facing Screening Programs

The medical equipment level was assessed where health care professionals were asked about challenges and issues faced in providing screening programs to detect the disease early and thus prevent it early.
The questions mainly focused on the medical equipment level of the care unit and how the population is empowered to take part in the program.

3.3.3. Mixed Methods Research Questions for Experimental Research Designs

1. Effect of remote cardiological care in regions with a high prevalence

The effect will be assessed in the frame of an upcoming empirical study.

2. Effects of a Smart pervasive screening system on prevalence

The effect will be assessed in the frame of an upcoming empirical study.

3.4. Data analysis

Table 1 summarizes the data analyses carried out.

Table 1
Summary of the data analysis processes

Seq.	Data analysis methods	Description
1	*Quantitative Data Analysis*	Quantitative data analysis was carried out using the ANOVA group means comparison to measure the difference between the level of the prevalence of diseases in different regions
2	*Qualitative Data Analysis*	Qualitative data analysis was conducted using the thematic analysis paradigm as described in(Braun & Clarke, 2006). The recorded interviews were transcript and labeled
3	*Mixed-Method Data Analysis*	Qualitative and quantitative analyses were synthesized into each other to perform mixed-method data analysis where qualitative data were turned into qualitative data and vice versa, (quantitizing).

4. Findings

This section presents the results of the study on the level and quality of medical equipment in healthcare units, access to medical care for CVD, and the level of CVD incidence in geographical regions with their associated impact factors and, in addition, the strategy for early disease detection, prevention and awareness campaigns in the country.

We did not, unlike past studies, make any difference between the different CVDs in the scope of this study.

4.1. Prevalence in geographical regions

A total of 159 people out of 466 interviewed suffer from cardiovascular disease, 39% of whom are women and 61% of whom are men (Figure 2). The greatest proportions of participants suffering from the disease were recorded in Donga (70%), Plateau (70%), Atacora (63%) and Alibori (56%). On the other hand, the lowest proportions of participants suffering from the disease were recorded in the Ouémé (8.4%), Borgou (10.4%) and Littoral (20%) departments. The other departments have a significant proportion: 40.0% for Zou, 37.5% for Mono, 36.0% for Atlantique, 31.6% for Couffo, and 30.0% for Collines.

The departments of Alibori and Atacora account for 27% and 25.2%, respectively, of the country's disease burden. The latter contribute more to the emergence of

the disease in the country, while Zou's share of sufferers in Benin is the lowest (1.3%). This share is not as negligible for the other departments: 11.3% for Atlantique, 9.4% for Littoral, 4.4% for Ouémé, 3.8% for Couffo and Mono, 3.1% for Borgou and 1.9% for Collines.

Elderly individuals (50+) are mostly affected by this disease. People living in rural Benin are more affected. In Alibori, 65.1% of people are affected by the disease in rural areas, compared with 30.2% in urban areas. The remaining 4.7% of the population represents the number of people in Alibori whose place of residence is not specified. The rural areas of the Atacora department accounted for 92.5% of the department's patients, compared with only 7.5% in urban areas. The other departments where rural areas broke the record were Collines (66.7% vs. 33.3% in urban areas), Couffo (83.3% vs. 16.7% in urban areas), Donga (85.7% vs. 14.3% in urban areas), Littoral (66.7% vs. 33.3% in urban areas), Ouémé (57.1% vs. 42.9% in urban areas) and Plateau (85.7% vs. 14.3% in urban areas). On the other hand, this trend was reversed in the departments of Atlantique (72.2% in urban areas vs. 27.8% in rural areas), Borgou (100% in urban areas) and Mono (66.7% in urban areas vs. 33.3% in rural areas), where urban areas recorded a greater proportion than did rural areas.

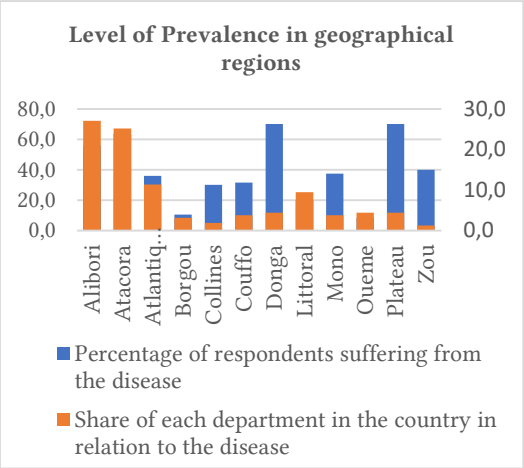

Figure 2: Prevalence level in each selected region

4.2. Prediction of the prevalence

Predictive analytics encompasses a variety of statistical and machine learning techniques used to forecast future outcomes based on historical data. In the context of CVDs, predictive models typically analyze patient data, including demographic, clinical, and lifestyle factors, to predict the likelihood of developing cardiovascular conditions. These models range from traditional regression analyses to more complex machine learning algorithms like decision trees, random forests, and neural networks.

One of the primary challenges in predicting CVD prevalence is the quality and availability of data. Many predictive models rely on high-quality, longitudinal data, which may not be available in all regions. Additionally, data discrepancies, especially in low-resource settings, can lead to inaccurate predictions.

Random forest aa supervised learning algorithm requesting a labeled data set where people are diagnosed as suffering or not from CVDs was used. Independent features included in the labeled data set are 1) rate of the CVDs risk factors (12 levels), 2) medical equipment level of each medical unit (5 levels), level of the accessibility to CVDs care (2 levels), level of the accessibility to prevention services or prescreening.

4.3. Medical equipment

The level of medical equipment is determined by the amount and quality of medical equipment, such as ECG devices (Figure 3).

Blood pressure equipment is available in almost all health centers. The full range of diagnostic equipment required for the proper management of patients suffering from CVD is available only in the departments of Borgou, Littoral and Ouémé, which have special status in Benin.

Using documentation on the organization of Benin's healthcare system and information from the National Health Development Plan (PNDS) and the 2018 edition of the Health Statistics Yearbook and then exploited in the context of this work, it was found that the healthcare system is organized into several types of health facilities (FS) for the care of populations. These SFs can be categorized according to departments as follows:

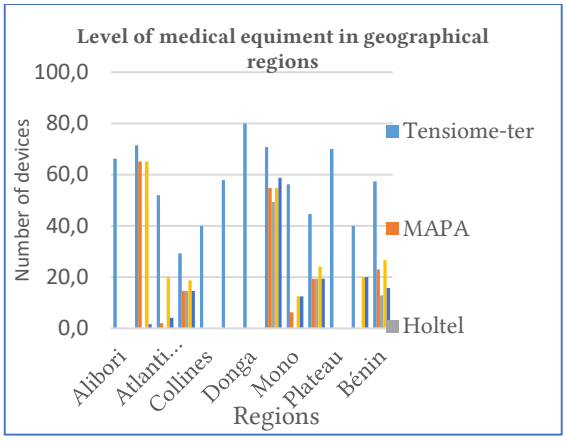

Figure 3: Medical equipment in the different regions. Most of the care units are poorly equipped. Tensimeter is the main equipment available at these units.

Table 2 summarizes the content **Error! Reference source not found.** and classifies the medical equipment.

Table 2
Medical equipment availability per department

Level	Classes	Depart-ments	ECG device	Hottel	Tensiome-ter	MAPA	Cardiac echography device
Very high	1	Borgou	++	++	++	++	++
		Ouémé					
		Littoral					
High	2	Atlantique	+++	+	+++	+	-
Middle	3	Atacora	+++	-	++	+	-
		Zou	+++	-	++	-	+
Low	4	Alibori	++	-	-	-	-
		Donga					
		Plateau					
Very low	5	Collines	+	-	+	-	-
		Couffo					

The regional prevalence of CVDs revealed a discrepancy between geographical regions (Table 3).

Table 3
Categorization of care units based on medical equipment

Departments	Level of medical equipment in all care units	Regional prevalence
Borgou – Littoral – Ouémé	Very high	10 to 20% (low)
Atlantique - Mono	High	30 to 40% (middle)
Attacora	High*	60 to 70% (high)
Zou	Middle	30 to 40% (middle)
Plateau – Donga - Alibori	Low	60 to 70% (high)
Colline - Couffo	Very low	30 to 40% (middle)

As summarized in Table 3, care units in Borgou, Littoral, and Ouémé are highly equipped and show a low cardiac disease incidence, while Atlantic and Mono departments, which are equipped with almost all devices, show an average prevalence.

The department of Zou, with average medical equipment, shows an average prevalence level. Moreover, Donga and Alibori, which have low levels of medical equipment, have a low prevalence.

These results confirm that the level of prevalence is associated with the level of medical equipment and infrastructure in the region. However, even though the medical equipment available for the Department of Attacora* is like that available for the departments of Atlantique and Mono, it is highly prevalent. This could be explained by the fact that either

1. The existing medical equipment is defective. or
2. Qualified staff to use the equipment is missing, or
3. The population is visiting other closer care units in another neighboring department. For example, Atacora and Borgou are neighboring departments, and Borgou has a low incidence of CVDs.
4. People mostly use traditional medicine. Lassale C et al. stated in [5] that "The overall proportion (24%) shows that self-reported use of TM is common in patients with diagnosed hypertension and matches the literature with a mean prevalence of published studies in sub-Saharan Africa of 27%."

The case of the Department of Atacora revealed that the quality of medical equipment, the availability of qualified medical staff, and other factors are associated with the prevalence.

In the department of Collines and Couffo, although it has very low-level medical equipment, it has an average prevalence. This could be explained by the fact that the medical staff regularly raise awareness at home with only the basic type of device (tension device) they have or that there could be other causal factors that another study could identify.

4.4. Early detection and screening programs

The country lacks appropriate campaigns for raising public awareness. In 2021, USAID collaborated with the government through the National Program for the Prevention of Communicable Diseases (PNLMT). The partnership aims to launch digital technology in the

Onchocerciasis Detection and Public Awareness Campaign6.

We found that the country has not implemented public awareness-raising campaigns for cardiovascular disease, and no early detection or prevention programs have been properly implemented.

We deduce that University Hospitals (HUs), whether departmental or zone hospitals, are located within a radius of 40 km of the Faculties of Health Sciences (FSS) or medical schools. According to this categorization, most cardiology services are available in hospitals of classes 1, 2 and 3. Specialty services such as cardiology are mostly available only in hospitals of these classes. They are in urban areas, more specifically in the special-status towns of Cotonou (Littoral), Porto-Novo (Ouémé) and Parakou (Borgou).

4.5. Access to cardiological care

According to these quantitative results, the major accessibility difficulties encountered by patients are poor road conditions, excessive loss of time in line, no time for consultations, and no money for the consultation. All these difficulties become minor in the departments of Borgou, Littoral and Ouémé.

Figure 4 presents the different causes of poor access to healthcare services.

Regarding patients' statements on difficulties accessing care (multiple-choice question), the survey results revealed the following:

- Eighteen percent said they had no money to make regular trips to the hospital for clinical appointments.
- A total of 26.2% said they had no money to pay for consultations or medical procedures on a regular basis.
- A total of 4.9% declared that they had mobility problems for reasons of health or old age. This makes it difficult to reach the health center to maintain appointments.
- A total of 26.8% said they had no time to maintain regular clinic appointments.
- A total of 46.6% mentioned the difficulty of maintaining clinical appointments due to poor road conditions.
- A total of 24.7% said they lost too much time in line with hospital consultations.
- A total of 24.7% said they lived more than 5 km from the nearest health center.

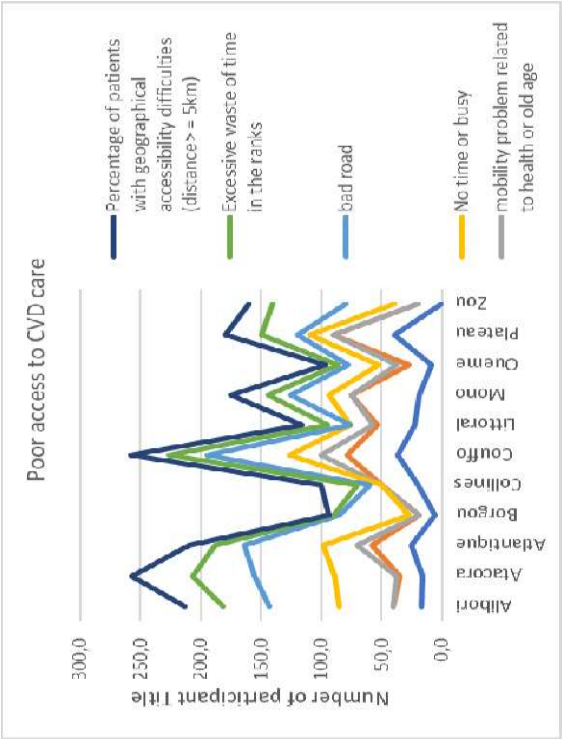

Figure 4: Causes of poor care access. The main cause of poor access to CVD care is the lack of care units at the residence place of the patients. Therefor, they face financial and economic issues to visit the next medical unit

5. Analysis and Discussion

5.1. Analysis

This section analyzes the results obtained above, with a view to determining the extent to which improving the technical platform for cardiology care using new technologies could have an impact on the cardiac health of affected populations, irrespective of their geographical and socioeconomic situation.

5.1.1. One factor impact on the prevalence of CVDs

5.1.1.1. Impact of medical equipment on cardiac disease incidence

- **Hypothesis testing**

[6] https://www.usaid.gov/benin/news/feb-14-2022-onchocerciasis-control-campaign-goes-digital-reach-millions-benin

H1: The regional distribution of cardiovascular disease shows a statistical relationship between the prevalence of the disease and the level and quality of medical equipment used for cardiology diagnosis and management, depending on the region.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5	11	33	3	2,2
10	11	410	37,27273	381,8182
20	11	520	47,27273	381,8182

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Between Groups	11860,55	2	5930,273	23,23057	8,04E-07	3,31583
Within Groups	7658,364	30	255,2788			
Total	19518,91	32				

The F test statistic (23.23057) is greater than the F critical (3.31583). Based on the test statistics, there is sufficient evidence to reject the null hypothesis, and the P value of 8,04E-07 is less than the alpha $\alpha = 0.05$.

- **Rejection of the hypothesis**

The medical equipment level is not the sole factor impacting the regional disease incidence. The departments of Coline and Couffo have a moderate disease prevalence, and their care units are less equipped than the department of Attacora, which has a high disease prevalence (Table 2).

The high disease prevalence in Attacora could be explained by the poor quality of medical equipment in its care units. However, why do the departments of Colline and Couffo, which have poor medical equipment, have a moderate disease incidence, while Atlantique and Mono, which have high medical equipment, have the same disease prevalence?

5.1.1.2. Impact of cardiac disease prevention, screening programs, and early detection on disease incidence

H2: The incidence of cardiac disease is significantly related to early cardiovascular disease detection, prevention programs, and diseases awareness campaigns.

- **Hypothesis Testing**

While the khi-deux test carried out on the collected data reveals a weak relationship between the prevalence of CVDs in certain geographical regions (example Atacora) ($p<10\%$), place of residence and suffering from the disease are significantly related ($p<1\%$). Though, the hypothesis could be partially rejected since the statistical relationship between both elements is weak and seems to be affected by further factor(s).

5.1.2. Two factors impact on the prevalence of CVDs

H3. The level of prevalence in geographical regions is statistically related to the level of population accessibility to early disease detection (prescreening), prevention programs and the number and quality of existing cardiology equipment in regional care units.

All geographical regions severely lack pre-screening, prevention, and disease awareness campaigns. The analysis of variance (2-way ANOVA) shows that the prevalence of CVD in geographical regions depends on two independent factors. The analysis reveals high prevalences of CVD in regions with high levels of medical equipment but of poor quality and benefiting from pre-screening campaigns (example of Attacora).

5.2. Discussion

The present study investigated the prevalence of CVDs in geographical regions and the statistical relationship between CVD incidence and medical equipment. It further investigates factors (e.g., early disease detection and treatment) amplifying the effects of medical equipment on the incidence of CVDs and additional factors, such as disease awareness raising campaigns, which impact disease prevention and individuals' health lifestyle behaviors.

The integration of AI and information technology in CVD management holds immense promise, particularly in low-resource settings. AI-driven solutions can enhance the accuracy of CVD risk assessments, improve patient outcomes through personalized interventions, and reduce healthcare costs by preventing costly complications. However, several challenges must be addressed to fully realize the potential of AI in this context. These include the need for high-quality data,

robust infrastructure, and trained personnel to implement and maintain AI systems.

Moreover, ethical considerations related to data privacy and algorithmic bias must be carefully managed to ensure that AI-driven interventions are equitable and do not exacerbate existing health disparities. Despite these challenges, the potential benefits of AI in reducing CVD prevalence are significant, particularly in regions like sub-Saharan Africa, where the burden of these diseases is growing rapidly.

5.2.1. Theoretical Contribution

The study highlighted four factors, namely, the level and quality of medical equipment, early disease detection, disease prevention and health lifestyle behavior, and disease awareness raising campaigns, as building blocks impacting the regional prevalence level. Furthermore, the fourth building block, disease awareness raising campaigns, directly amplifies the effect of the third building block (diseases prevention). The level and quality of medical equipment supports and impacts the effect of the second building block (early disease detection and treatment). the level of the prevalence. Figure 5**Error! Reference source not found.** shows the theoretical model of the ecosystem for the prevalence of CVDs.

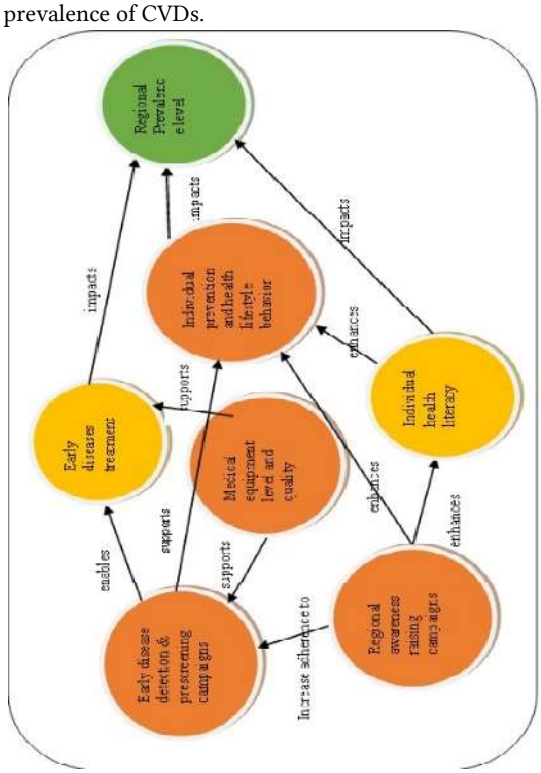

Figure 5: Relationships between the number of building blocks and the level of regional prevalence

- **Level and quality of medical equipment**

The results revealed that the full range of CVD medical equipment is available only in the departments of Borgou, Littoral and Ouémé, which are in classes 1, 2, and 3, respectively. However, certain care units own the full range of medical equipment but are classified as classes 2 and 3 because of the low amount of equipment in each category (Mapa, ECG device, etc.). This situation not only disadvantages populations affected by cardiovascular disease and located in rural areas but also reveals the uneven distribution of these services, thereby disadvantaging their geographical accessibility to care.

According to the results and analysis, the regional prevalence of CVD is associated with people's place of residence and the level and quality of medical equipment, which supports early disease detection and treatment. Regions with low levels and/or low-quality CVD medical equipment are mostly affected by the disease (with a high prevalence, we investigated the incidence of CVDs in these regions to obtain a complete picture of the issues).

Although urban regions are favored over rural regions, there is a difference between urban regions (CHUD of Porto-Novo and CHD of Abomey; CHUZ of Abomey Calavi and CHZ of Kandi); the same is true for rural regions. This could be explained by the uneven distribution of infrastructure and facilities for the diagnosis and management of specialty care, particularly for cardiovascular disease patients.

According to Amidou A. Salmane (PNLMNT), in 2023, a public awareness raising campaign was rolled out in three departments, namely, Attacora, Donga, and Mono. The objectives of the campaign were as follows:

- Raising disease awareness
- Early detection of the disease
- Increased involvement of healthcare professionals in
- upgrading the technical platform (medical equipment)

This campaign had a positive effect on the disease prevalence in these departments. A more in-depth analysis of the situation revealed that prevention, early detection, and public awareness campaigns combined with high-quality medical equipment impact the disease incidence. According to Amidou A. Salmane, the campaign failed to upgrade/improve the technical platform in Attacora. This fact explains why despite the pre-screening and prevention as well as diseases awareness campaign, Attacora is still showing a high disease level, while the department of Zou shows a middle level of prevalence.

The departments of Colline and Couffo are thought to be less equipped but show a middle level of

prevalence. They benefit from the high quality of the existing medical equipment and local campaigns.

- **Access to CVD care**

Studies [11], [12], [13], [35], [36] that we conducted from early 2010 to 2017 to 2020 revealed poor access to health care services in Benin. These issues remain unclear, and there is a slight need for improvement. This study focused on the level of access to CVD care. Enormous difficulties remain in resolving the issue of affordability regarding cardiological care. In addition to consultation fees, patients face costs such as medical costs and transportation to care units. All these costs are some of the factors that impact access to CVD care. The transportation costs increase when the patient needs to visit a remote care unit because the one closer to him or her lacks appropriate medical equipment and/or adequate healthcare staff.

Table 4 summarizes the obstacles to adequate access to CVD care.

Table 4
Obstacles to accessing CVD care

Nr.	Issues	Description
1	linguistic barriers	Communication issues during a medical visit, Difficulties to explain to the care staff health problems one is facing. CVDs specialists are mostly from large cities and are proficient with local tongues
2	Traditional believes	Attachment to tradition, which favors the trivialization of health advice. Visiting a medical doctor means call on self a disease.
3	Poor prescreening/early detection/early treatment	Delays in presenting for consultation, sometimes leading to serious complications.
4	Poor prevention or bad health lifestyle behavior	Lack of knowledge about the diseases. Awareness raising campaigns missing
5	Low level and/or quality of medical equipment	Lack of equipment and qualified staff to provide adequate care Care units lack mobile equipment for care at home and follow-up

- **Early disease detection and prevention**

The relationship between early disease detection and disease prevention is well documented. We noted that prescreening individuals at high risk of NCDs impacts their health status (T. Edoh, 2018; T. Edoh et al., 2018).. Recent studies [37], [38], [39] have shown that early disease detection enhances disease prevention through appropriate early medical treatment, which the present study identified as a building block impacting the prevalence of disease.

The results show that the country lacks early CVD detection campaigns despite the presence of WHOPEN. However, the analysis revealed that the lack of early disease detection campaigns is one of the factors affecting the regional prevalence level. Regional care units with high-quality medical equipment in their entirety have a low prevalence rate, and medical equipment supports care units in early disease detection procedures.

Launching artificial intelligence-based noninvasive pervasive disease prescreening could help to overcome the issues of poor medical equipment in certain regions and thus increase the rate of pervasive early detection of the disease. Mohammad Shafiquzzaman Bhuiyan et al. conducted their recent study [39] on the use of machine learning in the early detection of lung cancer by "… there's a positive development in using machine learning for early-stage detection, which proves highly effective in diagnosing this disease".

- **Promising disease awareness campaigns**

The rationality of health perceptions depends on the social and educational values of individuals. Compared with illiterate people, well-educated people mostly self-educate about diseases and have greater health literacy [34], [40].

Educating people about disease increases their awareness level and empowers them to follow a healthy lifestyle[41], [42]. However, following a healthy lifestyle may positively impact the prevalence of diseases. However, the country has not implemented the WHOPEN initiative, and only sporadic awareness-raising campaigns have taken place at some institutions. The results and analysis have shown that the level and/or quality of medical equipment does not effectively impact the prevalence of diseases. Further factors that might co-impact the prevalence of disease have determined health literacy as an amplifier of the effect of medical equipment. However, disease awareness-raising campaigns should be considered building blocks to amplify the effects of medical equipment that supports early disease detection and treatment.

- **Predicting the regional prevalence of CVDs**

The classifier with high sensibility identifies the prevalence of CVDs, ranking the independent features according to their importance to predict the prevalence of the disease. The rate of the risk factors is the most important feature.

5.2.2. Practical Contribution

The present study identified four building blocks that impact the incidence of CVDs in geographical regions. Addressing these 4 levers simultaneously could significantly reduce prevalence rates.

5.2.3. Implications for future research

Analysis from a computer sciences point of view revealed a lack of information or health education material about CVDs to increase awareness about these diseases. The adoption of digital disease awareness-raising campaigns could assist in overcoming this gap and enhancing people's healthy lifestyle behaviors. A digital learning program using gamification theory could enhance people's adherence to awareness-raising programs[43] and thus enhance their health literacy (knowledge) about CVDs. This would support them in participating in early detection campaigns and prevention.

People living in remote areas and facing poor access to care services such as early disease detection could be provided with mobile prescreening systems such as telemetry to continuously assess certain early parameters of the disease.

Based on the results obtained, it is necessary to work on an adapted telemetry system to overcome issues related to the level and quality of medical equipment using action research methodology to assess how it can bring rural populations up to the same level of quality of life as that currently achieved in urban areas through community health supported by mobile applications.

6. Conclusion

This study investigated factors impacting the regional prevalence of cardiovascular diseases (CVDs) in Benin. Unlike prior studies, this study focused on the impact of the level and/or quality of CVD-requiring medical equipment on the incidence of CVD. Specifically, the study deep dives into what levers in the CVD care ecosystem the medical equipment assists in becoming active.

Artificial intelligence offers a powerful tool for investigating the distribution and impact factors of cardiovascular diseases, particularly in regions with limited healthcare resources like sub-Saharan Africa. By leveraging AI, healthcare providers can gain deeper insights into CVD prevalence, develop more effective interventions, and ultimately reduce the burden of these diseases. Information technology plays a crucial role in supporting these efforts, providing the infrastructure and tools necessary to implement AI-driven solutions. Future research should focus on overcoming the challenges associated with AI implementation and exploring new ways to harness the potential of AI in CVD management.

The study results reveal a discrepancy between the different regions of the country in terms of the prevalence of CVDs, where rural regions are more severely affected by the disease than are urban regions or large cities. The different regional prevalences of CVDs are impacted by the level and quality of medical equipment, and the early disease detection or prescreening of medical equipment could support and increase awareness of the programs implemented in the region. However, early detection (prescreening) and prevention programs are poorly implemented. Regions are facing poor accessibility awareness-raising programs.

The prevalence of cardiovascular diseases in geographical regions in Benin is statistical related the effectiveness of pre-screening, prevention programs, whose effects are amplified by the level and quality of medical equipment and disease awareness campaign in the living environment of the affected population.

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