The Application of Systems Engineering to Address CKD Healthcare Disparities

By

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DEDICATION

This thesis is deeply dedicated to Almighty Allah for giving me the grace of life and knowledge throughout its writing process. I also emotionally dedicate this research to my Late Father, Yinusa Saliu Adeniyi. May Almighty Allah continue to rest him in peace. Additionally, my ever-loving mother, Faidat A. Yinusa, for her prayers and support from my cradle till this moment. Additionally, an astounding dedication goes to my ever-supportive, Fathia Omowunmi Orebiyi Yinusa, the mother of my lovely kids, Abdulzahir O. Yinusa and Fauziyah I. Yinusa. Thank you all.

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ABSTRACT

Chronic Kidney Disease (CKD) is one of the most prevailing national health problems in the United States. According to CDC (Centers for Disease Control and Prevention), as of 2019, 37 million of the US's adult population (about 15% of the population) have been estimated to have CKD. In this respect, health inequities are major national concerns regarding the treatments for patients with CKD nationwide. The disparities observed in the healthcare interventions for patients with CKD are usually some significant healthcare gaps in the national public health system. However, there is a need for immediate intervention to improve the present healthcare conditions of minorities experiencing CKD nationwide. A systems engineering approach is employed to address and understand these interventions by representing the complex factors associated with health disparities for chronic kidney disease. Hence, in this research, the application of system dynamics modeling (SDM) is proposed to model chronic kidney disease health disparities. This process is based on the health interventions administered to health minorities experiencing chronic kidney disease. The graphical results from the model showed that there are relationships among the dynamic factors influencing the incidence and prevalence of CKD. Hence, healthcare disparities are inherent challenges in the treatment and management of this disease.

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$\mathbf{D_1}$: Initial diagnosed population value

$\mathbf{D_2}$: Final diagnosed population value

K: Present stage of CKD

$\mathbf{K^P}$**:** The previous stage of CKD

$\mathbf{K^N}$**:** The next stage of CKD.

$\mathbf{p_1}$: Initial value of the model population

$\mathbf{p_2}$: Final value of the model population.

$\mathbf{ps_1}$: Initial value of the susceptible population

$\mathbf{ps_2}$: Final value of the susceptible population

$\mathbf{PS_{11}}$: Initial value CKD Population in all stages and

$\mathbf{PS_{12}}$: Final value CKD Population in all stages.

$\mathbf{U_1}$: Initial Undiagnosed population value

$\mathbf{U_2}$: Final Undiagnosed population value

AKF: American Kidney Fund

AKI: Acute Kidney Injury

CDC: Centers for Disease Control and Prevention

CKD: Chronic Kidney Disease

CLM: Causal Loop Model

CMS: Centers for Medicare and Medicaid Services

eGFR: Estimated Glomerular Filtration Rate

ESRD: End-Stage Renal Disease

ETC: ESRD Treatment Choice

GFR: Glomerular Filtration Rate

KDOQI: Kidney Disease Outcomes Quality

NKF: National Kidney Foundation

NSAIDs: Non-steroidal anti-inflammatory drugs

NGOs: Non-governmental Organizations

OMB: Office Management and Budget

PCPs: Primary Care Provider

PKD: Polycystic Kidney Disease

PPS: Prospective Payment System

QIP: Quality Incentive Program

SFM: Stock and Flow Model

SD: System Dynamics

SDM: System Dynamics Modeling

SDH: Social Determinant of Health

SES: Socioeconomic Status

US: United States

USA: United States of America

CHAPTER 1: INTRODUCTION

The burdens of chronic illnesses are great adversities in human lives, and their consequences usually lead to mortalities globally. Chronic diseases, such as diabetes, hypertension, kidney diseases, and stroke come with significant comorbidities, and they always serve as risk factors for each other. As a result, their impacts result in higher hospitalization costs and sometimes poor quality of life [1]. Additionally, their incidence and prevalence need to be monitored. Furthermore, to alleviate the burdens associated with chronic conditions, effective healthcare intervention is essential. Therefore, this research focuses on a case study of chronic kidney disease incidence, prevalence, and healthcare disparities. The research employs systems engineering by using system dynamics modeling (SDM) to address the healthcare disparities experienced by the minority populations in Tennessee. The SDM is utilized to simulate and visualize the various interacting dynamic factors, including the incidence, prevalence, and disparities specifically associated with chronic kidney disease (CKD).

Moreover, the remainder of the research is arranged into the following chapters as follows. Chapter 2 provides CKD background information, its prevalence, and the literature review of healthcare disparities. The SDM background information and literature review are also explained in Chapter 2. The research methodology and research design are provided in Chapter 3. The simulation and graphical results are presented and discussed in Chapter 4. Finally, concluding remarks, interventions, and recommendations are illustrated in Chapter 5.

1.1. General Overview

CKD is a prevalent global and national health concern affecting people from all backgrounds, ethnicities/races, and genders in the United States. It is an irreversible and progressive disease that results from the kidneys' inability to filter blood and adequately eliminate wastes and poisons. It starts with undiagnosed kidney damage and develops into a complete kidney failure, End-Stage Renal Disease (ESRD). At this stage, the individual involved will require a total kidney transplant or replacement for survival [2]. Often, CKD comes with a higher risk of comorbidities such as hypertension, diabetes, cardiovascular disease, and complications with financial and physical challenges on patients and the concerned communities, usually resulting in clinical cost implications and sometimes death [3]. The intensity in its prevalence differs based on several factors because it affects patients at a different rate. As of 2019, approximately 37 million adults in the United States (about 15% of the population) have CKD [4]. This chronic disease represents the ninth leading cause of death nationally [4]. Because of the financial and economic commitment involved in the procedures and treatment at every stage of the disease, minority populations, including Black or African Americans, American Indians or Alaska Native, Native Hawaiian or Pacific Islanders, Asians, and Hispanic Americans, in the United States usually experience disparities in healthcare intervention toward CKD. Its high mortality rate is rampant among these populations. Complex interacting nontraditional risk factors such as physical environmental, social-economic, and genetic factors contribute to the racial/ethnic CKD health disparities among the minority populations in the United States [5]. Moreover, despite the vast cost (around $81.8 billion in 2018) [4] of the budget involved for CKD Medicare beneficiaries, CKD health disparities still exist.

1.2. Background of the Problem

The disproportionate burden of CKD incidence and prevalence is a global concern; hence, it creates emotional, physical, financial, and mental stress for the patients involved. Healthcare intervention should be unbiased to improve the health of CKD patients. Generally, healthcare disparities are apparent in the United States because it is home to many different individuals with various racial or ethnic backgrounds. Subsequently, these populations get access to the healthcare system differently. In several chronic diseases, particularly CKD, the health disparities have increased the disease's progression. There is also a greater chance that racial and ethnic minorities will progress from CKD to ESRD [2]. Though the term “disparities” refers to racial or ethnic and socioeconomic disparities, these exist in many dimensions, including health in the United States. Patients' health disparity can be defined as a specific type of health difference that is strongly associated with social, economic, and environmental disadvantage, according to Healthy People 2020 [6]. The National Institute of Health reported that inequalities influence health disparities in and interactions among multiple health determinants, including biological characteristics, the environment, habits, sociocultural factors, and how healthcare systems interact through complicated multilevel pathways [7]. These complex and diverse interactions lead to adverse impacts on health [7].

More crucially, health disparities in CKD are a complex issue including a range of factors such as race or ethnicity, gender, age, disability, socioeconomic status, and geographic location, all of which have an impact on a patient's health.

Distinctively, the US Office of Management and Budget (OMB) categorized the US population into a race (American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, and White) and ethnicity (Hispanic or Latino and Not Hispanic or Latino) [8]. These populations have a great deal of experience with CKD burdens and its progression. The most affected communities today are comprised of Black or African-American, Native Hawaiian or other Pacific Islander, Asian, American Indian or Alaska Native, and other ethnic groups. Furthermore, health disparities in CKD are frequently linked to a number of interconnected factors, including the healthcare system, patients, physicians, and clinical characteristics [9].

1. The healthcare system factors include:

- The lack or inadequate provision of CKD medical tools by the system.
- The inefficient deployment of CKD medical experts to various hospitals or medical centers by the system.
- The irregular CKD care seminar or training for the physicians by the system.

2. The patient factors include:
    - The genetic structure risk variants present in the minority population, especially the African American minority population.
    - The limited access to CKD healthcare in the minority communities.
    - The insufficient health literacy, cultural, personal beliefs, and personal faith.
    - Communication barriers between the patients and the physicians and a lack of trust in the healthcare system.

3. Clinical factors include:
    - The inadequate medical experts' adherence to CKD care and management guidelines regarding testing and screening.
    - Physicians' inability to bear the complexity of the multiple comorbidities associated with CKD.
4. Physician factors include:
    - The physicians' inadequate knowledge of CKD incidence and prevalence.
    - Most physicians are overwhelmed by the complexity of the disease.
    - Communication barriers in health education exist between physicians and CKD patients.

Furthermore, these outlined interacting factors in the CKD healthcare intervention are responsible for the core health disparities in its management.

Although the earliest stages of CKD are not usually apparent in patients because individuals are asymptomatic at these stages, the crucial and deadliest CKD stage is when there is damage or a case in the function of the kidneys. This stage is considered ESRD. This stage calls for regular long-term dialysis or a complete kidney transplant.

Since the United States encompasses a large population with a mixture of ethnicity and race, CKD outcomes' adverse effect overburdens this population differently. The ESRD poses more threats to patients' lives; hence, more frequently, emphasis is on it than other CKD stages. However, disproportionate healthcare intervention exists in the treatment of CKD stages, particularly ESRD, which usually involves either kidney dialysis or kidney transplant.

Despite government intervention, kidney medical associations, and non-governmental organizations (NGOs) efforts in eradicating or alleviating CKD health disparities in the US through various healthcare systems or mechanisms, inequity still exists in CKD healthcare.

- Although Black Americans make up only 13% of the US population, they account for 35% of those with kidney failure.
- Kidney failure is 3.6 times more common in African Americans.
- Compared to the general population, Hispanic and Native Americans are about twice as likely to have kidney failure, and Asian Americans are likewise at a higher risk.
- Diabetes increases the risk of kidney disease. Diabetic African Americans are 3 to 5 times more likely to have renal disease.

Figure 1 below shows the statistics of CKD prevalence in the various stages involved in kidney disease. The bar chart displays the study conducted by the Center for Diseases Control and Prevention (CDC) to analyze the adjusted age of patients between 1999 and 2016. The colored legends represent the various races/ethnicity in the United States. Comparing the general diabetic population to African Americans, Mexican Americans, and Native Americans, end-stage renal disease (ESRD) is four to six times more common in African Americans, and four to six times more common in Latinos, Asians, and Native Americans [10].

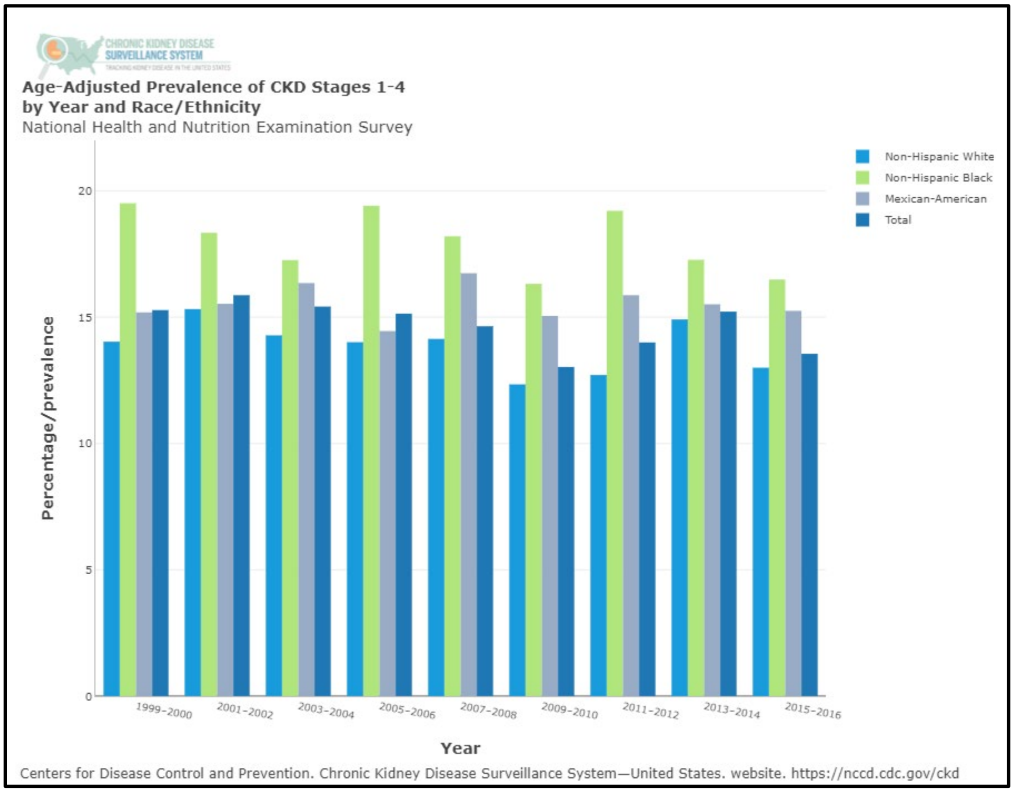

Figure 1. The Age-adjusted prevalence of CKD stages 1-4 by Year and Race/Ethnicity [10]**.**

After age adjustment, the prevalence of CKD stages 1-4 fluctuated from around 13 % to 16 % between 1999 and 2016. Non-Hispanic blacks and Mexican-Americans outnumbered non-Hispanic whites, while females outnumbered males. CKD was more common among non-diabetics and hypertensives than diabetics and hypertensives when age was adjusted.

The above statistical analysis shows that the burden of this disease rests more on the nation's vulnerable populations than the majority population. However, there have been several propositions aiming toward tackling its health disparities. The Centers for Medicare

& Medicaid Services (CMS) recommends changes to address health equity disparities by improving access to care for Medicare patients with ESRD through the annual rulemaking for its Prospective Payment System (PPS) [11]. It is proposed that the ESRD PPS payment rates, the ESRD Quality Incentive Program (QIP), and the ESRD Treatment Choices (ETC) Model, among other things, be revised as part of the new rule.[11].

Moreover, since the interactive factors associated with CKD health care disparities are complex and interdependent, a linear proposition toward the health care intervention will not suffice. The healthcare system's structure and the dynamics of socioeconomic and genetic CKD determinants in the minority-populated society necessitated a broad, holistic approach that would comprehensively examine the causes and effects. There have been research studies on CKD care and improvement using SDM. However, there have only been a few studies conducted on the review and analysis of CKD health disparities that have made use of SDM, and they have all been simplistic. Therefore, studies are needed to analyze and address the complex interacting factors associated with CKD healthcare intervention disparities.

1.3. Purpose of the Research

The factors involved in CKD incidence, prevalence, and disparities in its treatment nationwide are complex factors and variables. Therefore, a linear view of these variables is not appropriate; instead, a deeper insight into the factors will generate the right approach toward healthcare improvement and equity in minority populations. The study dives deep into the root causes of CKD and the different challenges present in the minority populated communities using system dynamics (SD) to model, simulate and visualize the possible healthcare disparities involved. In addition, the SDM tools are utilized to analyze the causes and impacts of the various CKD risk factors involved. Mathematical equations of the variables are developed that represent the non-linear relationships and the nature of the factors and their connections. Validation tests of the model are also performed during the SD design with different run tests and scenarios. This research employs a systems engineering application to address the complexities of CKD incidence, prevalence, and health disparities involved in treatment interventions specifically in Tennessee.

1.4. Research Questions

The following research questions provided the basis for the research:

1. Why is it essential to identify CKD in the minority populations in Tennessee?
2. Why is it crucial to address CKD health disparities involved in the health care intervention in Tennessee?
3. Why is it crucial to monitor and treat the CKD incidence and progression in the minority populations in Tennessee?
4. What steps are required to inform and educate CKD patients in the minority populations in Tennessee?

1.5. Nature of the Research

The nature of the research was both quantitative and qualitative because it involved methodological and visual representative approaches toward the healthcare intervention policies for CKD patients in Tennessee. The goal of the qualitative procedure is to acquire much information and make a deeper understanding of the research. In this case, qualitative research methodology is an open, exploratory research strategy that can study exceedingly difficult problems that conventional quantitative research methods cannot describe [12]. On the other hand, the quantitative procedure analyzed the numerical data obtained and technical facts about the topic [12]. The qualitative research procedure employed in this study made it possible to address the "Why" and "How" involved in the healthcare disparities associated with CKD and allowed for a more in-depth interpretation of events, occurrences, and context involved in the policies and healthcare intervention involved [13]. The quantitative research procedure allowed for numerical data on CKD health disparities in the minority populated areas in Tennessee and the simulation and modeling of its incidence and prevalence processes. Therefore, in this research, the simulation and modeling processes depicted the graphical correlations and relationships among the complex interacting factors associated with the incidence, prevalence, and health disparities involved at every stage of this disease.

1.6. Assumptions and Limitations

The following are the assumptions and hypothesis of the research:

- CKD risk factors and other parameters involved at every stage were taken as variables with 100% units in the SDM irrespective of their various generic units.
- It was assumed that there were health disparities at every stage (i.e., stages 1 to 5) of CKD in the simulation model.
- The two categories of stage 3 CKD were taken as one stage.

- It was also assumed that the patients, physicians (Primary Care Providers (PCPs) and Nephrologists), and the healthcare system were involved in the CKD health disparities.

1.7. Research Scope and Delimitation

The scope of this research focused on the health disparities that exist in the healthcare intervention provided to the minority communities in Tennessee, USA. And the effect associated with the interventions and policies in the care centered on patients in these minority populated areas. The research is based on the CKD health disparities in the treatment provided to the patients in these various communities. Also, the scope covered the interacting factors such as Socioeconomic Status (SES) of patients, Social Determinants of Health (SDH), residential segregation, discrimination, uninsured/underinsured patients, unemployment, genetic factors, access to care, low literacy, and other CKD risk factors causing its progression and disparities.

1.8. Research Limitation

The domain of this research is limited to the population of the minorities in Tennessee. Hence, numerical data and graphs were regarding this geographical region. The study did not involve physical contact (patients' interviews, questionnaires), gathering data and information from various minority populations. As a result, data was only collected from the websites of several national health institutions working toward kidney care nationwide.

1.9. Significance of the Research

The mixed qualitative and quantitative research approach employed in this research provides a deeper understanding of the health disparities in CKD patients' healthcare intervention. Since there is no recent literature that analyzes the health disparities in this disease using a modeling methodology, this research has added to the global CKD health inequity concerns in the minority communities. The analysis gained from this research may positively contribute to the healthcare intervention policies by the government and the medical experts in charge of CKD medical treatment and management.

Furthermore, the recommendations in the research could also serve as a means to reduce CKD prevalence at every stage and the socioeconomic burden involved in its progression. The results may also help to create awareness and educate its patients in minority communities. In addition, the results can help inform the PCPs about the early referral of CKD patients to nephrologists. Moreover, since the research was carried out using models and simulations by capturing nearly every factor affecting the CKD incidence and its health disparities in Tennessee, the results may assist the healthcare system in properly deploying adequate medical practitioners to these communities. Moreover, the healthcare system can create seminars and further training for the medical experts about CKD treatment and care.

CHAPTER 2: BACKGROUND INFORMATION

This research section discussed the etymology of CKD, its causes, and its symptoms. It also reviewed the literature of the previous analyses concerning the health disparities associated with CKD and the reviews of the earlier studies on the application of the system dynamics model in healthcare in general and CKD healthcare improvement.

2.1. Definition and Classification of CKD

CKD shows itself in various stages, ranging from a mild loss of renal function to total renal failure, depending on the stage of the disease. Not all cases of chronic kidney disease, on the other hand, progress to the most severe stage of the disease. Approximately the vast majority of patients are believed to be suffering from mild to moderate symptoms that do not require hospitalization or other inpatient treatment.

Furthermore, CKD has become a prominent concern of medical and epidemiologic research in the recent decade. CKD terminology and categorization have undergone significant changes in recent years. In 2002, the current international guidelines for this disease, according to the Kidney Disease Outcomes Quality Initiative (KDOQI), developed by the National Kidney Foundation (NKF), defines this chronic disorder as glomerular filtration rate (GFR), usually less than 60 mL/min/1.73 m^2 or symptoms of kidney damage less than three months, regardless of the underlying etiology [14]. It is a broad term that refers to various illnesses that impair the structure and function of the kidney [15].

2.1.1. Staging of CKD

CKD has five stages in its progression. The results of the eGFR test, and the effectiveness with which kidneys remove waste and extra fluid from the blood, are used to determine what stage of renal impairment is experienced by a patient. As the disease progresses, the kidneys' condition deteriorates, and they become less effective at performing their functions. At every stage of the disease, it is essential to make every attempt to maintain kidney damage to a minimum. Moreover, to assess the stage of kidney disease, a patient's glomerular filtration rate (GFR) must first be evaluated in the laboratory by a physician. The evaluation uses an (eGFR) formula that includes patients' gender, serum creatinine level, cystatin C, age, and other crucial factors.

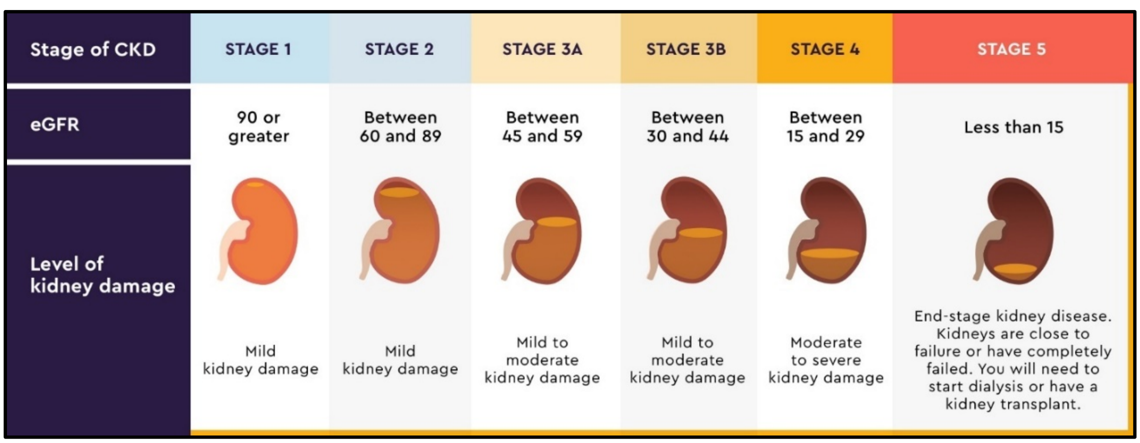

Figure 2. The Diagram Depicting the Five Stages of CKD Progression [16].

Apparently, from figure 2, the eGFR determines the functionality of the kidney. As the kidney stage progresses, the less the eGFR number. And each phase of the disease is associated with symptoms and causes. It is typical for patients not to notice the signs and symptoms of kidney disease until the disease has progressed significantly.

2.2. Kidney Failure and ESRD

Kidney failure occurs when the kidney disease is acute and renal function is impaired, requiring dialysis or a kidney transplant to survive. ESRD is renal failure requiring dialysis or a kidney transplant [17]. This failure is frequently caused by underlying health issues that have developed irreversible kidney damage over time. Suppose the kidneys are damaged by an inability to regulate risk factors, recurrent kidney infections, or medications or chemicals that damage the kidneys. Hence, CKD is likely to progress to renal failure. Moreover, these factors have been associated with severe kidney disease, including income instability and the circumstances that lead to food insecurity and limited access to high-quality healthcare treatment [17].

2.3. The Causes of CKD

As mentioned earlier, CKD develops when a condition affects kidney function over months or years. Therefore, there are several latent and apparent causes of this disease. Still, hypertension and diabetes are the primary causes of renal failure in the United States, and medication for these two disorders can often prevent or delay the start of renal failure According to estimates, glomerulonephritis is a disease of the kidney's glomeruli. It is the third most common cause of renal failure and the most common cause of end-stage renal disease in the United States. Other causes of CKD are polycystic kidney disease (PKD), kidney infection, a toxic medicine that is harmful to the kidney, lupus, heavy metal poising, rare genetic condition (Alport Syndrome), and renal artery stenosis [18].

2.3.1. CKD Signs and Symptoms

Patients with chronic kidney disease regularly report lethargy, irritability, anxiety, and nausea. Clinical treatment requires understanding the symptom burden experienced patients. Chronic kidney disease patients have a wide range of symptoms due to the condition and a vast range of treatment options. These early signs, on the other hand, are frequently ignored [19]. Moreover, there are different symptoms and signs experienced at every stage of this disease; however, prompt medical response is vital to curtail its progress.

2.4. Literature Review of CKD Health Disparities

The health of different cultures and societies can vary dramatically, and specific populations may have higher disease rates than others. As discussed earlier in chapter one, inequalities in health or medical issues that can substantially impact a community's public health are known as health disparities. Moreover, CKD health disparities represent the disproportionate outcome of the affected populations' treatment, particularly the minority communities. At the same time, CKD is the outcome of a complex interaction of genetic and environmental factors, which adversely affect the lifestyle and wellbeing of humans.

Furthermore, CKD is prevalent in its causes and effect on the minority populations in the US. Therefore, this section of the paper reviews the literature of the previous researches on the health disparities involved in the healthcare intervention for CKD patients in these minority populations. Since various interacting factors (genetic, environmental, socioeconomic, etc.) are associated with the cause and incidence of CKD, it is necessary to delve deeply into the root causes of the disease.

In the case of CKD care, PCPs have considerable roles to play in educating individuals to identify the causes and symptoms of this disease earlier. At the same time, creating awareness of known racial, economic and ethnic disparities in CKD care can improve the healthcare intervention for the most vulnerable populations. The issues of CKD health disparities have been discussed extensively in related research work. Moreover, individuals who might otherwise be denied medical care due to their socioeconomic situation, lack of insurance, or underinsurance can now receive it. Those from ethnic minorities who are poor or ignorant in healthcare are the majority who rely on safety-net services. American's die from CKD, which affects a disproportionate number of African-Americans [20].

For instance, Jenna et al. suggested that CKD results from complex genetic (age, treatment, developmental programming, etc.) and environmental factors that reflect the balanced interaction of nature and nurture [21]. Their research emphasized the strong effect of SDH (socioeconomic status, psychosocial factors, healthcare access, and neighborhood) as an essential environmental component, particularly for Black and other minority populations. Their study also emphasized that patients have numerous social aspects that must be understood by PCPs, nephrologists, and other CKD medical experts who care for them and how these concerns may interfere with effective disease treatment. Keith et al., in their research, explained that several studies had indicated disparities in CKD incidence, prevalence, and management across various minority populations [22].

However, many aspects of this chronic disease, including the existing inequities, remain unknown despite this progress. Besides modifiable risk factors (socioeconomic status, environmental factors, culture, ethnicity, and access to healthcare), other risk factors, such as biological factors associated with CKD, are still unclear. Susanne et al. discussed that several socioeconomic factors, such as poverty and unemployment, have been related to kidney disease progression and death, leading to ESRD [23]. Furthermore, Winfred et al. explained that in order to uncover and deconstruct the structural drivers of systematic racism in the healthcare profession, efforts have been made since spring 2020. Based on race, disparities in predicted total renal filtrate flow rate have spawned several controversies in recent years (eGFR). Table 1 shows the previous works addressing the challenges of CKD healthcare disparities. The table is a literature matrix of the above-cited papers [24].

Table 1. Previous Literature on CKD Health Disparities.

S/N	Author	Year	Research Title	Contribution
1	Jenna et al.	(2016)	"Social Determinants of Racial Disparities in CKD."	The authors suggested that CKD results from complex genetic (age, treatment, developmental programming, etc.) and environmental factors that reflect the balanced interaction of nature and nurture.
2	Keith et al.	(2008)	"Racial Disparities in Chronic Kidney Disease: Tragedy, Opportunity, or Both?"	Their research explained that several studies had indicated disparities in CKD incidence, prevalence, and management across various minority populations.
3	Susanne et al.	(2015)	"Socioeconomic Disparities in Chronic Kidney Disease."	Discussed that several socioeconomic factors, such as poverty and unemployment, have

				been related to kidney disease progression and death, leading to ESRD.
4	Winfred et al	(2021)	"Time to Eliminate Health Care Disparities in the Estimation of Kidney Function"	explained that in order to uncover and deconstruct the structural drivers of systematic racism in the healthcare profession, efforts have been made since spring 2020. Based on race, disparities in predicted total renal filtrate flow rate have spawned several controversies in recent years (eGFR).

Even after controlling various factors such as demographics, clinical and laboratory parameters, poor socioeconomic status was still related to an increased risk of progression or mortality from ESRD. The previous literature reviews analyzed the impacts of genetic, environmental, and socioeconomic factors influencing the incidence and prevalence of CKD, also relating these factors with the level of disparities existing in the management of this disease. The reviews dived critically into the sources of these disparities and how they can be curtailed using different clinical and social tools by the PCPs and nephrologists, including the healthcare system. However, no research study has dealt with the disparities in this chronic disease by addressing the possible bias that may result from the side of the patients and the medical experts, the inclusive healthcare system. To transparently address the incidence, prevalence, and healthcare in CKD, it is clinically and socially necessary to understand the basics and the sources of these health inequities by independently considering the patients' lifestyle, social determinants of health. We also need to address the bias on the side of the physicians and the healthcare system. To this end, this research study addresses the health disparities surrounding CKD by factoring in the vital variables involved in its occurrence and how these variables influence the differences therein.

2.5. Systems Engineering and System Dynamics Approach

Generally, factors associated with the incidence of CKD are interrelated. These factors create dynamic, complex challenges that cannot be addressed at the surface using the usual approach. Since these factors are interactive, analyzing them linearly to provide a possible panacea to CKD would be tasking. For this reason, to proffer equal and considerable healthcare intervention for CKD patients across the board nationwide, it is necessary to dive deep into the root causes of CKD health disparities rather than addressing the after effect involved. Furthermore, to address the overburdened healthcare disparities associated with CKD in Tennessee, a systems engineering concept called the system dynamics modeling approach is employed in this research.

System Dynamics (SD) is a mathematical modeling technique that simulates, analyzes, and helps comprehend complex subjects, problems, and systems. It adopts causal loops (cause and effect relationships), stocks, flows, time delays, and feedback concepts to understand the non-linear characteristics of dynamic systems. SD employs a real-time inbuilt mathematical calculus technique to present policy-oriented results of events. SD observes how the feedback mechanisms of complex systems create or cause events around us. This concept of modeling was developed originally in the mid-nineteenth century in the 1950s at MIT by Jay W. Forrester [25] to address issues in various fields ranging from engineering, education, economics, psychology, biology to management. It is currently employed by both the public and private sectors for decision analyses and policy designs.

SD models create reciprocal causation between variables, time delays, balancing and reinforcing feedbacks, and other techniques are employed to structure interactions and control [26]. This modeling approach comprises high-order non-linear and stochastic differential equations that reflect the agents' decisions, natural processes, and physical structures in the environment. A complete model may have a large number of equations and numerical inputs of this type. Numerical methods are often employed to solve high order and non-linear equations with unknown analytical solutions and nontrivial models. This model differs from other dynamic models in how the equations are presented and how the modeling approach is implemented [27]. Variables with no recorded data are not automatically excluded from consideration in SD. We include vital elements in the model that researchers believe are essential and quantify them as best. To achieve this goal, inference from related information, reasoning, educated guessing, and other methods may be employed.

2.5.1. Literature Review of SDM in Healthcare Systems

This section explores previous research literature that used SD as the simulation software in the health industry to model social and environmental issues. System dynamics has been applied in various aspects of health, and it is crucially extensive in the analysis and understanding of complex ecological and health interactive situations. As a result, this modeling approach is employed to decipher the interrelated factors and root causes of CKD in Tennessee and the associated disparities in its care within the minority populated communities.

J.Fernandez et al., in their research, using SD, employed open Modelica as the object-oriented simulation software in the application of a multicompartmental cardiovascular model for short-term arterial pressure regulation exerted by the baroreceptor reflex [28]. For instance, according to Danielle J Curie et al., system dynamics applications to environmental health decision-making due to shortage of reporting and dispersed applications across sectors [29].

Mohammad et al. reviewed previously published literature from 2000 to 2019 to present a comprehensive view of the applications of system dynamics to challenging and complex healthcare issues [30]. SD modeling was utilized by Mohamed et al. [31] to develop the application of the theory of constraints using AnyLogic as the execution environment to simulate a medium-sized hospital where the same limited resources were served to different patients. The model described the system bottleneck resource and leverages and regulated it. Negar et al. examined the significant trends and techniques adopted by various literature by classifying SD contributions into three categories: regional health modeling, disease-related modeling, and organizational modeling [32]. Moreover, the findings of Atkinson et al. provided additional support to the advantages mentioned in the present literature's review of applications of system dynamics modeling to improve policymaking in the health sector [33]. Kathryn and David developed a comparison between standard and SD simulation techniques using the waiting periods for coronary heart treatment [34].

Furthermore, Jack B et al. explained that when it comes to public health challenges, the dynamic complexity that defines many of them makes system dynamics modeling a good fit for the problem. Besides representing a wide range of diseases and dangers, a system dynamics model can also be used to reflect the interaction between delivery systems and diseased populations and issues for national and regional policy [26]. Hyojung et al. investigated the significance of employing a system dynamics approach to evaluate interventions in the care of patients with CKD. With the implementation of SD, their research showed that physician education had the most significant influence on reducing sickness progression from Stage 3 to Stage 4. In contrast, care coordination had the highest impact on slowing disease progression from Stage 4 to Stage 5 [35]. Table 2 shows the previous literature cited on the application of SDM in healthcare sectors.

Table 2. Previous Literature on System Dynamics

S/N	Authors	Year	Research Title	Contribution
1	J.Fernandez et al.	(2019)	"System dynamics modeling approach in Health Sciences. Application to the	Their research employed open Modelica as the SD object-oriented simulation software to apply a multicompartmental

			regulation of cardiovascular function".	cardiovascular model for short-term arterial pressure regulation exerted by the baroreceptor reflex.
2	Danielle J Curie et al.	(2018)	"The application of system dynamics modeling to environmental health decision-making and policy - a scoping review."	They applied SD to address environmental health decision-making due to the shortage of reporting and dispersed applications across sectors.
3	Mohamed et al.	(2018)	"A system dynamics-based model for implementing the Theory of Constraints in a healthcare system."	SD modeling was used to develop the application of the theory of constraints using AnyLogic as the execution environment.
4	Negar et al.	(2020)	"System dynamics modeling in health and medicine: a	They examined the significant trends and techniques adopted by various literature by classifying

			systematic literature review."	SD contributions into three categories: regional health modeling, disease-related modeling, and organizational modeling.
5	Atkinson et al.	(2015)	"Applications of system dynamics modeling to support health policy."	They provided additional support to the advantages mentioned in the present literature's review of applications of system dynamics modeling to improve policymaking in the health sector.
6	Kathryn et al.	(1998)	"Simulation applied to health services: opportunities for applying the system dynamics approach."	They developed a comparison between standard and SD simulation techniques using the waiting periods for coronary heart treatment.
7	Jack B et al.	(2006)	"System Dynamics Modeling for Public	Besides representing a wide range of diseases and dangers, a system dynamics model can also be used

			Health: Background and Opportunities."	to reflect the interaction between delivery systems and diseased populations and issues for national and regional policy.
8	Hyojung et al.	(2018)	"A system dynamics approach to planning and evaluating interventions for chronic disease management."	They investigated the significance of employing a system dynamics approach to evaluate interventions in the care of patients with CKD. With the implementation of SD, their research showed that physician's education had the most significant influence on reducing sickness progression from Stage 3 to Stage 4. Meanwhile, care coordination had the highest impact on showing disease progression from Stage 4 to Stage 5.

As previously mentioned, there have been several studies on the evaluation of CKD healthcare interventions and other healthcare concerns using SDM. However, specific research on the implementation of SDM to evaluate and graphically visualize the various factors influencing the healthcare disparities inherent in CKD has not been delved into. In this research, the various agents involved in the influence of CKD healthcare interventions and its healthcare disparities are considered in the model using SDM. Generally, SDM has been applied in different sections of healthcare and medicine. Other modeling methods such as Markov Model, Gravity Model, and Predictive Models are usually employed in the healthcare sector to analyze situations and predictions. Nevertheless, SDM is often applied because it involves a thorough overview of complex, interrelated events, and it understands their relations, dissects their causes, and simulates them.

2.6. Sources of CKD Health Disparities

Generally, lots of factors contribute to the disparities experienced with CKD. Since over 37 million adults have severe kidney impairment in the US, it is recorded that the minority populations bear the brunt of the sources of this disease. Moreover, the origins of CKD disparities are interwoven with societal population categorization, environmental and genetic factors. These sources play significant roles in the incidence and prevalence, but the social determinant of health (SDH) has contributed immensely to the inequities associated with the disease. SDH underlying factors are interactive and interrelated.

For this reason, for minority communities, coping with the burden of CKD is challenging in terms of the financial implications, physical and psychosocial stress involved. Figure 3 depicts how SDH factors are related to CKD. Furthermore, disparities exist in CKD incidence and prevalence at every stage of the disease and access to kidney dialysis and transplantation.

Figure 3 further shows that factors associated with CKD are root causes that usually lead to unbearable stages of CKD progression.

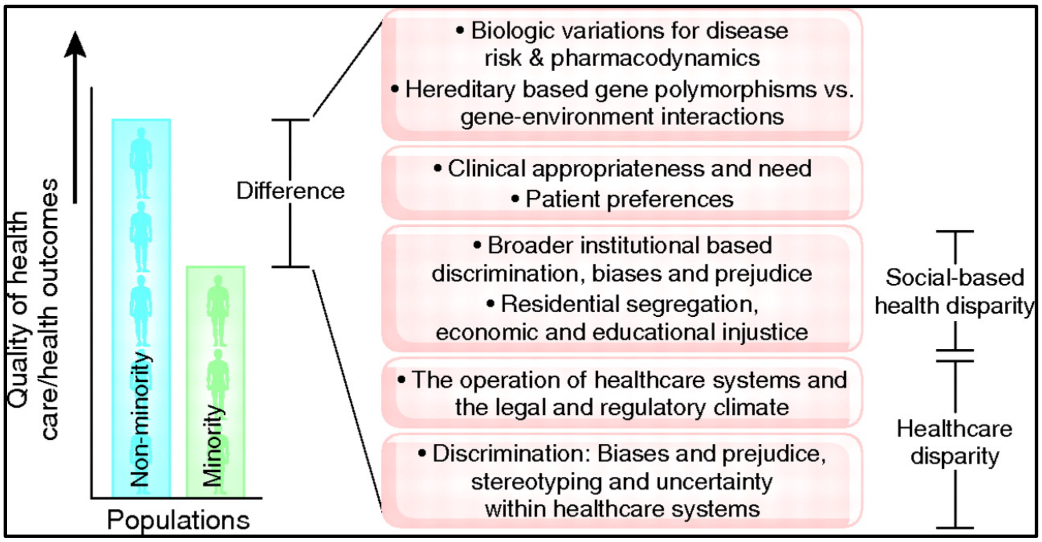

Figure 3. Chart Showing the Impacts of SDH on Populations [22].

In the chart above, the disparities in healthcare intervention for any disease, including CKD, have always been ingrained in the genetic pattern of humans. Social interactions entwine with environmental factors determine how we perceive ourselves as humans; hence, there are complexities involved in CKD care based on the population size of a nation, the major communities, the minority communities, and the economic status of that nation.

2.6.1. CKD Health Disparities in Minority Communities in Tennessee

This research section explains the disparities involved in CKD intervention in Tennessee. But before delving into the review of the CKD healthcare provision in the state, it is essential to understand the present population figure in the state.

Tennessee is the 36th most populated state in landmass but the 20th most densely populated. It is positioned in the country's southeast. Its population density data are remarkable, despite its modest population. It has an area of 42,143 square miles and a population density of 153.9 people per square mile of 109,247 kilometers. It has a population density of 153.9 people per square mile. Statistically, Memphis is the most populous city in Tennessee, with 655,770 people as of 2015. In terms of Population, Nashville is the state's second-largest city, with 654,610 residents. By contrast, with a population of 1,757,912 compared to 1,341,746 in Memphis, the Nashville metropolitan area is significantly larger than the Memphis metropolitan area [36].

Moreover, the 2020 Census shows a 6.910,840 growth in Tennessee's Population in the last decade. Since 2010, the city's population has grown by 564,735 (or 8.9%). Tennessee now represents the 16th most populous state in the nation, up to one spot from 2010, and it is behind 15th-place Massachusetts with 119,077 and 17th-place Indiana with 125,312 [37]. Figure 4 below shows the current Population of Tennessee, depicting the percentage breakdown of the race and ethnicity of the residents in the state.

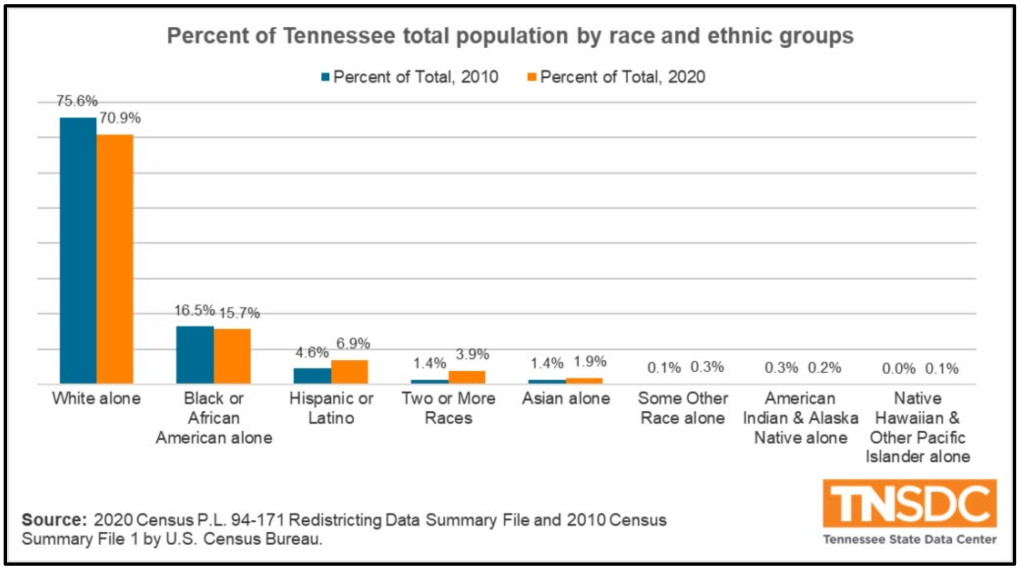

Figure 4. Tennessee Population by Race and Ethnic Groups According to 2020 Census Data [38]**.**

The state's two largest racial categories, "White alone" and "Black or African American alone," both fell 5.6 percentage points. Over 70% of Tennesseans identify as "white alone," down from 76 percent in 2010. Also, "Black or African American alone" people declined from 16.5% to 15.7% within the same period. "Hispanic or Latino" gained 2.3 percentage points to 6.9%. The state's overall population grew the highest, by 3.9 percent, to "Two or More Races." Overall, the 2.5 percentage point increase was the greatest [38]. The graph below in figure 5 shows the ESRD beneficiaries in Tennessee between 2013 and 2019.

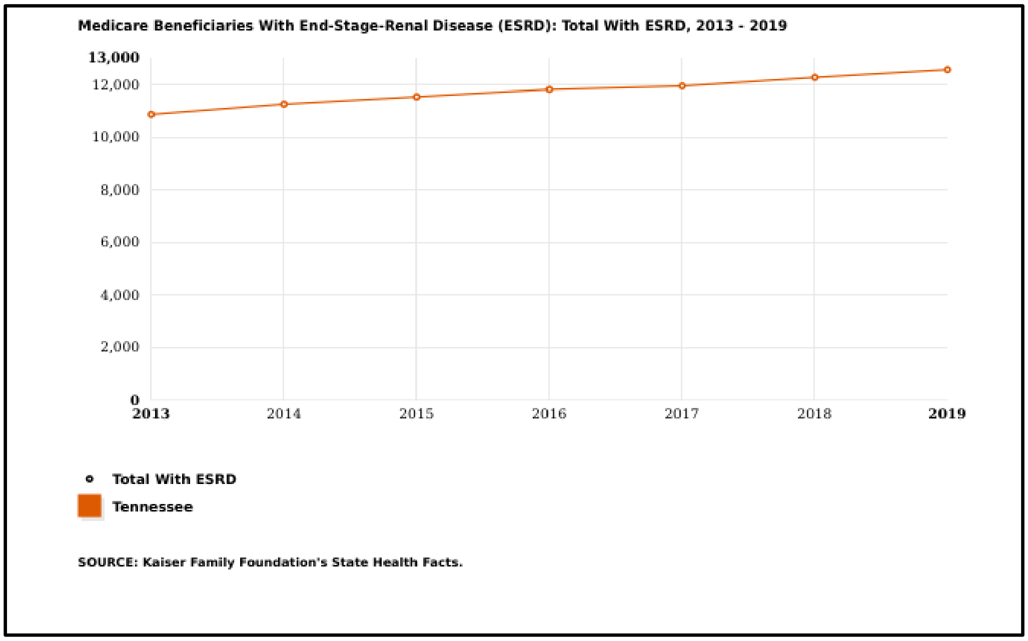

Figure 5. Medicare Beneficiaries with ESRD in Tennessee between 2013 and 2019 [39].

The data include those on Medicare Part A or B for the calendar year. Medicare enrollment is based on administrative enrollment statistics from the Centers for Medicare and Medicaid Services (CMS).

2.6.2. CKD Annual Report Charts in Tennessee

Figure 4 shows that the population of white is higher than the rest of the people based on race and ethnicity between 2010 and 2020. According to America's health rankings, Tennessee is ranked 40 based on CKD, which amounts to 3.7% of the total US population with CKD [40]. Considering the percentage of adults by race and ethnicity in Tennessee, 3.8% of the White population has CKD, and 3.6% of the Black/ African American Population has CKD as of 2019 [40]. Hence, with the percentage population of Tennessee in figure 4 above, where the white people were (75.6% in 2010 and 70.9% in 2020), and black people were (16.5% in 2010 and 15.7% in 2020). Comparatively, more Black or African American communities have CKD than white communities.

Moreover, based on racial classification, from figure 4, the White and Black populations are the largest racial categories in Tennessee. Therefore, there are not enough data and charts to analyze other minorities in the state having CKD. Currently, the data available are for the populations of White and Black in Tennessee. Figure 6 below shows the trend of CKD in Tennessee between 2015 and 2019, according to the 2020 annual report. The graph compares the CKD rate in Tennessee with the US.

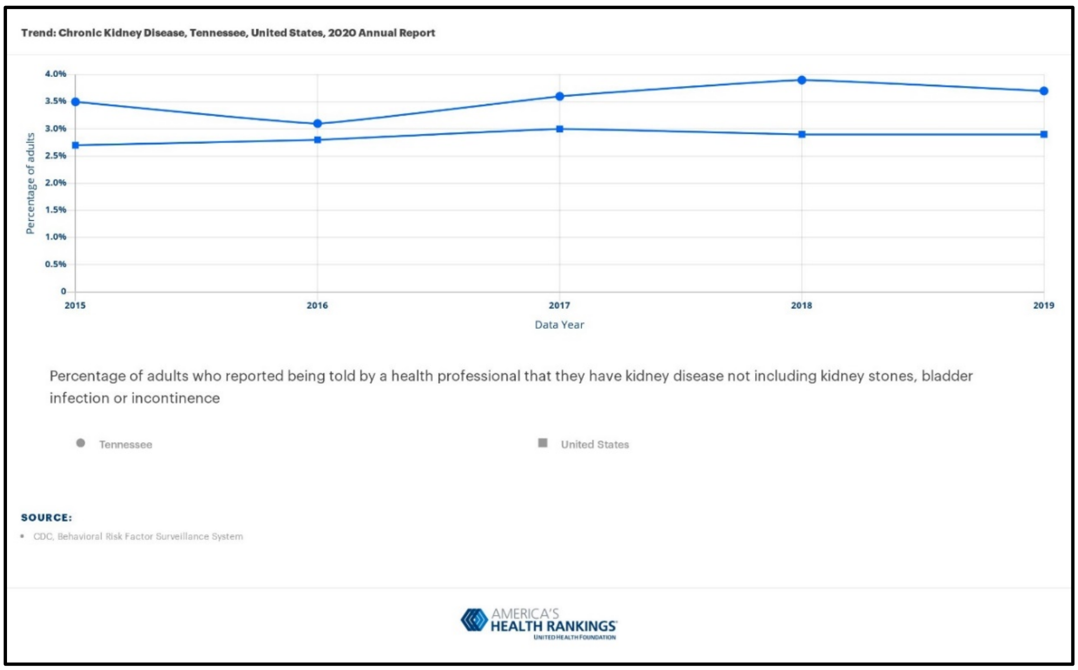

Figure 6. Percentage Population with CKD in Tennessee, US, 2020 Annual Report [40].

The graph below shows the total percentage of the White population in Tennessee between 2015 and 2019 according to the 2020 annual report.

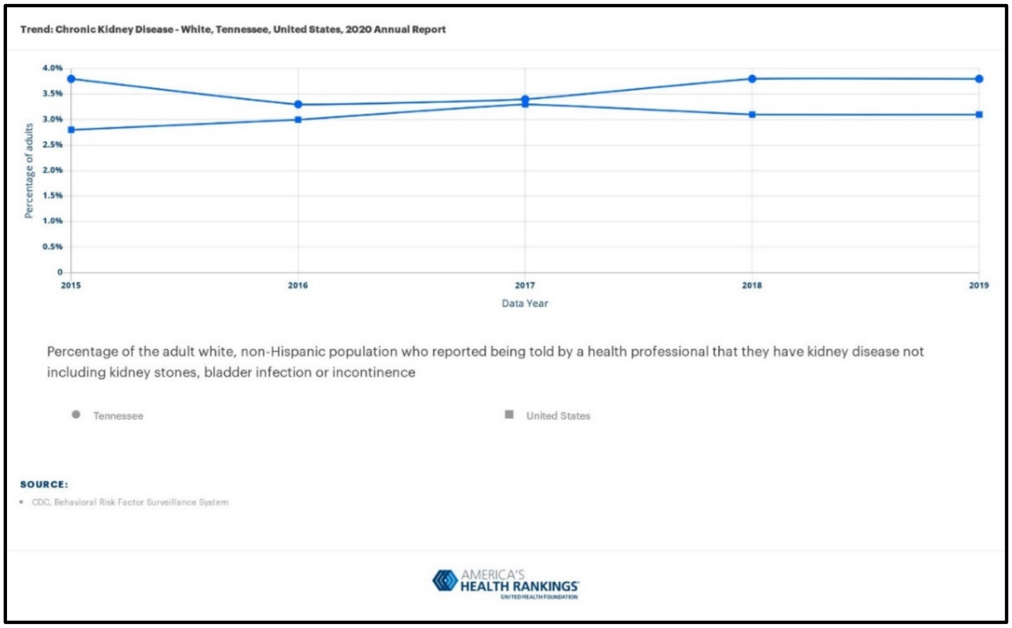

Figure 7. Percentage Population of White with CKD in Tennessee, the US, 2020 Annual Report [40]**.**

In figure 8, the total percentage of the Black population in Tennessee between 2015 and 2019 according to the 2020 annual report.

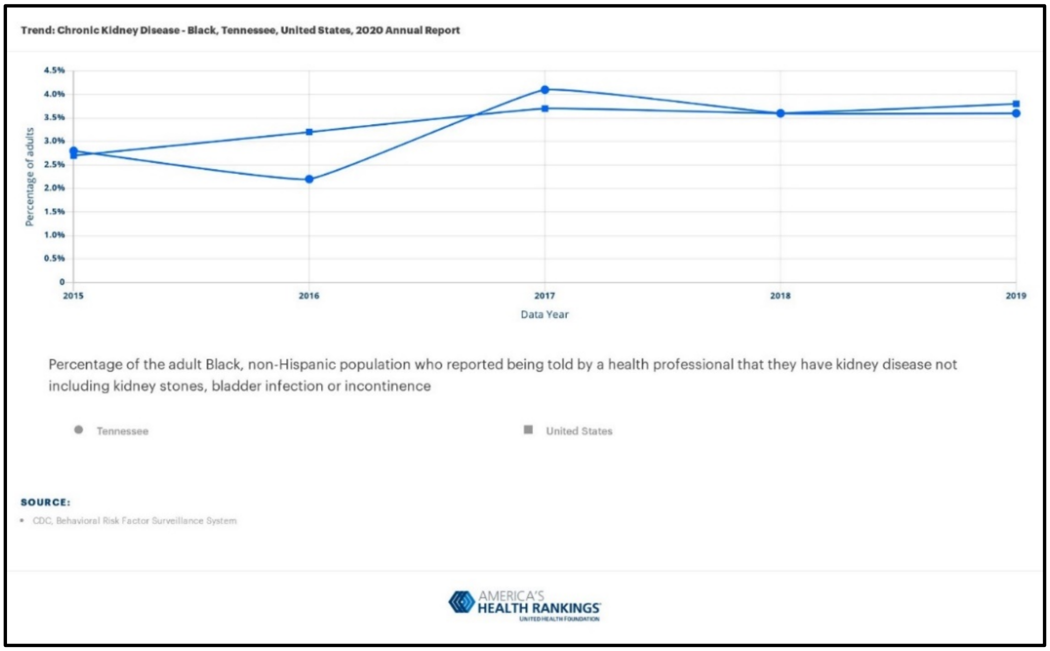

Figure 8. Percentage Population of Black with CKD in Tennessee, US, 2020 Annual Report [40].

Moreover, to comprehend health disparities associated with CKD, the agents involved in the bias toward the treatment interventions of this chronic disorder should be carefully observed and understood. In its entirety, discrimination or disparity is somewhat inherent, and sometimes, it could arise as a result of a previous event. In this case, the agents involved in CKD health disparities, according to the research, are the patients, the primary care providers, the nephrologists, and the healthcare system. Table 3 below shows the challenges faced by these agents and how these challenges could lead to biases on the agents' side.

Table 3. Challenges and Health Disparities among the Agents Present in CKD Management.

S/N	Agent	Challenge	Bias Toward Treatment
1	Patients	1. Most patients with CKD are asymptomatic. 2. Patients' limited understanding or lack of education about CKD management and implications. 3. Patients' limited access to care. 4. Patients' lack/Inadequate finance to handle CKD care due to multiple medication tests and referrals.	1. Patients' limited adherence to recommended treatment because of lack of CKD symptoms at an early stage. 2. Patients' medical preferences.

2.	PCPs	1. The PCPs' limited knowledge of CKD care and management. 2. The excessive workload on the PCPs. 3. PCPs' limited or lack of CKD care guidelines. 4. The PCPs' challenges in being up to date with the CKD guidelines. 5. It is difficult for the PCPs to manage patients' CKD risk factors (e.g., High blood pressure, diabetes, Obesity). 6. The PCPs' limited access to incentives or reimbursement.	1. The PCPs' late patients' referrals to Nephrologists are based on several factors. 2. Unhealthy communication exists between the PCPs and the nephrologists. 3. The communication barrier existing between PCPs and CKD patients. 4. The PCPs' ethnicity/race, gender, and age preferences.

		7. The PCPs' initial belief that CKD is irreversible, hence, their inability to improve it. 8. Patients' preferences.	5. The PCPs' availability or visit for CKD treatment. 6. The ratio of PCPs to patients (The number of PCPs to patients). 7. PCPs' time availability for CKD treatment.
3.	Nephrologists	1. The late referrals of CKD patients to the nephrologists for care by the PCPs. 2. The limited reimbursement of funds by the system (e.g., Medicare) for CKD management. 3. The limited number of screenings available for	1. The communication barrier existing between PCPs and Nephrologists. 2. The communication barrier existing between Nephrologists and CKD patients. 3. The nephrologists' ethnicity/race,

		CKD patients due to Late referrals. 4. The limited knowledge of CKD treatment by both PCPs and patients. 5. Inadequate Nephrological health technology equipment. 6. Patients' preferences. 7. The nephrologists' limited adherence to CKD care guidelines (e.g., KDOQI). 8. The nephrologists' Excess workload.	gender, and age preferences. 4. The nephrologist availability for CKD dialysis or transplant. 5. The nephrologists' time availability 6. The ratio of Nephrologists to Patients.
4.	Healthcare system	1. The provision of the limited availability of time visits for advanced CKD treatment. 2. The limited reimbursement for renal disease experts or	1. The organization of CKD treatment intervention based on quota. 2. CKD treatment based on ethnicity/

		multidisciplinary medical experts for CKD care management. 3. The insufficient availability of PCPs, Nephrologist, and other medical experts in the management of CKD. 4. The inadequate medical and healthcare technological tools in some areas (e.g., in the minority populated areas). 5. The limited adoption of the electronic medical record (EMR).	race, gender, age preferences. 3. The inadequacies in the deployment of renal medical experts in the minority communities.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Methodology

This chapter explains the research methodology, design, simulation software, data collection, and study analysis. Since health disparity is prevalent in the nation's healthcare system, it is necessary to find the root causes. Because CKD is irreversible, a well-planned healthcare intervention is needed to curtail its progression. As health disparities are inherently associated with CKD nationwide, this study focuses on Tennessee's CKD healthcare disparities. Despite the Medicare, Medicaid, and Medigap health insurance plans provided by both the federal government and Tennessee, these health disparities are still prevalent in the state. From chapters one and two, it is evident no matter what the health insurance package rendered by the nation, and there are still existing disparities in both the majority and minority communities in the state. With the graphs outlining the prevalence of CKD in the minority communities presented in chapter two, it is mandatory for the government to critically look into the root causes of the CKD health disparities in the state since the population of the minorities is increasing year by year. To this end, this study dives into the critical causes associated with CKD and the health disparities involved in Tennessee.

Furthermore, the methodological approach adopted involves simulating various interactive factors involved in the CKD incidence, prevalence, and healthcare disparities. CKD has several risk factors associated with it, and these factors are complex and dynamic with interrelated characteristics. In order to understand the inequities in the care of patients with CKD, a dynamic modeling approach is appropriate. This study employs a systems engineering modeling concept called system dynamics to simulate various instances associated with health disparities in CKD. This modeling concept creates graphs to illustrate the relationships that exist with the CKD factors. Hence, the results are analyzed based on the correlations to provide a proper CKD healthcare intervention for the minority communities in Tennessee. In order to do this, all the variables necessary in CKD care are utilized for transparency and policy decisions.

3.1.1. Causal Loop Models (CLM) for CKD Health Disparities in The Minority Communities in Tennessee

The SDM software used is Vensim PLE 8.2.1. version (Double precision) [41], which serves as the modeling environment. This software is employed for both causal loops, stock, and flow models. This section utilizes the SD casual loop model to explain the complex interacting factors associated with CKD in the minority communities in Tennessee.

The CLM is a cause-and-effect tool used in system dynamics to create interactive relationships between variables such as causes, events, and processes. It utilizes descriptive arrows to explain the balancing and reinforcing loops involved in events. This looping idea is essential to critically explain the causes and effects in complex situations that an ordinary linear approach cannot illustrate. As described in SD, the causal loop model is basically of two types: balancing loop and reinforcing loop. A balancing loop is produced when a variable change (effect) is generated due to an opposite variable's change (cause). While when a variable change (cause) in one direction results in more variable change (effect) in another direction, a reinforcing loop is generated. A positive sign (+) is assigned to the path of A to B when a variable, B (effect), moves in the same direction as a variable, A (cause). Additionally, when the variables move in opposite directions, a negative sign (-) is assigned to their path.

The causal loop diagram approach is appropriate to illustrate the challenge with CKD care in Tennessee. As initially explained in the previous chapters, there are factors associated with CKD incidence, prevalence, and management. CKD health disparities are better understood, considering the biological, environmental, and social factors involved.

Moreover, from chapter two, with other CKD risk factors, SDH in figure 6 illustrates CKD health disparities' interactive root causes. Therefore, the causal loop model employed in this research creates the cause and effect of these causes using appropriate loops necessary to comprehend the challenges involved in these disparities.

In this model, to describe the minority communities for better understanding, a single SD stock is used to represent these communities (Black/African Americans, Asian Americans, Hispanic Americans, American Indians/ native Alaska Americans, and native Hawaiians/ pacific islanders).

3.1.2. CKD Risk Factors CLM for Susceptible Minority Populations in Tennessee

This section explains the risk factors involved in CKD incidence in minority populations in Tennessee. CKD risk factors are majorly the primary cause of health disparities with CKD. This situation occurs because the causes of CKD are attached to several factors, including:

- Lifestyle

- The Genetic Formation of The Individual
- Family History of Kidney Disease
- Gender
- Sex (Male or Female)
- Acute Kidney Disease
- Alcohol Consumption
- Cardiovascular Disease (CVD)
- Diabetes
- Hypertension
- Obesity
- Smoking
- Age
- Nonsteroid anti-inflammatory (NSAIDs)
- Race/Ethnicity

The interactivity of these factors is modeled to explain the incidence of CKD in minority populations. Most of these risk factors come in the form of comorbidities and undoubtedly serve as risk factors for one another.

Therefore, the CLM in figure 9 below shows the influence of CKD risk factors on these communities. In the model, the factors are organized to show the dynamic relationships that exist among them. Most of these risk factors influence each other, thereby creating a clear view of how they should be observed and monitored. In the CLM, loop R1 shows that the family history of kidney disease can influence and, in turn, make the population prone to CKD. Loop R2 models the influence of age of the individual in the population on diabetes, hypertension; that is, an increase in the individual's age can be a factor in their being diabetic and hypertensive.

Moreover, this effect can, after that, lead to CKD. A family history of kidney disease also affects diabetes and hypertension. In the model, cardiovascular disease and obesity are risk factors for hypertension. Loop R3 shows the influence of race and ethnicity in the minority communities on the family history of kidney diseases. Moreover, loop R3 also depicts the increase in sugar consumption rate influencing diabetes rate.

Furthermore, loop R4 models the effects of smoking on hypertension and nephrotoxins in these communities. Loop R5 creates the effect of nephrotoxins on acute kidney injury (AKI), and the impact of excessive alcohol intake influences diabetes, hypertension, and obesity. Furthermore, loop R6 shows the effect of NSAIDs on AKI, and both independently lead to the cause of CKD. Additionally, malnourished diets in the communities can serve as a risk factor for all the comorbidities influencing CKD.

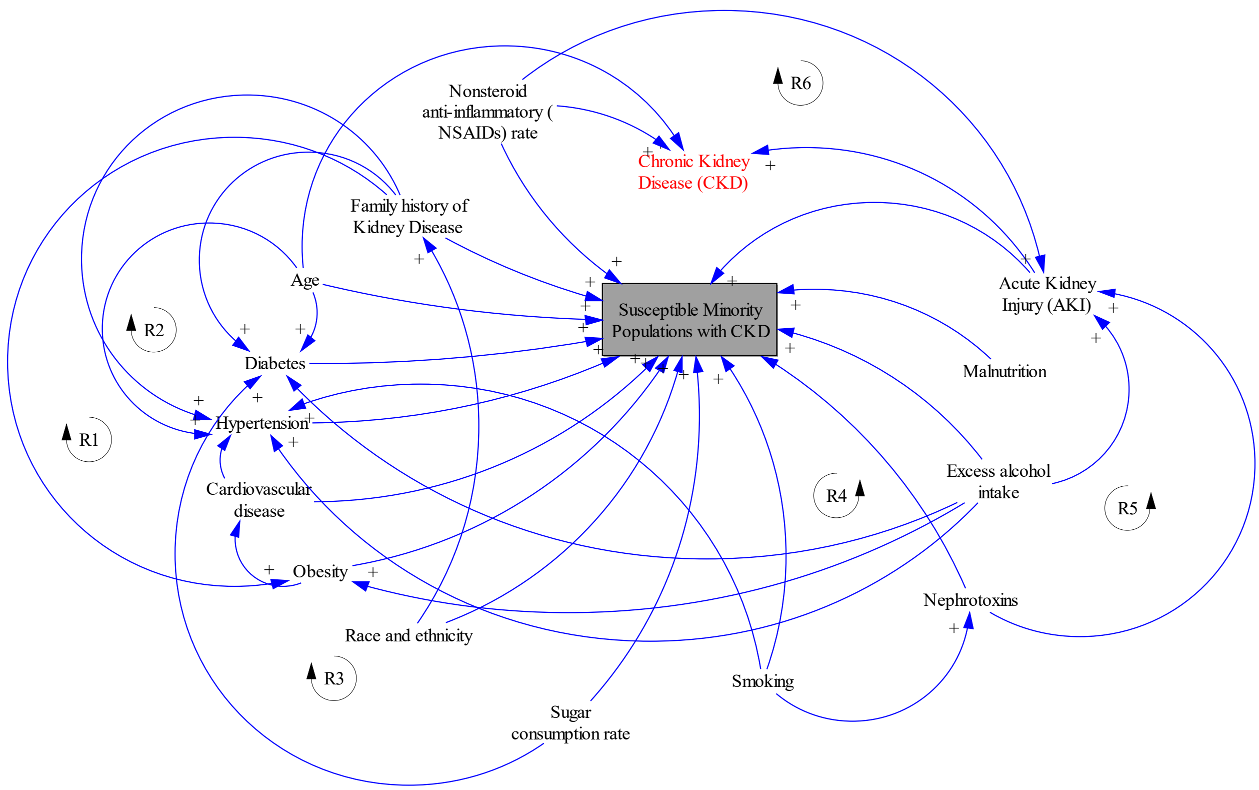

Figure 9. The CLM Showing the Influence of CKD Risk Factors on the Minority Populations.

SDH has an overwhelming impact on the lives of individuals in the US and globally. This instance presents an influence on the risk factors associated with CKD.

The CLM in figure 10 below exemplifies the impact of SDH on the wellbeing and healthcare interventions in minority communities. In the model, loop R1 creates an influence by showing that underpaid employment leads to low income, resulting in poverty and, in turn, unemployment. In loop R2, substandard education results in underpaid employment. Furthermore, in loop R3, the underpaid employment and poverty in the minority populated areas usually lead to stress. For loop B1, an increase in underpaid employment gives access to fewer sick leaves.

Moreover, fewer sick leaves do provide limited access to standard medical care. At the same time, unemployment results in low health, housing, and motor insurance. Loop B2 creates an influence on limited access to healthy food as a result of poverty and poor neighborhood. In loop B3, standard quality and stable housing usually reduce stress and environmental toxins and pollutants. Furthermore, in loops R4 and R5, the high mortality rate in the minority populations is due to a high morbidity rate and poor health. In loops B4 and R6, there is usually lower social support when there is poverty which at the same time provides limited access to care and poor transportation in these communities.

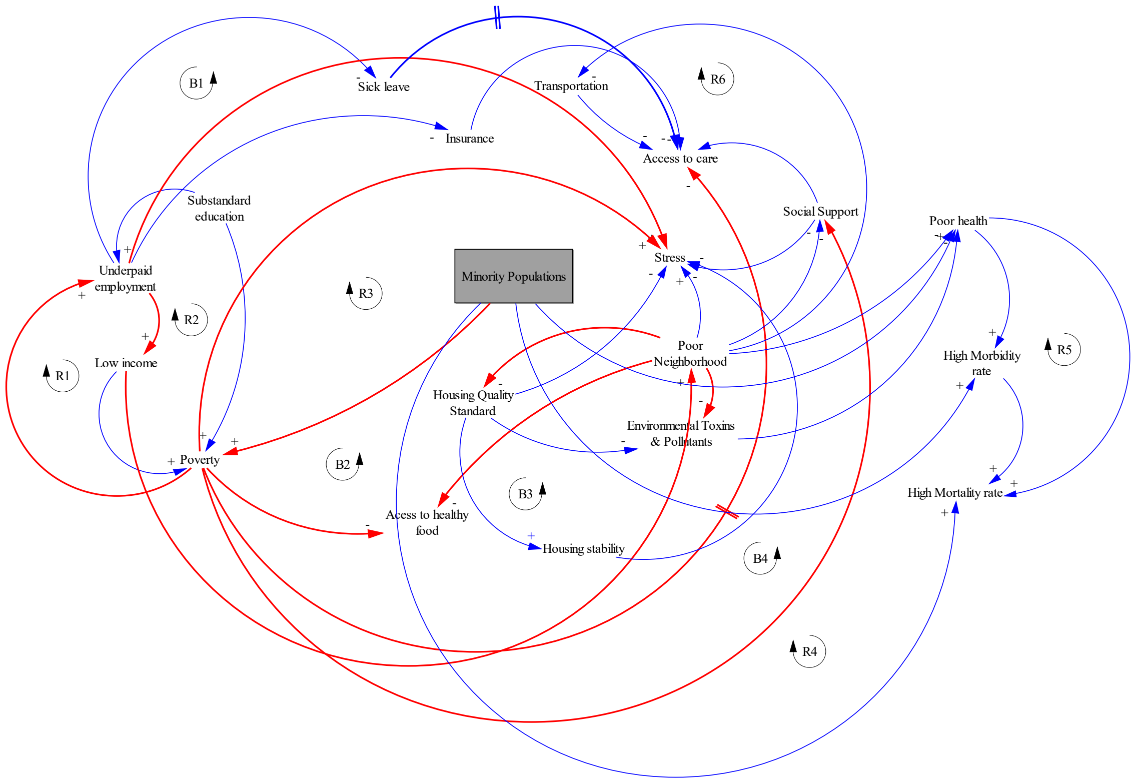

Figure 10. The CLM Showing the Influence of SDH on the Minority Populations.

3.1.3. Stock and Flow Model (SFM) for CKD Incidence and Prevalence in The Minority Communities in Tennessee

The SFM employed in this research involves possible factors necessitating the incidence, prevalence, and health disparities associated with CKD.

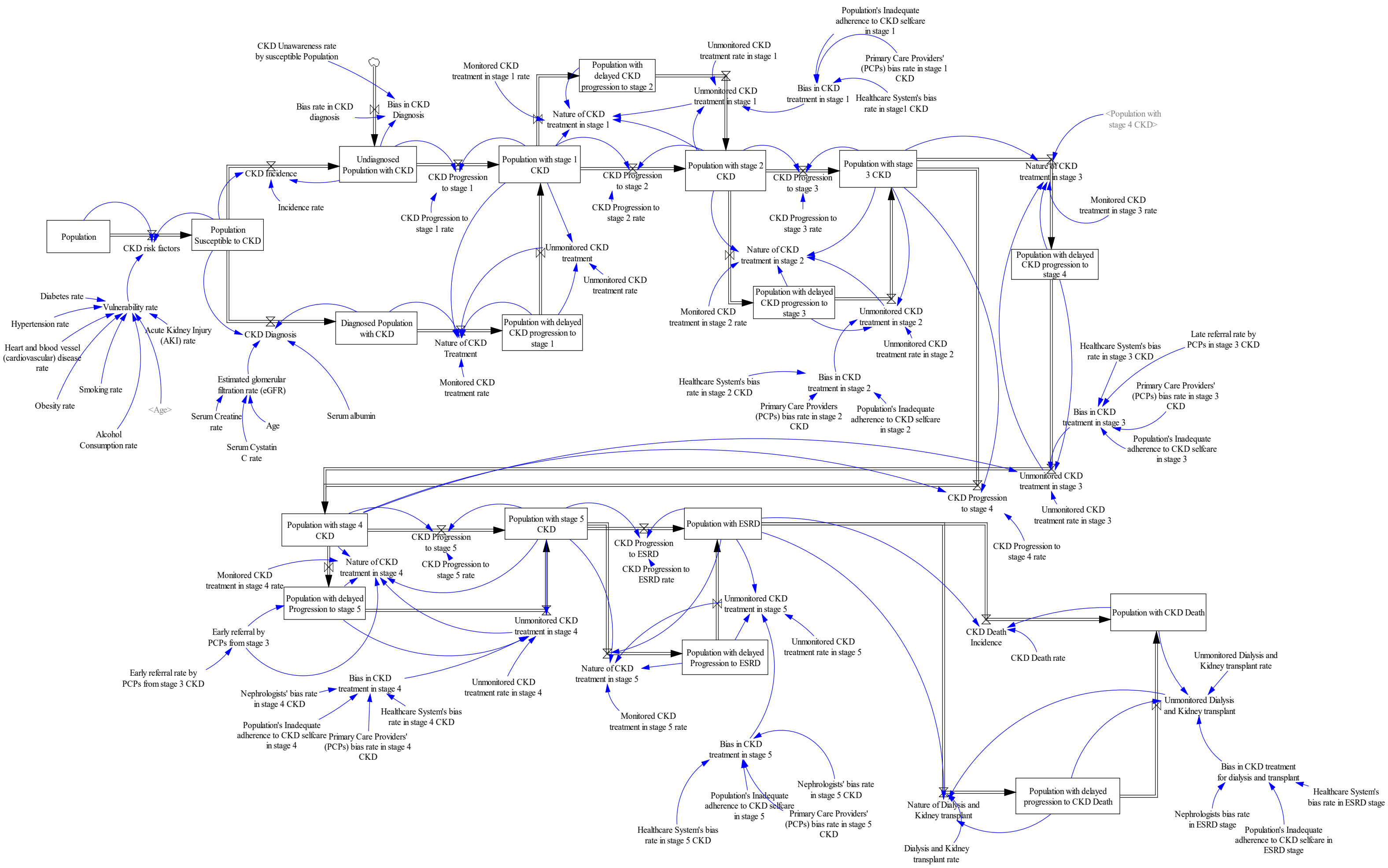

Figure 11. The SFM Showing the Stock and Flow Variables Representing CKD Incidence, Prevalence, and Health Disparities.

To get a better view of the simulator architecture, it has been shown in different sections in the following figures.

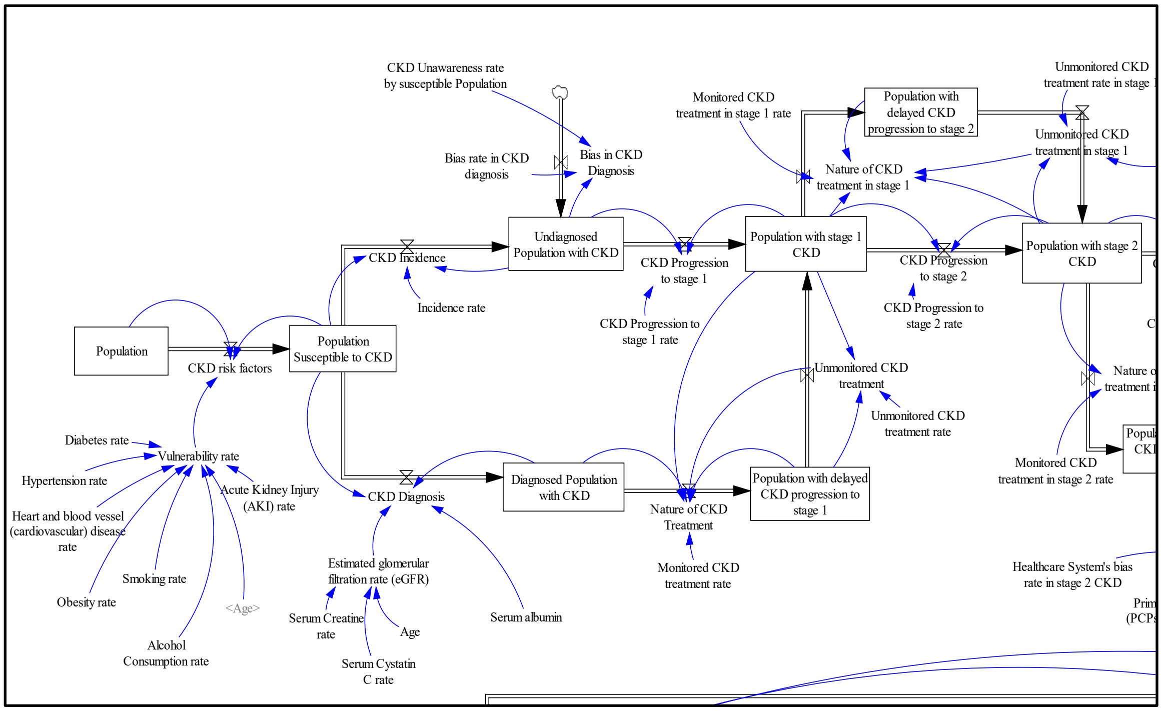

Figure 12. Section one of the SFM

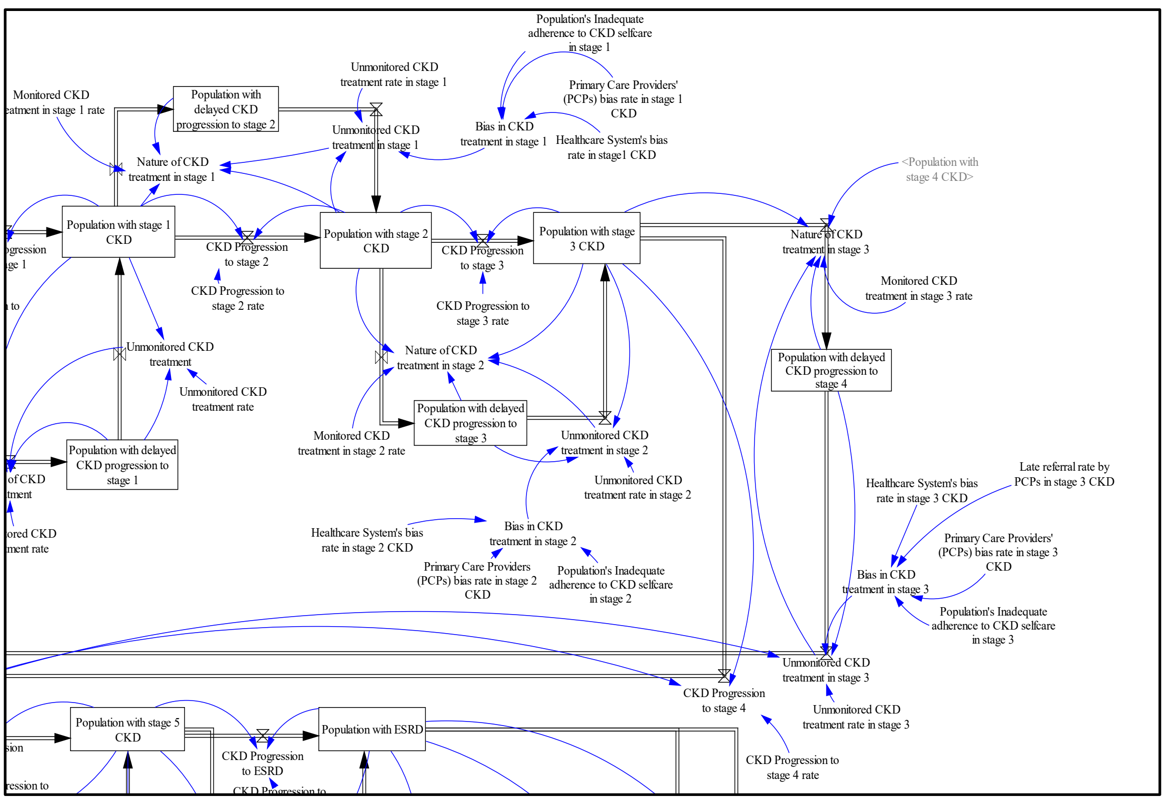

Figure 13. Section Two of the SFM

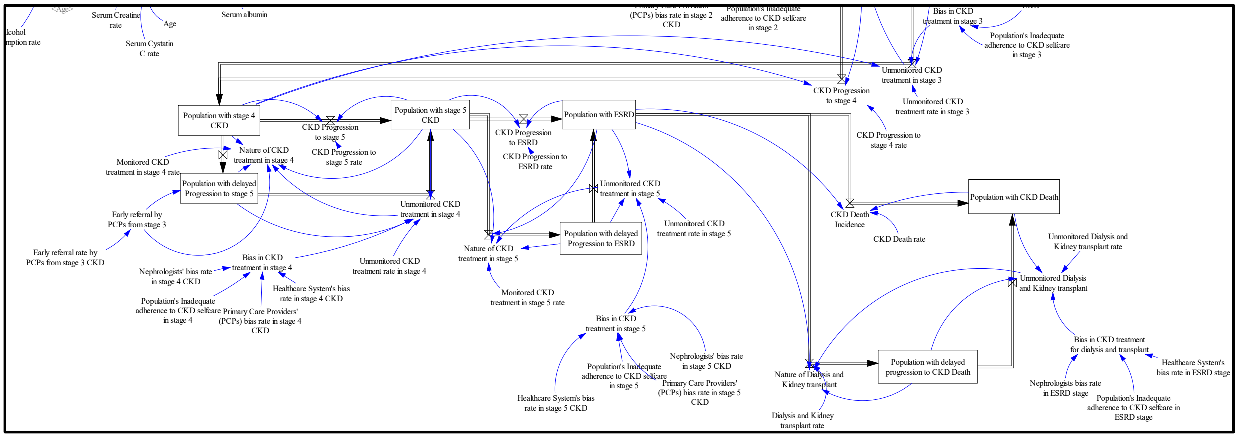

Figure 14. Section Three of the SFM

3.1.4. Vensim's Setup Settings for the SFM

The following setup settings are used for the simulation modeling in the Vensim software.

Table 4. The Vensim's Setup Setting for the Stock and Flow Model.

INITIAL TIME	FINAL TIME	TIME STEP	UNITS FOR TIME	INTEGRATION TYPE
2010	2022	0.0078125	Year	Euler

The stock and flow variables are briefly highlighted below as follow:

1. **Population**: The Population in the model represents the Population of Tennessee.
2. **CKD risk factors**: These variables are the general risk factors associated with CKD in the model.
3. **Population Susceptible to CKD**: This Population represents the minority communities susceptible (prone) to CKD in Tennessee.

4. **Vulnerability rate**: This variable links each factor to the CKD risk factors (flow rate) in the SFM.
5. **CKD Incidence**: This variable represents the occurrence of CKD.
6. **Undiagnosed Population with CKD**: This variable represents the Population with CKD diagnosis in the minority communities.
7. **Diagnosed Population with CKD**: This variable represents the population with diagnosed CKD.
8. **Bias in CKD diagnosis:** This variable represents the bias involved in the early stage of CLD, resulting in health disparities at this stage.
9. **CKD unawareness rate by susceptible Population**: This variable is a part of the bias involved in CKD. It depicts the latent health disparities on the side of the patients or vulnerable population.
10. **CKD progression**: This variable represents CKD advancement to every stage.
11. **Population with CKD**: This variable represents the population at every stage of CKD (that is, stages 1, 2, 3, and 5).
12. **Nature of CKD treatment**: This variable represents the type of treatment provided to patients with CKD. It can be a monitored treatment that results in the delay of CKD to the next stage or an unmonitored treatment that results in a biased CKLD care intervention that can lead to CKD progression to the next stage.
13. **Population with delayed CKD progression**: This variable represents the population with suppressed CKD to the next stage.
14. **Bias in CKD treatment**: This variable represents the cumulative bias (in terms of health disparities) involved at every CKD stage. It can arise due to the population's

inadequate adherence to self-care management, PCPs' bias in CKD, Nephrologists' bias, and the healthcare system's bias associated with CKD.

15. **Early referral by the PCPs from every CKD stage**: This variable is instrumental to delaying CKD progression to the next stage, and it is usually essential at stage 3 and beyond.
16. **CKD progression to ESRD**: This variable represents the advancement of CKD at 5 to ESRD.
17. **Late referral by the PCPs**: This variable represents the delay in the involvement of the nephrologists due to the late referral of the CKD patient by the PCPs.
18. **Healthcare system Bias**: This variable represents the bias toward CKD treatment by the healthcare system.
19. **Nature of dialysis and kidney transplant**: This variable represents the type of dialysis and transplant given to CKD patients.
20. **CKD Death incidence**: This variable represents the occurrence of the patient's death due to CKD.
21. **Population with delayed progression to CKD death**: This variable shows the Population with ESRD that progresses to renal death.
22. **Bias CKD treatment for dialysis and transplant**: This variable represents the health disparities involved in CKD dialysis and transplant care.

Furthermore, to fully understand CKD's root causes, impacts, and health disparities, it is crucial to view the relationships among the dynamic complex factors involved in its incidence and prevalence.

Using the SFM to establish the relationships within these varying factors shows the possible CKD healthcare disparities presented by the patients (populations), healthcare system, the PCPs, and nephrologist. In this research, the SFM displays vital graphs of the relationships and correlations with CKD health disparities. These graphs depict the interacting factors' analytical results to establish possible healthcare disparities at every stage of CKD. In order to show clarity, the rates employed in the model are based on 100% because some variables have their unique units while some do not (unquantifiable factors). As a result, the rate variables are on percentage rate units.

All other stocks are kept at zero initial values except the population stock. Moreover, each rate variable is based on a percentage rate approximated to two decimal places to avoid model complications and variable overflow. Table 2 below shows the classification of the stocks and flows used in the model. In the model, Tennessee's Population, according to the current 2020 census, is entered into population stock.

The SFM is usually developed to enhance the simulation of the connecting dynamic variables CLM. In this model, some variables are used as stocks and while some as flows. Stocks are quantities or variables that can increase or decrease in value. At the same time, the term "flow" refers to the ability of an element or a variable to change over time.

Table 5. The Stock and Flow Variables in The Model.

S/N	Stock	Unit	Flow	Unit
1	Population	People	CKD risk factors	Risk Factor

2	Population susceptible to CKD	People	Bias in CKD Diagnosis	Bias
3	Undiagnosed Population with CKD	People	CKD incidence	Incidence
4	Population with CKD stages	People	Nature of CKD treatment in stages	Treatment
5	Population with delayed progression to CKD stages	People	CKD progression to stages	Progression
6	Population with ESRD	People	Nature of dialysis and kidney transplant	Treatment
7	Population with CKD Death	People	Unmonitored CKD treatment in stages	Treatment

8	Population with delayed progression to CKD Death.	People	Unmonitored dialysis and kidney transplant.	Treatment
9	Diagnosed Population with CKD	People	CKD Death Incidence	Incidence

Generally, two CKD risk factors variables are altered from one initial value to another in the model to create and observe CKD incidence, prevalence, and bias changes. Although any of the interacting variables can be changed to initiate changes or variables, in this case, the risk factors are altered to establish a complete dynamic change in the whole model. The initial assumed values of the CKD risk factors are listed below, and the modified values in any two of them.

Table 6. The CKD Risk Factors with Initial Assumed Values and Altered Values in The Model.

S/N	CKD Risk Factor	Initial Assumed Value (0.01)	Altered Value (0.01)
1	Diabetes rate	0.80	1.15

2	Hypertension rate	0.80	1.25
3	Heart and Blood Vessel (Cardiovascular) disease rate	0.70	-
4	Obesity rate	0.59	-
5	Smoking rate	0.68	-
6	Alcohol Consumption rate	0.80	-
7	Age	0.65	-
8	Acute Kidney Injury (AKI)	0.56	-

The following procedures depict the plotting variables of CKD incidence and the general factors involved in each CKD stage and the mathematical formulae therein.

3.1.5. CKD Incidence Stage and The Nature of Bias Present

This section presents the model's population, risk, diagnosis, undiagnosed population, diagnosed process, nature of CKD treatment, and bias toward CKD. This is followed by some essential equations for a better understanding of the variable changes and analysis.

3.1.5.1. The Mathematical Model of Population

d(Population) = $\int_{p_1}^{p_2}$ -(-CKD risk factors) dt……………………………………… (1)

Where $\mathbf{p_1}$ and $\mathbf{p_2}$ represent the initial and final values of the model population.

3.1.5.2. The Mathematical Model of Vulnerability Rate for CKD Risk Factors in the Minority Communities

Vulnerability rate = Acute Kidney Injury

(AKI)×Age× Diabetes rate× Heart and blood vessel(cardiovascular) disease rate

× Hypertension rate× Smoking rate× Obesity rate× Alcohol Consumption rate (2)

3.1.5.3. The Mathematical Model of CKD Risk Factors

CKD risk factors =

(Population-Population Susceptible to CKD)×Vulnerability rate………………… (3)

3.1.5.4. The Mathematical Model of the Population Susceptible to CKD in the Minority Communities

d(Population Susceptible to CKD) =

$\int_{ps_1}^{ps_2}$ (CKD risk factors-CKD Incidence-CKD Diagnosis) dt………………………… (4)

Where $\mathbf{ps_1}$ and $\mathbf{ps_2}$ represent the initial and final values of the model susceptible population.

3.1.5.5. The Mathematical Model of CKD Diagnosis Process in the Minority Communities

Diagnosis = (Population Susceptible to CKD-Diagnosed Population with CKD

×Estimated glomerular filtration rate (eGFR)×Serum albumin……………………… (5)

3.1.5.6. The Mathematical Model of Undiagnosed Population with CKD in the Minority Communities

$$d(\text{Undiagnosed Population with CKD}) = \int_{U_1}^{U_2} (\text{CKD Incidence} + \text{Bias in CKD Diagnosis} - \text{CKD Progression to stage 1})\, dt \quad \ldots\ldots (6)$$

Where $\mathbf{U_1}$ and $\mathbf{U_2}$ represent the initial and final values of the model undiagnosed population.

3.1.5.7. The Mathematical Model of Diagnosed Population with CKD in the Minority Communities

$$d(\text{Diagnosed Population with CKD}) = \int_{D_1}^{D_2} -(\text{CKD Diagnosis} - \text{Nature of CKD Treatment})dt \quad \ldots\ldots (7)$$

Where $\mathbf{D_1}$ and $\mathbf{D_2}$ represent the initial and final diagnosed population values.

3.1.5.8. The Mathematical Model of the Population with Delayed CKD Progression to Stage 1 in the Minority Communities

d(Population with delayed CKD progression to stage 1) =

∫ -(Nature of CKD treatment-Unmonitored CKD treatment)dt…………………… (8)

3.1.5.9. The Mathematical Model of Bias in CKD Diagnosis in the Minority Communities

Bias in CKD Diagnosis = (Undiagnosed Population with CKD)

×CKD Unawareness rate by susceptible Population ×Bias rate in CKD diagnosis…… (9)

3.1.5.10. The Mathematical Model of CKD Progression to Stage 1 in the Minority Communities

CKD Progression to stage 1 =

(Undiagnosed Population with CKD-Population with stage 1 CKD)

×CKD progression to stage 1………………………………………………………. (10)

3.1.6. CKD Stages and the Bias Present

This model section presents the general factors in all stages with their mathematical formulae. The formulae include variables such as the Population with CKD, the population with delayed CKD progression, the unmonitored CKD treatment, CKD progression, and the bias in the stages.

In the following formulae, **K** denotes present stage of CKD, $\mathbf{K^P}$ represents the previous stage of CKD, and $\mathbf{K^N}$ indicates the next stage of CKD.

3.1.6.1. The Mathematical Model of the Population with CKD in All Stages

d(Population with stage **K** CKD) =

$\int_{PS_{11}}^{PS_{12}}$ (CKD Progression to stage **K** + Unmonitored CKD treatment in stage $\mathbf{K^P}$-CKD Progression to stage $\mathbf{K^N}$-Nature of CKD treatment in stage CKD Progression to stage $\mathbf{K^N}$) dt………………………………………………………………………………….. (11)

Where $\mathbf{PS_{11}}$ and $\mathbf{PS_{12}}$ represent the initial and final values CKD Population in all stages.

3.1.6.2. The Mathematical Model of the Population with Delayed CKD Progression to All Stages

d(Population with delayed CKD progression to stage **K**) = ∫ (Nature of CKD treatment in stage $\mathbf{K^P}$-Unmonitored CKD treatment in stage $\mathbf{K^P}$) dt…………………………………….. (12)

3.1.6.3. The Mathematical Model of Unmonitored CKD Treatment in All Stages

Unmonitored CKD treatment in stage **K** =(Population with stage **K^N** CKD-Population with delayed CKD progression to stage **K^N**) ×Unmonitored CKD treatment rate in stage **K**× Bias in CKD treatment in stage K ………………………………………………………………………………….. (13)

3.1.6.4. The Mathematical Model of CKD Progression to All Stages

CKD Progression to stage **K** = (Population with stage **K^P** CKD-Population with stage **K** CKD) ×CKD progression to stage **K** rate…………………………………………………(14)

3.1.6.5. The Mathematical Model of Bias Involved in CKD Treatment in All stages

Bias in CKD treatment in stage **K =** ("Primary Care Providers (PCPs) bias rate in stage **K** CKD") ×Population's Inadequate adherence to CKD self-care in stage **K** × Healthcare System's bias rate in stage **K** CKD………………………………………………… (15)

The relationships among the varying and interrelated variables in the model provide a comprehensive understanding of how the influence of the CKD risk factors create the effects of its incidence, prevalence, and health disparities in all the stages. In addition, how these impacts can be observed and studied to develop possible policies that will enhance equity CKD treatment.

3.2. Research Design

The research involves the causal-comparative and quasi-experimental procedure that establish the causes and effects of the influences created by the dynamic factors associated with CKD, resulting in the health disparities existing in CKD care interventions. The study design is organized to maintain the typical relationship between CKD incidence, prevalence, and progression. The causal factors are employed using the SDM to observe the relationships among the variables and the effects of the possible health disparities in each stage of CKD.

3.3. Data Collection

The research involves quantitative and qualitative approaches using data and simulation procedures to establish the effects of health disparities in CKD care intervention in Tennessee. However, the data was not collected using face-to-face or questionnaire methods; instead, data and graphs from different websites, journals, articles, and blogs were consulted. Besides, for the simulation modeling, initial assumed values were employed to establish the desired results of the study. These results come in the form of graphs that any research procedure can also adopt to predict and estimate the effects of disparities in CKD care anywhere.

CHAPTER 4: SIMULATION RESULTS

4.1. Result Illustration

This chapter explains the relationships among the varying factors associated with CKD resulting from the SFM model in the previous chapter.

The CKD incidence occurs due to the prevalence of the risk factors present in the general population, specifically, the minority populations susceptible to CKD. In order to test the presence of CKD in a patient, several tests are involved. The ones employed in the model are the estimated glomerular filtration rate test and the patient's protein urine (Serum albumin).

Generally, some patients are diagnosed either by self-reported cases or by laboratory procedures. In the case of CKD, most minority populations are not usually diagnosed early, which results in late detection of CKD. The undiagnosed CKD incidents in the minority populations arise due to inadequate literacy about CKD or the high unawareness rate of CKD by these populations. However, the undiagnosed incident can also occur when the minority populations are not financially buoyant enough to have standard medical treatment. Hence, this arises from the bias on the social determinant of health on the side of these populations. Consequently, these instances usually lead to CKD progression to the next stage.

The bias in CKD treatment and management is assumed to be a cumulative disparity between patients, PCPs, neurologists, and healthcare systems in this research. In the model, the bias arises from the population's inadequate adherence to CKD self-care, PCPs', nephrologists', and the healthcare system's biases toward CKD. The nature of treatment in the model is based on the monitored treatment and the unmonitored treatment experienced by the patients.

4.2. Graphical Interpretation

This research section interprets the results generated by the graphs in the SFM using the modeled variables: CKD risk factors, the population at every stage, the nature of the treatment, bias, and the progression of the CKD to the different stages present. And each of these variables is plotted against each other to initiate the desired results of the study. In the following graphs, the base simulation of the model is displayed. Afterward, the current simulation presents the change in the results when one or two CKD factors are altered. The current simulation is based on the change in diabetes rate [0.80 to 1.15 Percentage Rate] and hypertension rate [0.80 to 1.25 Percentage Rate]. To have proper simulations and graphical results, the current population of Tennessee, which is 6,910,840, according to the 2020 census, is entered into the population stock in the model. The time duration for the model for the provision of desired results is from 2010 to 2022. This duration is employed to give enough room for simulation comprehension since the incidence and prevalence of CKD take a long time to occur.

A. CKD Incidence and The Nature of Bias Involved

As previously mentioned, every stage of CKD experiences disparity, even at the occurrence stage. All the possible CKD factors in the model, including the bias at every stage, are employed. At the CKD incident stage in the model, vital variables are plotted against each other to establish the existence of disparities in CKD.

A1. The Relationship between CKD Risk Factors and the Population Susceptible to CKD

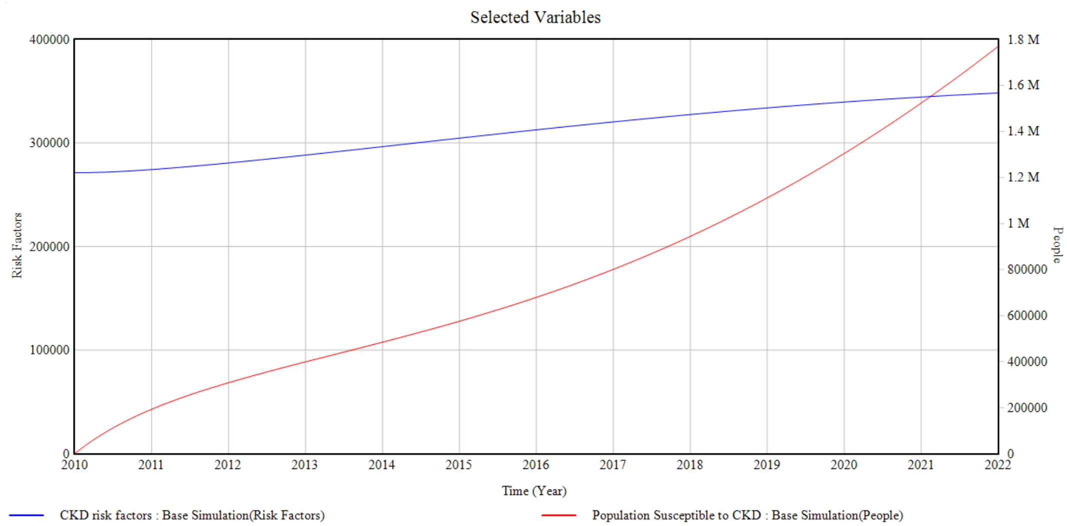

Figure 15. The Graph of CKD Risk Factors against Population Susceptible to CKD in the SFM Simulation Result (Base Simulation).

Figure 15 above shows the effects of CKD risk factors on the populations vulnerable to CKD. The minority communities in Tennessee and most other states in the US have challenges coping with the surge of CKD because the root causes of this disease are overwhelmingly present in these communities. The values of CKD risk factors are plotted from the graph against the values of the population susceptible to CKD. From the graph, an increase in the CKD risk factors results in [≈1500 Risk Factor] an increase in the population susceptible to CKD [≈1.8M People].

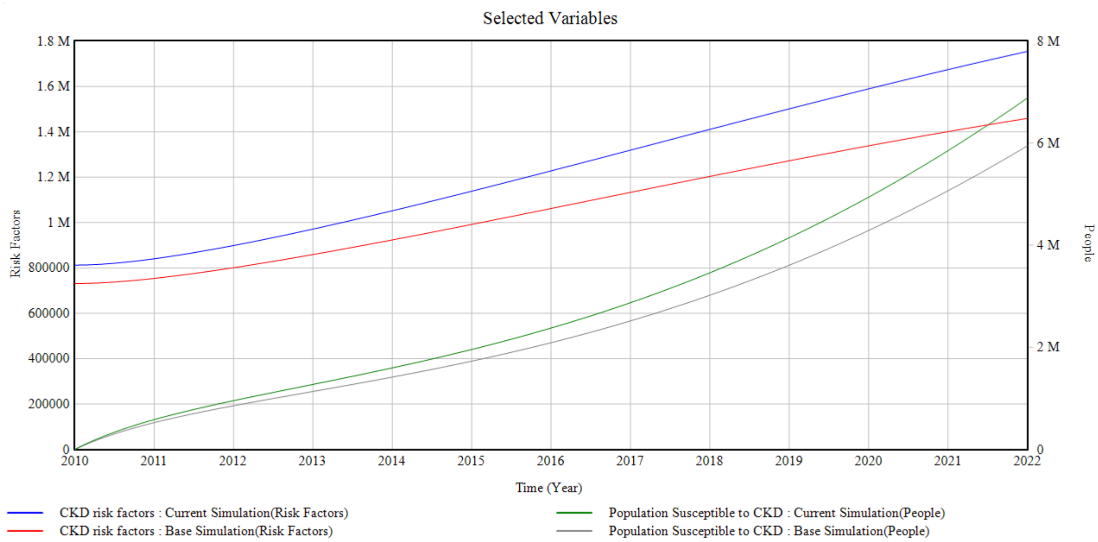

Figure 16.The Graph of CKD Risk Factors Against Population Susceptible to CKD In the SFM Simulation Result (Base Simulation and Current Simulation).

In the base and current simulations, an [≈8000 Risk Factor] increase in CKD risk factors causes [≈1.8M People] an increase in the population susceptible to CKD.

A2. The Relationship between the Bias in Diagnosis and the Undiagnosed Population with CKD

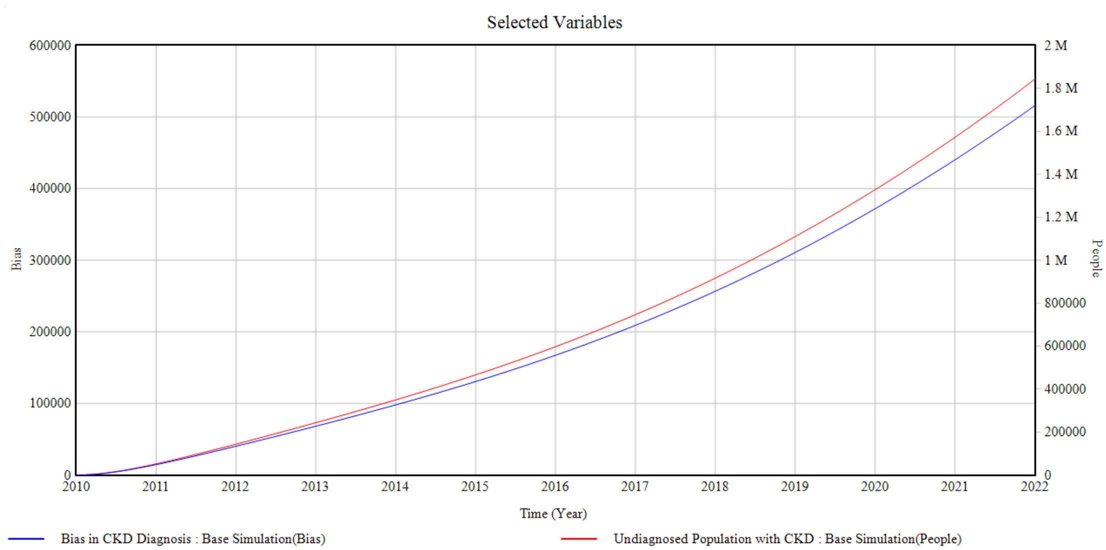

Figure 17.The Graph of Bias in CKD Diagnosis against Undiagnosed Population with CKD in the SFM Simulation Result (Base Simulation).

Figure 17 shows the impacts of Bias in Diagnosis on the undiagnosed populations with CKD. Often, the undiagnosed population is due to the influence of the disparities present on the risk factors at CKD incidence. From the graph, the relationship between these factors is proportional, which means as the bias increases, there is always the possibility of some populations experiencing undiagnosed CKD, most often, the minority populations. The trend from 2010 to 2022 from the graph shows the impacts of these disparities.

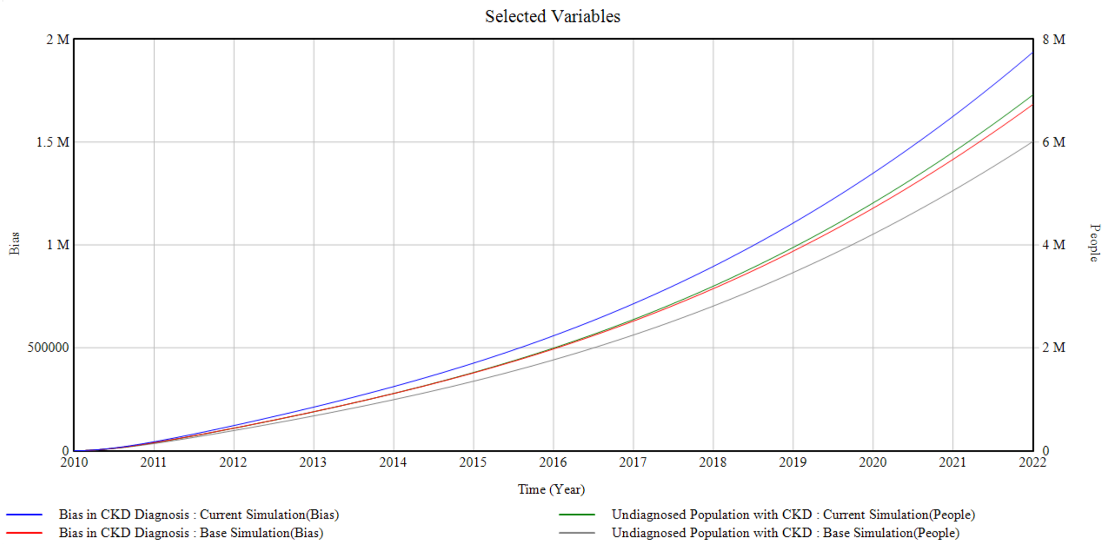

Figure 18.The Graph of Bias in CKD Diagnosis against Undiagnosed Population with CKD in the SFM Simulation Result (Base Simulation and Current Simulation).

Figure 18 represents the base and current simulations of figure 17. The graph still depicts the proportional relationship that exists between the factors when one of the parameters of bias is altered from the model with the values [0-≈7M People] between 2010 to 2022 for undiagnosed population and [0-≈1.85M Bias] between 2010 to 2022 for Bias in Diagnosis.

A3. The Relationship between the Nature of Treatment and the CKD Progression to Stage 1

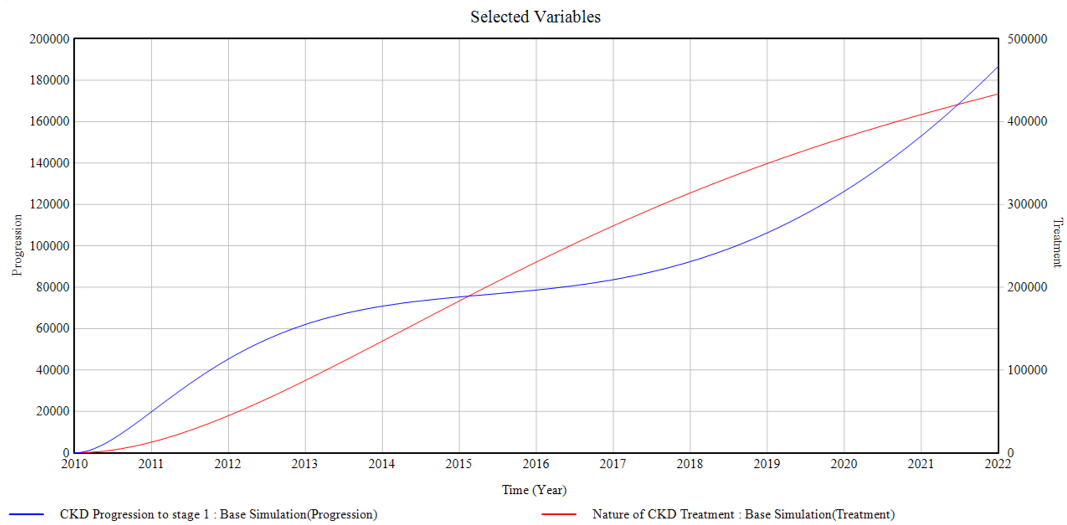

Figure 19.The Graph of CKD Progression to Stage 1 CKD against Nature of CKD Treatment in the SFM Simulation Result (Base Simulation).

In figure 19 above, the graph depicts the relationship between the Nature of Treatment at CKD incidence and CKD progression to stage 1. The graph presents fluctuating correlations between these variables. As the nature of CKD treatment at the early stage increases, CKD progression to stage 1 increases and afterward decreases, depending on the type of treatment gibe. In the graph, the CKD progression to stage 1 declined below [8000 Progression] between 2015 and 2016 when the nature of CKD treatment drops to **[**≈250000 Treatment] between these years. Afterward, CKD progression to stage 1 increases to [≈470000 Treatment].

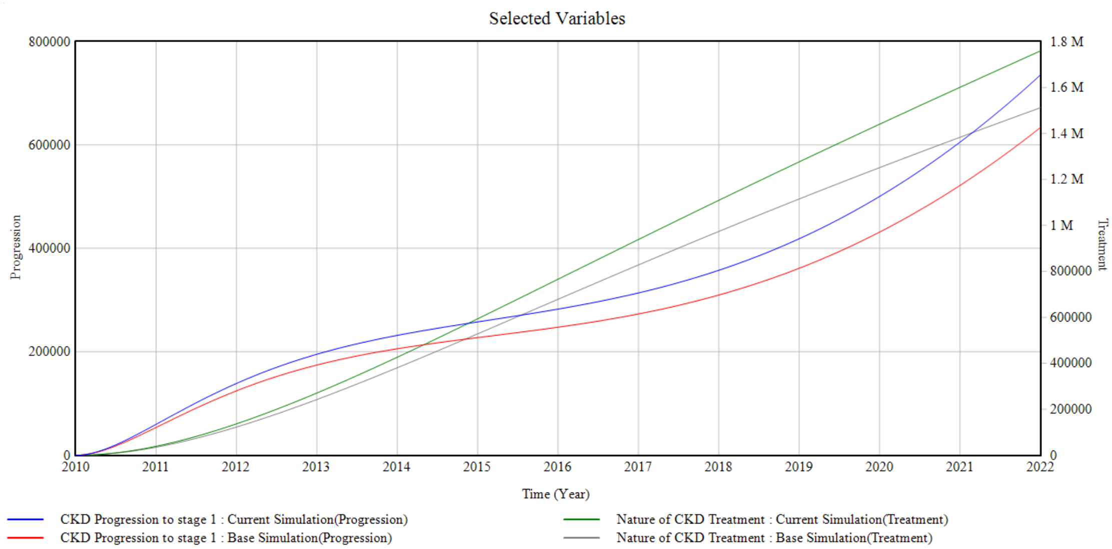

Figure 20.The Graph of CKD Progression to Stage 1 CKD against Nature of CKD Treatment in the SFM Simulation Result (Base Simulation and Current Simulation).

In figure 20, the base and current simulation graph above shows similar results after an alteration in the values of CKD risk factors. The change in the values from 2010 to 2022 results in a shift in the values of the nature of CKD treatment, and these changes confirm the relationship between these factors.

A4. The Relationship between the Nature of Treatment and the Bias in Diagnosis

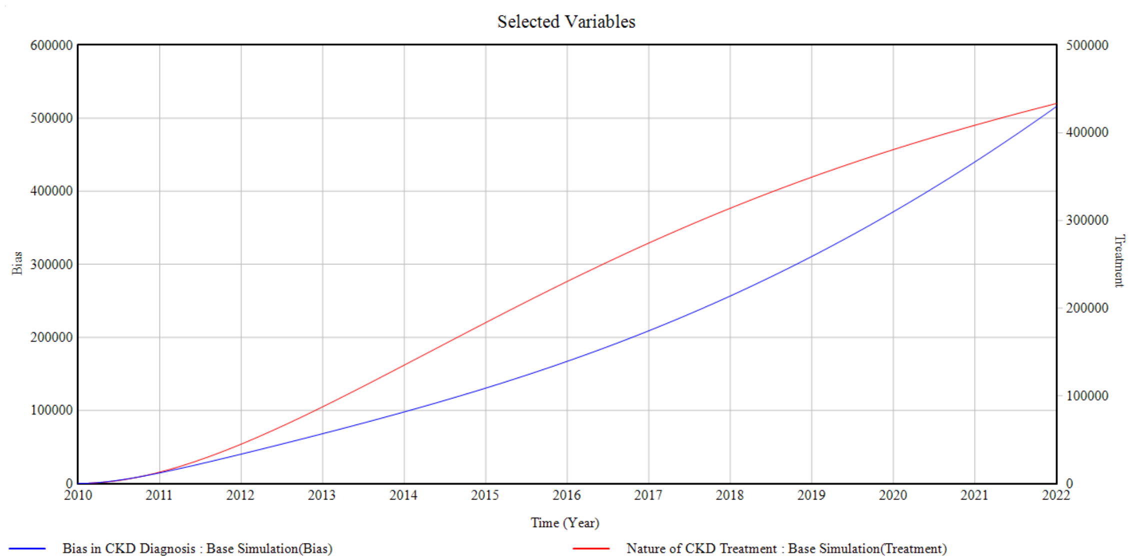

Figure 21.The Graph of Nature of CKD Treatment against Bias in CKD Diagnosis in the SFM Simulation Result (Base Simulation).

The graph in figure 21 shows the relationships between the nature of treatment and the bias in diagnosis. It is evident from the graph that between 2020 and 2022, there is an increase in the values of bias in CKD diagnosis at the early occurrence of CKD, which changes depending on the type of bias present. From the graph, both factors picked up, but eventually, the nature of CKD treatment increases due to a decline in the value of the bias involved in the treatment during 2017.

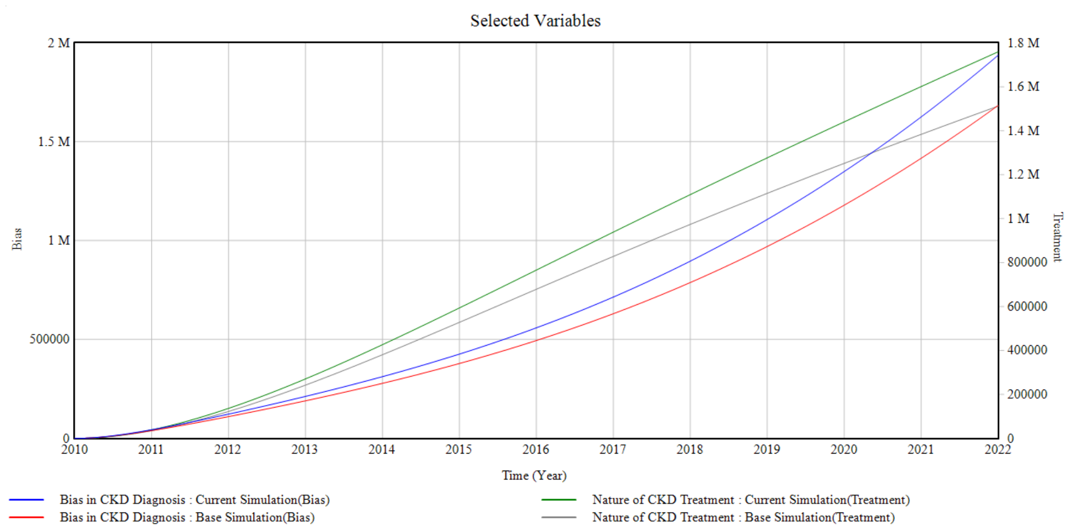

Figure 22.The Graph of Nature of CKD Treatment against Bias in CKD Diagnosis in the SFM Simulation Result (Base Simulation and Current Simulation).

In figure 22, the base and current simulations present a similar relationship between the nature of CKD treatment and the bias involved in CLKD incidence. The changes in the factors confirm the disparities that are possible in the early occurrence of CKD.

A5. The Relationship between the Increase Bias in CKD incidence and the CKD progression to stage 1

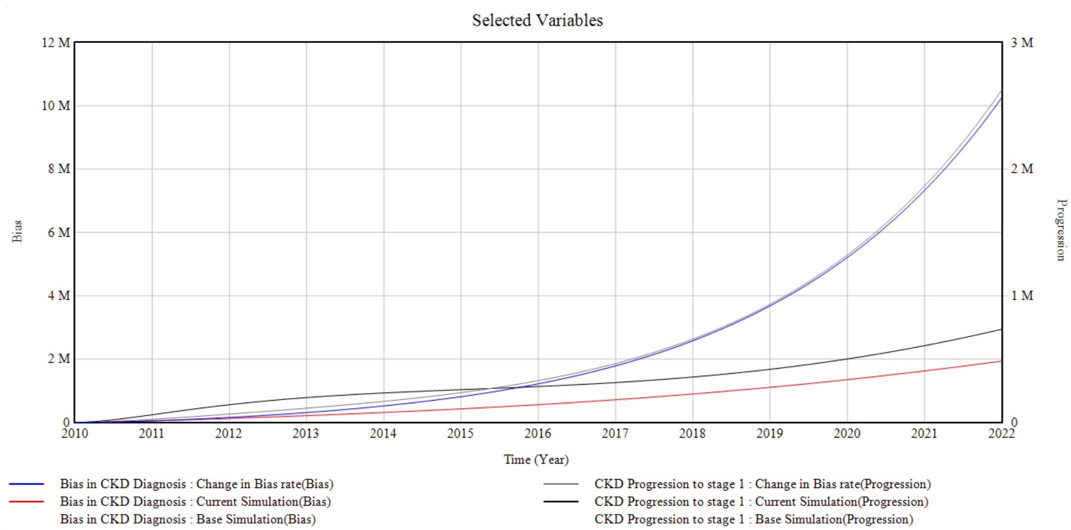

Figure 23.The Graph of Increase Bias in CKD Incidence against CKD Progression to Stage 1 CKD in the SFM Simulation Result (Current Simulation).

In Figure 23, the graph shows a corresponding increase in CKD progression to stage 1 CKD as the bias in CKD incidence increased between 2010 and 2022. In this case, the CKD unawareness rate by susceptible population (which is a variable in bias diagnosis) is altered from [0.7 to 1.35 Percentage Rate] to increase the value of CLD progression to stage 1 CKD.

B. CKD in Stage 1 and the Bias Involved

Health disparities occur at stage 2 of CKD. At this stage, many patients do not know they have it, and as a result, it is crucial to examine the inequities that might arise in this stage.

The following graphs show the trends and relationships among the factors influencing CKD stage 2 incidence and prevalence.

B1. The Relationship between the Increased Bias in CKD treatment in stage 1 and the CKD progression to stage 2

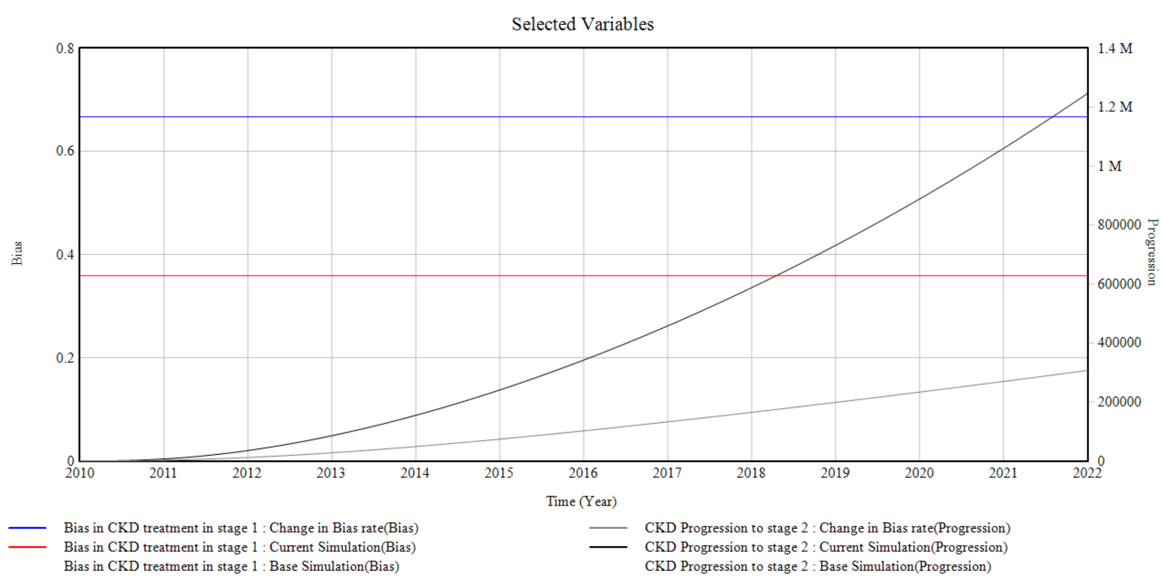

Figure 24.The Graph of Increased Bias in CKD Incidence against CKD Progression to Stage 2 CKD in the SFM Simulation Result (Current Simulation).

In figure 24, the above graph shows a corresponding change in CKD progression to stage 2 when the bias in CKD treatment in stage 1 is increased. In this case, the PCPs' bias rate is changed from [0.8 to 1.3 Percentage Rate], giving rise to CKD progression in stage 2 to a value of [≈1.24M Progression] in 2022 from 0 in 2010.

C. CKD in Stage 2 and the Bias Involved

The following graphs show the trends and relationships among the factors influencing CKD stage 2 incidence and prevalence.

C1. The Relationship between the Bias in CKD treatment (the PCPs' Bias rate) in stage 2 and the CKD progression to stage 3

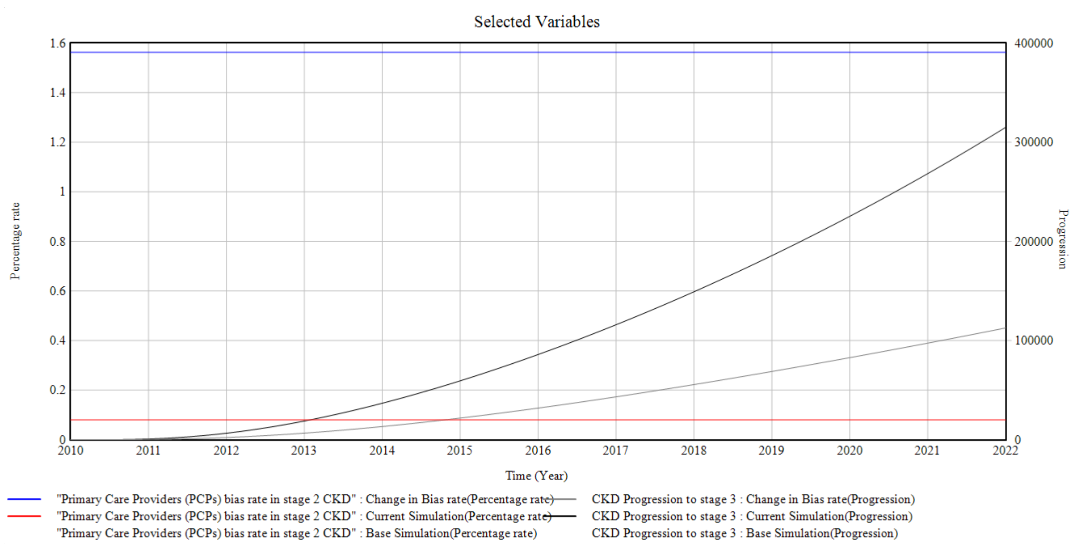

Figure 25.The Graph of Bias rate in Stage 2 CKD against CKD Progression to Stage 3 CKD in the SFM Simulation Result (Current Simulation).

In figure 25, the graph shows a change in CKD progression to stage 3 when the bias in CKD treatment in stage 2 is increased correspondingly. In this case, the PCPs' bias rate is changed from [0.08 to ≈1.55 Percentage Rate], giving rise to CKD progression in stage 3 to a value of [≈310,000 Progression] in 2022 from 0 in 2010.

D. CKD In Stage 3 and the Bias Involved

The following graphs show the trends and relationships among the factors influencing CKD stage 3 incidence and prevalence.

D1. The Relationship between the Bias in CKD treatment in stage 3 and the CKD progression to stage 4

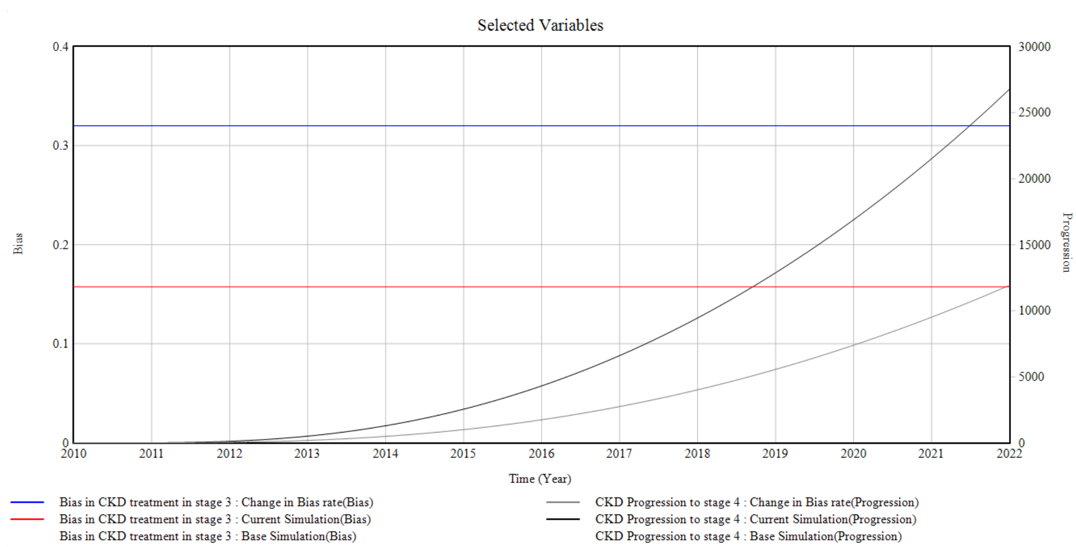

Figure 26.The Graph of Bias rate in Stage 3 CKD against CKD Progression to Stage 4 CKD in the SFM Simulation Result (Current Simulation).

The graph in figure 26 depicts a proportional increase in CKD progression to stage 4 when the bias in CKD treatment in stage 3 is changed. The Bias rate, in this case, is increased from [0.16 to ≈1.32 Bias], giving rise to CKD progression in stage 4 to a value of [≈26,5000 Progression] in 2022 from 0 in 2010.

E. CKD In Stage 4 and the Bias Involved

The following graphs show the trends and relationships among the factors influencing CKD stage 4 incidence and prevalence.

E1. The Relationship between the Bias in CKD treatment in stage 4 and the CKD progression to stage 5

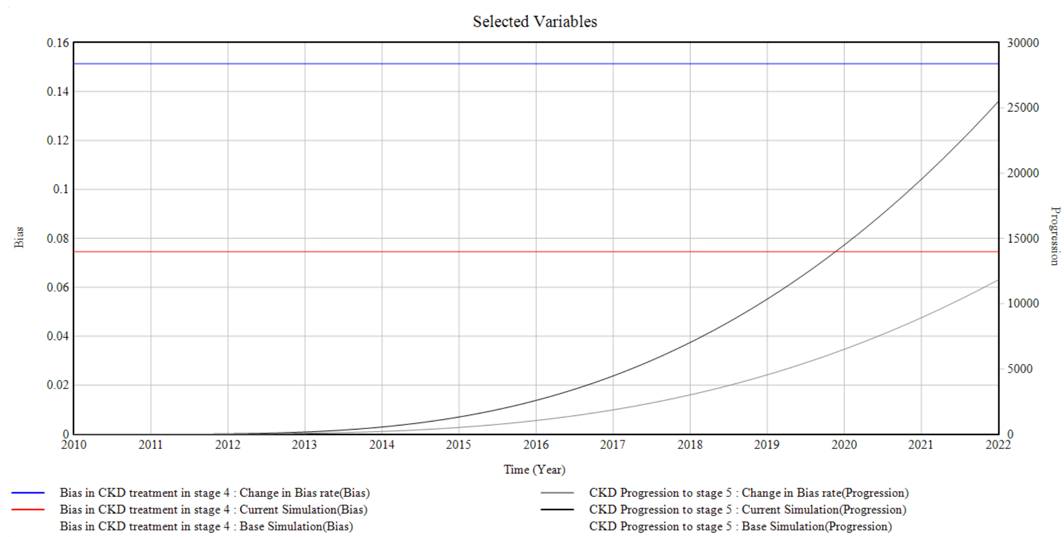

Figure 27.The Graph of Bias rate in Stage 4 CKD against CKD Progression to Stage 5 CKD in the SFM Simulation Result (Current Simulation).

The graph in figure 27 shows a corresponding increase in CKD progression to stage 5 when the bias in CKD treatment in stage 4 is altered. The Bias rate is changed from [0.073 to ≈1.151 Bias], giving rise to CKD progression in stage 5 to a value of [≈25,1000 Progression] in 2022 from 0 in 2010.

F. CKD in stage 5 and the bias involved

The following graphs show the trends and relationships among the factors influencing CKD stage 5 incidence and prevalence.

F1. The Relationship between the Bias in CKD treatment in stage 4 and the CKD progression to ESRD

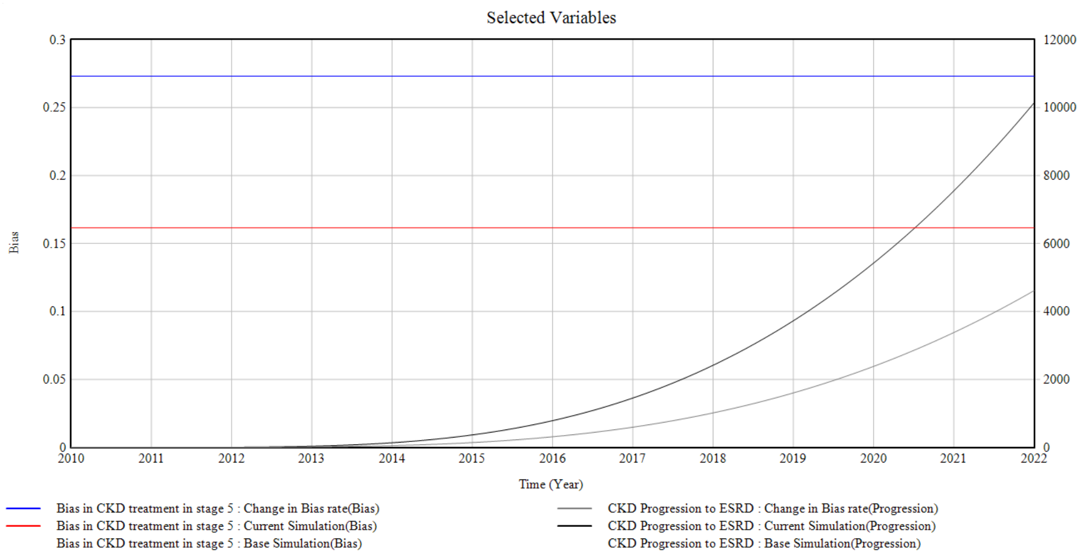

Figure 28.The Graph of Bias rate in Stage 5 CKD against CKD Progression to ESRD in the SFM Simulation Result (Current Simulation).

The graph in figure 28 shows an increase in CKD progression to ESRD when the bias in CKD treatment in stage 5 is changed. The Bias rate is changed from [0.152 to ≈ 0.275 Bias], giving rise to CKD progression in ESRD to a value of [≈1000 Progression] in 2022 from 0 in 2010.

G. ESRD and the Bias Involved

The following graphs show the trends and relationships that exist among the factors influencing ESRD incidence and prevalence.

G1. The Relationship between the Bias in CKD for Dialysis and Transplant and the CKD Death Incidence

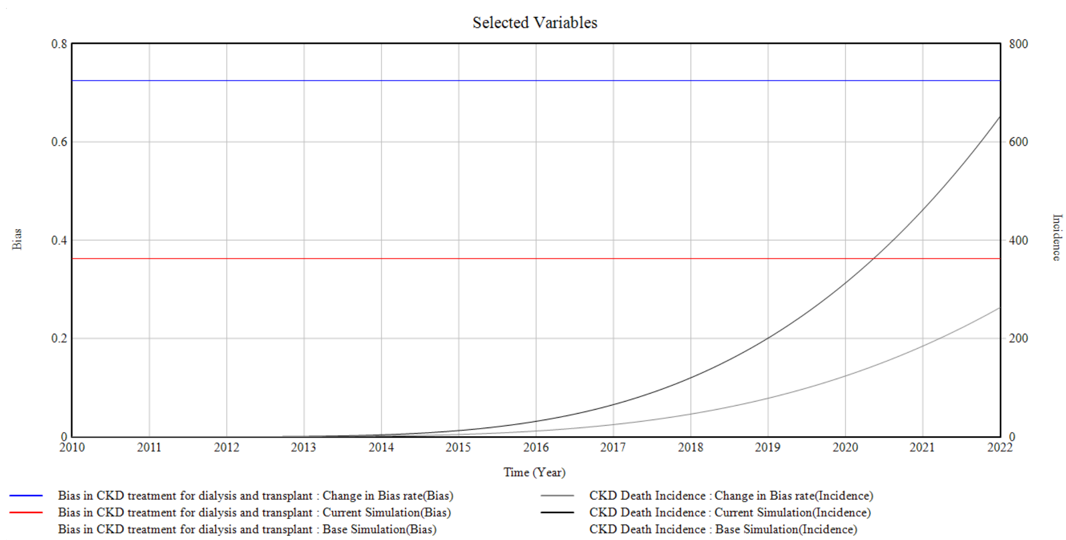

Figure 29.The Graph of Bias rate in ESRD CKD against CKD Death Incidence in the SFM Simulation Result (Current Simulation).

The graph in figure 29 shows an increase in CKD Death Incidence when the bias in CKD for Dialysis and Transplant is changed. The Bias rate is changed from [0.33 to ≈ 0.72 Bias], giving rise to CKD Death Incidence of a value of [≈650 Incidence] in 2022 from 0 in 2010.

CHAPTER 5: DISCUSSIONS

This chapter explains the challenges and the impacts of the disparities that exist in the management of CKD. The challenges and the bias toward CKD treatment are tabulated in Table 4 below to analyze how interactive the CKD health disparities factors can be.

5.1. Discussions

The purpose of the research is to address the health disparities lingering around the management of CKD in the minority communities in Tennessee; the approach employed involves using SD as a systems engineering application to simulate and analyses the dynamic complex factors associated with CKD. Health disparities cut across medical proceedings nationwide. Globally, CKD is a burden that affects diverse populations around the world. It is essential to address this chronic surge in the US, specifically Tennessee, which serves as a case study in the research. By addressing the importance of identifying CKD in the minority populations in Tennessee, it is necessary to be aware of the facts about the disease in the state.

ESRD attracts more attention globally, and hence, it takes a large part of the medical allocation to kidney treatment nationwide. This is why more concerns are raised at this stage of CKD because the kidney often requires dialysis or transplant.

Furthermore, in Tennessee, according to the American Kidney Fund in 2021 [42]:

- 15,662 populations are burdened with ESRD without dialysis treatment or kidney transplants.

- 11,495 populations are on dialysis to stay alive, while 4,167 have undergone kidney transplants.
- In 2020, 2783 Tennesseans required kidney transplants and were on a waiting list
- In 2020, Tennessee had 655 successful kidney transplants.

As previously mentioned, in Tennessee, the minority populations bear the most burdens that come with ERSD. For this reason, this research addresses the challenge associated with the bias present in the management of this disease.

From the models, the use of CLM is to investigate the sources of these disparities. From figure 11, since the incidence of CKD begins with the risk factors, this model creates the interconnectivity and influences within these risk factors to show whether they can be part of the sources of CKD disparities. Afterward, figure 18 modeled the impacts of the social determinant of health within the minority communities to establish the root causes of the bias generally contributed to CKD.

Moreover, in addressing the influence of the bias in the medical management and treatment of CKD, the SFM in figure 11 created a simulation to analyze the health disparities from the patients, the medical experts, and the healthcare system. Typically, the current population of Tennessee, according to the 2020 census, served as the population stock in the model to produce the desired simulation results. Furthermore, each influencing factor associated with CKD was included in the model.

Conclusively, the model generated graphical results that showed the effect of the disparities in the CKD healthcare interventions in the minority communities. From the model, graphs depict the trends required to ascertain the existence of bias in the CKD.

5.2. Conclusions

Unlike other chronic diseases, CKD comes with overwhelming physical, mental, and financial burdens. In its earlier stages, most people are asymptotic, not knowing they have it. It is becoming a global concern with its incidence and prevalence. And often, if CKD is not discovered and monitored earlier, it progresses gradually to kidney failure or ESRD, giving the patients two alternatives, either continuous dialysis or kidney transplant. Furthermore, CKD treatment and management involve loads of medical attention and expenses. The weight of all these conditions disproportionately affects the minority populations nationwide. Hence, it creates several burdens in these communities. As a result of the challenges involved in CKD incidence and prevalence, it is essential to address the treatment of disease across the board. The healthcare intervention provided by the healthcare system should be unbiased to improve the health of CKD. since the US is home to a diverse population with different racial and ethnic backgrounds, the minority populations' CKD healthcare needs to be addressed equitably as other populations. Therefore, specifically, this research focused on the minority communities in Tennessee. A systems engineering application is employed to address the healthcare interventions provided to these communities in Tennessee. The application is based on the system dynamics modeling to simulate various interrelated dynamic complex factors associated with CKD, beginning with the risk factors involved to the nature of treatment rendered and the health disparities involved. Moreover, the graphical results showed the relationships that exist within these factors, most significantly, how some of these factors trended with the nature of disparities from the patients, the PCPs, the nephrologist, and the healthcare system, the research showed that SD could be applied to model various dynamic, interrelated factors in CKD incidence and prevalence to uncover the healthcare disparities associated with it. The development of the SDM and the underlying mathematical equations would aid policymakers and decision-makers in the healthcare area to make more informed decisions regarding CKD health disparities. They would be able to use the model as a decision support tool to understand the dynamic behavior of all the variables and understand the different interactions and how changes in various factors would impact other key variables and to what extent.

Furthermore, based on the statistical data showing the variance in the populations of the minority communities in Tennessee, disparities exist in CKD healthcare intervention, and there is a need to address earlier generally, and specifically, in the minority populated area.

5.3. Intervention and Recommendations

5.3.1. Interventions

The CLM visualizes the possible healthcare interventions necessary to curtail the challenges of healthcare disparities in CKD management. In order to comprehend entirely the root causes and effects of the various interrelated factors associated with CKD and its comorbidities, it is vital to address the evident and latent disparities in CKD care. These healthcare disparities can result from the patients, PCPs, nephrologists, and the healthcare system. Therefore, a dive into the causes and influences of these healthcare agents are necessary. The CLM in figure 30 creates different loops to analyze the interventions required to reduce or eradicate health disparities in CKD.

Moreover, in loop R1 and R2, since CKD progresses to different stages, the early referral of its patients to the nephrologists by the PCPs and the appropriate implementation of its treatment guidelines by PCPs would reduce CKD progression to other stages. In loop R3, every population, either majority or minority, experiences the influence of SES and SDH. As such, the CKD physicians need to understand these social factors and the psychosocial factors that exist in minority populations to reduce the progression of CKD and create its delay to ESRD. In the model, proper awareness of CKD treatment and management by the patients can delay CKD progression. Furthermore, in loop R4, establishing cordial relationships between physicians and the populations can also help reduce CKD progression and curtail the health disparities. Loop R5 models an influence of lack of ethnicity/ race, age, and gender bias by both PCPs and nephrologists on the delay of CKD prevalence. In loop R6, the healthcare system's continuous CKD care training for PCPs and nephrologists can delay its progression to other stages and ESRD.

Moreover, more physician visits for the patients' advanced CKD care with more multidisciplinary research on CKD treatment in loop R7 can reduce CKD progression and eradicate the health disparities in the minority populations. In the model, adequate reimbursement for CKD treatment and more CKD medical experts to these communities can reduce health disparities. Proper use of the CKD map risk by both physicians and patients can help reduce disparities in the CKD.

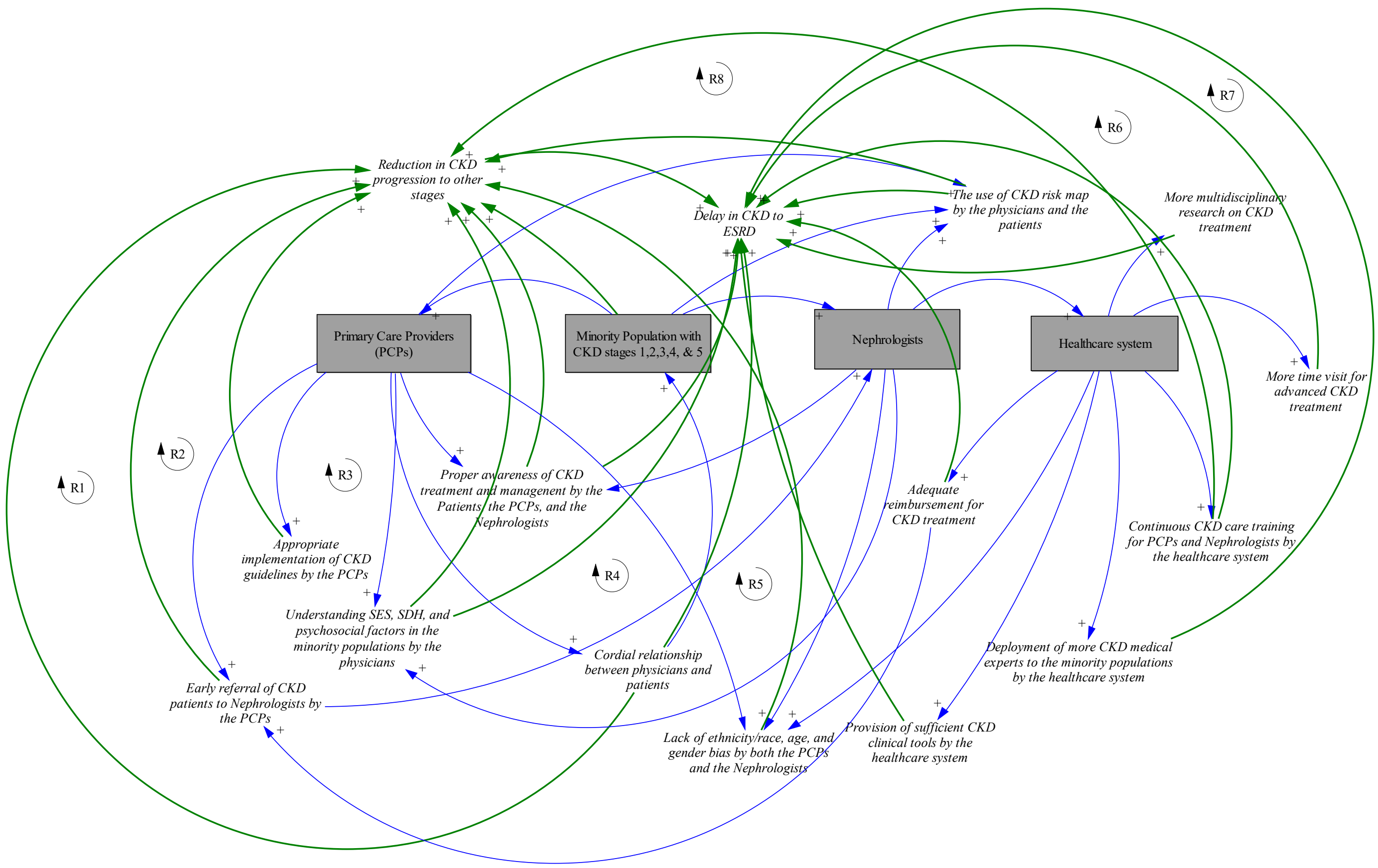

Figure 30.The CLM Showing the Interventions for Health Disparities in CKD Care.

5.3.2. Recommendations and Future Directions

5.3.2.1. Recommendations

This research serves as a novel application of SD in addressing healthcare disparities, precisely in CKD treatment and management. The CLMs and SFM in the study produced the desired simulated results to visualize the possible existence of inequalities in CKD stages in Tennessee. In order to comprehensively investigate health disparities, it is crucial to employ a modeling approach such as SDM to critically create the simulation of the interacting factors involved in the occurrence of the disease. Furthermore, SDM could be applied to similar research to establish further results that enhance the best decision-making policies nationwide and globally. The interventions provided in the study using the CLM showed the recommended approaches and procedures required to curtail the surge of healthcare disparities in CKD. Additionally, the model has been validated with the current population figure of Tennessee according to the 2020 census to ensure and enhance proper decision and policymaking in the state. The table below shows the possible recommendations derived from the research model when there are observable healthcare disparities in every stage of CKD.

Table 7. Recommendations to Alleviate Healthcare Disparities

1.	Early referral of CKD patients in the minority populated areas to the nephrologists by the PCPs.
2.	Proper awareness of the CKD treatment and management by PCPs and Nephrologists.
3.	Adequate reimbursement of optimal CKD care and management support to the healthcare system by the government.
4.	Appropriate implementation of CKD care guidelines (e.g., KDOQI) by both the PCPs and Nephrologists in the minority populated environments.

5.	Better understanding of the interaction between the SES, SDH, psychosocial factors of patients in the minority populated areas by the PCPs and the Nephrologists.
6.	The existence of improved and proper cordial relationships between the physicians and the patients.
7.	Allocation of more preferential treatments by the PCPs and Nephrologists based on the patients' ethnicity/race, age, and gender.
8.	The training and deployment of more medical CKD experts to the minority populated areas by the healthcare system.
9.	Th provision of sufficient CKD clinical tools in the minority populated areas.
10.	The involvement of more medical experts in the minority areas in the minority populated areas.
11.	The consultation and involvement of more multidisciplinary research concerning the management and treatment of CKD in these areas.
12.	The rendering of more available time visits for advanced CKD treatment by the PCPs and the Nephrologists.
13.	The provision of improved CKD treatment educational tools for both PCPs and patients by the healthcare system.

14.	Adequate understanding of patients' ethnicity/race, gender, age, and family history of kidney disease by the PCPs and the nephrologists without bias
15.	Accountability for CKD patients' health outcomes by the PCPs and Nephrologists.
16.	The continuous provision of unbiased CKD care training for both the PCPs and Nephrologists by the healthcare system.
17.	Proper understanding of the CKD risk map by both physicians and PCPs.
18.	The education of the CKD patients on the prevalence and treatment of CKD by the physicians and the healthcare system.

5.3.2.2. Future Directions

Since some factors, specifically the risk factors influencing the incidence and prevalence of CKD are not instant and take time to develop. Therefore, time lags could be considered for such variables in future studies. Also, as explained in previous chapters, several risk factors initiate the incidence of CKD, and for this model, not all the factors are considered. In future studies, risk factors such as the patient's family history of kidney disease, gender, and race/ethnicity could be considered.

Furthermore, clinical trials to evaluate patients' wellbeing in various stages of CKD considering bias in treatment can be considered which would require a long amount of time. Additionally, the model could be generalized to other type of chronic diseases. In each specific case, the factors, inputs, and equations need to be adjusted.

CHAPTER 6: REFERENCES

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