Mathematical Modeling on the Obesity Epidemics and Effectiveness of Control Programs in the State of Georgia

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Obesity has remained a major contributing factor of morbidity and impaired quality of life in the state of Georgia for the last few decades. The health complications from obesity and its huge negative impact on the well-being has lowered the life expectancy of the people. In this paper, we present the data on obesity and obesity related health issues in Georgia. We devise a mathematical model to explain the epidemiological dynamics of obesity in Georgia. We also provide the comparative study of obesity prevalence in Georgia withthe prevalence in Colorado, and West Virginia. The model can beusedto numerically assess the effectiveness of intervention programto control obesity.

I. INTRODUCTION

Georgia has been ranked in the nation as the 24th state with the highest adult obesity rate and the 18th state with the highest obesity rate for youth ages 10 to 17 [1]. Currently 31.6% of adults in Georgia are obese compared to 20.6% in the year 2000 and 10.1% in 1990 [2]. According to the most recent data published in 2017, adult obesity rate has exceeded 35% in seven states, 30% in 29 states, and 25% in 48 states [1]. Colorado and Hawaii are the only states with adult obesity below 25%.

Obesity is defined as a systemic disease that causes excessive accumulation of body fat leading to adverse health conditions [3]. Three different measures are often used in epidemiological studies to assess obesity: body mass index (BMI), waist circumference (WC), and waist to hip circumference ratio (WHR). BMI is most practiced. It equals the ratio of weight in kilograms divided by the square of the height in meters (kg/m^2) [4]. The numeric value of BMI interpreted by World Health Organization (WHO) are 18.5- 24.9 kg/m^2 for normal, 25.0 – 29.9 kg/m^2 for overweight and 30 kg/m^2 or higher for obesity.

Obesity is detrimental to physical and mental health and it imposes a huge financial toll on individuals and society. It is strongly associated with higher death rates driven by the comorbid conditions such as type 2 diabetes, hypertension, heart disease, stroke, osteoarthritis, obstructive sleep apnea, and certain cancers [5], [6].A 2017 study estimated the medical cost of obesity to be as high as $342 billion (in 2013 dollars) [7]. In Georgia, the annual cost of obesity is estimated at $2.4 billons which is $250 per Georgia resident [8]. The average length of hospital stay for an obese individual is 60% longer than for normal-weight individual nationwide [9]. An obese adult spends on medical care an average of $3,490 annually more than an adult with healthy weight. Despite many efforts to increase awareness, the obesity epidemic is staggering high in an alarming rate [10].

Obesity is a complex condition that can affect every individual [5].The major contributing factors to obesity aresocial and physical environment, genetics, low physical activity, poor diet and some diseases.Poor diet and physical inactivity have contributed to the rise in obesity in Georgia. Only one in four adults in Georgia consume 5 or more servings of fruits and vegetables daily and only 48% of adults in Georgia are involved in physical activities on a regular basis [11].

According to the analysis of BRFSS 2017 data, prevalence of obesity in Georgia is higher in some specific group of population than the others [5]. Adults aged 45- 64 have the highest prevalence of obesity (35.6%). Adults aged 18-44 have the lowest prevalence of obesity (26.7%) followed by adults aged 65 and older (28.5 %).Asian adults have the lowest prevalence of obesity (11.2%) compared with white (29.3%), Hispanic (32.4%) and multiracial (32.8%) adults. Adults who live in urban areas have lower prevalence of obesity (30.3%) compared with adults living in suburban (30.6%) and rural (34.8%) areas.Adults who have not graduated high school have the highest prevalence of obesity (37.4%) compared with high school graduates (36.1%), adults with some college education (34.8%), and college graduates (23.3%). Adults who earn $75,000 or more a year have lower prevalence of obesity (27.2%) than adults who earn less than $25000 a year (38.0%).

II. PREVALENCE OF ADULT OBESITY IN COLORADO, GEORGIA, AND WEST VIRGINIA

Provided below is the data summary of adult obesities for Colorado, Georgia, andWest Virginia by age, gender, and ethnicity.

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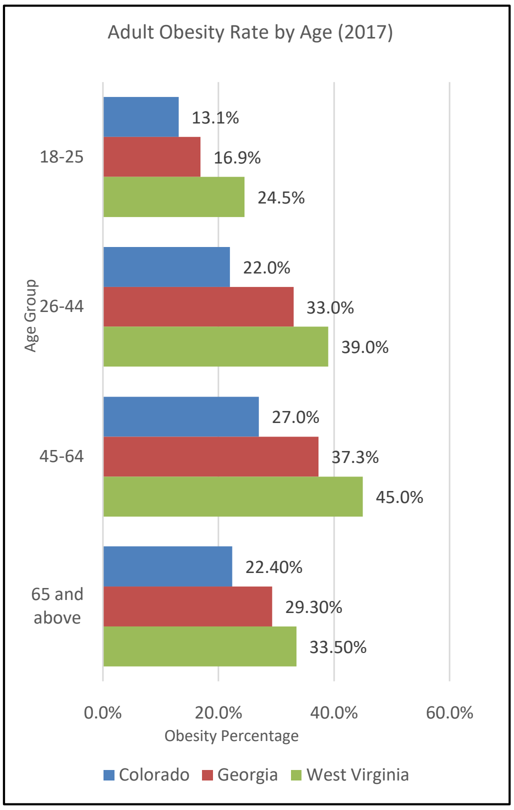

FIG. 1: Data summary of adult obesities for Colorado, Georgia, andWest Virginia by age.

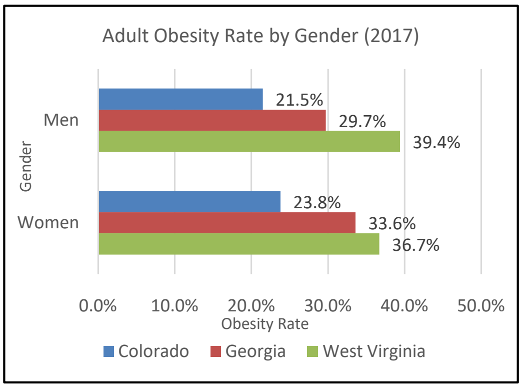

FIG. 2: Data summary of adult obesities for Colorado, Georgia, andWest Virginia by gender.

III. ADULT OBESITY TREND IN COLORADO, GEORGIA, AND WEST VIRGINIA

In the table below, we present the obesity statistics in Georgia, Colorado, and West Virginia. Colorado and West Virginia are currently the states with the lowest the highest adult obesity rates in the nation [12].

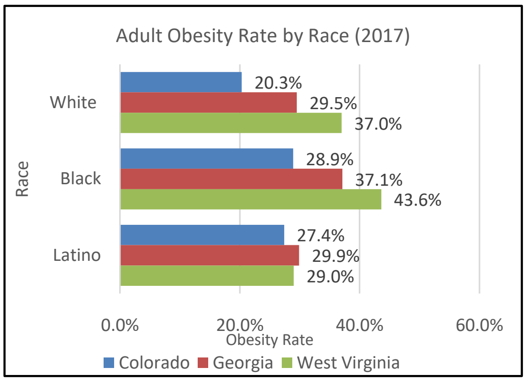

FIG. 3: Data summary of adult obesities for Colorado, Georgia, andWest Virginia by ethnicity.

IV. OBESITY GROWTH PATTERN

Chirstakies and Fowler demonstrated in their study that obesity can spread from person to person through a social network [13]. The growth pattern of the obesity is similar to that of the contagious disease [14]. When a person is born and exposed to an obesogenic environment having overweight and obese individuals, he or shewould gradually gain weight and grow to become an obese person.

V. METHODS

A simple S-I-R model is used to capture the obesity dynamics. Ejima et al used the model to demonstrate that the intervention programs that can check the contagious hazard would be effective to control the obesity [14]. Our study focuses in the obesity of Georgia. We compare the obesity growth pattern of Georgia with that of Colorado and West Virginia, the states with the lowest prevalence of obesity and the highest prevalence of obesity in the US.

A. SIR Model

In this model never obese individuals are taken as susceptible. It is assumed that all the new born babies are not obese but when born in the obesogenic society they are susceptible to weight gain to become overweight and gradually become obese. People who always have maintained healthy weight are also in the susceptible group. Obese people are taken as infectious, and the obesity is contagious. Ex-obese individuals are treated as recovered. We represent the number of people that are susceptible, infected, and recovered at time t as S(t), I(t), and R(t) respectively. They all are functions of time.

We assume the population N(t) to be constant. Obviously, N(t)=S(t)+I(t)+R(t). Birth rate and death rate

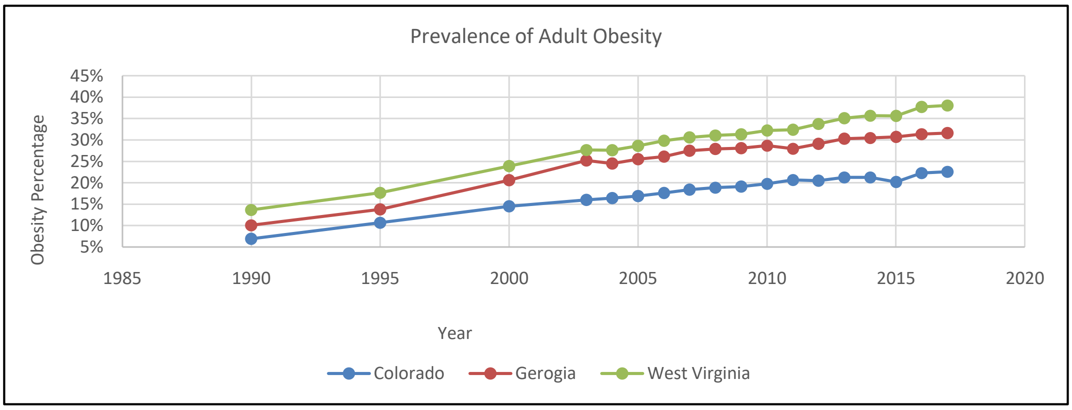

FIG. 4: Obesity statistics in Georgia, Colorado, and West Virginia.

are the same and the rate is represented by μ. Transmission coefficient of obesity is denoted by β. The physical activity level and eating pattern developed by socializing in group or community affects the value of β. The quantity β I(t) is the contagious hazard of obesity. The hazard of obesity due to non-contagious reason is denoted by ϵ. Many factors like genetics, health condition and other lifestyle components affect its value. For simplicity, we assume the value of ϵ to be constant. There is a natural tendency among the newly obese people to get recovered back from obesity. The natural recovery rate is denoted by γ. The recovered or ex-obese individuals have stronger tendency to fall back to obesity as compared to never obese individuals. The relative risk of regaining the weight among ex-obese individuals is denoted by σ.The numerical value is always greater than 1. The empirical value of σ from literature is found to be close to 8.0. The sum, $\lambda(t) = \beta I(t) + \epsilon$, of contagious hazard and non-contagious hazard of obesity is known as the force of infection.

As new born are not obese, they are susceptible to obesity. A portion of the susceptible μS die out at the natural death rate. Because of the force of infection $\lambda(t) = \beta I(t) + \epsilon$, the portion λ(t)S(t) of never obese individuals enter into the obese or infected group. From infected group, a portion μI die out. Because of the natural tendency of recovery from obesity, γ I people bounce back to non-obese stage. Out of these recovered people, μR die out, and $\sigma\gamma$R fall back to the obese state. The detailed diagram is given below.

B. System of Differential Equations

The pattern of change of obesity demonstrated in the above diagram can be represented by a system of ordinary differential equations.

$$\frac{ds}{dt} = \mu N - [\lambda(t) + \mu]S(t)$$

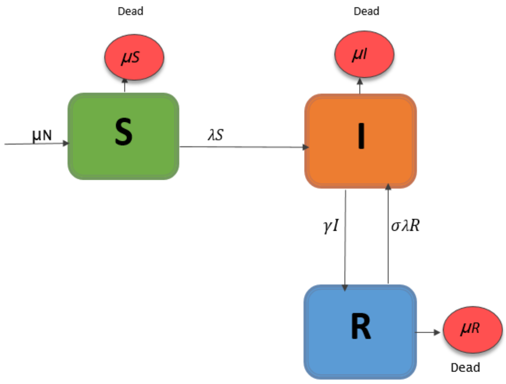

FIG. 5: A detailed diagram of the Model.

$$\frac{dI}{dt} = \lambda(t)S(t) + \sigma\lambda(t)R(t) - (\mu + \gamma)I(t)$$

$$\frac{dR}{dt} = \gamma I(t) - [\sigma\lambda(t) + \mu]R(t)$$

where, $\lambda(t) = \beta I(t) + \epsilon$

The system of equations can be solved with initial condition S(0) = N. We can solve $d(S, I, R)/dt = 0$ numerically and get anasymptotically equilibrium solution point $(S*, I*, R*)$, where all the trajectories of the system converge.

C. Parameter Setting and their values

The values of the parameter were estimated in such a way that the trajectories show a good fit to the obesity prevalence data from the year 1990 to 2010. We take the value of N to be constant and equal to 100,000. The values of the average life expectancy at birth are consistent with the state's values obtained from the website of Center for Disease Control and Prevention (CDC). The values of transmission coefficient of obesity, non-contagious hazard of obesity, relative hazard of obesity among ex-obese and average duration of obesity are consistent with empirical values in the literatures.

Table 1: Parameters Values

Description	Notation	Baseline Value	Reference
Population size	N	100,000	Assumed, as in [14]
Average life expectancy at birth	$1/\mu$	72.7 - 78.1(yrs.)	[12]
Transmission Coefficient of obesity	β	1.99×10^{-7} - 4.33×10^{-7}	[14]
Non-contagious hazard of obesity	ϵ	0.012 (per yr.)	[14], [12]
Relative hazard of obesity among exobese	σ	5.0 - 8.0	[14], [15]
Average duration of obesity	$1\ \gamma$	35.8 (yrs.)	[14], [16]

D. Obesity Pattern by SIR Model

The picture below shows the pattern of the numerical solution of the differential equations in the SIR model. It represents the baseline dynamics of the obesity epidemic. The graphs in the picture are the time dependent epidemiological trajectories. Never-obese population is represented by the blue graph, obese population by red and the ex-obese population by orange. The high number of never obese individuals at the beginning is because all the new born are taken as non-obese. The graph shows that as time passes by the prevalence of obesity converges to an equilibrium level. From the numerical solution, we can see that it takes almost 200 years for the obesity to get to the saturation state.

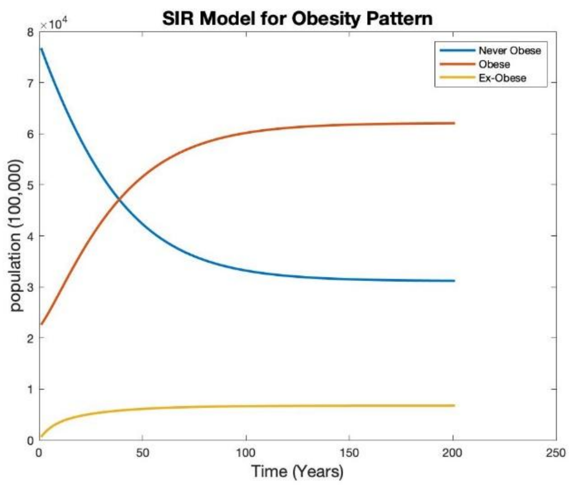

FIG. 6: SIR Model for Obesity Pattern.

VI. OBESITY PREVENTION INITIATIVES IN GEORGIA

Obesity is a complex problem in Georgia, and a multifaceted approach is necessary to deal with it. State has already implemented a number of policies to prevent obesity. State has regulations requiring licensed Early Childhood Education (ECE) programs to have healthy eating policies. There is a defined physical activity requirement in the ECE settings, and the meals and snacks must meet the dietary guidelines. State also has regulations requiring the licensed ECE programs to allow or encourage on-site breast feeding. ECE programs are required to make drinking water available to all the children. In schools, state requires all students to participate in physical education. To promote healthy eating and active living in the community level, state has adopted a Complete Streets policy. It also provides funding for Healthy Food Financing Initiatives.

It is imperative that more environmental features and organizational policies are needed in early child care education facilities, schools, communities, worksites, and health care settings to promote healthy eating and active living. Adults are more likely to be active on a regular basis if they have access to a safe and convenient place to walk.

VII. EFFECTIVE WEIGHT LOSS STRATEGY

A. Level 1 Intervention

We consider a hypothetical intervention program known as the level 1 intervention. We assume it to be a multifaceted intervention program which can control contagious and non-contagious hazard of obesity and significantly lowers the overall hazard rate $\lambda(t) = \beta I(t) + \epsilon$ of obesity. The intervention program includes the initiatives in ECE facilities, schools, communities, worksites, and healthcare settings. Early screening for overweight and obesity, healthy lifestyle changes aiming to maintain a heathy weight are the goals of the level 1 intervention. We assume that the level 1 intervention program keeps the value of transmission coefficient of obesity β at a lower end which is 1.99×10^{-7}. It reduces the relative hazard of obesity σ among exobese individuals form 8.0 to 5.0. The reduction in the hazard is achievable by constant counselling, consistent engagement in physical activities and healthy eating practices.

B. Predicted Obesity Growth with and without the Intervention

Predicted prevalence of obesity by current trend and that after level 1 intervention are shown in the adjacent pictures. Under the model, the prevalence of obesity significantly lowered in the states of Colorado, Georgia, and

West Virginia.

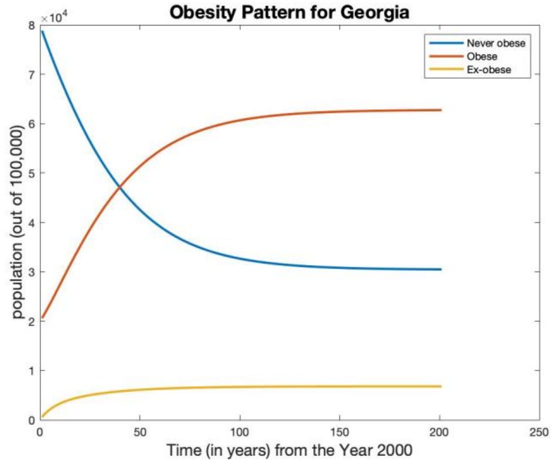

FIG. 7: Obesity Pattern for Georgia.

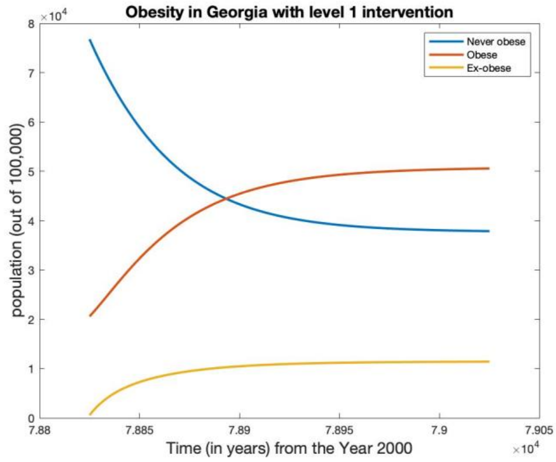

FIG. 8: Obesity in Georgia with level 1 intervenation.

VIII. OBESITY RATES IN THE YEAR 2100 AS PREDICTED BY THE MODEL

Table 2:Prevalence of Obesity in Percentage

State	Year 2000 (base year)	Year 2100 (Expected by the current trend)	Year 2100 (Expected after level 1 Intervention)
Georgia	20.60%	60.69%	47.8%
Colorado	14.50%	61.92%	48.84%
West Virginia	23.90%	61.38%	48.11%

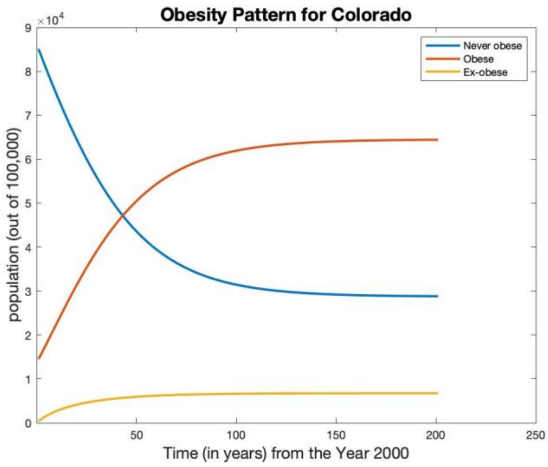

FIG. 9: Obesity Pattern for Colorado.

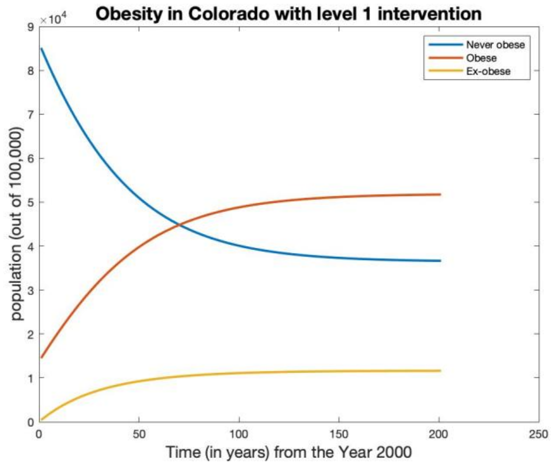

FIG. 10: Obesity in Colorado with level 1 intervenation.

IX. RESULTS

The prevalence of adult obesity is rising in an epidemic level. If the current trend continues, the percentages of adult obesity in the states of Georgia, Colorado, and West Virginia will get to lower sixties within eight more decades. The percentage of the prevalence of obesity among adults can be lowered in Georgia, Colorado, and West Virginia by 12.89%, 13.08%, and 13.27%, and respectively by the year 2100 with the help of level 1 intervention.

X. CONCLUSION

Obesity has a huge negative impact on health and quality of life of people in Georgia. If current trend follows, the obesity continues to rise in an epidemic level. Inter-

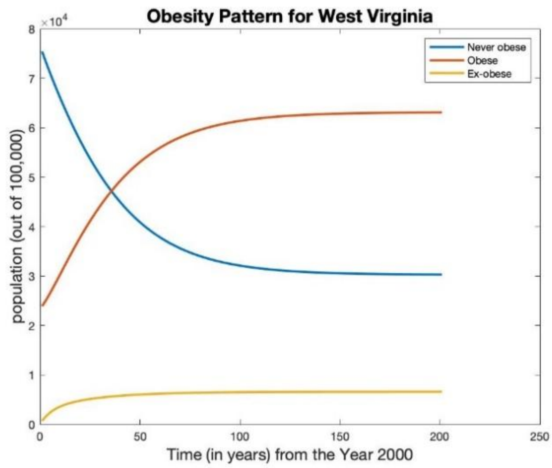

FIG. 11: Obesity Pattern for West Virginia.

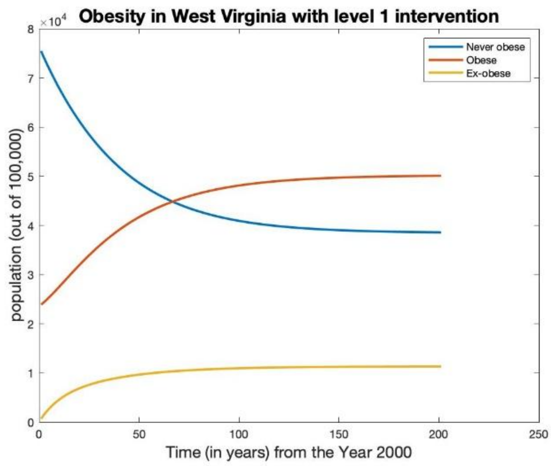

FIG. 12: Obesity in West Virginia with level 1 intervenation.

vention programs, especially the ones that can controls the contagious factor of obesity would be very effective. With intervention program the rise in prevalence of adult obesity can be lowered significantly. The effect of intervention program is very similar on the obesity dynamics of Georgia, Colorado, and West Virginia.

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