Trends in BMI, overweight and obesity among South African adults: 1998-2012

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Benjamin Walwyn (WLWBEN001)

bwalwyn@gmail.com

Supervisors: Prof. Rob Dorrington and Dr. Debbie Bradshaw

Abstract

Cross-sectional data for different survey years can be used to estimate the trends in mean BMI and prevalence rates over time. Co-morbidities associated with BMI are used to measure the affect these trends have on public health. Overweight and obesity rates are used for public communication of the serious concerns. Data from five national surveys from 1998-2012 were used to investigate trends. Statistical analysis of trends was undertaken with bayesian and normal linear regression models. Mean BMI increased by 0.08 kg/m^2 from 23.3 in 1998 to 24.3 kg/m^2 in 2012 for men and by 0.12 kg/m^2 from 27.2 to 28.5 kg/m^2 for women. Prevalence of overweight increased by 9% and 8%, and obesity by 4% and 7% for males and females respectively. A flattening of the BMI distribution was observed but prevalence trends associated with this change were not found to be significant. The increases were in mainly white and Asian/Indian population groups, while urban areas had higher levels than rural. Trends are expected to continue and increase the burden of disease associated with excess weight. Possible intervention and prevention is recommended with further investigation of the causes of different trends to inform policy.

1 Introduction

Excess weight is associated with a higher risk of a number chronic diseases and is considered to increase mortality and morbidity. Studies have shown that the mean Body-Mass Index (BMI) as well as the related categorical definitions of excess weight have been increasing for a number of decades globally (Finucane *et al.*, 2011), with mean BMI growing by about 0.4 kg/m^2 per decade since 1980. These trends are expected to continue, and global recognition of the burden of disease caused by high BMI and obesity have led to their inclusion as one of the leading risk factors for mortality and morbidity (Ezzati *et al.*, 2005). Survey analyses of anthropometric measures in South Africa have previously noted the risk associated for high levels (Puoane *et al.*, 2002; Joubert *et al.*, 2007)

Moreover, no recent study on the mortality and morbidity effects of obesity exists. Increasing levels of excess weight place South Africa further increase the risks to the population and pose further economic risks. Future obesity scenarios require our attention, but without estimates of trends, it is difficult to perceive the situations and the outcomes.

There are multiple nationally representative health surveys which can be used to estimate trends in BMI and overweight and obesity prevalence. Based on recent studies, this research aims to fit models to investigate the the trends and examine population changes in weight, and provide information for future predictions and studies. It explores the relationship of BMI and overweight and obesity prevalence over time and across all sampled subpopulations.

2 Background

Recent global estimates (Finucane *et al.*, 2011) show 1.46 billion overweight (34% of global population) and over 500 million obese people. Data extracted from the

1998 South African health survey estimate mean BMI of 24.1 for males and 28.6 for females, 28% of the population overweight and 38.6% of females obese (Joubert *et al.*, 2007).

Studies all use the same measurements for excess weight in adults. Such a convention allows researchers to quantify trends and effects of excess weight, and then make comparisons. The World Health Organisation (WHO) provides a set of guidelines for appropriate measures in epidemiological studies of various life-stages, and the corresponding public health implications in determining risk of mortality and morbidity (de Onis and Habicht, 1996). It suggests BMI as an anthropometric measure for adults, with strong identification of at-risk individuals (WHO, 1995). BMI studies have found excess weight to be a significant contributor to mortality and morbidity worldwide (Guh *et al.*, 2009). Figure 2.1 from Willett *et al.* (1999) shows the relationship of BMI with diabetes, chronic heart disease and other disorders.

There is a significant rise in all-cause mortality of both sexes above 25 kg/m^2 (Stevens *et al.*, 1998). The study of causes and effects (Haslam and James, 2005; Kopelman, 2000) of excess weight shows that body weight increases when there is a positive energy imbalance between intake and expenditure. Individuals in excess of recommended healthy weights are at higher risk of various forms of cancer, cardiovascular diseases, respiratory disorders, diabetes (type II), osteoarthritis (Haslam and James, 2005; Kopelman, 2000), reproductive function complications, liver and gall bladder disease (Kopelman, 2007), stroke, chronic back pain and asthma (Guh *et al.*, 2009). BMI is also linearly correlated with cholesterol (Ezzati *et al.*, 2005), and other risk factors (Ezzati *et al.*, 2002), meaning excess weight acts in association with and through other conditions to increase mortality and morbidity risk.

Descriptive statistics provide a useful overview of the size of the risk by coun-

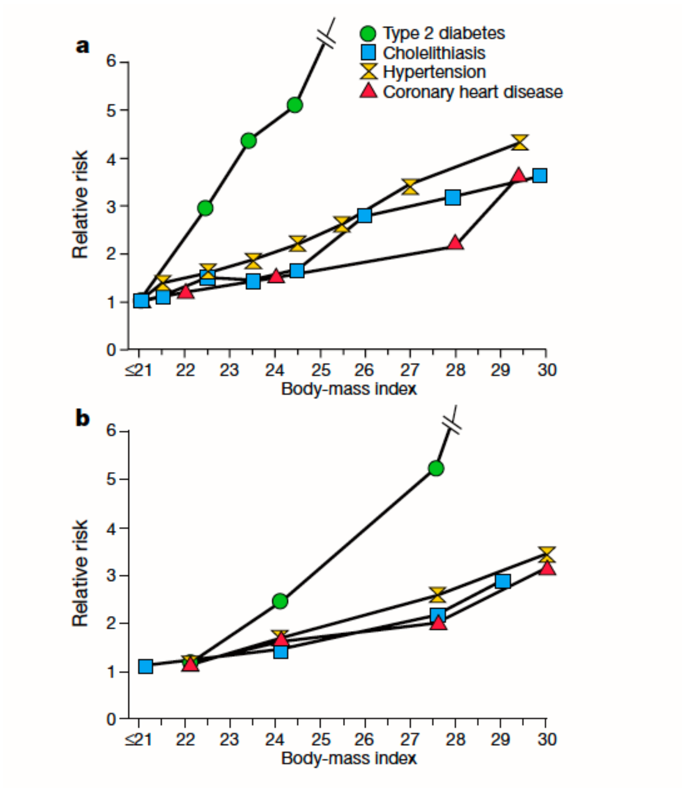

Figure 2.1: Co-morbidities for female (a.) and male (b.) BMI up to 30 kg/m^2

try, region or on the global level. Mean BMI is highest in North America and Australasia and lowest in Sub-Saharan Africa (Finucane *et al.*, 2011). Southern Africa has a relatively high BMI although it is surrounded by countries of the Sub-Saharan region with low BMI (Stevens *et al.*, 2012). Variation is related toenvironmental, genetic and psychosocial factors, relating largely to diet and physical activity, that cause and influence the effect of overweight and obesity (Kopelman, 2000; Haslam and James, 2005). Some of these factors are measurable (Ezzati *et al.*, 2002) and, hence, many studies have estimated trends in BMI means and overweight and obesity prevalences over time and across the corresponding social interactions. Studies have, therefore, informed on the relationships with these various indicators. Models must take into account these covariate factors in order to provide a better understanding of BMI, whether on a community, national or global level.

BMI is usually of interest for studies investigating effects of excess weight because of its continuous relationship with related diseases and health concerns. Prevalence rates are used to publicly communicate the corresponding risk, since they are easier to understand and distinct categorise at-risk individuals (Ezzati *et al.*, 2005).

Variation with covariates can be seen between men and women (Ezzati *et al.*, 2005; Sassi *et al.*, 2009; Stevens *et al.*, 2012), indicating interaction effects. The magnitude of the interactions effects are dependant on the factors – country, age, population group, income and others. There are also differences in health implications for men and women. For example, men are at higher risk of hypertension for all BMI levels above 25. Models are, therefore, usually fitted and results presented separately for both sexes.

Using different survey years allows for analysis over time. Trend studies have been done previously using national health survey data in the US for 1999-2004

(Ogden *et al.*, 2006) and 1988-2010 (Ladabaum *et al.*, 2014), in the UK over 1993-2004 (McPherson *et al.*, 2007), and most other developed nations through periods dating from the early 1990's to the late 2000's (Sassi *et al.*, 2009). Whereas the US now runs a continuous national survey (Ogden *et al.*, 2006), data are often scarce in time for developing countries (Prentice, 2006).

3 Materials and Methods

3.1 Data

This study used data from the South African Demographic and Health Surveys (SADHS) in 1998 and 2003 and all three waves of the National Income Dynamics Survey (NIDS) in the years 2008, 2010 and 2012. The samples for these studies were selected using a stratified, two-stage clustered sampling design. Oversampling of certain provinces is required to provide sufficient data on all population groups.

Strata differ between surveys. SADHS sampling units are stratified by province and residence type (urban and rural), while the NIDS strata are 53 district councils. This means that the NIDS was not designed to be representative at a provincial level. The waves of the NIDS are repeated with the same households and are, therefore, not independent.

The number and demographic characteristics of participants from each survey are shown in table A.1. There were a number of unlikely BMI observations less than 12 kg/m^2 and greater than 60 kg/m^2 that were removed. Incomplete observations were also excluded. The 2003 SADHS had the smallest study population with 7,813 complete observations and NIDS 2012 had the largest, with over 17,000. The total increased from wave one. Apart from an increased number of respondents, previously excluded individuals became eligible after growing older than the adult threshold of 15 years old in the second and third waves.

Data are sparse in time with no data for 9 of the 14 years included in the period of study from 1998-2012. Between 1998 and 2008 the only data are from the 2003 SADHS, the smallest of the studies.

Finally, height and weight was measured and not self-reported.

3.2 Methods

Analyses were performed to investigate trends in mean BMI and overweight and obesity prevalences for both sexes. Ages were grouped into pre-defined categories of ten years beginning with 15-24. All ages over 65 were merged due to lack of tail data. The midpoints of these groups were used for modelling with age as a continuous variable. The midpoint of the oldest age category was taken to be 70. Four population groups for African, Coloured, White and Asian/Indian and all nine provinces were included in the analyses.

National means and prevalences for ages, populations groups and residence type were extracted for descriptive analysis and comparison with previous studies. Average BMI and corresponding standard deviation for all subpopulations in each survey year were calculated with appropriate survey methods to examine trends. Table 3.1 summarises the number of extracted means. Missing data are mainly in older age categories, among the smaller population groups in certain provinces. All means with missing standard errors were removed. The same procedure was used to extract data for overweight and obesity analyses, which is summarised in table A.2. Here, individuals were categorised as overweight and obese using the WHO cut-offs of BMI greater than 25 and 30 kg/m^2 respectively.

A bayesian regression model was used to fit trends in mean BMI with covariates. Posterior distributions include uninformative prior distributions for all parameters. Estimation was undertaken in OpenBUGS with Monte Carlo Markov Chain algorithms and models were compared based on Deviance Information Cri-

Table 3.1: Summary of mean BMI data extraction

	Survey year					**Total**
	1998	2003	2008	2010	2012	
Means						
Male						
extracted	170	141	146	144	153	754
no standard error	28	31	23	34	35	151
means with standard error	141	110	123	110	118	603
Female						
extracted	172	156	154	149	154	785
no standard error	20	27	21	27	18	113
means with standard error	152	129	133	122	136	672

teria (Web Appendix).

The BUGS procedures are highly flexible, using appropriate methods to handle different specifications as the models were developed and additional parameters included. This flexibility causes a number of drawbacks, however, mainly the possibility of correctly specified models producing meaningless results. The model results were, therefore, reviewed in each case to validate a model specification. For instance, uncertainty is reflected in the credibility intervals for parameter estimates, which were considered to evaluate plausibility of final estimates. The final model was chosen based on the lowest deviance.

The distributions of transformed proportions were plotted in figuresC.1 and C.2, and observed to be approximately normally distributed. Therefore, logit-transformed proportions were fitted using normal linear regression to estimate trends in overweight and obesity prevalence. Proportions were fitted with mean

BMI as a covariate in addition to age, population group and province. Including BMI changes the interpretation of the trend parameter from that of the BMI model. It measures the increased risk of being overweight and obese per year over and above the effects of increasing mean BMI.

Quadratic and cubic splines for age and mean BMI were included in the initial models based on exploratory analysis of their relationship with the transformed proportions. The corresponding plots are shown in figures C.3, C.4, C.5 and C.6.

Complexity and reduction in deviance were considered to select final models, achieving an R^2 of 0.68-0.73 for all models. Further model validation was performed with residual analysis. Plots are included in appendix C, which reveal approximate normal histograms of residuals, homogeneity in variance and few outliers. These outliers were mainly in higher age categories of small population groups, which were expected to have high sampling variability.

Extended data and model descriptions are included in the online appendix, including code for Stata and R, and the BUGS model specifications.

4 Results

There was a shift in the distribution of BMI in South Africa from 1998 to 2012 (figure 4.1), as mean BMI and prevalences of overweight and obesity increased for both sexes in all ages, population groups, provinces and in both urban and rural areas (see tables 4.2, A.3 and A.4). Over this period, national mean BMI increased from 23.3 to 24.3 kg/m^2 for males and from 27.2 to 28.5 kg/m^2 for females. While the distribution remained skew and still peaked marginally below the overweight cut-off of 25 kg/m^2 in 2012, it was more symmetrical around a higher mean. This means there was an increase in the number of individuals with BMI above the average. Figure 4.2 shows the resulting national increases in overweight and obesity prevalence rates for males and females across the five surveys.

The proportion of men and women overweight increased from 29% and 57% to 38% and 65% respectively. Women are most at risk of obesity, with prevalence increasing from 30% to 37%. Male obesity only increased by 4% over the period, from 9% to 13%.

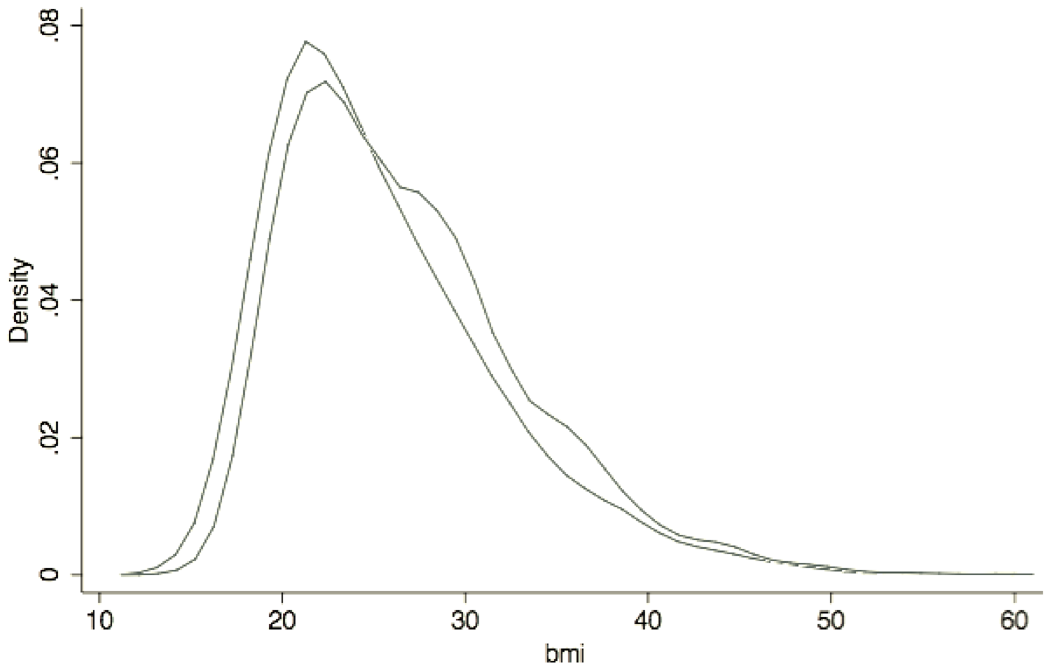

Figure 4.1: Shift to the right in the distribution of BMI from 1998 to 2012

Male and female mean BMI, plotted with confidence intervals in figure 4.3, show clear increases for the five surveys. The largest increase occurred between 2003 and 2008. However, the 2003 mean was unexpectedly lower for females than in 1998. The confidence intervals for both years overlap, so it could equally be that the 1998 data were higher than the true population means. There was also a peak in mean BMI at 24.5 kg/m^2 for men and 28.9 kg/m^2 for women in 2010. The means in 2012 consequently showed decreases, though they remained within confidence intervals for the results of the previous survey. These discrepancies are

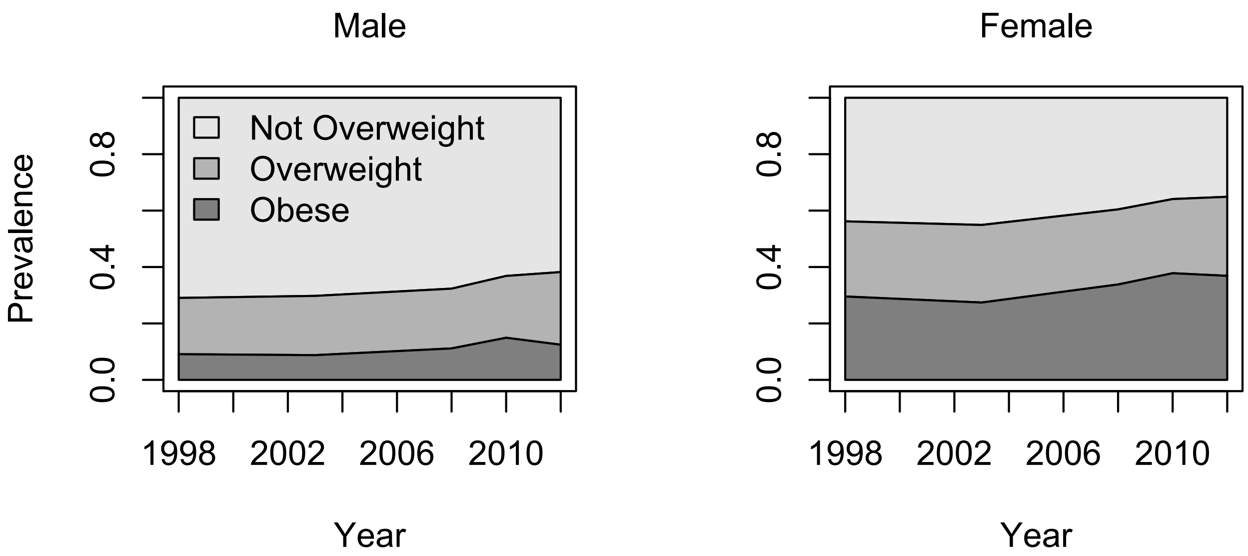

Figure 4.2: Prevalence growth in overweight and obesity for both sexes

also observed in equivalent plots for prevalences (see figure B.1).

Modelling estimated that mean BMI increased by 0.08 (0.05-0.11) kg/m^2 for males and 0.12 (0.08-0.17) kg/m^2 for females per year between 1998 and 2012. Trend analyses estimates are reported in table 4.1. Other parameter estimates for the mean BMI model can be seen in table A.5 for males and A.6 for females.

Table 4.1: Trends in BMI and obesity by sex

	Mean BMI	Overweight RR	Obese RR
per year (95%)			
male	0.078 (0.045, 0.108)	1.006 (0.996, 1.016)	1.003 (0.991, 1.015)
female	0.124 (0.079, 0.171)	1.0063 (0.995, 1.015)	1.0008 (0.992, 1.010))

The credibility intervals for year and age parameter estimates have plausible

Figure 4.3: National male and female average BMI for each survey year with 95% confidence intervals

bounds when considering the exploratory analyses of time and age (see figures 4.3 and 4.5). Also, considering the proximity of provincial and population group means around the national mean, shown in table 4.2, it is unsurprising that the credibility intervals for fixed effects include zero.

Figure 4.4 plots the linear trend with confidence regions for mean BMI since 1998 and for the next five years for both sexes. The magnitude of increase has been much larger for females, seen by the scale of the each figure. Males could, however, reach mean BMI of 25 kg/m^2 in five years if the same increases continue.

Relative risk estimates in table 4.1 indicate an increase in time of overweight and obese for any subpopulation mean BMI. This means that distribution is widening on the right tail, as observed in the histogram of BMI above (figure 4.1). Note, however, these are potentially spurious results as confidence intervals include one.

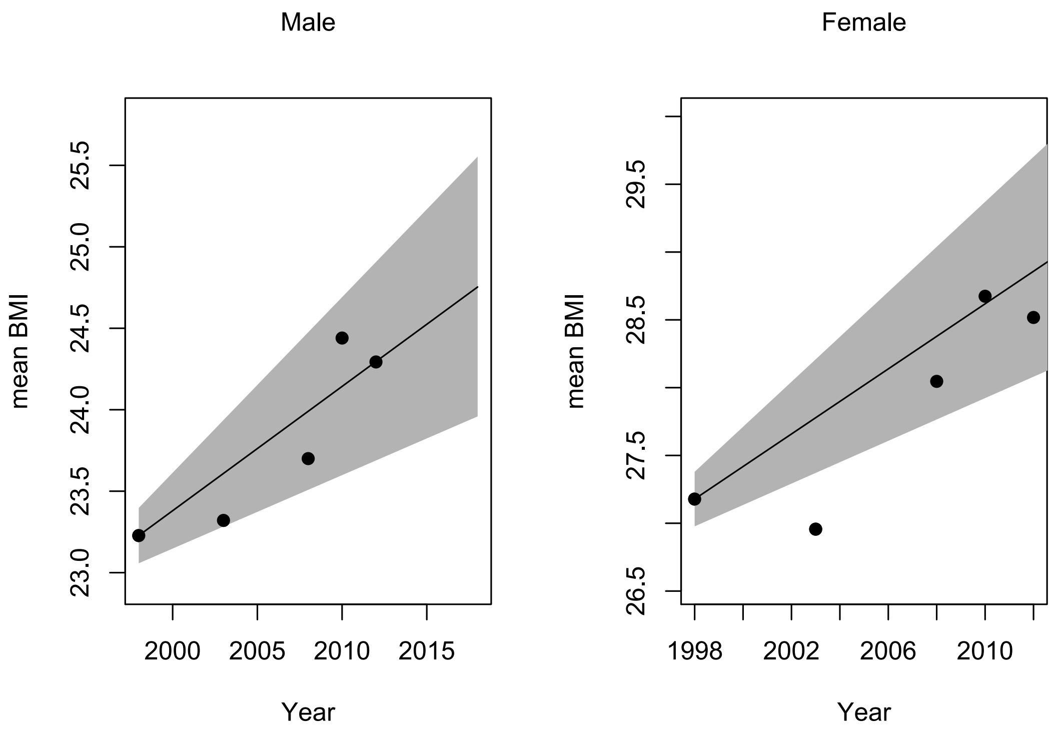

Figure 4.4: Age distribution of BMI in African population in 1998 and 2008

Mean BMI terms, on the other hand, were significant in all models (see online appendix).

Other coefficients and relative risks for the male and female overweight models are reported in table A.7 and A.8 of the appendix. As in the BMI model, province and population group fixed effects were inconclusive when considering confidence intervals. Age, however, see was significant and has a relationship with mean BMI and overweight and obesity prevalences.

Age distributions of weight in 2012 exhibit a steady increase with age until a peak at around 60 years for men and 50 for women before mean BMI decreases, shown in figure 4.5. Mean BMI is highest for female middle age categories (35-54), above 30 kg/m^2. There is a more gradual increase for males and a less significant decrease after the peak.

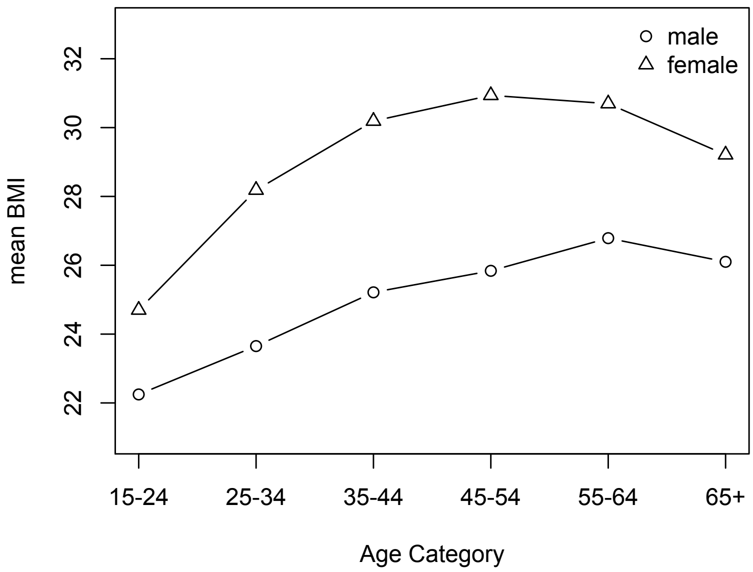

Figure 4.5: Age distribution of BMI nationally in 2012

Figure 4.6 shows the age distribution by population group. White male BMI was much higher than the other groups and did not show the same curved age-BMI relationship. This is reflected in the corresponding white male obesity rate of 35%, more the twice the rates for other groups. Similarly, the female coloured population had a higher increase in BMI with age and did not decline at any age group. Female Asian/Indian have a lower overall level of mean BMI for all ages, which in fact declines after age 40. The African curves in figure 4.6 relate similarly to those in D.1 by Wittenberg (2011), indicating that the age relationship remained relatively constant throughout the period.

For both sexes, increases in mean BMI over the period of study for population groups were largest for white and Asian/Indian populations. These were also the most uncertain increases, however, reflected in the standard deviations of table

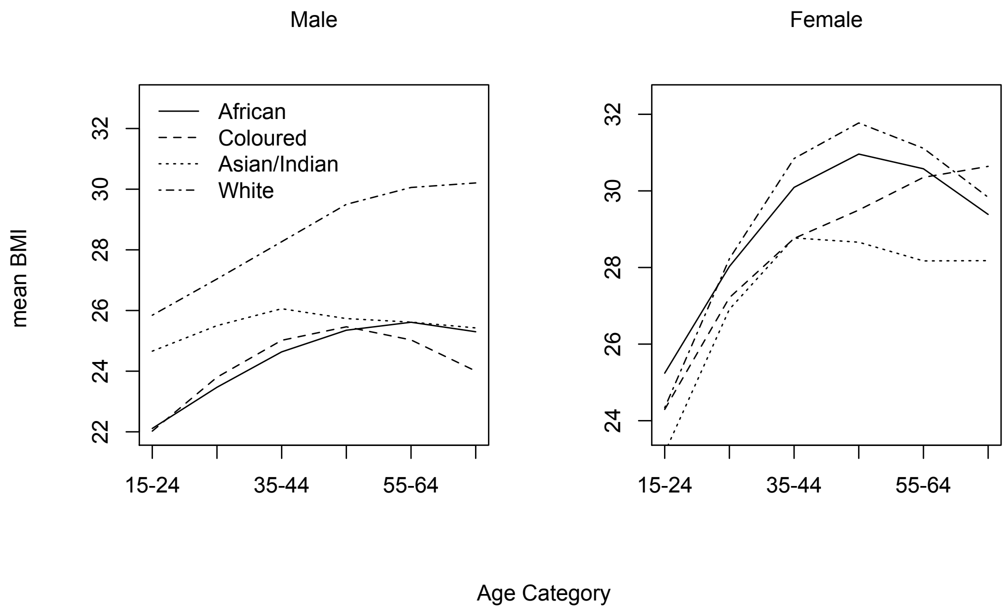

Figure 4.6: Age distribution of BMI by population group in 2012

4.2. Coloured population mean BMI increased the least over the period. The 2012 level of BMI was highest for females in white and African groups, and in white and Asian/Indian for males. The african male population had the lowest mean BMI of 23.8 kg/m^2. Increases in overweight and obesity prevalence were highest for white males and females. White male and female obesity increased by 15% and 18% respectively.

Provincially, 2012 overweight and obesity rates were the lowest for men in the Free State and Limpopo and highest in the Western Cape. Rates for women in all provinces were clustered around the national rates (see tables A.3 and A.4. The increases in weight were very similar for urban and rural areas, though urban areas tended to have higher levels of mean BMI and prevalence rates.

Table 4.2: Means and standard errors in 1998 and 2012

	Male				Female			
	1998		2012		1998		2012	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
Age								
15-24	21.2	0.1	22.2	0.2	23.7	0.1	24.7	0.2
25-34	23.4	0.2	23.7	0.2	26.9	0.2	28.2	0.2
35-44	24.3	0.2	25.2	0.3	29.0	0.2	30.2	0.3
45-54	25.2	0.2	25.8	0.4	29.6	0.3	30.9	0.4
55-54	24.7	0.2	26.8	0.3	29.8	0.3	30.7	0.3
65+	24.4	0.3	26.1	0.5	27.5	0.3	29.2	0.4
Population Group								
African	22.8	0.1	23.8	0.1	27.4	0.1	28.5	0.2
Coloured	23.6	0.2	24.1	0.6	26.8	0.3	27.8	0.4
Asian/Indian	23.1	0.4	25.6	0.6	25.1	0.4	27.5	0.7
White	26.2	0.3	28.6	0.6	26.5	0.3	29.9	0.7
Province								
Eastern Cape	23.4	0.2	24.1	0.3	27.0	0.2	28.4	0.4
Free State	22.6	0.3	23.3	0.4	26.9	0.3	29.7	0.4
Gauteng	23.6	0.3	24.5	0.4	28.2	0.3	28.6	0.4
KwaZulu Natal	23.6	0.2	24.5	0.5	28.1	0.3	28.9	0.2
Limpopo	22.2	0.3	23.1	0.3	25.4	0.3	27.1	0.4
Mpumalanga	22.5	0.3	24.7	0.5	26.6	0.3	28.3	0.5
North West	22.2	0.2	23.8	0.3	25.2	0.2	28.3	0.4
Northern Cape	22.2	0.3	24.2	0.5	25.9	0.4	28.2	0.5
Western Cape	24.6	0.2	25.3	0.5	27.6	0.3	29.1	0.3
Residence								
Urban	23.8	0.1	27.7	0.1	24.8	0.2	29.0	0.2
Rural	22.3	0.1	26.4	0.1	23.5	0.1	27.8	0.2
National	23.3	0.1	24.3	0.2	27.2	0.1	28.5	0.2

5 Discussion

Global mean BMI trends were 0.04 kg/m^2 (0.02-0.06) for men and 0.05 kg/m^2 (0.03-0.07) per year over the same period (Finucane *et al.*, 2011). Therefore, South African mean BMI has risen faster than the worldwide average for both sexes. Prevalence continues to increase as the distribution of BMI changes, flattening over the higher range and widening to a higher mean.

The increases match those of high-income countries like Australia and the United States (Finucane *et al.*, 2011; Ladabaum *et al.*, 2014). The absolute level of obesity is as high as most high income countries for women, if not higher. Current policy has not been effective in preventing the burden of disease spreading. Obesity ranks in the top ten global risks (Lim *et al.*, 2013), and results suggest that South Africa is one of the most affected countries. It is a matter of serious public health concern.

The bayesian model used to examine trends in adult mean BMI has two strengths. First, it allows the standard errors, which increase for the smaller samples of subpopulations, to be carried into the model and increase the variance component of the likelihood during the MCMC estimation procedure. The hierarchical structure allows a second variability component of the likelihood for each study, which accounts for further variation in the age and trend affects, which might not be constant between surveys. Secondly, during estimation, data for missing subpopulations is randomly sampled based on parameter values, thus 'borrowing strength' from age, time, and fixed effects components. The uncertainty from this procedure is then reflected in the credibility intervals and resulting predictions for the model. Hence, posterior credibility intervals reflect the true availability of information.

The trend estimates are similar to those produced by Finucane *et al.* (2011) using a bayesian model, with more accurate intervals. That model, on which much of this analysis was based, had a different hierarchical structure, however. While South Africa was the highest level in this study, country was the lowest level for the studies by Finucane *et al.* (2011) and Stevens *et al.* (2012). This influenced the analysis in two ways. Firstly the model had to be adapted to fit the within-country data. Although this makes the model a lot simpler, it means fewer aspects could be replicated. Secondly, survey data is divided into subpopulations for age, sex, provinces and population groups for this analysis, while for country analysis it would have been stratified by age and sex only, and is hence subject to lower sample variance. This shows in the significance of many coefficients in both sets of models fitted in this analysis. In fact, the trend estimates were relatively insensitive to these variables, and hence they could have been removed.

This analysis does not include nonlinear trend effects either. Hence, projections are unreliable over the long-term. It is unlikely that mean BMI increases will continue indefinitely on the straight trajectory fitted by this study. Overweight and obesity rates are limited from zero to one, meaning continuously large increases are unlikely in future. The scope for including nonlinear terms was, however, limited due to lack of survey year data.

The surveys used in the study were cross-sectional. Age and birth cohort effects, therefore, cannot be estimated using the trends and age category relationships. The age effect refers to how BMI changes throughout the life cycle of an average individual, while birth cohort is the effect of a specific generation. Data for individuals during they life cycle and from a specific birth cohort are required to fit those effects.

The cross-sectional data are further limited by the changes in survey design. Different demographic data was used in each survey by Statistics South Africa to draw random enumeration areas from the strata, which also differ between the SADHS and NIDS surveys. Apart from using sampling weights applied to each of the five surveys in calculating means and prevalences, the age structure of the population was not taken into account. Studies use age standardisation to weight age categories according to the proportion of demographic represented by those ages.

This may have an impact on the results from the NIDS waves, which are not independent. Wave 2 in 2010 showed a higher average BMI than the following wave in 2012. This might be due to respondents turning 15 between waves. Since mean BMI is lowest for 15-24, this might bring down the national average, seen in 4.3. This would not affect the models and trend estimates, for which means were stratified by age. The time between waves two and three was also shorter than between the first and second wave, hence a lower increase would be expected, which is within the upper confidence bound.

It could alternatively be caused by other dependencies, such as the U-curve findings of the age and cohort effects observed in some studies of obesity (Sassi *et al.*, 2009). Overweight and obese individuals are also more likely to withdraw from the study (von Ruesten *et al.*, 2011) and have a higher risk of mortality.

The low male and females means for 2003 SADHS, the smallest survey, might be due to larger sample variance. They could also indicate a nonlinear trend, whereby mean BMI rose more sharply from 2003-2012. Therefore, current trends may be higher than estimated in this study if increasing nonlinear effects, observed in the plots of mean BMI over time, are significant.

Increasing income for developing nations poses an additional possibility for higher trends in future. Rising BMI in countries has been associated with increasing levels of income and related socio-economic factors like education and urbanisation (Ezzati *et al.*, 2002; Sassi *et al.*, 2009). Data from the US (Ezzati *et al.*, 2005) indicates an upward shift of the income-BMI relationship over time (1980-2000). This places developing nations on a higher BMI trajectory than previously estimated, assuming GDP continues to rise. This may partly explain the higher BMI in SA relative to the region (Finucane *et al.*, 2011) and other less developed African countries. On the other hand, income growth over the period of study could partly explain the increasing mean BMI in middle and high income groups, due to the disease of affluence paradigm (Ezzati *et al.*, 2005), where constant access to transport and overconsumption of food are the cause of energy imbalance.

The uncertainty of the linear regression models leads us to conclude the affect of the flattening distribution was insignificant in increasing female obesity prevalences beyond the affect of mean BMI. The estimates are slightly stronger but still not significant for male overweight and obesity. If estimates are taken at value, it would mean that prevalence of overweight and obesity are higher in 2012 for the same levels of mean BMI than in 1998.

The research aim was to estimate the trends in BMI and prevalences of overweight and obesity. It does not try to explain why weight is increasing nationally or among any specific subpopulations. However, other research has given much insight into the causes of obesity. Further analysis of diet, physical activity, socioeconomic factors and urban migration might inform the policy decisions that will be made to curb increasing excess weight and negative public health consequences.

Different trend estimates for population groups and ages should be considered to understand specific dynamics which can be used to target policy, and might uncover specific reasons for increasing BMI. For instance, the increase in mean BMI for males is larger for whites and Asians/Indians indicating there could be different trend than compared to African or coloured, which might be characteristic of an underlying income relationship with BMI.

Excess female weight in SA has been well-documented (Puoane *et al.*, 2002; Joubert *et al.*, 2007; Stevens *et al.*, 2012), and the difference in mean BMI trends indicates the gap is widening further. The possible cause of trends in African women might be related to cultural influences and perceptions of weight described by Kopelman (2000), while low mean BMI for coloured populations might be associated with the combination of geographic and income effects. However, we cannot isolate such effects in this study, or distinguish underlying causes.

Including the effects of socio-economic variables might improve models. Income and education have been found to have on affect on overweight and obesity in other countries (Sassi *et al.*, 2009), or even just using a social class category (McPherson *et al.*, 2007). Though population group could conceivably act as a proxy for income in South Africa, this study would not show meaningful results, as made clear by high levels of BMI for both high and lower-income population groups. A more effective method would be to include different levels of income within population groups.

Further consideration of other variables might help inform prevention, such as childhood malnutrition or an appropriate proxy like childhood height-adjusted weight, since early weight gain might have larger long-term effects than during adulthood (de Onis and Habicht, 1996; Kopelman, 2000).

Although this study cannot show a causal relationship with BMI, urban areas are related to higher BMI. This is probably linked to transport in urban areas and the minimal demand for physical activity. With the proportion of the population living in urban areas likely to increase with urban migration, the exact relationship and the possible extent of this effect should be investigated.

Study into the affect of physical activity, diet and caloric intake can inform individuals about lifestyle consequences. These affects have been studied in other countries (Lim *et al.*, 2013; Ladabaum *et al.*, 2014), however, the context of a developing economy is different, such as the affects of western diet. We require sufficient understanding of risks, dynamics and causes to implement policy intervention and social preventative measures.

We must continue to monitor this important risk factor, to provide reliable data for policy intervention and assessment. Environmental and cultural factors need to be investigated to understand different trends and how they might be curbed. Estimated trends in this study indicate the country is facing further increases in the near future. This needs to be considered in the context of existing public health challenges and also the planned changes in healthcare provision.

There is no single contributor to the rise of overweight and obesity in South Africa, and no single intervention will reverse its effects. There are many possible solutions, involving complex consideration of various factors affecting weight like urban planning, nutrition in child and adult years and socio-economic class. Like other communicable diseases, future prevention is highly important. Losing weight is difficult, and hasn't been shown to reduce risk. It is therefore essential to raise public awareness that makes energy intake and expenditure of relevance and institutes changes in individual behaviour.

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A Tables

Table A.1: Individuals

	Male					Female				
	Survey year					Survey year				
	1998	2003	2008	2010	2012	1998	2003	2008	2010	2012
Age										
15-24	1 622	1 065	1 711	2 122	2 453	1 827	1 238	2 095	2 351	2 774
25-34	1 075	672	1 075	1 271	1 562	1 592	927	1 517	1 747	2 255
35-44	999	545	857	856	1 039	1 317	828	1 412	1 462	1 761
45-54	690	410	673	732	883	1 064	735	1 217	1 275	1 562
55-54	518	289	476	434	630	921	472	835	907	1 169
65+	535	239	433	404	513	878	398	835	885	1 064
Population Group										
African	4 218	2 454	4 163	5 024	5 810	6 036	3 385	6 181	7 337	8 750
Coloured	759	972	698	680	971	995	628	1 074	1 025	1 440
Asian/Indian	176	704	67	66	79	263	410	105	84	105
White	479	274	297	149	220	578	164	348	181	284
Province										
Eastern Cape	1 294	237	673	673	825	2 005	392	1 062	1 081	1 217
Free State	548	244	341	295	474	643	370	441	450	621
Gauteng	392	348	640	672	884	686	538	809	871	1 096
KwaZulu Natal	808	381	1 293	1 827	1 845	1 180	518	2 302	2 791	3 133
Limpopo	446	701	443	505	664	720	569	738	838	1 055
Mpumalanga	514	328	414	543	520	702	493	576	698	740
North West	563	352	409	426	476	663	412	557	524	684
Northern Cape	548	354	420	422	528	689	504	582	556	740
Western Cape	532	270	592	536	864	593	502	841	818	1 217
Residence										
Urban	3 267	1 881	2 508	2 667	3 489	4 312	2 597	3 580	3 677	4 885
Rural	2 378	1 334	2 717	3 192	3 591	3 569	2 001	4 328	5 527	5 700

Table A.2: Proportions: numbers of extracted subpopulations and numbers of missing data points

	Survey year					Total
	1998	2003	2008	2010	2012	
Overweight proportions						
Male						
extracted	170	141	146	144	153	754
no standard error	42	41	32	45	48	208
proportions remaining	128	100	114	99	105	546
Female						
extracted	172	156	154	149	154	785
no standard error	35	45	37	38	30	185
proportions remaining	137	111	117	111	124	600
Obese proportions						
Male						
extracted	170	141	146	144	153	754
no standard error	50	61	47	52	54	264
proportions remaining	120	80	99	92	99	490
Female						
extracted	172	156	154	149	154	785
no standard error	38	56	32	33	41	200
proportions remaining	134	100	122	116	113	585

Table A.3: Overweight proportions and standard errors in 1998 and 2012

	Male				Female			
	1998		2012		1998		2012	
	prop.	s.e.	prop.	s.e.	prop.	s.e.	prop.	s.e.
Age								
15-24	0.11	0.01	0.18	0.02	0.31	0.01	0.39	0.02
25-34	0.28	0.02	0.33	0.02	0.56	0.01	0.64	0.02
35-44	0.38	0.02	0.50	0.03	0.70	0.02	0.77	0.02
45-54	0.45	0.02	0.49	0.03	0.72	0.02	0.78	0.02
55-54	0.43	0.03	0.63	0.04	0.72	0.02	0.77	0.02
65+	0.42	0.03	0.54	0.04	0.60	0.02	0.73	0.03
Population Group								
African	0.25	0.01	0.34	0.01	0.57	0.01	0.65	0.01
Coloured	0.31	0.02	0.36	0.06	0.54	0.02	0.58	0.03
Asian/Indian	0.33	0.03	0.52	0.06	0.49	0.03	0.64	0.07
White	0.57	0.03	0.77	0.05	0.53	0.03	0.75	0.03
Province								
Eastern Cape	0.31	0.01	0.36	0.03	0.55	0.01	0.65	0.03
Free State	0.24	0.02	0.30	0.03	0.55	0.02	0.68	0.02
Gauteng	0.31	0.03	0.39	0.04	0.62	0.02	0.66	0.02
KwaZulu Natal	0.32	0.02	0.41	0.05	0.63	0.02	0.67	0.02
Limpopo	0.22	0.02	0.26	0.03	0.44	0.02	0.58	0.03
Mpumalanga	0.24	0.02	0.44	0.04	0.51	0.02	0.64	0.03
North West	0.21	0.02	0.38	0.05	0.45	0.02	0.64	0.03
Northern Cape	0.22	0.02	0.40	0.05	0.50	0.02	0.62	0.03
Western Cape	0.38	0.02	0.44	0.05	0.57	0.02	0.65	0.02
Residence								
Urban	0.33	0.01	0.42	0.02	0.59	0.01	0.67	0.01
Rural	0.22	0.01	0.31	0.02	0.51	0.01	0.62	0.01
National	0.29	0.01	0.38	0.02	0.57	0.01	0.65	0.01

Table A.4: Obesity proportions and standard errors in 1998 and 2012

	Male				Female			
	1998		2012		1998		2012	
	prop.	s.e.	prop.	s.e.	prop.	s.e.	prop.	s.e.
Age								
15-24	0.03	0.01	0.04	0.01	0.10	0.01	0.13	0.01
25-34	0.08	0.01	0.09	0.01	0.27	0.01	0.36	0.02
35-44	0.13	0.01	0.14	0.02	0.39	0.02	0.46	0.02
45-54	0.17	0.02	0.23	0.03	0.45	0.02	0.52	0.02
55-54	0.14	0.02	0.22	0.03	0.45	0.02	0.53	0.02
65+	0.14	0.02	0.22	0.04	0.32	0.02	0.40	0.03
Population Group								
African	0.08	0.01	0.10	0.01	0.31	0.01	0.36	0.01
Coloured	0.09	0.01	0.14	0.02	0.28	0.02	0.35	.02
Asian/Indian	0.09	0.02	0.14	0.04	0.21	0.03	0.35	0.07
White	0.20	0.02	0.35	0.05	0.25	0.02	0.43	0.05
Province								
Eastern Cape	0.10	0.01	0.10	0.02	0.29	0.01	0.34	0.02
Free State	0.08	0.01	0.10	0.02	0.29	0.02	0.44	0.03
Gauteng	0.10	0.02	0.14	0.02	0.35	0.02	0.37	0.03
KwaZulu Natal	0.10	0.01	0.12	0.03	0.35	0.02	0.39	0.02
Limpopo	0.06	0.01	0.08	0.02	0.19	0.02	0.28	0.02
Mpumalanga	0.07	0.01	0.12	0.02	0.26	0.02	0.34	0.03
North West	0.05	0.01	0.10	0.01	0.19	0.02	0.37	0.04
Northern Cape	0.08	0.01	0.10	0.02	0.25	0.02	0.38	0.04
Western Cape	0.13	0.02	0.20	0.03	0.30	0.02	0.42	0.03
Residence								
Urban	0.11	0.01	0.15	0.01	0.33	0.01	0.40	0.01
Rural	0.06	0.01	0.08	0.01	0.25	0.01	0.32	0.01
National	0.09	0.01	0.13	0.01	0.30	0.01	0.37	0.01

Table A.5: Estimates for bayesian model of mean BMI - males

Variable	Posterior Estimate	(95% Cred. Interval)
(Intercept)*	23.62	(23.42, 23.89)
Year	0.078	(0.045, 0.108)
Age	0.037	(0.002, 0.073)
Age^2	0.024	(0.015, 0.026)
Age^3	0.0014	(-0.011, 0.012)
$(\text{Age-40})_+^3$	-0.0025	(-0.012, 0.011)
$(\text{Age-60})_+^3$	0.0003	(-0.011, 0.011)
Province		
Western Cape	-0.02	(-0.61, 0.58)
Northern Cape	-1.55	(-2.14, -0.95)
Free State	-1.18	(-1.82, -0.53)
KwaZulu Natal	-0.49	(-10.7, 0.08)
North West	-1.35	(-1.99, -0.73)
Gauteng	-0.69	(-1.24, -0.11)
Mpumalanga	-0.59	(-1.20, 0.03)
Limpopo	-0.58	(-1.26, 0.08)
Population Group		
Coloured	-0.54	(-0.95, -0.14)
Asian/Indian	0.33	(-0.3, 0.9277)
White	2.97	(2.59, 3.35))

*Baseline group is African/Eastern Cape

Additional variability for each survey

Term	Posterior Estimate	(95% Cred. Interval)
τ_1	0.5022	0.3755,0. 6264)
τ_2	0.4403	(0.1038,0. 5939)
τ_3	0.4392	(0.0935,0. 5863)
τ_4	0.3267	(0.0711,0. 4270)
τ_5	0.5215	(0.1189,0. 6717)

Table A.6: Estimates for bayesian model of mean BMI - females

Variable	Posterior Estimate	(95% Cred. Interval)
(Intercept)*	28.02	(27.22, 28.84)
Year	0.124	(0.079, 0.171)
Age	0.118	(0.065, 0.166)
Age^2	-0.0038	(0.004, 0.014)
Age^3	0.000097	(-0.012, 0.012)
$(Age\text{-}40)^3_+$	-0.0001	(-0.011, 0.012)
$(Age\text{-}60)^3_+$	-0.00001	(-0.012, 0.011)
Province		
Western Cape	-0.44	(-1.34, 0.47)
Northern Cape	-0.18	(-1.09, 0.72)
Free State	-0.17	(-1.07, 0.74)
KwaZulu Natal	0.50	(-0.37, 1.33)
North West	0.10	(-0.77, 0.97)
Gauteng	0.42	(-0.44, 1.24)
Mpumalanga	-0.32	(-1.24, 0.58)
Limpopo	-0.52	(-1.49, 0.39)
Population Group		
Coloured	-0.63	(-1.23, -0.05)
Asian/Indian	-0.49	(-1.19, 0.21)
White	-0.25	(-0.82, 0.32)

*Baseline group is African/Eastern Cape

Additional variability for each survey

Term	Posterior Estimate	(95% Cred. Interval)
τ_1	0.2421	(01770, 0.3210)
τ_2	0.1865	(0.1349, 0.2489)
τ_3	0.1102	(0.0808, 0.1449)
τ_4	0.1265	(0.0914, 0.1684)
τ_5	0.1066	(0.0583, 0.1698)

Table A.7: Estimates for model of overweight prevalence - males

Variable	Estimate	Relative Risk
(Intercept)*	-30.354	-
Year	0.0063	1.0063
BMI	0.9788	2.6613
BMI^2	-0.0128	0.9873
Age	0.0444	1.0454
Age^2	-0.0004	0.9996
Province		
Western Cape	-0.0601	0.9417
Northern Cape	-0.1426	0.8671
Free State	-0.0580	0.9436
KwaZulu Natal	0.1738	1.1899
North West	-0.0080	0.9921
Gauteng	-0.0140	0.9861
Mpumalanga	-0.0291	0.9712
Limpopo	-0.0854	0.9181
Population Group		
Coloured	0.1078	1.1138
Asian/Indian	0.1424	1.1530
White	0.2968	1.3455

*Baseline group is African/Eastern Cape

Table A.8: Estimates for model of overweight prevalence - females

Variable	Estimate	Relative Risk
(Intercept)*	-26.373	-
Year	0.0049	1.0049
BMI	0.9236	2.5411
BMI^2	-0.118	0.9983
Age	0.0062	1.0062
Age^2	-0.00004	0.9999
Province		
Western Cape	-0.0301	0.9704
Northern Cape	-0.0576	0.9440
Free State	0.0290	1.0295
KwaZulu Natal	-0.0757	0.9271
North West	0.0671	1.0694
Gauteng	-0.0346	0.9660
Mpumalanga	-0.0955	0.9089
Limpopo	0.0701	1.0727
Population Group		
Coloured	0.0795	1.0828
Asian/Indian	0.1793	1.1964
White	0.1229	1.1308

*Baseline group is African/Eastern Cape

B Prevalence trend plots

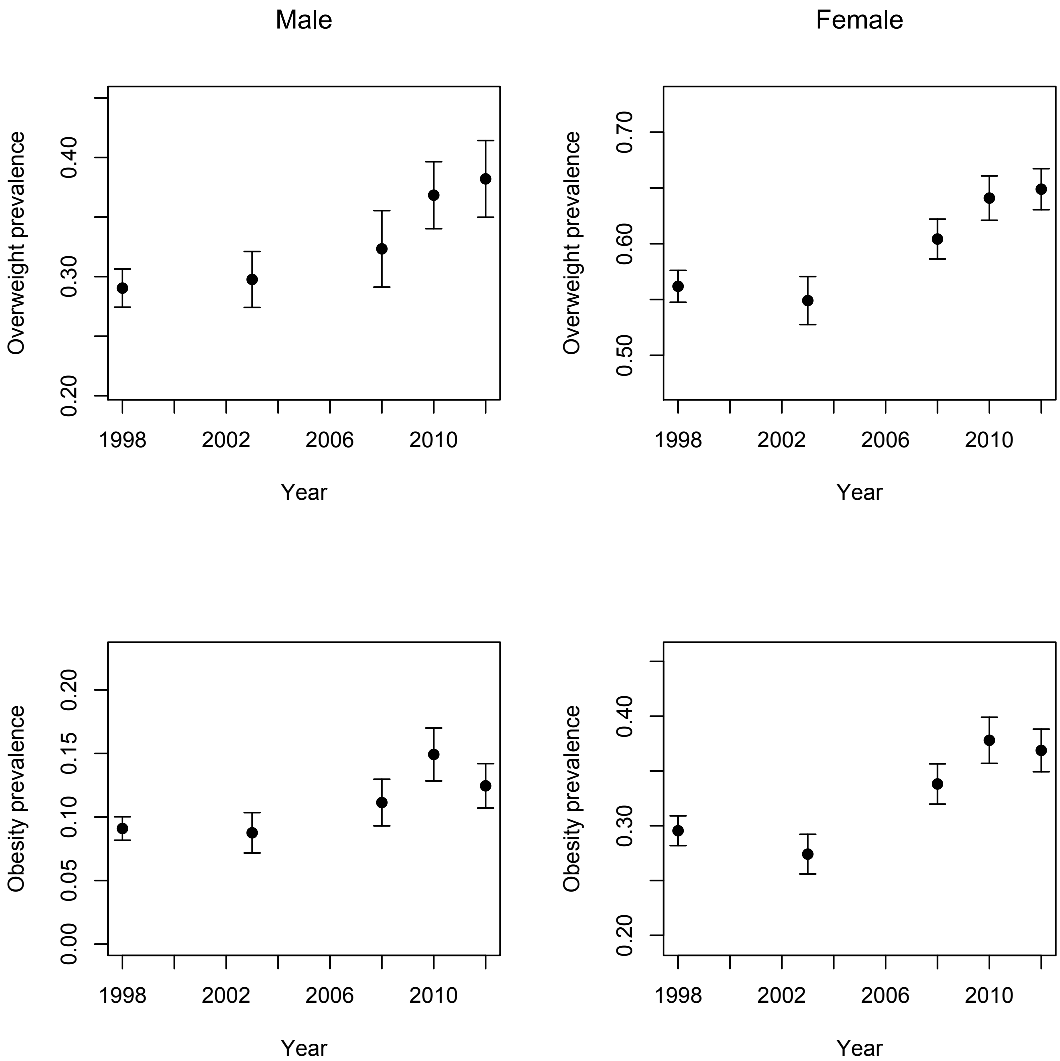

Figure B.1: Overweight and obesity prevalence for males and females in each survey year

C Linear regression analysis

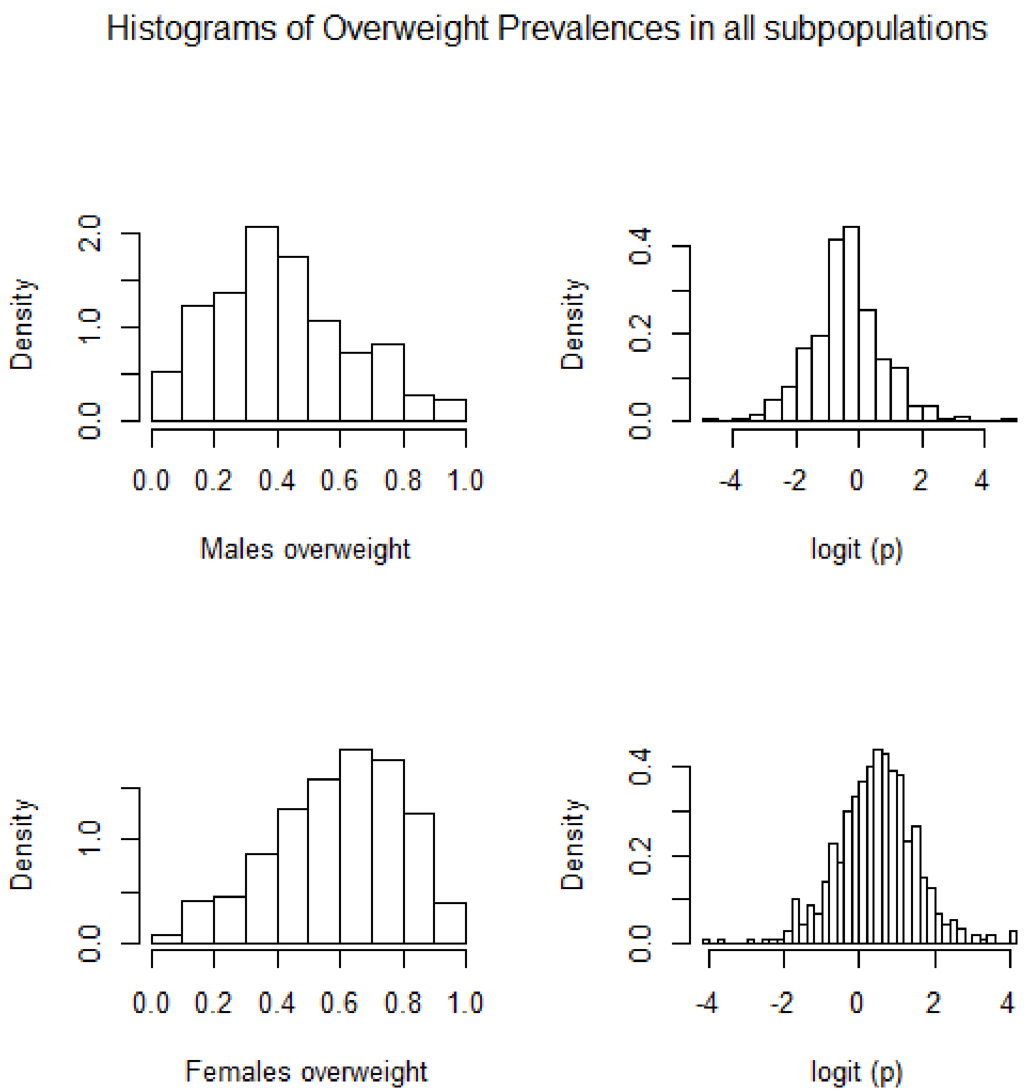

Figure C.1: Histograms of male and female overweight proportions and transformed proportions

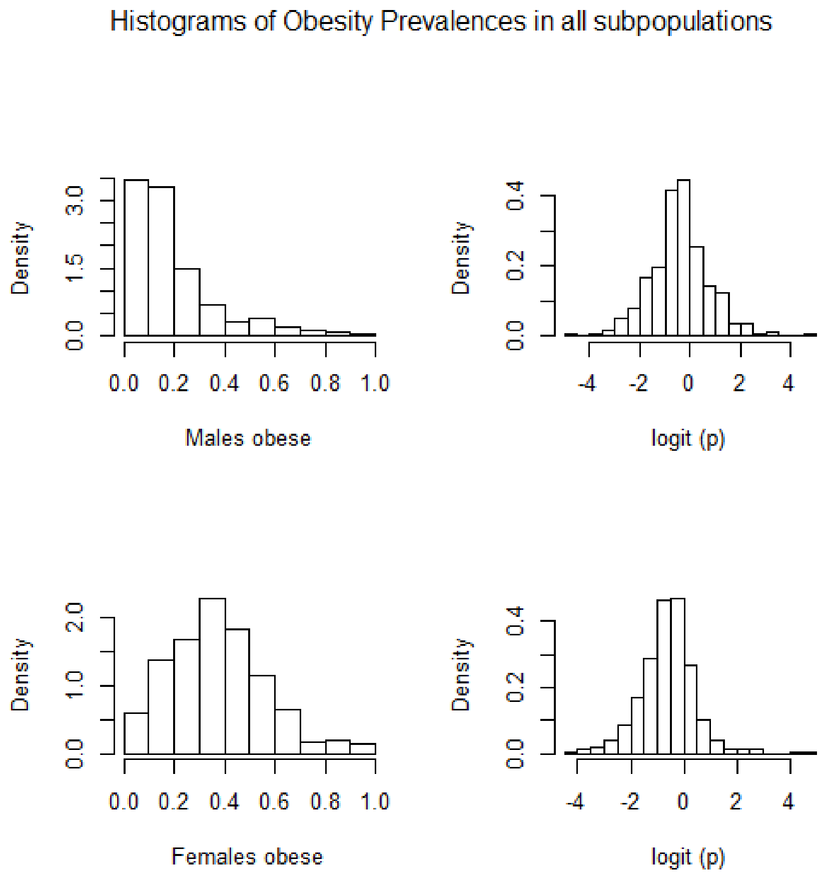

Figure C.2: Histograms of male and female obesity proportions and transformed proportions

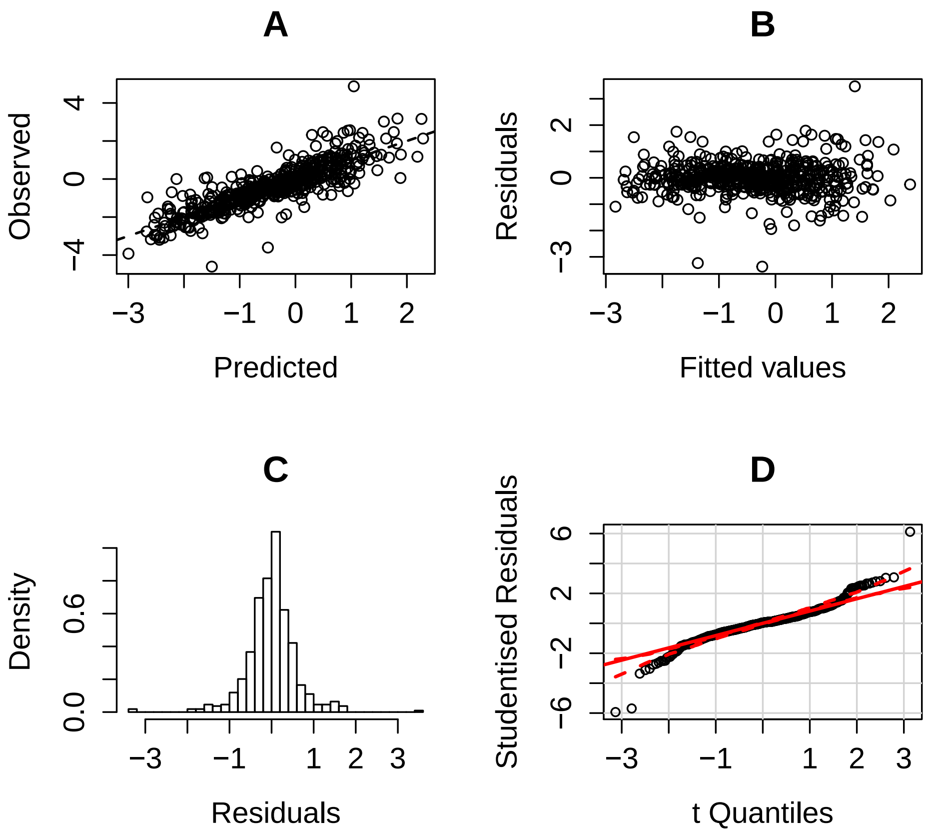

Figure C.3: Residual analysis for male overweight logit model

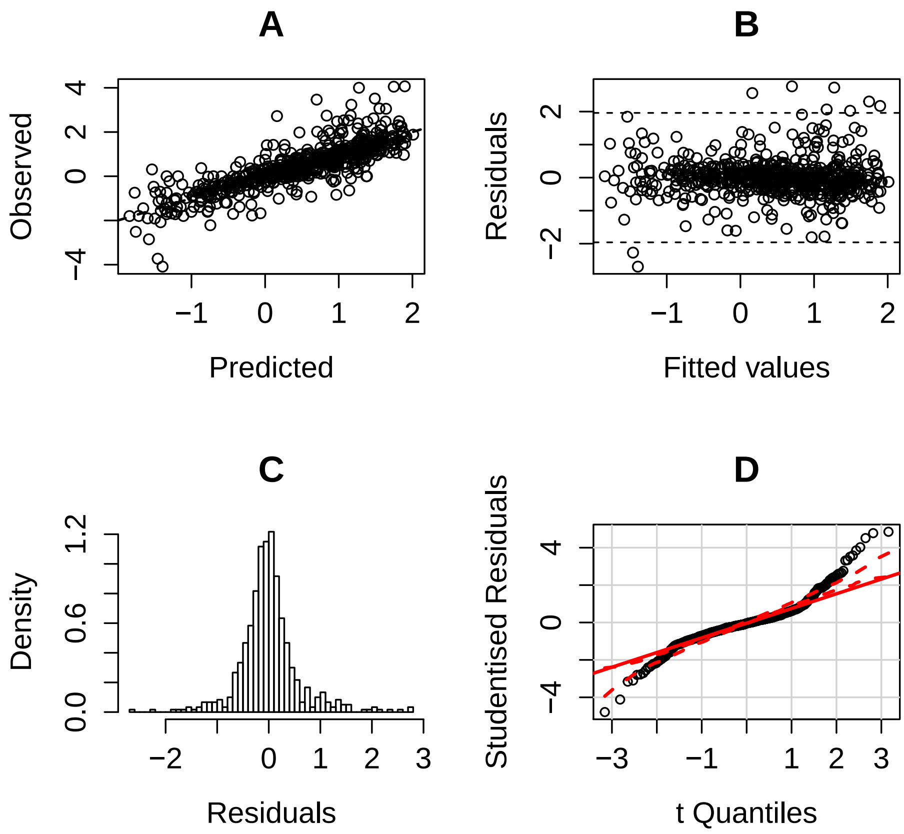

Figure C.4: Residual analysis for female overweight logit model

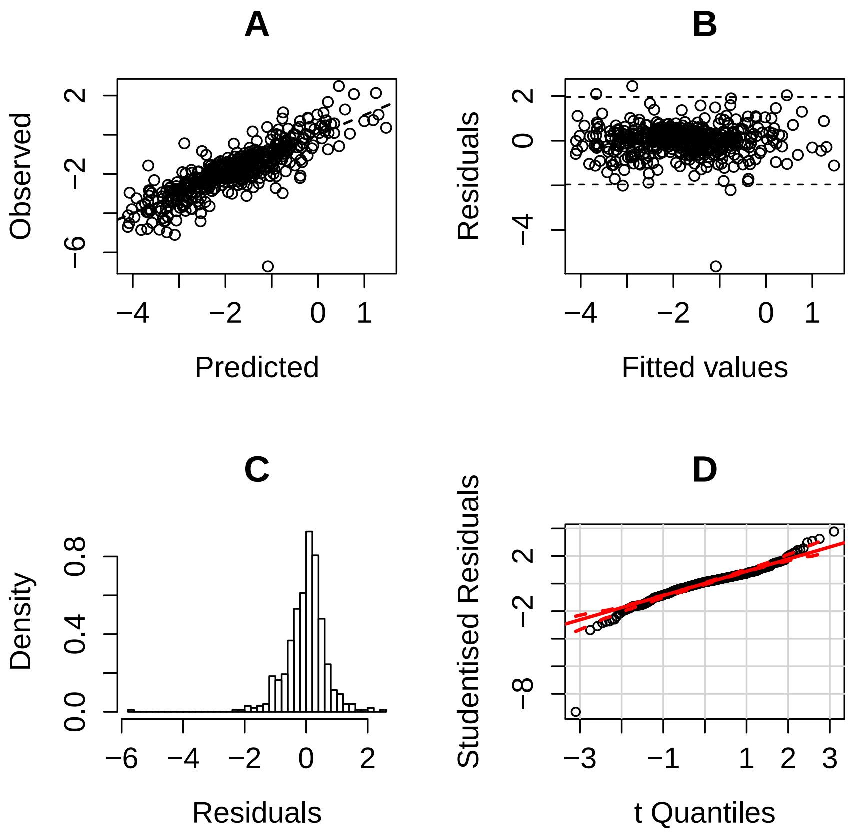

Figure C.5: Residual analysis for male obese logit model

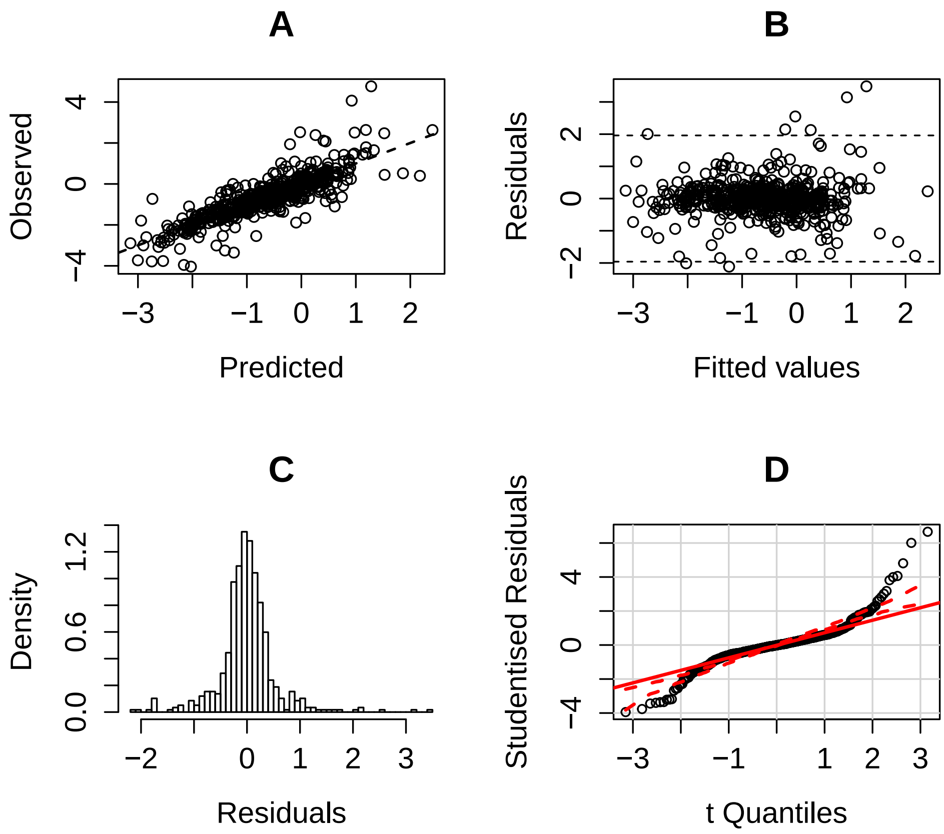

Figure C.6: Residual analysis for female obese logit model

D Age comparison

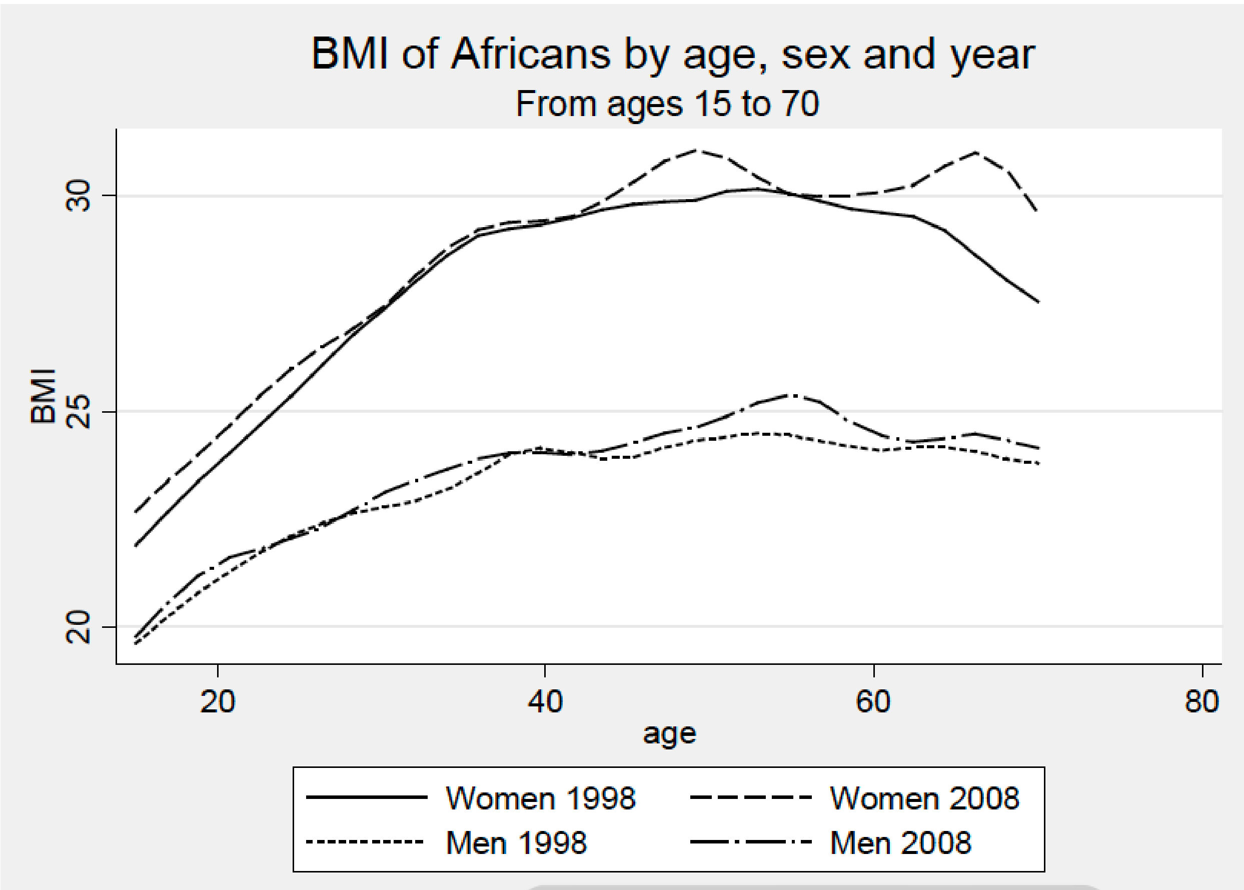

Figure D.1: African mean BMI relationship with age 1998-2008