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The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action

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Full Title:	The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action
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Abstract:	Background : In recent decades, the prevalence of obesity in children has increased dramatically. This worldwide epidemic has important consequences, including psychiatric, psychological and psychosocial disorders in childhood, and increased risk of developing non-communicable diseases later in life. Treatment of obesity is difficult, and children with excess weight are likely to become adults with obesity. These trends have led World Health Organization (WHO) member states to endorse a target of no increase in childhood obesity by 2025. Main body : Estimates of overweight in children aged under 5 years are available jointly from UNICEF, WHO and the World Bank. Country-level estimates of obesity in children aged from 2 to 4 years have been published by the Institute for Health Metrics and Evaluation (IHME). For children aged from 5 to 19, obesity estimates are available from the NCD Risk Factor Collaboration. The global prevalence of overweight in children aged under 5 years has increased modestly, but with heterogeneous trends in low- and middle-income regions, while the prevalence of obesity in children aged from 2 to 4 has increased moderately. For children aged 5 to 19, obesity was relatively rare in 1975, but was much more common in 2016. Conclusions : It is recognised that the key drivers of this epidemic form an obesogenic environment, which includes changing food systems and reduced physical activity. Although cost-effective interventions such as WHO “best buys” have been identified, political will and implementation have so far been limited. There is therefore a need to implement effective programmes and policies in multiple sectors to address overnutrition, undernutrition, mobility and physical activity. To be successful, the obesity epidemic must be a political priority, with these issues addressed both locally and globally. This must involve coordinated work by governments, civil society, private corporations and other key stakeholders.
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Response to Reviewers:	Reviewer #2: Sarah Garnett In my original review I suggested that the introduction could be more concise as the consequences of childhood obesity have been well described and reviewed in the literature. I also suggested that 41 references appear to be unnecessary. In the revised manuscript the introduction basically remains the same as the original submission with an additional paragraph describing the rationale for undertaking the study, as requested, and five additional references. The authors have responded by indicating the length and content of this section is appropriate, nevertheless they are happy to edit or remove any content felt to be redundant. I will leave the decision it to the editor if this is acceptable. Many thanks for your comment. We are happy to discuss the length of this section with the editor, and to revise it if the editor feels this is necessary. Specific comments: Page 9, Lines 15 -18 ...it has been suggested that the direct medical cost over the lifetime of a 10-year-old child with obesity compared to a similar child with normal weight is between US$12,660 and US$19,630 when weight gain in adulthood is allowed for [43]. This sentence needs context - is this globally? We have clarified that these estimates refer to the USA: “For example, it has been suggested that in the United States, the direct medical cost over the lifetime of a 10-year-old child with obesity compared to a similar child with normal weight is between US$12,660 and US$19,630 when weight gain in adulthood is allowed for” Page 9, Line 28: ...It should be noted that there are two definitions of childhood obesity: the International Obesity Task Force (IOTF) definition and the WHO growth reference. Could be better expressed as … the International Obesity Task Force (IOTF) definition and one based on the WHO growth reference data … or something similar. See response to next comment Page 9, Line 31: They have different age-specific cutoffs, and are therefore not comparable. The literature does not support this statement. The cut-points are comparable but may give different proportions for overweight and obesity at least in adolescents. For example Li et al http://dx.doi.org/10.1016/j.ypmed.2016.02.035 We have improved the wording of this paragraph and added the two references for the IOTF and WHO definitions: “It should be noted that there are two definitions of childhood obesity: the International Obesity Task Force (IOTF) definition [46] and one based on the WHO growth reference curve [47]. They have different age-specific cutoffs, and can therefore give different obesity estimates for a given set of data” There still are several places throughout the text where person-first language has not been used to describe 'children with overweight and or obesity'. For example Page 8 line 16, Page 13 line 39 & 46, Page 15 line 40 … We have revised the text accordingly throughout. This includes the examples stated: “Children who are overweight and obese also have elevated levels of metabolic and cardiovascular risk factors [14, 15]”, “Numbers of children and adolescents with obesity”, “By 2016 the number of children and adolescents with obesity”, “The effectiveness of interventions aimed at children who are overweight and obese has been widely studied [61–64]” Reviewer #3: Wayne Cutfield

	The authors have addressed most of the issues raised by reviewers. However, the authors still do not acknowledge in the results section that there is a growing body of evidence in developed countries (also now include across UK) in which in the under 5's the prevalence of overweight and obesity have progressively fallen. This is a key and important observation that is not shown in the results section and should be included. There is only fleeting mention in the discussion. This is a major and potentially important observation for the evolution of childhood obesity over the next 10 years. This should be addressed before publication considered. We agree that recent trends in some high-income countries have shown a decline in the under 5’s prevalence of obesity. We have expanded the paragraph in the discussion as follows: “Recently, declines in preschool-age children’s obesity levels have been observed in New Zealand [69], Leeds (UK) [70, 71], and Amsterdam (the Netherlands) [72] through interventions aimed at supporting families and communities by creating a healthier food environment and supporting families in enforcing healthy habits in children with an approach of shared responsibilities among multiple actors. This may have important implications for the future trends of obesity in childhood. However caution in causal interpretation is necessary, and more evidence is needed to establish that the implemented interventions are in fact responsible for the observed declines in obesity in childhood [69, 70]”. We believe that while some evidence of decline in under 5’s obesity prevalence has been observed, extrapolating future global trends may be misleading, and so more research to support a causal relation is needed.

The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action

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Abstract

Background: In recent decades, the prevalence of obesity in children has increased dramatically. This worldwide epidemic has important consequences, including psychiatric, psychological and psychosocial disorders in childhood, and increased risk of developing non-communicable diseases later in life. Treatment of obesity is difficult, and children with excess weight are likely to become adults with obesity. These trends have led World Health Organization (WHO) member states to endorse a target of no increase in obesity in childhood by 2025.

Main body: Estimates of overweight in children aged under 5 years are available jointly from UNICEF, WHO and the World Bank. Country-level estimates of obesity in children aged from 2 to 4 years have been published by the Institute for Health Metrics and Evaluation (IHME). For children aged from 5 to 19, obesity estimates are available from the NCD Risk Factor Collaboration. The global prevalence of overweight in children aged under 5 years has increased modestly, but with heterogeneous trends in low- and middle-income regions, while the prevalence of obesity in children aged from 2 to 4 has increased moderately. For children aged 5 to 19, obesity was relatively rare in 1975, but was much more common in 2016.

Conclusions: It is recognised that the key drivers of this epidemic form an obesogenic environment, which includes changing food systems and reduced physical activity. Although cost-effective interventions such as WHO “best buys” have been identified, political will and implementation have so far been limited. There is therefore a need to implement effective programmes and policies in multiple sectors to address overnutrition, undernutrition, mobility

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and physical activity. To be successful, the obesity epidemic must be a political priority, with these issues addressed both locally and globally. This must involve coordinated work by governments, civil society, private corporations and other key stakeholders.

Keywords: obesity, overweight, global health, children, adolescents

Background

Excess weight during childhood and adolescence remains one of the most important issues in global health, despite emerging as a concern several decades ago [1, 2]. Recent estimates suggest that 40 million children aged under 5, and more than 330 million children and adolescents aged between 5 and 19, were overweight or obese in 2016 [3]. Given the global emergency posed by excess weight in children, WHO Member States endorsed "*no increase in childhood overweight by 2025"* as one of the six global nutrition targets in the "Comprehensive Implementation Plan for Maternal, Infant and Young Child Nutrition". This is consistent with the same target for obesity and diabetes between 2010 and 2025 in the "WHO Global Action Plan for the Prevention and Control of Non-communicable Diseases 2013-2020" [4, 5].

Overweight or obesity during childhood has important short-term and long-term consequences. In the short-term, children who are overweight or obese are more likely to suffer from psychological comorbidities such as depression, anxiety, low self-esteem, and a series of emotional and behavioural disorders [6, 7], asthma [8], low-grade systemic inflammation [9, 10], liver complications [11, 12], as well as musculoskeletal problems, especially in the lower extremities [13]. Children who are overweight and obese also have elevated levels of metabolic and cardiovascular risk factors [14, 15] such as high blood pressure [16], dyslipidemia [17], type 2 diabetes [18] and other abnormalities of the cardiovascular system [19]. In the long-term, overweight or obesity during childhood increases the risk in adulthood of developing cardiovascular diseases, diabetes, some cancers, and musculoskeletal disorders, which can lead to disability [20] and premature death [21–23]. In addition, the treatment of obesity in adulthood has been shown to be difficult [24], with evidence that around three-quarters of children who are overweight or obese carry this status into adulthood [25]. Strong consistency of overweight status with age and low efficacy of available treatments highlight the need to prevent overweight and obesity at the earliest possible stage of life.

It is recognised that weight gain is partly owing to elevated energy intake, which often includes a disproportionate amount of refined carbohydrates and/or processed foods (increasing insulin release and fat storage), and decreased physical activity [26]. Weight gain is also promoted by a series of environmental, behavioural, biological, and genetic factors whose interactions have driven the current levels of worldwide obesity. Maternal health status during pregnancy, an obese intrauterine environment [27], and rapid changes in weight status during infancy [28] are other factors contributing to obesity in children. Moreover, the expanding "obesogenic" environment increases the propensity of children to consume foods and beverages that are high in calories, energy-dense, or low in nutrients, as well as promoting sedentary lifestyles through reductions in opportunities for active mobility in daily lives [29]. A key driver of the rapidly

increasing worldwide occurrence of obesity and diabetes across populations is the globalised market of inexpensive energy-dense foods and beverages, and the limited political will to address the economic causes of the obesity epidemic [3], which include a strong association with socioeconomic inequalities [30, 31]. In high-income settings, higher prevalences are observed in disadvantaged and marginalised communities than in groups with higher socioeconomic status [32–34], while in contrast, higher prevalences are seen in groups with higher socioeconomic status in some, but not all, low- and middle-income settings [30].

Over the past decade, genome-wide association studies have been used to identify genetic markers that increase predisposition to weight gain, with the goal of explaining the biological mechanisms that lead to obesity. For example, the *FTO* gene is recognised as playing a key role in the regulation of energy intake, with variants predisposing individuals to greater caloric intake and reduced feelings of satiety [35]. Genetic and epigenetic factors are also known to produce heterogeneity across populations in obesity phenotypes, such as characteristic metabolic profiles and greater central body adiposity in south Asians [36]. However, groups with almost identical genotypes can have very different obesity phenotypes, as shown by the large differences in prevalences between Samoa and American Samoa [37]. In addition, obesity-associated genes cannot explain the rapid onset and scale of the current obesity epidemic, even if genetic predisposition does make some individuals more susceptible to the obesogenic environment [38].

Finally, obesity in childhood has important economic and social costs, with increased burdens on health systems as well as later reduced economic productivity [39–42]. For example, it has been suggested that in the United States, the direct medical cost over the lifetime of a 10-year-old child with obesity compared to a similar child with normal weight is between US$12,660 and US$19,630 when weight gain in adulthood is allowed for [43].

Over the past decade, there has been a global effort to provide reliable and detailed estimates that describe the worldwide epidemic of excess weight in children and adolescents. Here we aim to provide a comprehensive description of this work, presenting global, regional, and national trends based on the most up-to-date information available. To do so, we use data from the UNICEF/WHO/World Bank Joint Child Malnutrition Estimates [44], IHME Global Burden of Disease Study [45], and the NCD Risk Factor Collaboration [46] (see Table 1). It should be noted that there are two definitions of obesity in childhood: the International Obesity Task Force (IOTF) definition [47] and one based on the WHO growth reference curve [48]. They have different age-specific cutoffs, and can therefore give different obesity estimates for a given set of data. In the following, estimates published by IHME use the IOTF definition, while estimates published by UNICEF/WHO/World Bank and NCD-RisC use the WHO growth reference. Readers interested in the differences in statistical models and regional definitions in these studies are referred to the original papers.

Children aged under 5 years

Global and regional trends in overweight

The most recent estimates of trends in overweight for children under 5 years of age were published jointly by UNICEF, WHO and the World Bank in April 2019 [44]. Globally, the prevalence of overweight rose modestly, from 4.8% in 1990 to 5.9% in 2018, but with estimates for low- and middle-income United Nations regions showing heterogeneous trends. Estimates were not published for high-income regions.

Table 2 presents results by region. In Africa as a whole, overweight prevalence changed little between 1990 and 2018. However, prevalence increased in Northern and Southern Africa, and also rose modestly in Middle Africa. This was offset by decreases in Eastern and Western Africa. Overweight prevalence in Asia rose, with increases in every region except Eastern Asia, where overweight was almost unchanged. In Latin America and the Caribbean, overweight prevalence increased, including a moderate increase in the Caribbean, and small increases in Central and South America. Finally, the overweight epidemic in Oceania (excluding Australia and New Zealand) became much more severe, with a three-fold increase in prevalence.

Trends in obesity prevalence

Obesity trends in children aged 2 to 4 years are available from IHME for the period 1980 to 2015 [45] and are the only source of comparable information at country level for children under 5 years old. Estimates for 1980 and 2015 at national level are shown in Figures 1 and 2 respectively.

At global level between 1980 and 2015, the prevalence of obesity increased from 3.9% to 7.2% in boys and from 3.7% to 6.4% in girls. In 2015, by far the highest levels of obesity were in American Samoa, where around 50% of girls and boys in this age group were obese. More than one in three girls were obese in Kiribati, and more than one in four in Samoa and Kuwait. For boys, the second highest prevalence was in Kuwait, followed by Qatar and Kiribati. The lowest obesity prevalences in girls in 2015 were in North Korea, followed by Eritrea, Bangladesh and Burundi. In boys, the lowest prevalences were in Eritrea, North Korea, Burundi and Bangladesh.

Table 3 presents estimates by region. As shown in Figures 1 and 2, patterns are heterogeneous in sub-Saharan Africa. In 1980, obesity was most common in girls and boys in South Africa, and least common in girls and boys in Mali. By 2015, the largest obesity prevalence for girls was in Equatorial Guinea, followed by Djibouti, Zambia and South Africa. The highest prevalence in boys was also in Equatorial Guinea, followed by Zambia, Djibouti and South Africa. In contrast, obesity was less than 2% in girls in Eritrea and Burundi, and less than 1% in boys in Eritrea.

In south Asia in 1980, prevalences were highest in girls and boys in Afghanistan, and lowest in girls and boys in Nepal (Figure 1). By 2015, prevalences were highest in Bhutan, and lowest in Bangladesh for both sexes (Figure 2). In 1980 in East and south-east Asia, prevalences were highest in girls in Malaysia and boys in Taiwan, and lowest in girls in the Philippines and boys in Viet Nam. In 2015, the highest levels of obesity in girls were seen in Malaysia, followed by

Thailand and China, while in boys, the highest obesity was also seen in Malaysia, followed by Taiwan and Thailand. The lowest levels of obesity were in North Korea for both sexes.

Obesity prevalence in 2 to 4 year olds was heterogeneous in Oceania. In 1980, while almost half of girls and boys in American Samoa had obesity, this was the case for fewer than 1 in 20 girls in Papua New Guinea and boys in Fiji. In 2015, obesity varied from approximately 50% in American Samoa to around 5% in Papua New Guinea in both sexes.

In Latin America and the Caribbean in 1980, the highest levels of obesity were in girls in Uruguay and boys in Chile. The lowest levels were in girls in Colombia and boys in Honduras. By 2015, the highest levels of obesity were seen in Puerto Rico for both girls and boys. For girls, the next highest levels of obesity were seen in Dominica and Uruguay, while for boys, Puerto Rico was followed by Chile and Barbados. The lowest prevalences were seen in Haiti and Colombia for both boys and girls.

In the Middle East in 1980, the highest levels of obesity were in girls in Kuwait and boys in Qatar, while the lowest levels were in girls in Iran and boys in Yemen. By 2015, the highest levels of obesity were seen in girls in Kuwait, Saudi Arabia and Qatar, and boys in Kuwait, Qatar and Oman. This contrasted with girls in Jordan and boys in Yemen where obesity was lowest. In North Africa in 1980, the highest prevalences were in girls and boys in Libya, with the lowest in girls and boys in Algeria. By 2015, the highest obesity prevalences were in girls and boys in Egypt, while the lowest levels were in Tunisia for both sexes.

In high-income countries, obesity prevalence increased between 1980 and 2015 (Figures 1 and 2). In high-income western countries in 1980, the highest obesity prevalences were in girls in Andorra and boys in Spain, with the lowest levels in girls in Switzerland and boys in the Netherlands. In 2015, the highest levels of obesity in girls were still in Andorra, followed by Malta, Greece and Portugal. In boys, the highest levels were in Luxembourg, Andorra, Canada and Malta. The lowest levels were in girls and boys in Switzerland. In high-income Asia-Pacific, the highest obesity prevalences in 1980 were in girls and boys in Singapore, and the lowest in both girls and boys in Japan. By 2015, obesity exceeded 10% in boys and 6% in girls in Singapore and South Korea. In contrast, obesity prevalence was less than 3% in both girls and boys in Japan.

In central and eastern Europe in 1980, the highest obesity prevalences were in girls in Albania and boys in Bulgaria, with the lowest in girls and boys in Ukraine. In 2015, obesity was particularly high in girls in Albania, followed by Montenegro, Bosnia and Herzegovina and Russia. Albania also had the highest obesity in boys, followed by Montenegro, Russia and Bosnia and Herzegovina. Obesity prevalence was lowest in girls in Ukraine, followed by Moldova, while in boys, the lowest obesity was in Moldova, followed by Ukraine. In central Asia in 1980, obesity was most common in girls and boys in Uzbekistan and least common in girls and boys in Kazakhstan. In 2015, prevalences were highest in girls in Georgia and boys in Azerbaijan, and lowest in both sexes in Kyrgyzstan.

The numbers of children aged 2 to 4 years with obesity were also published by IHME for the period 1980 to 2015 [45]. The division of these children by country in 1980 and 2015 is shown in Figures 3 and 4 respectively. In 1980, the country with the largest number of girls with obesity was India, followed by China, Russia and the USA. India, China and Russia also had the largest number of boys with obesity, followed by Mexico. By 2015, China had the largest number of girls with obesity, followed by India, the USA and Brazil. For boys, the largest numbers were in China, India, Brazil, and the USA.

Children and adolescents aged 5 to 19 years

Worldwide trends in obesity

The largest global database on obesity in children and adolescents aged 5 to 19 is held by the Non-communicable Disease Risk Factor Collaboration (NCD-RisC) [49]. The most recent estimates were published in 2017, and were based on 2,416 measured data sources [46]. The estimates showed that between 1975 and 2016, obesity prevalence increased from 0.7% to 5.6% in girls, and from 0.9% to 7.8% in boys. However, the global increase in obesity masked heterogeneous trends at national level, as shown in Figures 5 and 6.

Obesity trends by region

Table 4 presents results by region. As shown in Figure 5, obesity was rare across the world in 1975, but particularly so in sub-Saharan Africa, with an estimated prevalence of 0.1% for girls and 0.0% for boys. Prevalences greater than 0.5% were observed in only Djibouti and Seychelles for girls and in Seychelles for boys. By 2016, prevalences greater than 5% were seen in ten countries for girls and two for boys (Figure 6). Six of the seven countries with most obesity in girls were in southern Africa, with the highest prevalence seen in South Africa; the lowest prevalence was in Burkina Faso. For boys, Seychelles had the highest prevalence, followed by South Africa, with Uganda having the lowest prevalence.

South Asia also had extremely low levels of obesity in 1975, estimated at 0.0% for both girls and boys, reaching a maximum of 0.1% for boys in Pakistan. Obesity was less rare by 2016, with prevalences greater than 3% in Afghanistan for girls, and in Bhutan, Pakistan and Bangladesh for boys. More heterogeneous trends were observed in east and south-east Asia. In 1975, obesity was most common in Hong Kong in both girls and boys, but prevalences were less than 2% elsewhere. In 2016, the highest levels of obesity in girls were seen in Malaysia, and the lowest in Cambodia. For boys, prevalences were highest in Brunei Darussalam and lowest in Viet Nam. Meanwhile, in high-income countries in Asia-Pacific in 1975, obesity prevalence was highest in Singapore for girls and boys. By 2016, prevalences were highest in South Korea and lowest in Japan for both sexes.

In 1975, obesity levels were low in Latin America and the Caribbean (Figure 5). Obesity was most common in Bermuda for girls and boys, followed by Argentina and Uruguay for both sexes. By 2016, prevalences had become more heterogeneous. For girls, the highest levels of obesity

were seen in Puerto Rico, Bermuda and the Bahamas, while for boys the largest prevalences were seen in Bermuda, Argentina and Puerto Rico. Prevalences were lowest in Colombia for girls and boys, followed by Peru and Haiti for girls and Saint Lucia and Peru for boys.

Heterogeneous trends were observed across North Africa, the Middle East and Central Asia. In 1975, prevalences were highest in girls and boys in Kuwait. By 2016, obesity prevalence was highest in Kuwait and Egypt for girls, and in Kuwait and Qatar. Meanwhile, obesity prevalence was lowest in both sexes in Tajikistan.

There were heterogeneous patterns in high-income western countries in both 1975 and 2016. In 1975, the highest levels of obesity were in Malta for girls and boys, followed by the USA, Andorra and Israel for girls, and Andorra, Israel and the USA for boys. Meanwhile, prevalences were below 2% in girls in eight countries and boys in five countries. By 2016, the highest levels of obesity were observed mostly in English-speaking and Mediterranean countries. The USA had the highest prevalences for girls and boys, followed by New Zealand. Switzerland had the lowest prevalences of girls and boys with obesity.

In 1975, obesity prevalence was less than 2% for both sexes in every country in central and eastern Europe (Figure 5). By 2016, prevalences of obesity exceeded 13% in boys in Croatia, Hungary and Bulgaria, and 7% in girls in the same countries. Prevalences were lowest in boys in Moldova, followed by Bosnia and Herzegovina and the three Baltic states. For girls, Moldova, Russia and Estonia had the lowest prevalences.

Obesity was not common in children and adolescents aged 5 to 19 years in Oceania in 1975, with prevalence exceeding 5% only in girls and boys in Nauru and girls in Palau. By 2016, Oceania had the 13 countries with the highest obesity for girls and the eight countries with most obesity for boys; more than 30% of girls and boys in Nauru, the Cook Islands and Palau were obese. However, there was a contrast between patterns in Melanesia, and Polynesia and Micronesia, with obesity prevalence lower in all countries in Melanesia.

Changes in obesity at national level

Obesity prevalence increased in every country for both sexes, but there was wide variation in how much it increased. The proportional increases per decade are shown in Figure 7. For girls, the largest increase was in Botswana, with obesity increasing more than seven-fold per decade, followed by Lesotho and Cambodia, where prevalence increased more than six-fold per decade. In contrast, obesity prevalence only increased by about 10% per decade in Singapore and Belgium. For boys, the proportional increases were even greater, reaching a peak in Botswana, where obesity increased more than ten-fold per decade. Again, the increase in Singapore was only approximately 10% per decade.

Numbers of children and adolescents with obesity

Globally in 1975, there were 5 million girls and 6 million boys with obesity. The division of these children by country is shown in Figure 8. In 1975, the USA had the largest numbers for boys and girls, followed by Italy, Mexico and Germany for girls, and China, Italy and Mexico for boys. By 2016 the number of children and adolescents with obesity had increased to 50 million in girls and 75 million in boys. As shown in Figure 9, the largest numbers in both sexes were in China, followed by the USA and India.

Gender comparison

There are clear regional differences in the relationship between obesity levels and sex, as shown in Figures 10 and 11. In 2016, prevalences were higher in girls than boys in a large majority of countries in sub-Saharan Africa, in most countries in Oceania, as well as some other middle-income countries. In contrast, obesity was more common in boys than girls in all high-income countries, and all countries in east and south-east Asia. Figure 11 shows the absolute numbers of girls and boys with obesity by country, which again shows clear regional patterns. There were more girls than boys with obesity in almost all countries in sub-Saharan Africa, and in a few other countries, but in the rest of the world, there were more boys than girls with obesity in 2016. This is partly driven by substantial differences in the numbers of boys and girls in the general populations of some countries; for example, in both China and India in 2016 there were 19 million more 5 to 19 year old boys than girls.

Discussion

Obesity in childhood has increased worldwide over the past four decades in all age groups, as it also has for adults [46]. However, obesity appears to have increased more rapidly in 5 to 19 year olds than in younger children, with an eightfold increase between 1975 and 2016. This contrasts with an approximate doubling between 1980 and 2015 in obesity in children aged 2 to 4 years old, albeit using metrics that are not directly comparable. There is heterogeneity in levels and trends between regions and individual countries, depending on the stage of the global obesity epidemic they are experiencing. In particular, there has been some flattening of trends, especially among those with high socioeconomic status in high-income countries [50].

The need for high-quality and comparable data is recognised as a key component in monitoring malnutrition [3]. Data from pooled analyses allow examination of change over time, and the use of standardised and comparable metrics allows trends to be benchmarked across countries. Here we have used data from three different sources that cover different ages and countries. This limits their comparability [44–46], and in particular, there is less standardised and comparable country-level information for children under the age of 5 [44]. Equally, although national trends are of great interest, it is known that they mask subnational heterogeneity. Collection of disaggregated data at subnational level and across specific groups of the population is therefore essential for identification of groups at risk of malnutrition and to ensure progress in meeting global targets [3].

Despite overall increases in the prevalence of obesity in childhood, different forms of malnutrition coexist at global, national and subnational levels. Increases in obesity are linked to a reduction in the prevalence of children of normal weight, without there necessarily being decreases in the prevalence of children who are underweight. At a global level, the prevalence of underweight among children aged 5-19 has remained unchanged over the past four decades [46], and similar results have also been observed in individual countries. For example, in Seychelles only children in the upper percentiles of body-mass index (BMI) have increased in weight, with little or no increase observed among those with median and low BMI [51]. More studies are needed to describe the shift in distribution of BMI over time in populations, e.g. estimates of the whole distribution to examine whether increases in BMI have occurred in all children or only in subgroups.

It is recognised that the main drivers of the current obesity epidemic are related to changing food systems and reduced physical activity [52–54], with two key features. Firstly, there is increased availability of generally inexpensive energy-dense and ultra-processed foods and beverages. Food supply has been globalised, and it is often economically more profitable to produce and market processed energy-dense foods than fresh ones. Recent results from the Global Burden of Disease study show that consumption of healthy foods is suboptimal whereas that of unhealthy options exceeds recommended levels [45]. Secondly, there have been increases in sedentary lifestyles, with high levels of physical inactivity among children [55]. As children transition through childhood and adolescence, susceptibility to the food and physical environments increases. Children can increasingly choose which foods they eat and how much exercise they do, and this has a strong impact on current and future behaviour [56–59]; this may in part explain the rapid increase in the prevalence of obesity among this group. Further investigation is required to explain the more rapid increase in obesity in boys, including studies of whether they are more susceptible to obesogenic pressures.

The need to improve the food environment requires governments, international organisations, and other key stakeholders, including civil society and the private sector at local and global levels, to address global and local marketing of unhealthy energy-dense foods, and to improve availability and affordability of unprocessed healthy foods. Equally, healthy diets need to be integrated with food systems in a sustainable way, such that long-term health benefits are possible [60]. A constructive dialogue with the food industry and effective regulations are needed to improve availability of healthy foods and reduce unhealthy options, including prevention of unethical marketing of unhealthy foods aimed at low-income countries and other vulnerable members of the global population. The paradigm of energy imbalance (increased energy intake not balanced by energy consumption) is often used by the food industry to weaken policies aimed at tackling the use of energy-dense foods, arguing that this can be compensated for by adequate levels of physical activity; given the scale of the obesity epidemic, this must be viewed with scepticism. In the same vein, cities and urban planners need to rethink their role in society given that current physical environments substantially restrict mobility patterns. As sedentarism is becoming more common, coupled with future jobs that require less activity, our children will amass a substantial cumulative burden of inactivity that will become difficult to reverse.

The effectiveness of interventions aimed at children who are overweight and obese has been widely studied [61–64]. Most interventions have targeted behavioural changes, mainly in terms of nutrition and physical activity, with evidence that some have been effective in schools [65, 66]. In particular, promotion of physical activity in school-based settings may be beneficial given adequate resources [67], as well as being an important component of effective overweight prevention strategies in children [65]. Efforts to promote active mobility such as cycling lanes are being implemented in many cities in high-income countries, and increasingly in low- or middle-income countries, including the cities adhering to the Agita Mundo Network in Latin America [68]. Recently, declines in preschool-age children's obesity levels have been observed in New Zealand [69], Leeds (UK) [70, 71], and Amsterdam (the Netherlands) [72] through interventions aimed at supporting families and communities by creating a healthier food environment and supporting families in enforcing healthy habits in children with an approach of shared responsibilities among multiple actors. This may have important implications for the future trends of obesity in childhood. However caution in causal interpretation is necessary, and more evidence is needed to establish that the implemented interventions are in fact responsible for the observed declines in obesity in childhood [69, 70]. Equally, data and evidence on the effectiveness of community-based approaches are limited compared to school-based programmes [73, 74]. Discussions about the role of community knowledge, attitudes and awareness towards obesity in accepting policy-level solutions are ongoing, but data supporting such evidence are lacking or show unsuccessful examples [75, 76].

Despite this work, the effects of traditional behavioural change interventions will be too small to relieve the global burden of obesity in childhood, at least in the short- to medium-term [52]. Community-wide approaches matched with changes in government policies related to food advertising and food affordability are therefore also required. Current policies use tax and regulation to tackle obesity, such as sugar taxes, rules on food labelling, and restrictions on advertising of unhealthy foods and beverages. Other policies include provision of vouchers to mothers with low incomes in the USA for purchasing fruits and vegetables, low-fat or skimmed milk, and whole-grain instead of refined-grain products among other changes; this has been shown to reduce obesity rates among children aged 2 to 4 years [77]. However, high levels of heterogeneity in policy are observed across countries, with low- and middle-income countries relying more on such approaches (and implementing them earlier) than high-income countries. For example, Mexico was one of the first countries in the world to implement a sugar-sweetened beverage tax; two years after implementation, consumption had decreased by 8.2% [78]. In 2014, Chile started to implement a series of policies aimed at reducing obesity. Tax on beverages with high sugar content was increased from 13% to 18%, while tax on drinks with low or no sugar content was reduced from 13% to 10%. In 2016, a labelling system using black octagons on packaging was introduced for food and beverages high in sugar, calories, sodium and saturated fats. In addition, foods and beverages with such labels have been banned from schools, while marketing of these products to children under 14 years of age is not allowed [79, 80]. Initial results suggest a positive impact on knowledge and awareness, reductions in consumption of unhealthy foods, and a positive response from the food industry which is decreasing the amount of sugar and sodium in some food categories.

The heterogeneity in levels of obesity across the world also has important implications in terms of global targets and goals. While it is necessary to aim only for *no increase in obesity by 2025* in those regions and countries in which a clear upward trend in obesity is observed, much stronger political action is needed in those regions and countries where prevalences have plateaued at high levels, to raise the priority of multisectorial interventions to address obesity and other chronic conditions. In general, there is a need to examine how different policy agendas [4, 5, 81–83] can be integrated and strengthened to promote healthy nutrition and regular physical activity, including preventing overweight among children while also continuing to implement interventions to fight undernutrition. This will require additional efforts that should not overlook low- and middle-income countries simply because some have moderate levels of obesity and high levels of undernutrition.

Conclusions

Tackling the obesity epidemic in children will require integrated efforts in multiple sectors to provide equitable access to economic resources, education, healthy food and urban environments, and universal health coverage. Most importantly, bolder political will and accountability is needed from a broad range of actors, including government, civil society, academia, the private sector and other key stakeholders to spearhead efforts to promote production of and access to a healthier environment for all.

List of abbreviations

GBD. Global Burden of Disease study.
IOTF. International Obesity Taskforce.
IHME. Institute for Health Metrics.
NCD. Non-communicable disease.
UK. United Kingdom.
USA. United States of America.
WHO. World Health Organization.

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Figures

1. Obesity prevalence by country in 1980 for girls and boys aged from 2 to 5. These estimates

were published by IHME using the IOTF growth reference [45] (see Table 1).

2. Obesity prevalence by country in 2015 for girls and boys aged from 2 to 5. These estimates were published by IHME using the IOTF growth reference [45] (see Table 1).

3. Division of the number of girls and boys aged from 2 to 5 with obesity in 1980 by country. These estimates were published by IHME using the IOTF growth reference [45] (see Table 1).

4. Division of the number of girls and boys aged from 2 to 5 with obesity in 2015 by country. These estimates were published by IHME using the IOTF growth reference [45] (see Table 1).

5. Obesity prevalence by country in 1975 for girls and boys aged from 5 to 19. These estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

6. Obesity prevalence by country in 2016 for girls and boys aged from 5 to 19. These estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

7. Proportional increase in obesity between 1975 and 2016 for girls and boys aged from 5 to 19. The estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

8. Division of the number of girls and boys aged from 5 to 19 with obesity in 1975 by country. These estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

9. Division of the number of girls and boys aged from 5 to 19 with obesity in 2016 by country. These estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

10. Comparison of obesity prevalence in girls and boys aged from 5 to 19 in 1975 and 2016. The estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

11. Comparison of the number of girls and boys aged from 5 to 19 with obesity in 1975 and 2016. The estimates were published by NCD-RisC using the WHO growth reference [46] (see Table 1).

Table 1. Comparison of definitions of overweight and obesity across studies.

Metric	Age group	Source	Definition	Years
Overweight	Under 5 years	UNICEF, WHO and the World Bank [44].	WHO Child Growth Standard (https://www.who.int/childgrowth/standards/height_for_age/en/)	1990 to 2018
Obesity	2 to 4 years	IHME [45].	International Obesity Task Force definition (https://www.ucl.ac.uk/child-health/research/population-policy-and-practice/research/studies/obesity-measuring-obesity-children-iotf-cut)	1980 to 2015
Obesity	5 to 19 years	NCD-RisC [46].	WHO Growth Reference (https://www.who.int/growthref/en/)	1975 to 2016

Table 2. Overweight estimates by region for children under 5 years old, published jointly by UNICEF, WHO and the World Bank (see Table 1).

Region	Estimates in 1990 with uncertainty interval	Estimates in 2018 with uncertainty interval
Africa	**5.2% (4.2-6.2)**	**4.9% (3.6-6.1)**
Northern Africa	7.0% (4.2-11.4)	10.6% (4.8-21.8)
Middle Africa	4.1% (2.2-7.5)	4.6% (3.4-6.3)
Southern Africa	9.1% (6.4-12.9)	13.0% (9.3-17.9)
Eastern Africa	5.0% (3.7-6.7)	4.3% (3.5-5.3)
Western Africa	3.9% (2.8-5.5)	2.1% (1.6-2.6)
Asia	**4.0% (3.0-5.0)**	**5.2% (3.9-6.5)**
Eastern Asia	6.4% (5.8-7.0)	6.3% (5.5-7.2)
Western Asia	5.7% (3.0-10.5)	9.0% (3.5-21.1)
Southern Asia	2.3% (0.8-6.1)	3.1% (1.9-5.1)
South-eastern Asia	1.9% (1.5-2.4)	7.7% (4.0-14.2)
Oceania (excluding Australia and New Zealand)	**3.2% (2.4-4.2)**	**9.1% (5.9-13.8)**
Latin America and the Caribbean	**6.2% (4.7-7.7)**	**7.5% (6.6-8.4)**
Caribbean	4.2% (4.0-4.5)	7.0% (3.7-12.8)
Central America	5.3% (3.7-7.6)	6.9% (6.0-8.1)
South America	6.8% (4.9-9.3)	7.8% (6.7-9.1)

Table 3. Obesity estimates by region for children aged from 2 to 4 years, published by IHME (see Table 1).

Region	Sex	Estimates in 1980 with uncertainty interval	Estimates in 2015 with uncertainty interval
Sub-Saharan Africa	Girls	3.7% (3.1-4.4)	5.4% (4.5-6.5)
	Boys	4.3% (3.4-5.5)	5.8% (4.7-7.1)
South Asia	Girls	2.8% (1.5-4.9)	4.0% (2.1-7.1)
	Boys	2.4% (1.3-4.2)	4.5% (2.3-8.1)
East and SE Asia, and Oceania	Girls	2.3% (1.4-3.8)	6.8% (4.2-10.8)
	Boys	2.3% (1.4-3.7)	8.1% (4.8-12.5)
High-income countries	Girls	6.0% (4.9-7.2)	8.9% (7.2-10.9)
	Boys	6.1% (4.9-7.6)	10.0% (8.0-12.4)
Latin America and the Caribbean	Girls	3.9% (2.7-5.7)	8.7% (6.0-12.4)
	Boys	5.0% (3.2-8.0)	9.8% (6.4-14.1)
Middle East and North Africa	Girls	4.3% (3.7-5.1)	9.2% (7.6-10.9)
	Boys	3.5% (2.9-4.3)	8.8% (7.3-10.7)
Central and eastern Europe and Central Asia	Girls	9.0% (7.3-11.1)	9.3% (7.7-11.3)
	Boys	11.5% (9.4-14.1)	12.6% (10.4-15.0)

Table 4. Obesity estimates by region for children and adolescents aged from 5 to 19 years, published by NCD-RisC (see Table 1).

Region	Sex	Estimates in 1975 with uncertainty interval	Estimates in 2016 with uncertainty interval
Sub-Saharan Africa	Girls	0.1% (0.0-0.3)	3.2% (2.2-4.4)
	Boys	0.0% (0.0-0.2)	1.7% (0.9-2.8)
South Asia	Girls	0.0% (0.0-0.1)	1.8% (1.0-3.1)
	Boys	0.0% (0.0-0.2)	2.6% (1.4-4.5)
East and south-east Asia	Girls	0.1% (0.0-0.2)	5.9% (4.2-8.1)
	Boys	0.2% (0.0-0.7)	12.1% (9.0-15.7)
High-income Asia-Pacific	Girls	0.5% (0.3-0.9)	2.7% (2.0-3.6)
	Boys	1.5% (0.8-2.8)	7.5% (5.9-9.3)
Latin America and the Caribbean	Girls	1.6% (0.4-3.8)	10.4% (7.8-13.6)
	Boys	1.8% (0.3-4.9)	13.4% (10.0-17.2)
North Africa, the Middle East and Central Asia	Girls	0.9% (0.1-2.5)	11.3% (8.1-15.1)
	Boys	0.8% (0.1-2.8)	12.0% (8.6-15.9)
High-income western countries	Girls	3.8% (2.1-6.1)	13.3% (10.3-16.6)
	Boys	4.1% (2.3-6.4)	16.8% (13.2-20.6)
Central and eastern Europe	Girls	0.8% (0.1-2.8)	5.0% (2.8-8.3)
	Boys	1.1% (0.1-3.5)	10.1% (6.2-15.6)
Oceania	Girls	0.7% (0.1-3.9)	10.7% (4.2-21.0)

	Boys	0.7% (0.0-3.7)	9.9% (3.5-20.5)

Declarations

Ethics approval and consent to participate: not applicable.
Consent to publish: not applicable.
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Authors' contributions: the paper was drafted by MDC and JB. All other authors contributed to the final version.
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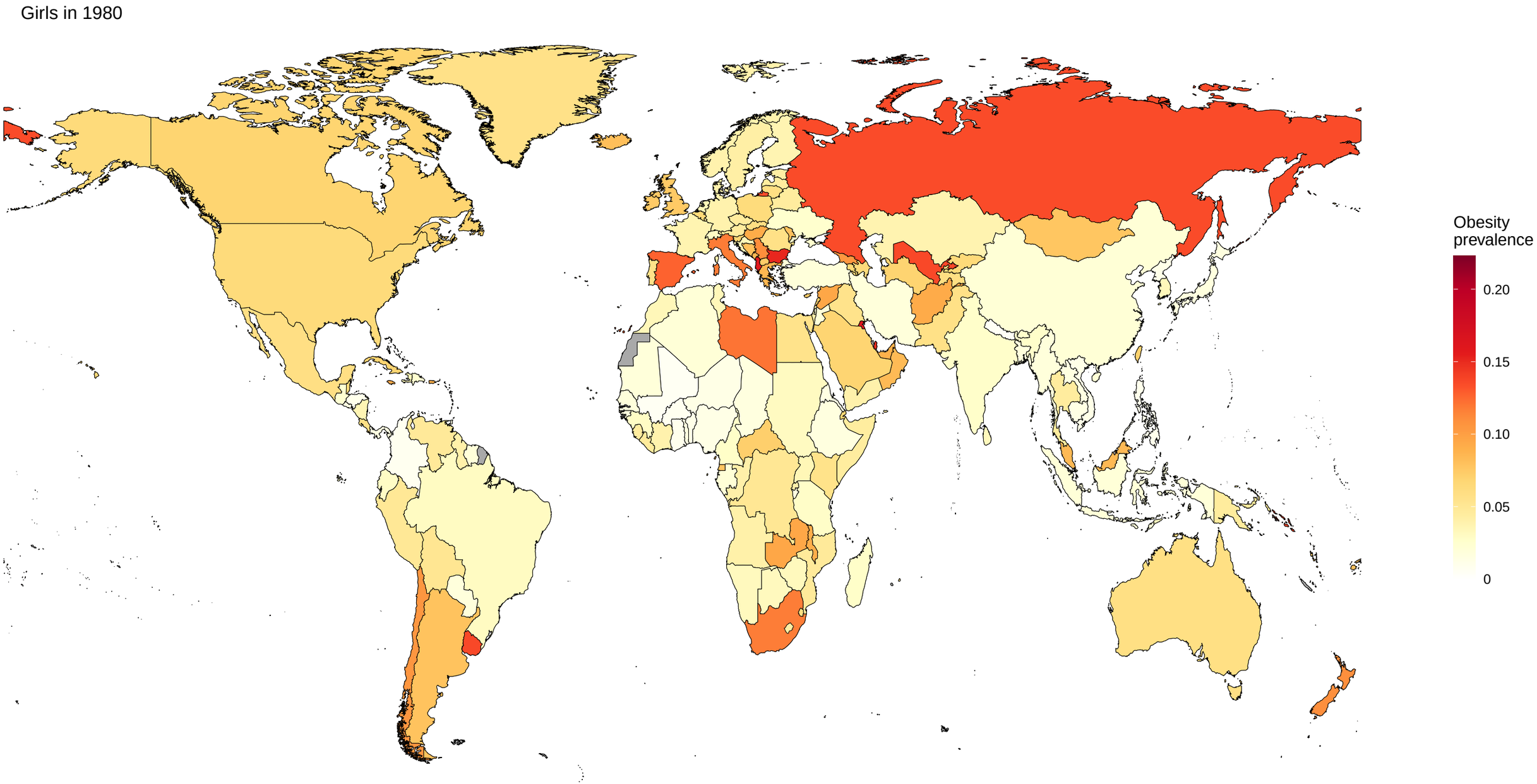
Figure 1

Click here to access/download;Figure;Figure1_obesity_maps_1980.pdf



Boys in 1980

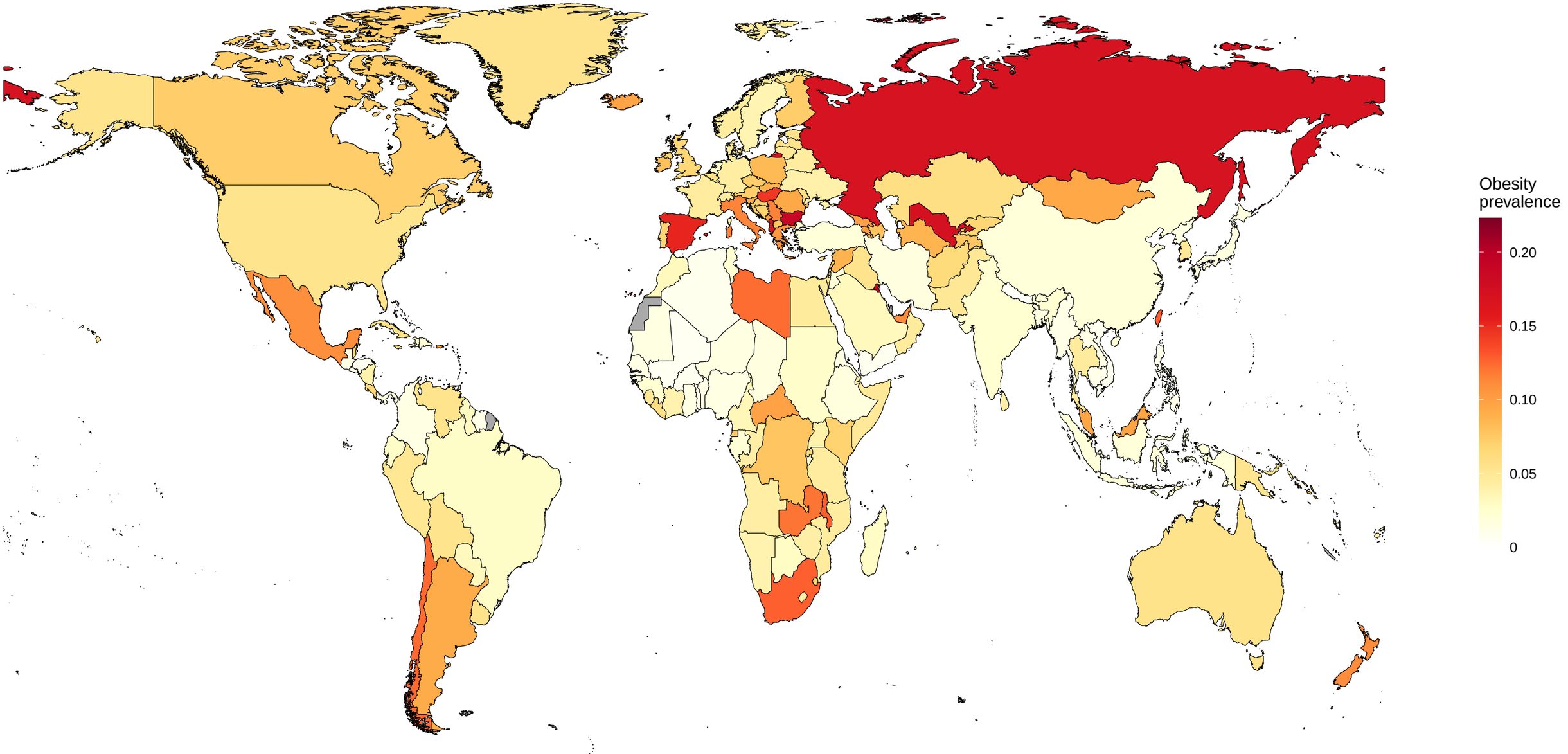
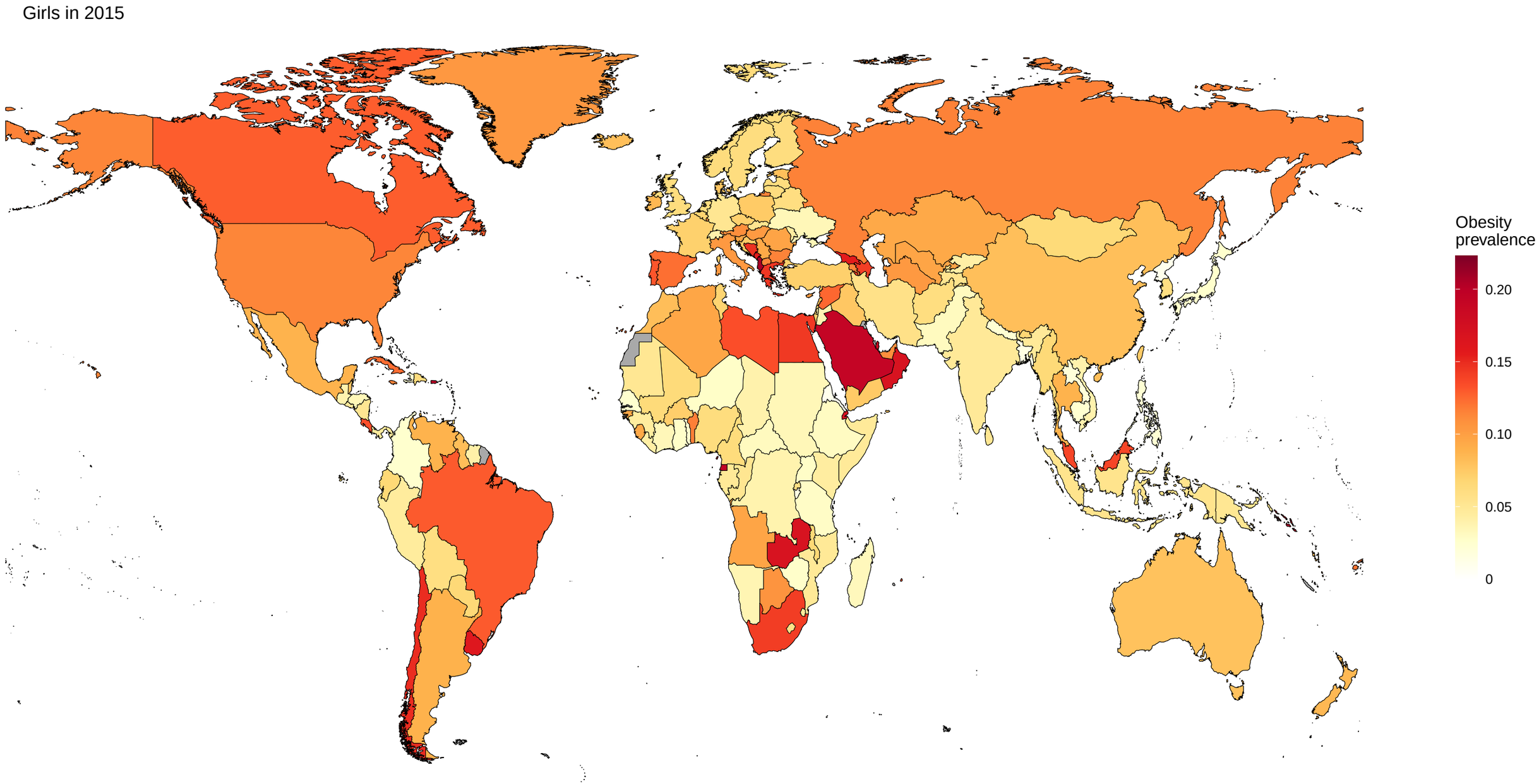


Figure 2

Click here to access/download;Figure;Figure2_obesity_maps_2015.pdf



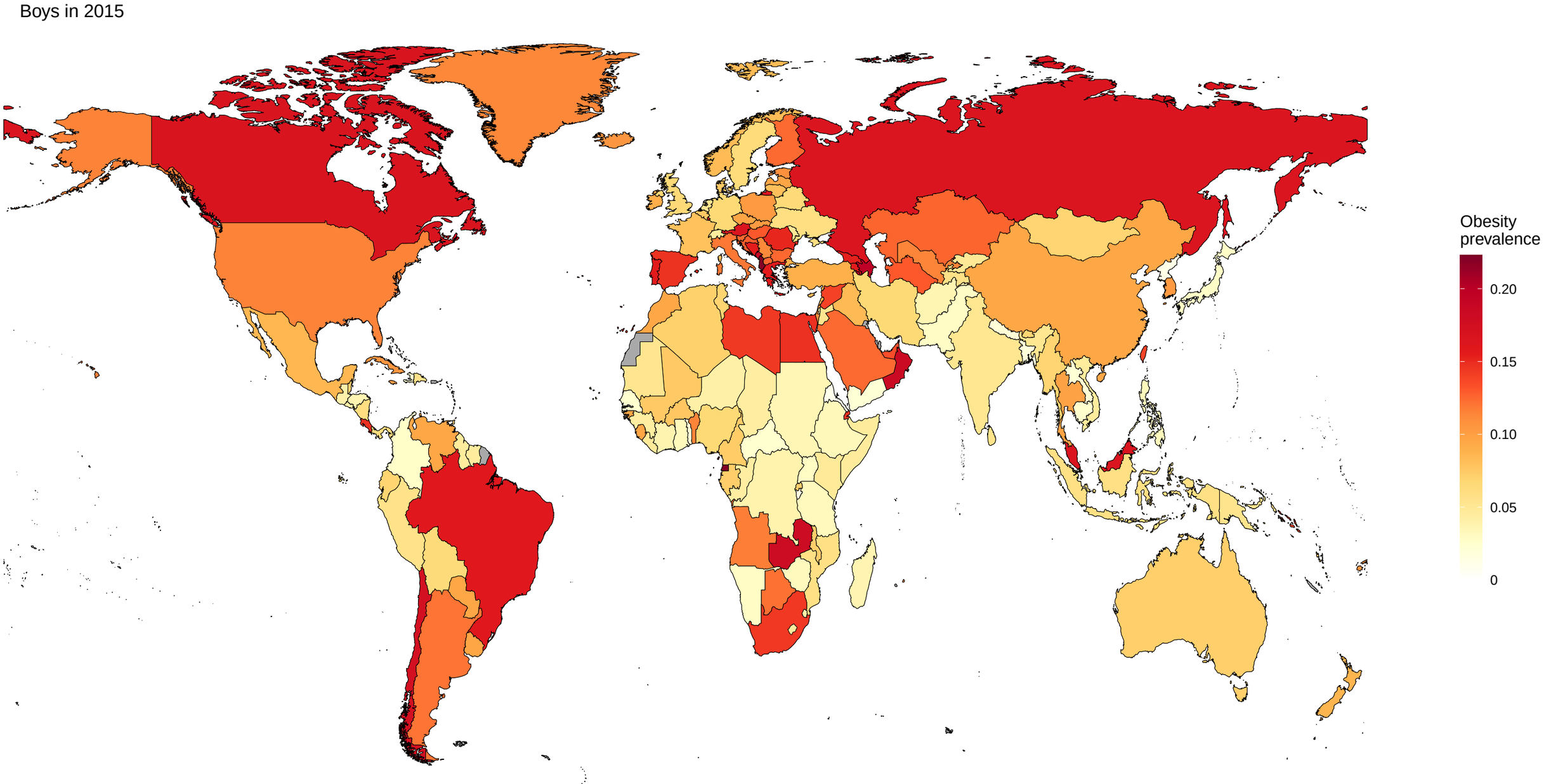
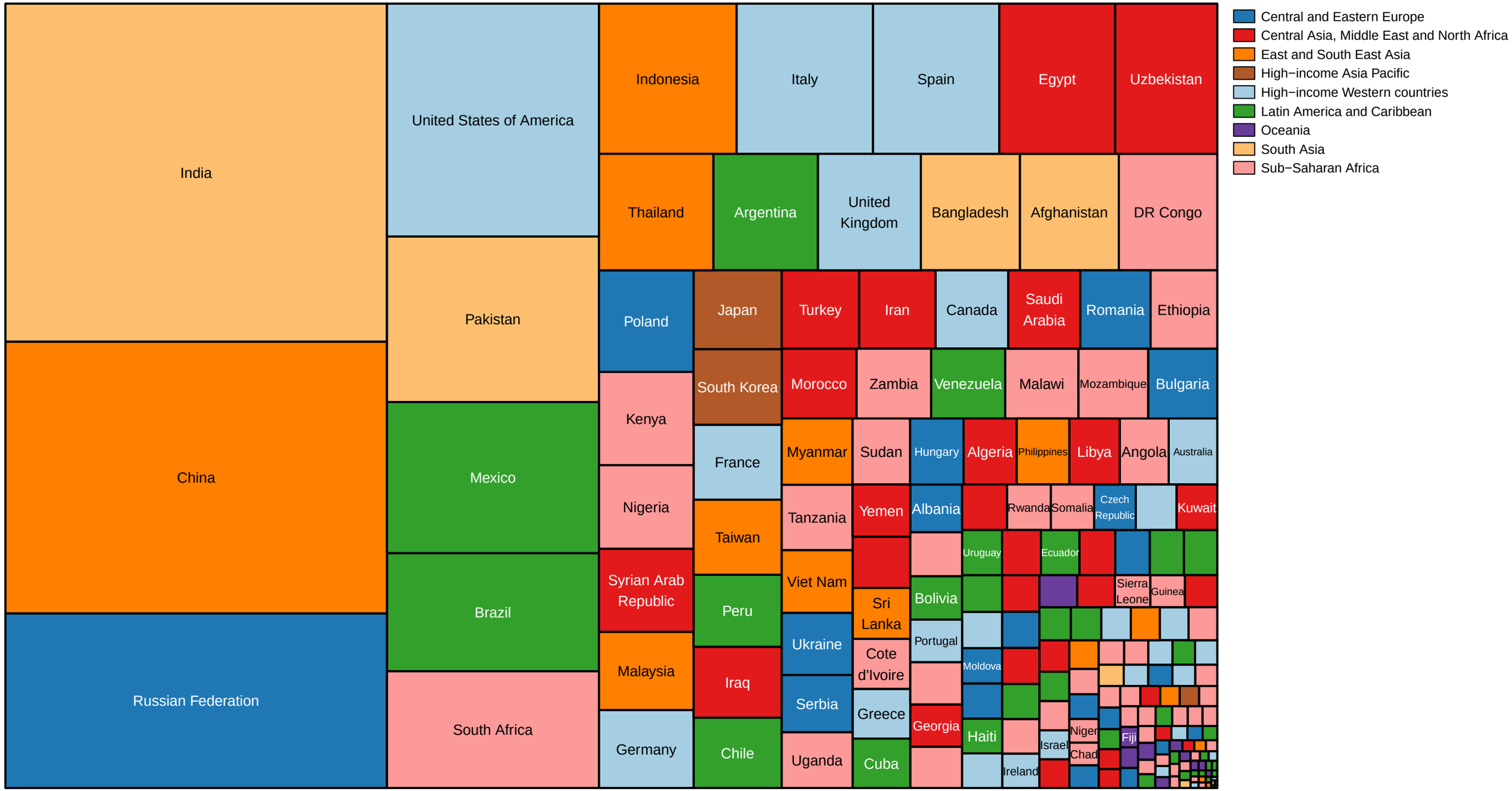

Boys in 2015
Obesity prevalence
0.20
0.15
0.10
0.05
0

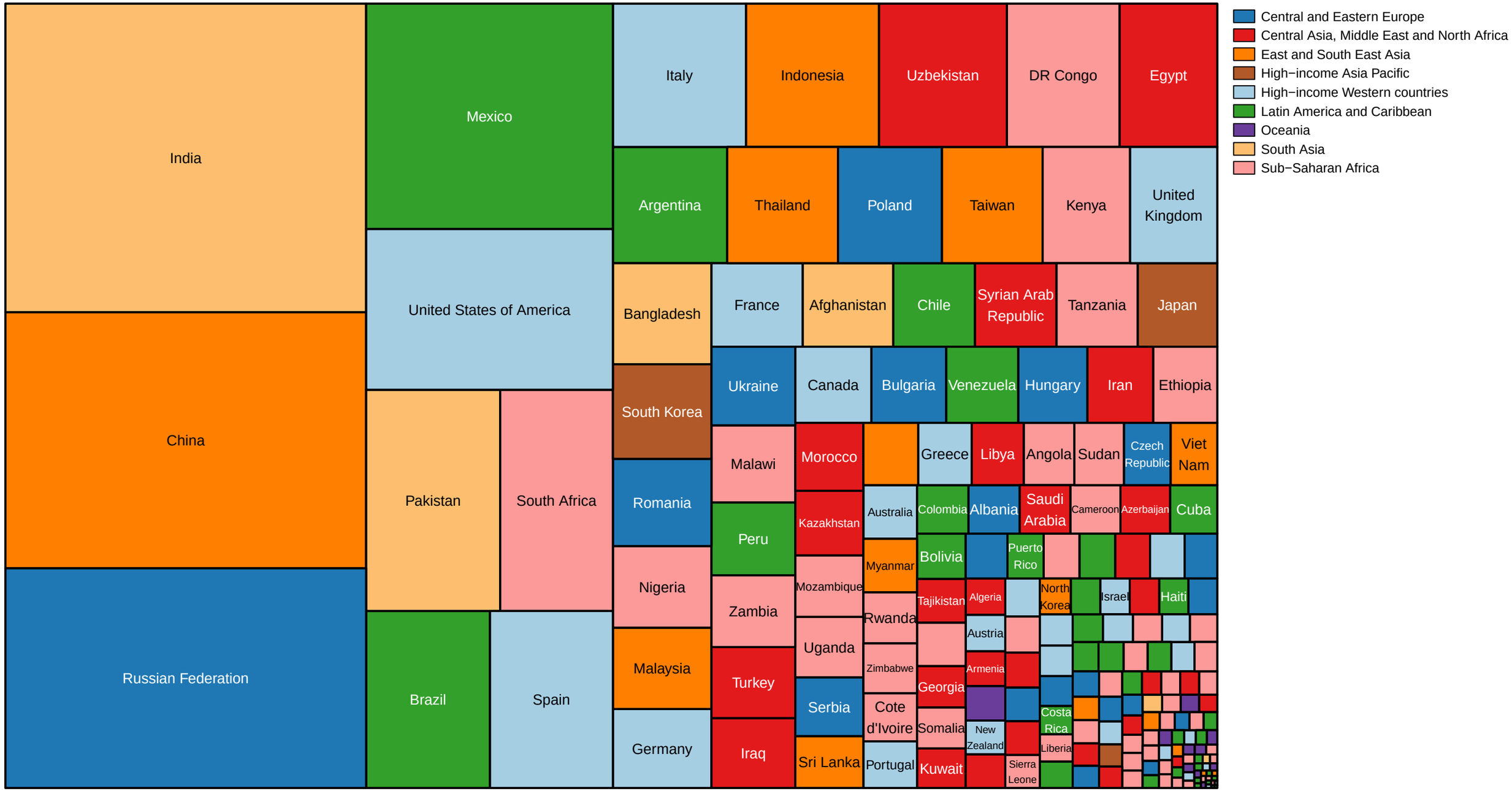
Figure 3

Girls in 1980

Click here to access/download;Figure;Figure3_treemap_1980.pdf



Boys in 1980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Central and Eastern Europe
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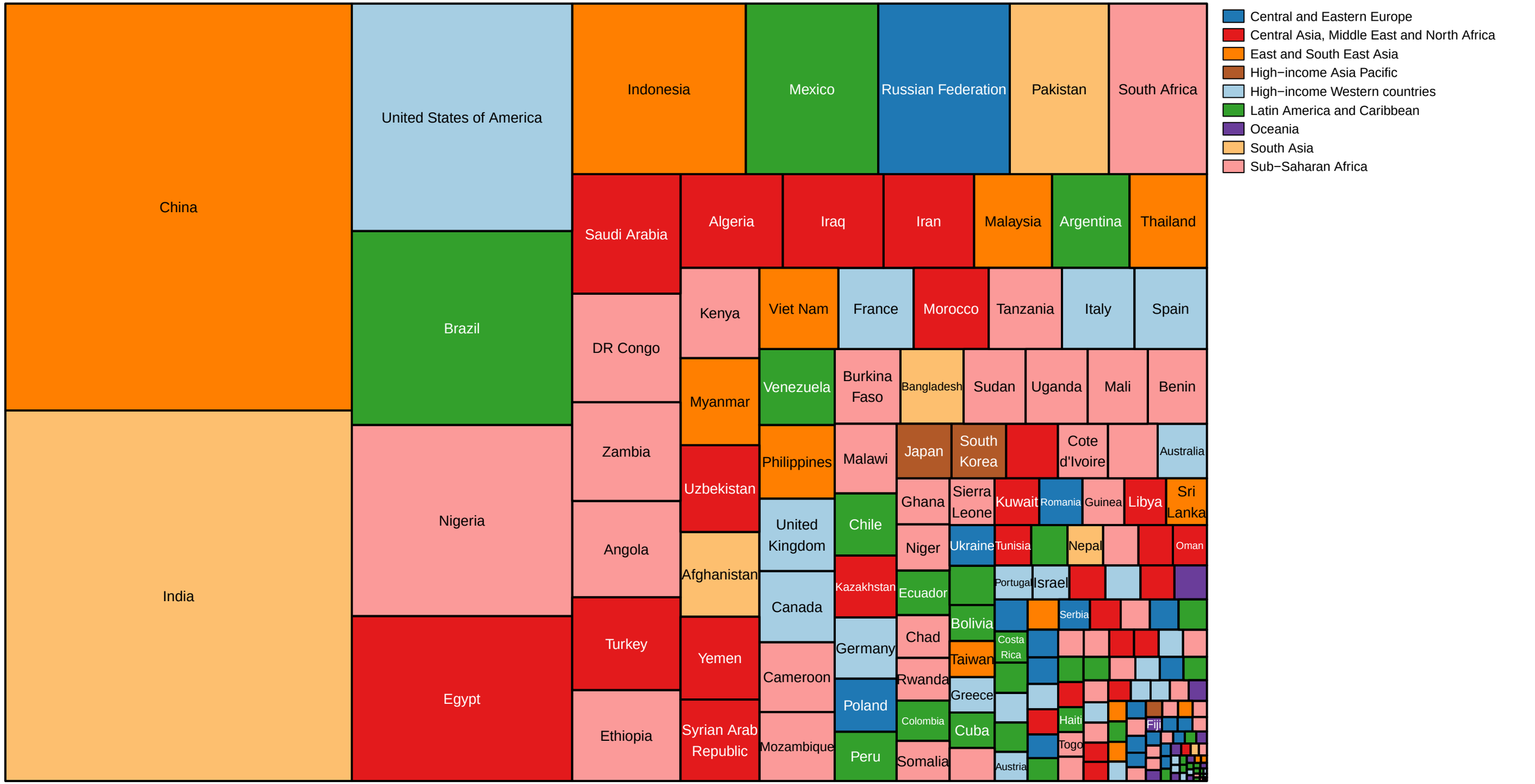
Figure 4

Girls in 2015

Click here to access/download;Figure;Figure4_treemap_2015.pdf



Boys in 2015

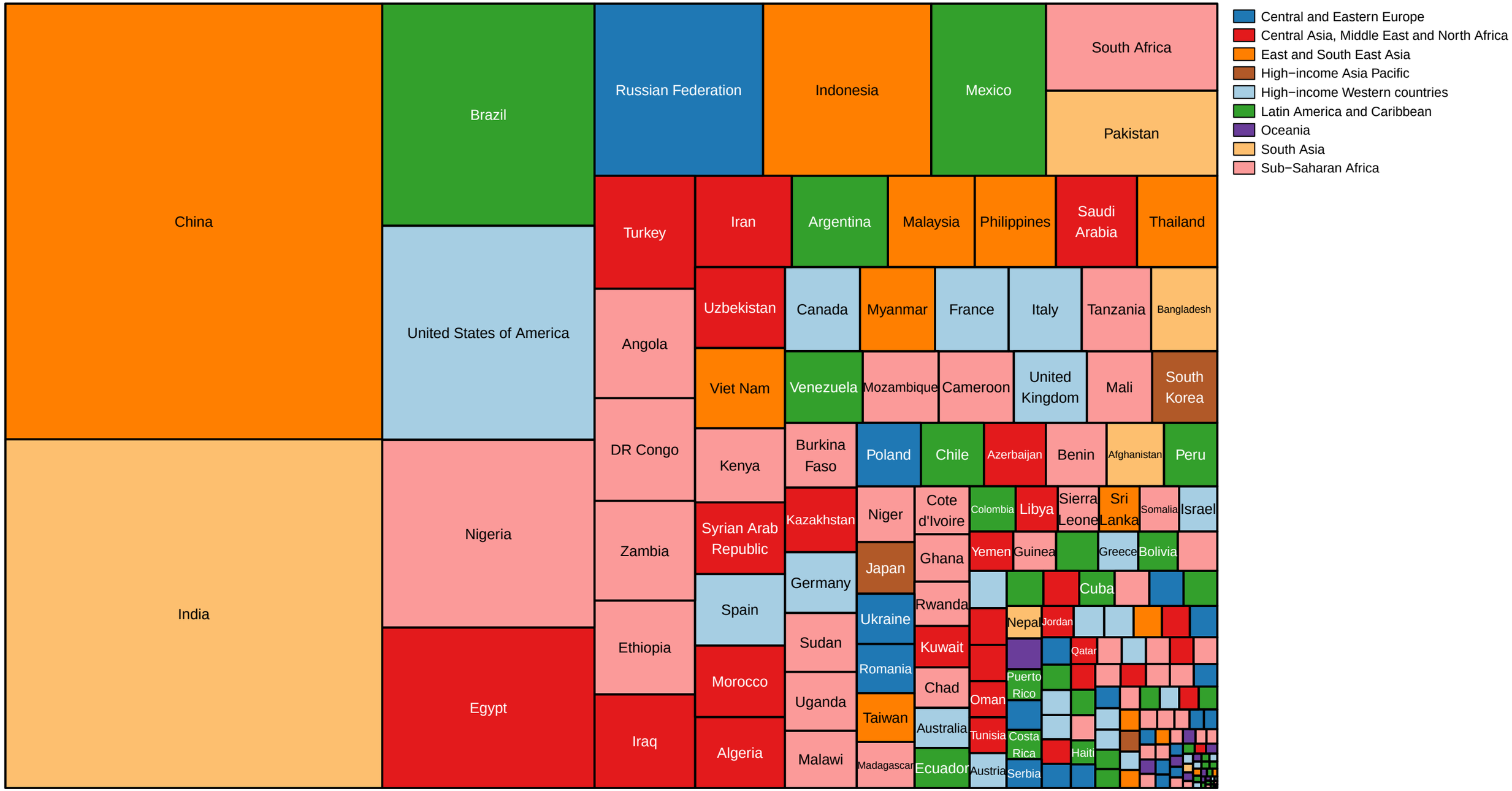

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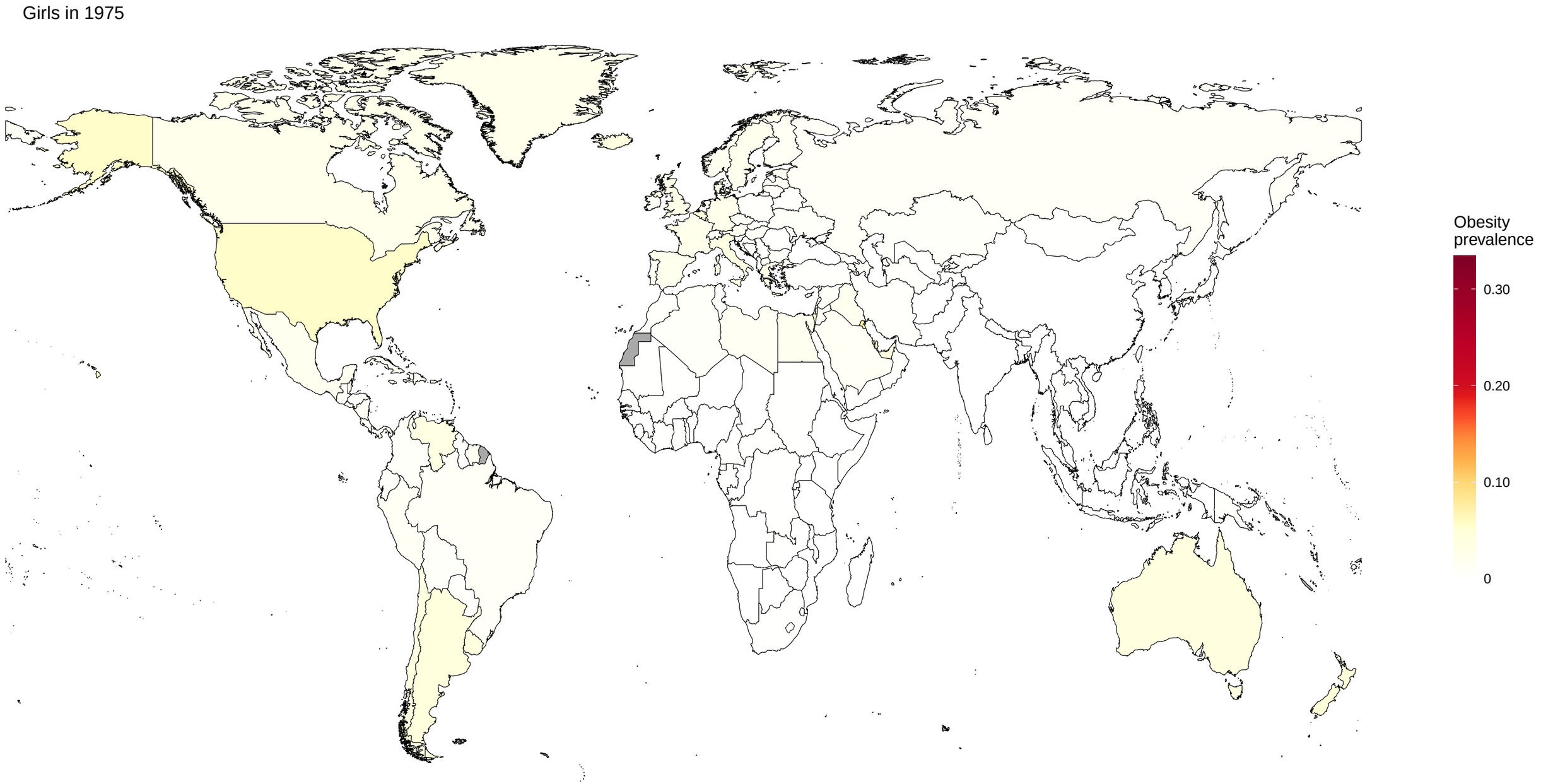
Figure 5

Click here to access/download;Figure;Figure5_world_map_1975.pdf



Boys in 1975

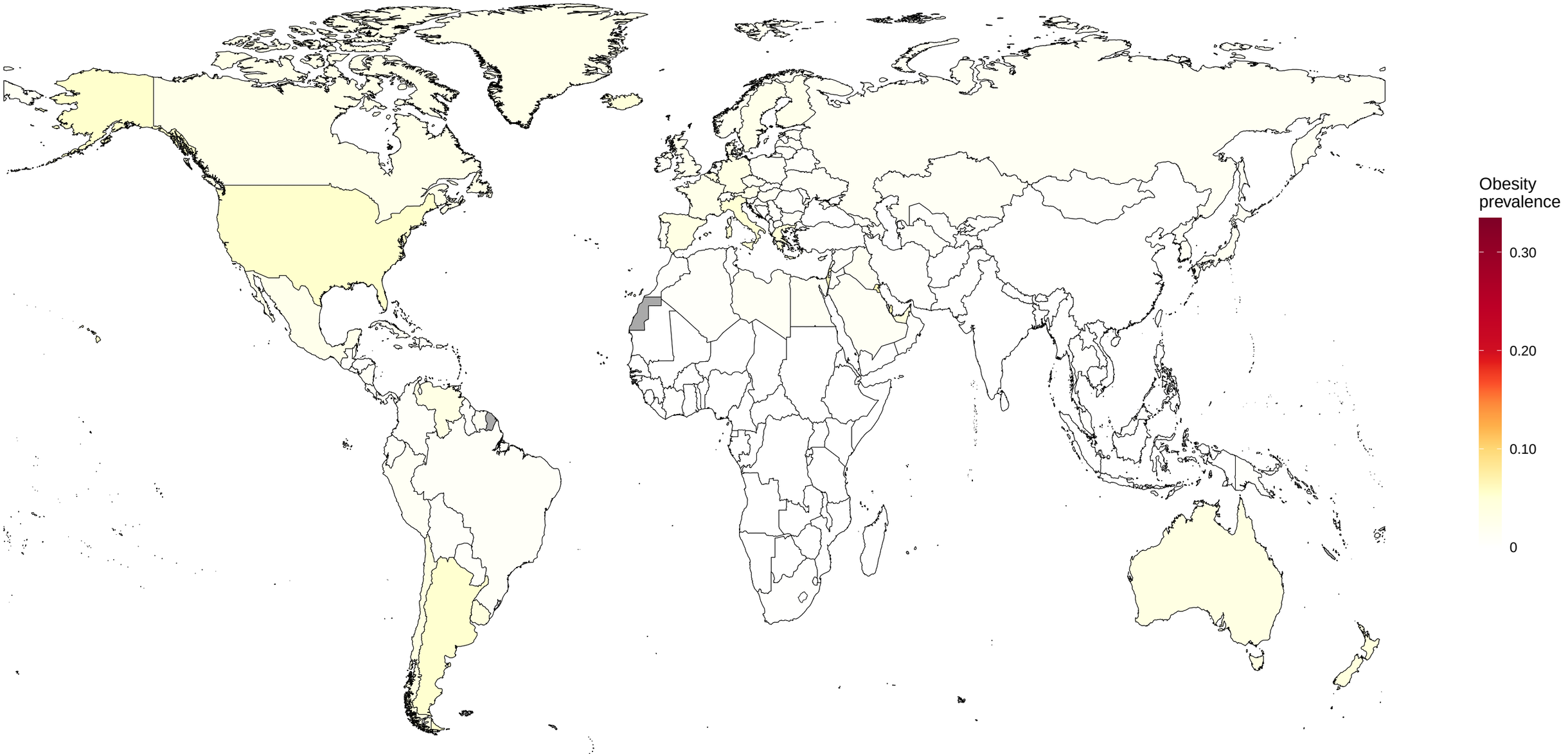
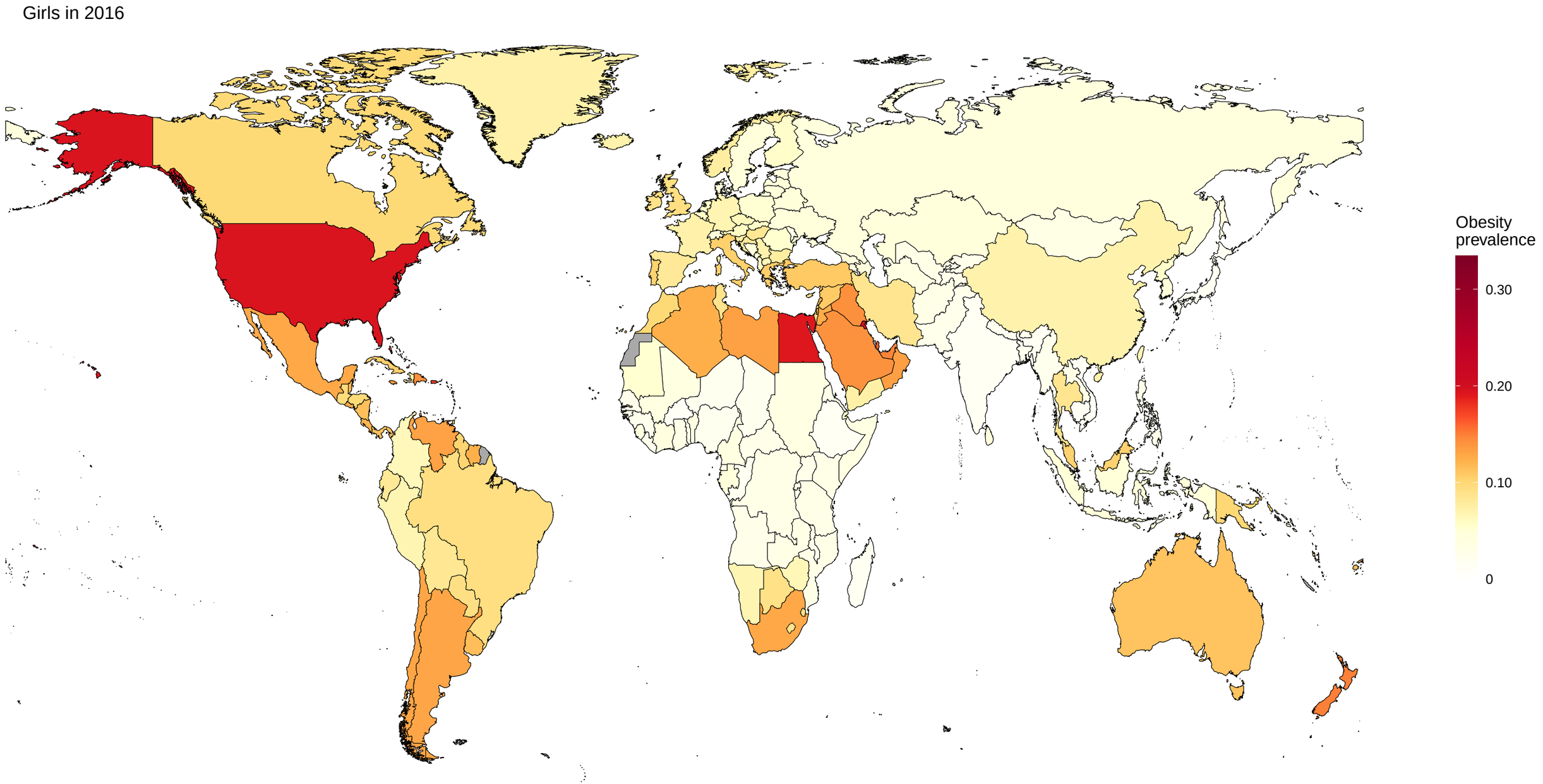


Figure 6

Click here to access/download;Figure;Figure6_world_map_2016.pdf



Boys in 2016

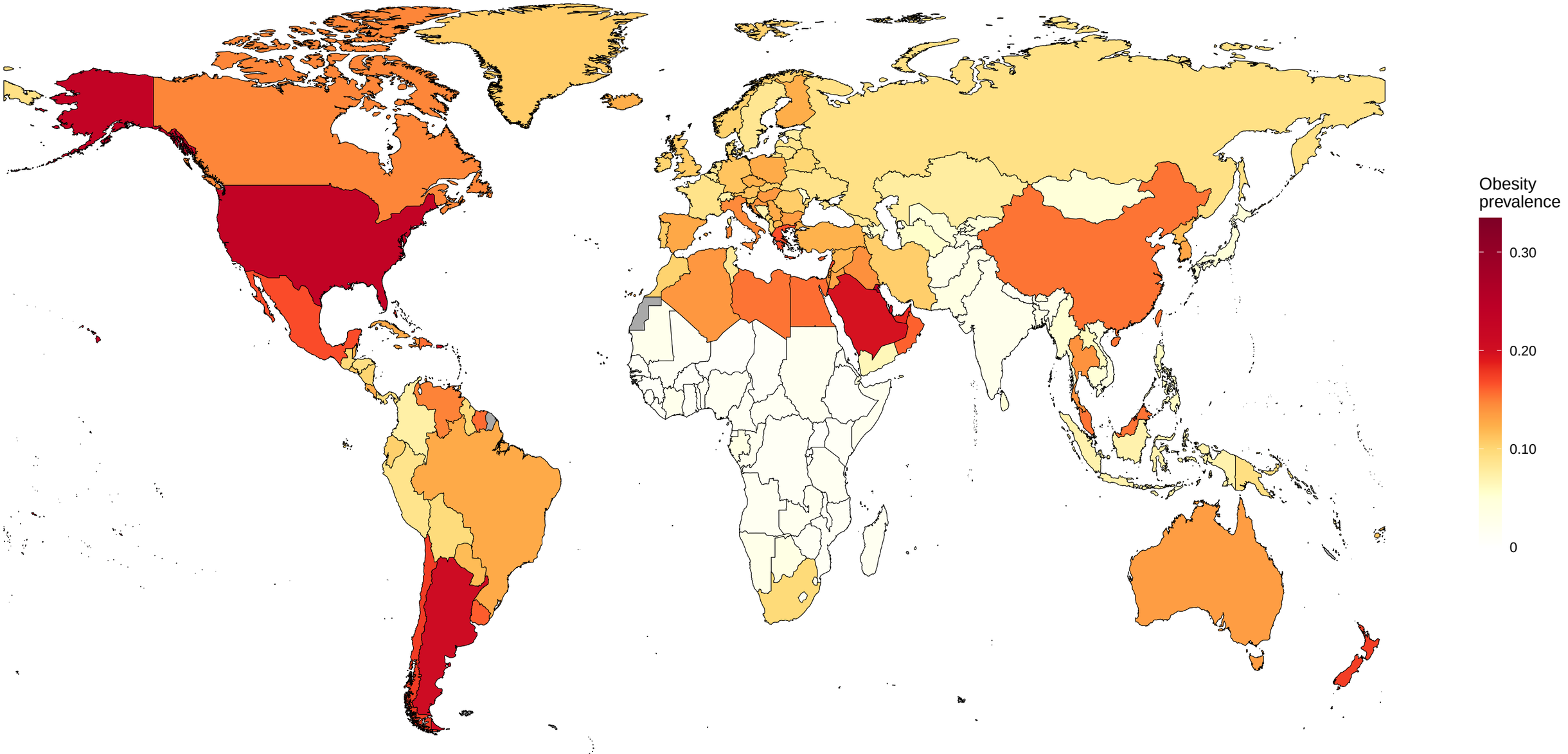
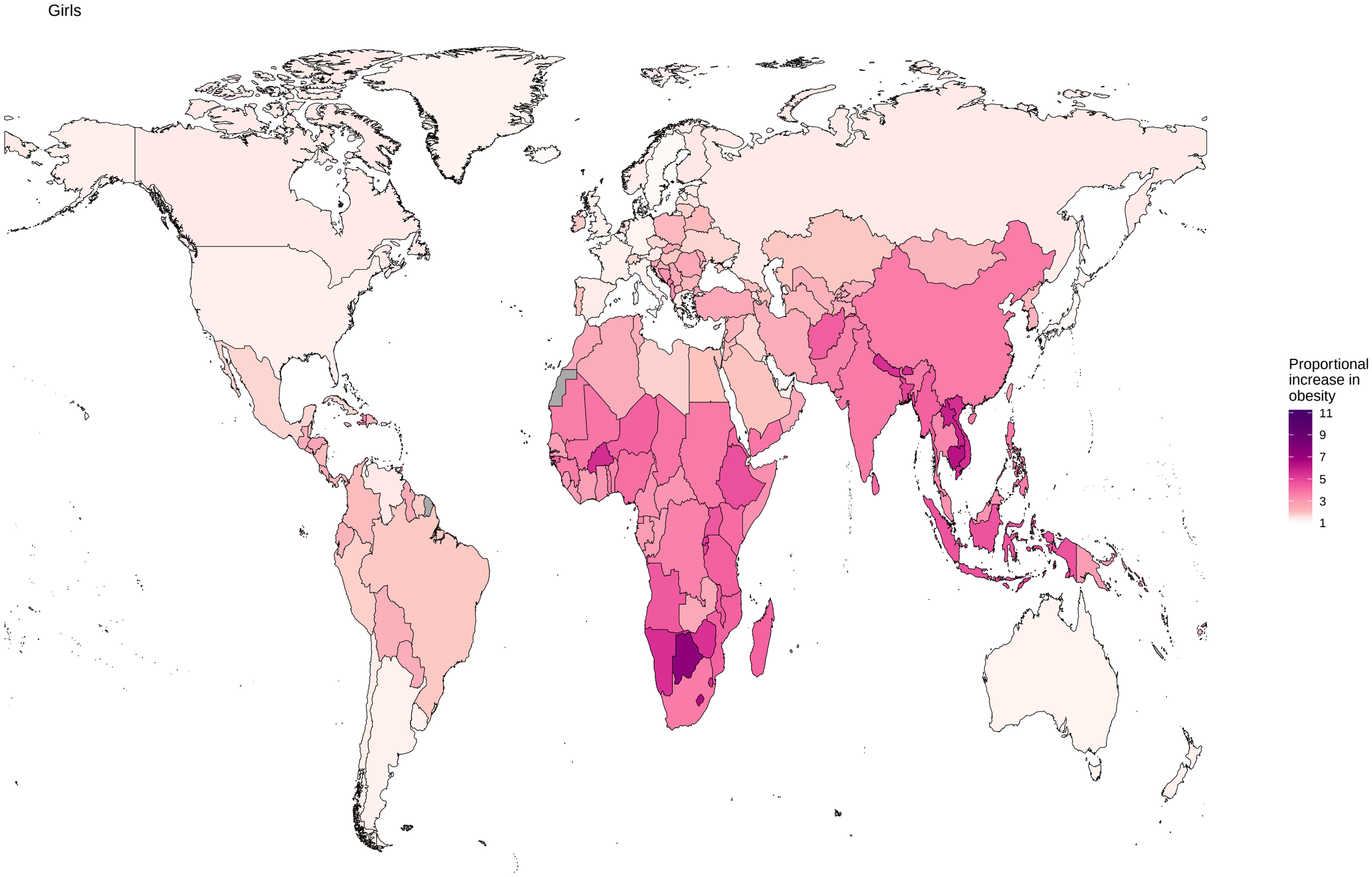


Figure 7

Click here to access/download;Figure;Figure7_proportional_increase.pdf



Boys

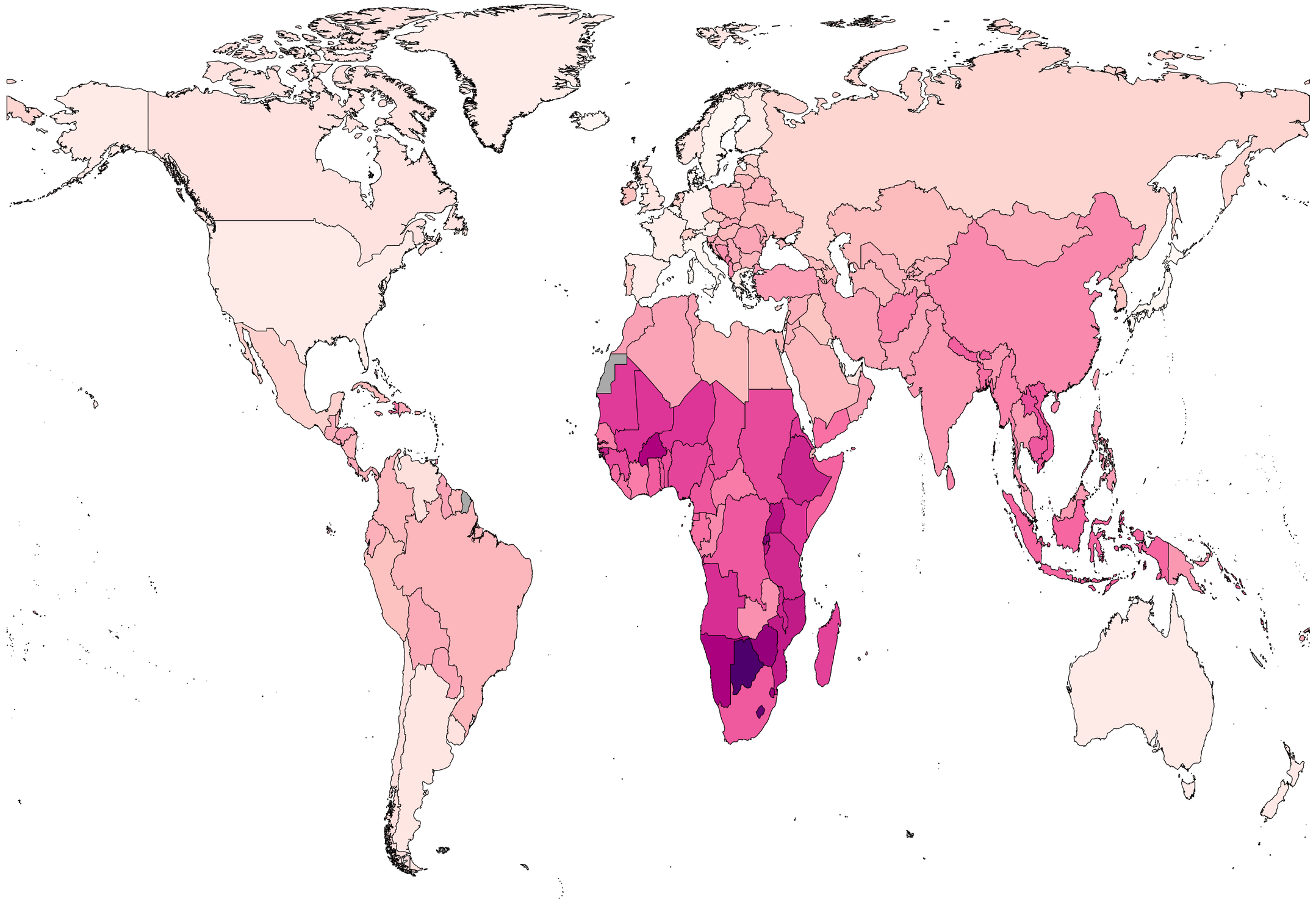
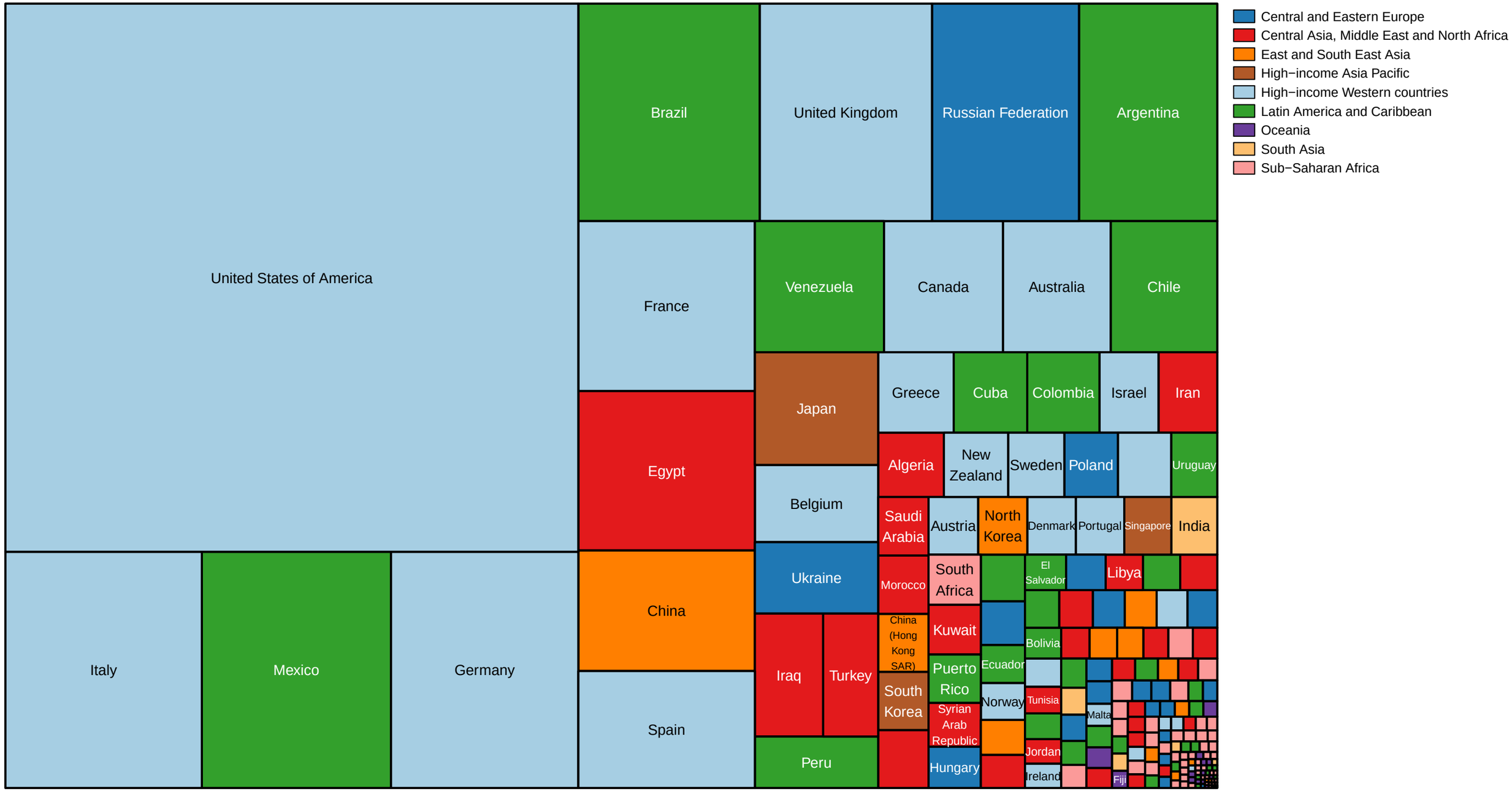


Figure 8

Girls in 1975

Click here to access/download;Figure;Figure8_treemap_1975.pdf



Boys in 1975

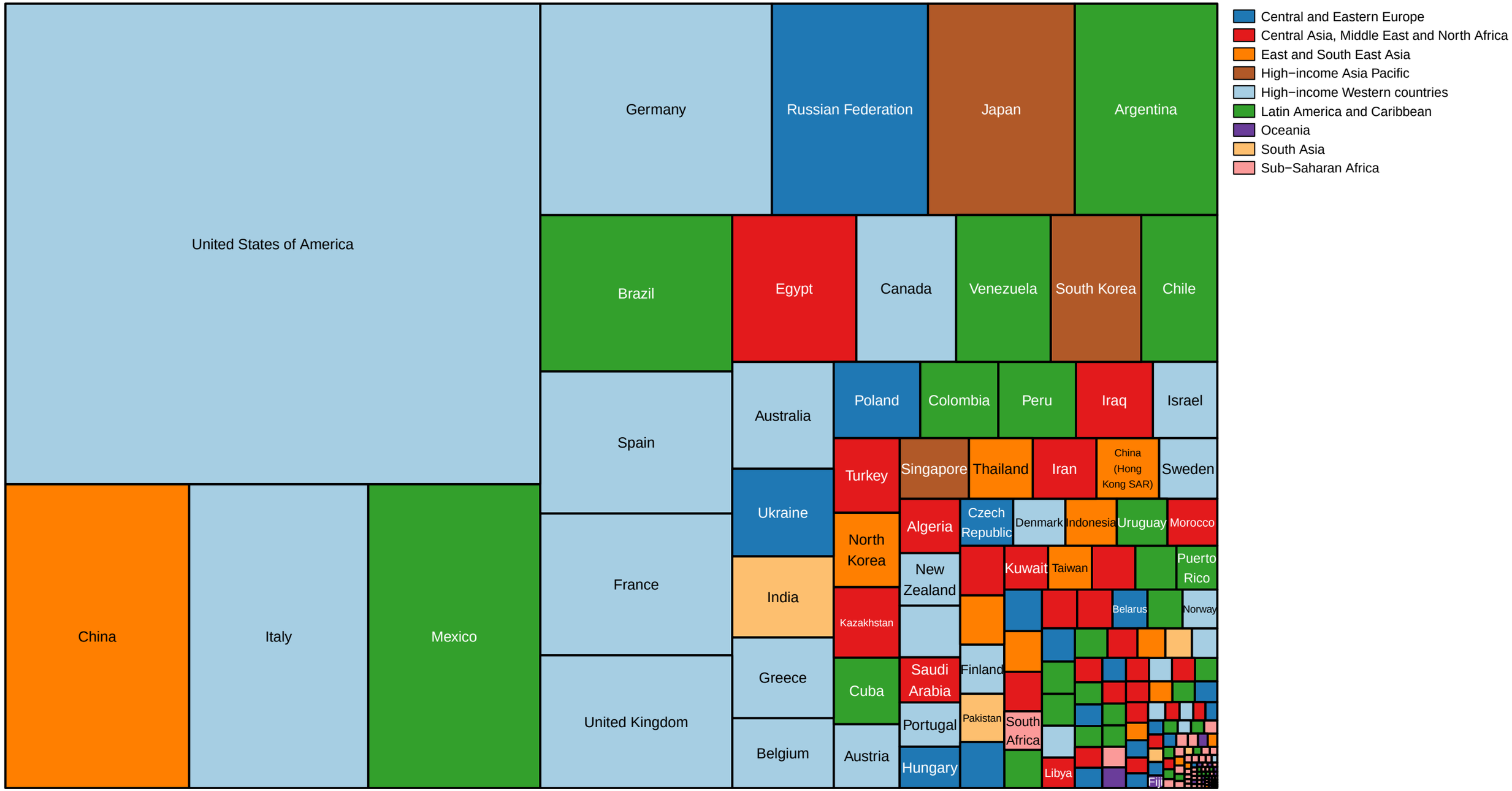

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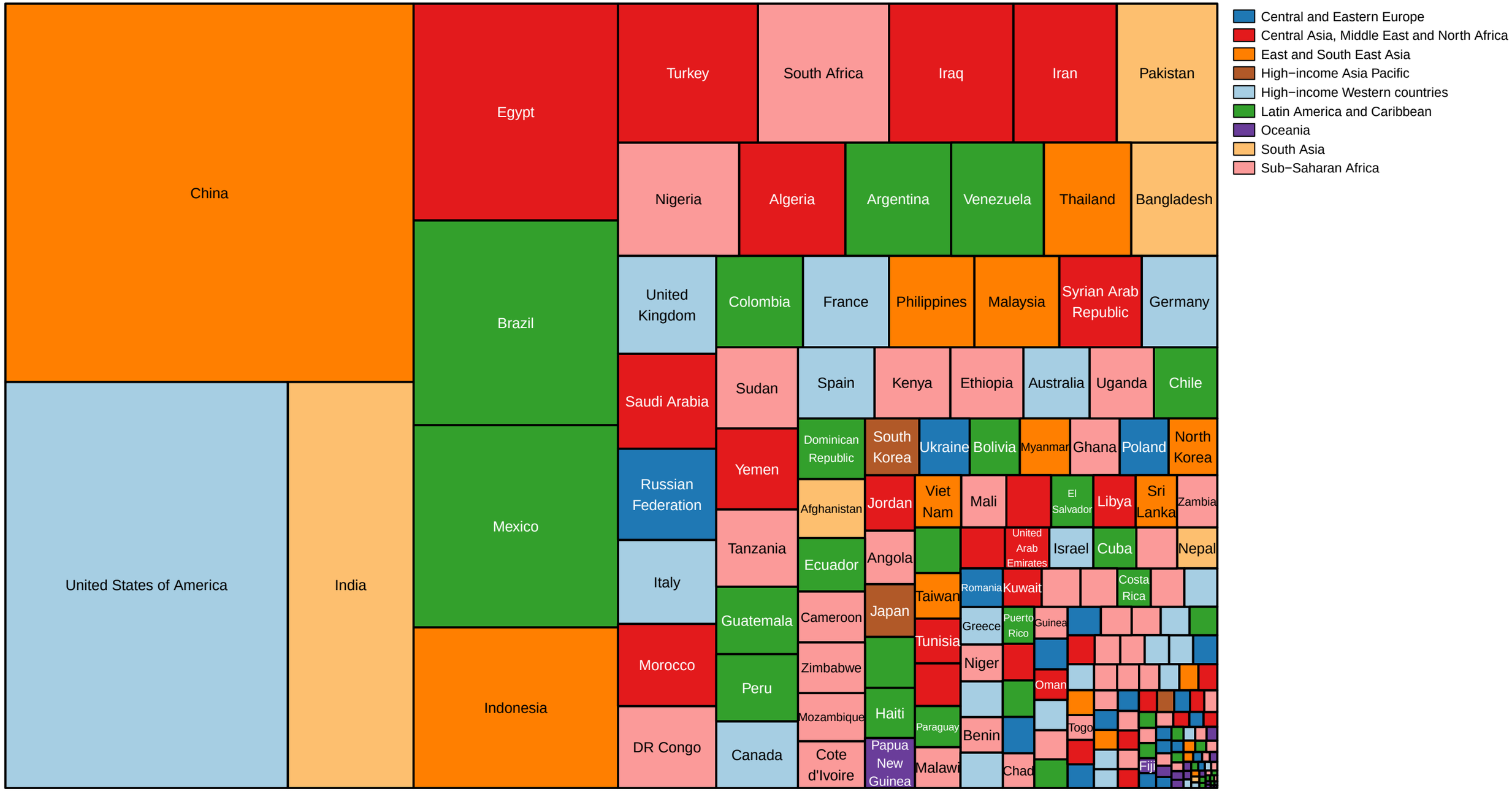
Figure 9

Girls in 2016

Click here to access/download;Figure;Figure9_treemap_2016.pdf



Boys in 2016

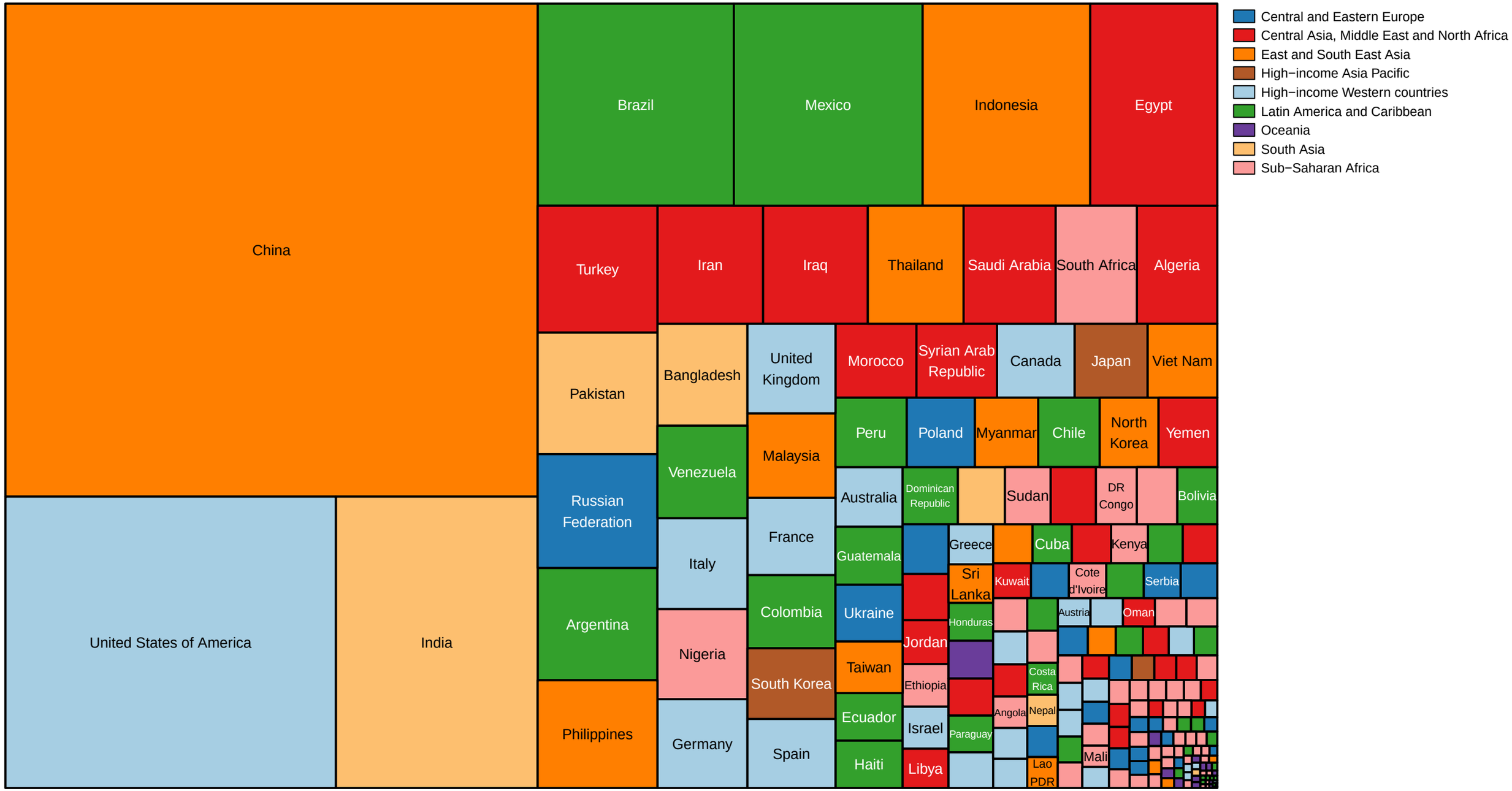

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Figure 10

Click here to access/download;Figure;Figure10_gender_comparison_prevalences.pdf

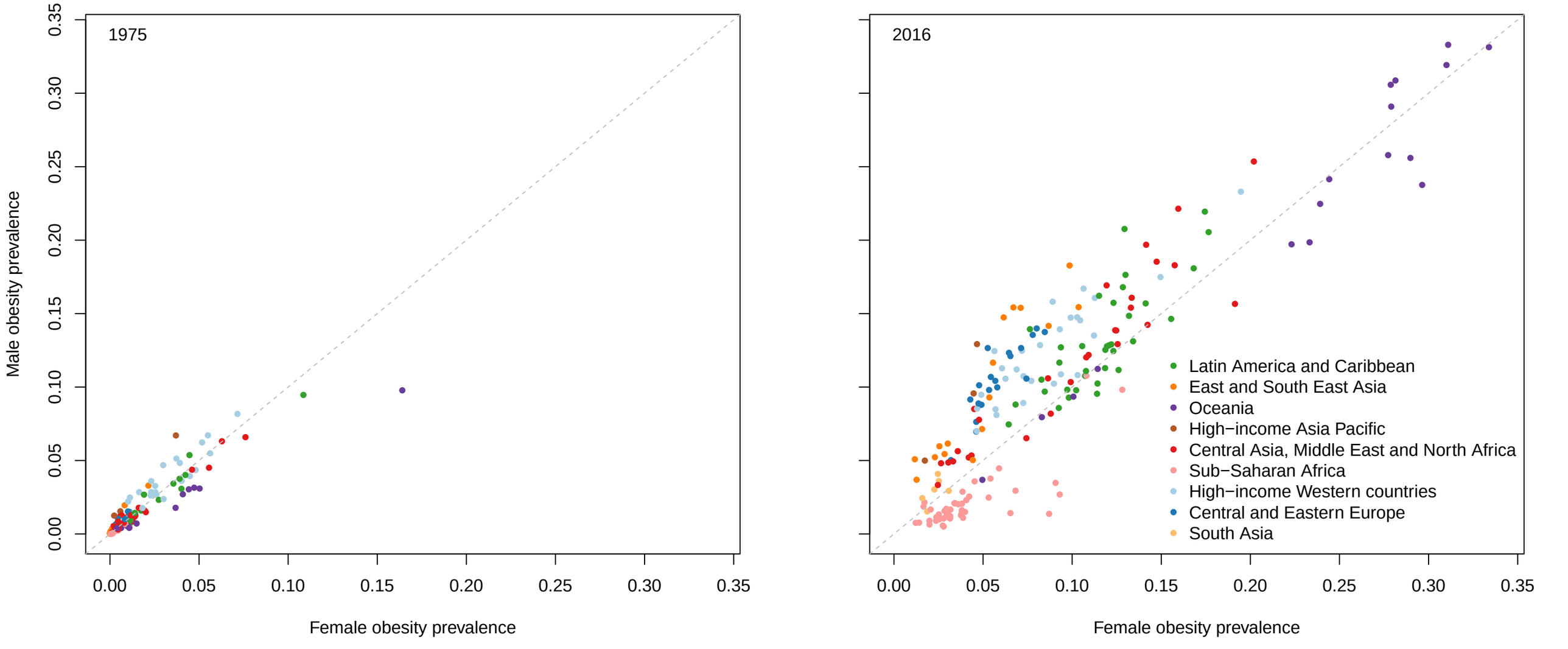

Figure 11

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