Socio-behavioural characteristics and HIV: findings from a causal modelling analysis of 29 sub-Saharan African countries

Zofia Baranczuk[a,b,c,#], Janne Estill[a,d,#,*], Sara Blough[a,e], Sonja Meier[f], Aziza Merzouki[a], Marloes H. Maathuis[f,#], Olivia Keiser[a,#]

[a]Institute of Global Health, University of Geneva, Geneva, Switzerland

[b]Department of Psychology, University of Zurich, Zurich, Switzerland

[c]Institute of Mathematics, University of Zurich, Zurich, Switzerland

[d]Institute of Mathematical Statistics and Actuarial Science, University of Bern, Bern, Switzerland

[e]Rollins School of Public Health, Emory University, Atlanta, GA, United States

[f]Seminar for Statistics, ETH Zürich, Zurich, Switzerland

[#]*equal contribution*

*Correspondence to:

Janne Estill, PhD
Institute of Global Health
University of Geneva
Chemin des Mines 9
1202 Geneva, Switzerland
Tel. +41 31 631 88 18
janne.estill@unige.ch

Word count: Abstract 288 words; main text 3272 words; 1 table; 4 figures; 1 appendix

Abstract

Background: Socio-behavioural factors may contribute to the wide variance in HIV prevalence between and within sub-Saharan African (SSA) countries.

Methods: We used Bayesian network models to explore socio-behavioural variables that may be causally related to HIV. A Bayesian network consists of nodes and edges, where nodes represent variables, and edges represent the conditional dependencies between them. We populated our models with data from Demographic and Health Surveys conducted in 29 SSA counties in 2010 or later. We predefined and dichotomized twelve variables that could be related to HIV, including age, literacy, HIV knowledge and testing, domestic violence, sexual activity, and women's empowerment. We first analysed data on men and women for each country separately and then aggregated the results.

Findings: We analysed data from 190,273 men (range across countries 2,295–17,359) and 420,198 women (6,621–38,948). The two variables with the highest total number of edges were literacy and rural/urban location. Literacy was negatively associated with false beliefs about AIDS (women 24, men 27 countries) and, for women, early sexual initiation (21 countries). Literacy was also positively associated with ever being tested for HIV (women 8, men 22 countries) and the belief that women have the right to ask their husband to use condoms if he has a sexually transmitted infection (women 12, men 13 countries). Rural residence was positively associated with false beliefs about AIDS (women and men 14 countries) and the belief that beating one's wife is justified (women 16, men 9 countries), and negatively associated with having been tested for HIV (women 12, men 11 countries).

Interpretation: Literacy and urbanity were strongly associated with several factors that are important for HIV acquisition.

Funding: This project was funded by the Swiss National Science Foundation (grant no. 163878)

Keywords: causal analysis, Bayesian network, HIV, DHS, socio-behavioural factors

Introduction

In sub-Saharan Africa in 2016, 25-27 million people were living with HIV.[1] HIV prevalence is high overall, but very heterogeneous in and between countries, ranging from under 1% in Senegal and Niger to up to 25% in Lesotho and eSwatini (previously Swaziland).[2–6] The HIV epidemic comprises concentrated micro-epidemics of different geographical scales.[7] The Joint United Nations Programme on HIV/AIDS (UNAIDS) has urged researches to pay attention to these variations, and to identify geographical areas where the risk of acquiring HIV is higher: "know your epidemic, know your response."[7] Without understanding the underlying reasons for this variation, it is hard to plan effective interventions. Variation has been attributed to many factors, socio-demographic, behavioural, and biological.[3,8] Among the factors associated with HIV burden are age, religion, marital status, high levels of HIV-related stigma, sexual coercion, education, occupation, and gender.[4,8]

Education can affect HIV prevalence. Even in countries where everyone knows HIV risk is high, the public may not know much about how the disease spreads. For example, those who have not been taught why and how to use condoms are less likely to protect themselves.[8] Attitudes and behaviour can also contribute to HIV risk. If false beliefs about HIV and AIDS are not corrected and replaced with specific, accurate knowledge about HIV, this can increase risky sexual behaviour and infection risk.[9] Women with little education are likely to be less informed about interventions that mitigate HIV risk,[9] but higher HIV rates among women cannot be fully explained by either lower educational levels or higher biological susceptibility. In countries with high HIV prevalence, gender inequality has been associated with HIV spread along with low levels of general education[10] and sexual education.[8] Women with limited or no income may engage in transactional sex to survive, [11] so socioeconomic and living conditions can also be factors in HIV transmission. Urban residence may increase the risk of infection by increasing the probability of high risk sexual contacts[12] though it may also decrease HIV risk because urban dwellers are more likely to be employed and have better access to care and treatment.[13]

Most studies of HIV risk factors or risk factors for the uptake of interventions against HIV have used logistic regression models to simultaneously adjust for a range of factors.[14,15] but this approach cannot account for the complex network of associations and causal pathways between various risk factors and HIV. Understanding this network could help us identify drivers of the epidemic to reach the global treatment targets set by United Nations Member States.[2] We thus explored socio-behavioural variables that could contribute to the HIV epidemic by analysing data from Demographic and Health surveys from 29 countries in Sub-Saharan Africa using Bayesian network analysis of predefined variables.

Methods

Data description

The Demographic and Health Surveys (DHS) Program collects and disseminates high-quality, nationally representative data on fertility, family planning, maternal and child health, gender, HIV/AIDS, malaria, and nutrition in low- and middle-income countries around the world. Typically, it collects data on between 3,300 and 5,300 variables per country every 5 years. The DHS surveys include women of reproductive age (15-49 years) and (depending on the country) men aged 15-49, 15-54 or 15-59 years.

We used data from the DHS and included all countries in sub-Saharan Africa where a DHS survey was administered during or after 2010.[6] We included the last available survey for each country (as of August 2018): Angola 2015-16; Benin 2011-12; Burkina Faso 2010; Burundi 2010; Cameroon 2011; Chad 2014-15; Congo 2011-12; Democratic Republic of the Congo 2013-14; Côte d'Ivoire 2011-12; Ethiopia 2016; Gabon 2012; The Gambia 2013; Ghana 2014; Kenya 2014; Lesotho 2014; Liberia 2013; Malawi 2015-16; Mali 2012-13; Mozambique 2011; Namibia 2013; Niger 2012; Nigeria 2013; Rwanda 2014-15; Senegal 2010-11; Sierra Leone 2013; Togo 2013-14; Uganda 2011; Zambia 2013-14; and, Zimbabwe 2015. We excluded Tanzania from the analysis because some essential variables were missing from their DHS data.

Two researchers (ZB and OK) preselected variables and dichotomized them before analysis. We included the following variables because they covered topics that could relate to HIV and were available for all selected countries: age 24 or younger (yes, no); rural location (yes, no); female head of household (yes, no); literacy (able to read whole sentence: yes, no/missing); access to media at least once a week (yes, no/missing); sexual initiation before 16 years (yes, no); currently working (yes, no/missing); judging wife-beating justified (yes/does not know/missing, no); married or living together either now or previously (yes, no); false beliefs about AIDS (yes/does not know/missing, no); judging it justified for a wife to ask her husband to use a condom if he has a sexually transmitted infection (STI; yes, no/does no know/missing); ever tested for HIV (yes, no/missing); and diagnosed HIV positive at the time of the survey (yes, no/no result).[16]

Data analysis

We conducted exploratory data analyses and Bayesian network analyses separately for men and women in each country and included all variables except HIV status in our main analysis. The information on HIV status was available only for 23 countries, so we performed separate analyses that included HIV status for these countries.

First, we calculated crude odds ratios for each pair of variables by country and sex. Then we conducted a Bayesian network analysis to determine the possible causal relationship between variables for each country, separately for men and women. Bayesian networks are graphical models in which nodes represent random variables and edges represent certain probabilistic dependencies between them. In particular, the presence of an edge means that the corresponding variables are dependent given any subset

of the remaining variables. Our analysis assumes that all important variables were measured, i.e., that there are no unmeasured confounders. While the presence or absence of an edge is always identifiable under our assumptions, the directions of edges may be unknown, so we can only learn a so-called completed partially directed acyclic graph (CPDAG).[17] The theoretical framework for learning CPDAGs is well-developed[18]. We used a fully automatic approach with the Incremental Association Markov Blanket (IAMB) algorithm[19] within the *bnlearn* package in R[20]. To improve the stability of the estimated graphs, we used bootstrap sampling. For each country and sex, we took 10,000 bootstrap samples, using weighted resampling to account for the sampling weights in the DHS data. For each bootstrapped data set, we obtained the corresponding estimated CPDAG. We then constructed a graph for each country as follows: two nodes were connected if the edge was present in at least 90% of the bootstrap samples, and edges were oriented if they were directed in that direction in at least 70% of the samples.

Finally, we calculated an overall summary graph by sex that combined the information for all countries. In this summary graph we only considered edges present in at least six countries for the analysis without HIV status, or five countries for the analysis with HIV status. The orientation of edges in the summary graph was determined as follows: For each edge, the number of countries with an orientation in one direction, and the number of countries with an orientation in the other direction was determined. If the difference between these numbers of countries was at least six, the edge in the summary graph was oriented according to the majority orientation. We estimated the sign of an association conditionally on all other variables using the Cochran-Mantel-Haenszel odds ratio[21] and marginally by calculating the crude odds ratio. We considered associations negative if both the crude and the conditional odds ratio were less than one, and positive if both the crude and the conditional odds ratios were above one.

We used the open source R language, version 3.5.0 for our analysis.[20] The code is available on github (https://github.com/ZofiaBTZ/DAGS_DHS).

Results

We included 190,273 men (range across countries 2,295–17,359) and 420,198 women (6,621–38,948) in the analysis. The age distribution and percentage of people living in urban areas were similar for males and females (Table 1). Women were less likely to be able to read (46% vs. 68%), to have media access (61% vs. 74%), to currently work (54% vs. 79%), and more likely to have been tested for HIV (49% vs. 31%).

We found both differences and similarities in crude odds ratios between variables across the sexes (Figure 1). For example, for both sexes, false beliefs about AIDS were positively associated with rural location and judging gender-based violence justified. Additionally, for women it was positively associated with sexual initiation before age 16. Having ever been tested for HIV was positively associated for both sexes with the belief that it is justified for a wife to ask the husband to use a condom if he has a sexually transmitted infection (STI), with being married, with media access, and with literacy. These findings were consistent across countries.

Figure 2 shows the estimated summary graphs from the Bayesian network analysis for women and men. The thickness of the edges is proportional to the number of countries for which the given edge was present, and the colour and pattern indicate if the association (i.e. the signs of both crude and conditional log odds ratios) was always negative (blue, dashed), positive (red, solid), or differed between countries (grey, dotted). In both men and women, literacy and urbanity had the largest number of edges, including many with variables potentially linked with the probability of acquiring HIV. For instance, for women, literacy was negatively associated with sexual initiation before age 16 and false beliefs about AIDS in most countries (21 and 24, respectively). Moreover, for women, literacy was positively associated with the belief that it is justified to ask the husband to use a condom if he has an STI (12 countries) and having ever been tested for HIV (8 countries). For men, literacy was positively associated with having been tested for HIV and negatively associated with having false beliefs about AIDS in almost all countries (20 and 27 countries, respectively). In 13 countries, literacy among men was also positively associated with believing the wife is justified to ask the husband to use a condom if he has an STI. For both men and women, living in a rural area was positively associated with accepting domestic violence against the wife (women 16 countries, men 9 countries) and having false beliefs about AIDS (14 countries for both men and women), and negatively associated with having been tested for HIV (women 12 countries, men 11 countries). Having been tested for HIV was positively associated with having access to media (women 8 countries, men 11 countries) and the belief that it is justified to ask the husband to use a condom (women 24 countries, men 8 countries). Among women, having been tested for HIV also was positively associated with being married in most countries. We found only very few directed edges, and will not interpret these in a fully causal way. Detailed results for each country are reported in the Appendix.

HIV data were unavailable for Benin, Congo, Kenya, Mozambique, Nigeria and Uganda. In the analysis of the remaining 23 countries where we included HIV status, testing HIV positive was negatively associated with younger age and living in a rural location for both sexes (Figure 3). Being HIV infected was positively associated with being married, thinking it is justified for a wife to ask a husband to use a condom if he has

an STI, and having ever been tested for HIV for both sexes. For women, having a female household head was also positively associated with HIV positivity.

For men, adding HIV status yielded little difference: HIV status was not associated with any other variable in the summary graph (Figure 4). For women, however, being HIV positive was positively associated with older age in four countries, ever being tested for HIV in two countries, living in an urban area in two countries and being married in one country. For women, being HIV positive was also positively associated with having a female household head, and negatively associated with younger age and living in an urban area.

Discussion

Our analysis revealed a detailed picture of crude and fully adjusted associations between many socio-behavioural variables that may be linked to HIV in sub-Saharan African countries. Literacy and urbanity were the most central variables: they were directly connected to at least half of the remaining variables for both men and women in at least six countries. Access to media, information on HIV and HIV testing differed greatly between urban and rural locations. Having false beliefs about AIDS was strongly connected with rural location, being illiterate and accepting domestic violence against women. The likelihood of ever being tested for HIV was higher among people who were married, literate, or living in urban settings. For women, HIV testing was also positively associated with feeling justified to ask the husband to use a condom if he had an STI. Many associations were also observed in only few countries. Causal relationships were confirmed for very few associations. Very few directed edges were found.

Literacy was directly associated with several factors that should protect against acquiring HIV. For example, literate women started sexual relationships later, and literate people were less likely to have false belief about AIDS. This is promising, since literacy is one of the few variables in our analysis that can be directly improved by interventions. The overall proportion of literacy in sub-Saharan Africa has been slowly increasing over the last decades, from 63% in men and 42% in women in 1990 to 72% in men and 57% in women in 2016.[22] The literacy rates among young men and women are considerably higher and likely to continue to rise.

Earlier studies have returned conflicting results about the association between literacy and HIV. For example, a study from Mozambique showed that literacy was associated with HIV knowledge among women living in rural settings.[23] In the Gambia, both the degree of literacy and level of education were positively associated with adherence to therapy among patients receiving ART.[24] In our study, illiteracy was also strongly associated with false beliefs about AIDS; both are likely linked to low level of knowledge about HIV in general. For example, in Malawi, people who knew more about HIV prevention were more likely to reject, rather than endorse, myths and misconceptions about HIV transmission.[25,26] But some studies suggest the opposite. A recent review found that highly educated people were at higher risk of HIV. This could stem from a variety of causes, since literacy often correlates with other factors like wealth, type of employment and travel, which may be associated with riskier sexual behaviour. Literacy is also strongly associated with living in an urban setting. Literate people may be more likely to access HIV care and treatment, prolonging survival and thus raising prevalence. Finally, the distribution of HIV burden may depend on the overall wealth and situation in the country. One study showed that in poorer sub-Saharan African countries, wealthier individuals were more likely to be HIV positive, but in wealthier countries, poorer individuals were more likely to be HIV positive.[27] A study from Zimbabwe that used DHS data found that people who could read parts of a sentence had a higher risk of HIV infection than those who could not read at all, or who could read complete sentences.[28]

We were slightly surprised by our results on the association between urbanity and variables with protective effects against HIV. HIV prevalence is generally higher in urban than rural settings:[29] for example, in the Democratic Republic of the Congo, distance to a city was negatively associated with HIV.[30] There are several possible explanations for these contradictory findings. Urban residents are likely to be more connected to other people, which may increase the risk of infection, despite other protective factors. HIV may also affect sub-populations differently in different settings; for example, in Kenya the poorest people are more likely to have HIV in urban than rural settings.[31] In Uganda, rural residence was associated with an increase in risky sexual behavior in people who were on long-term ART.[32]

In most of countries in sub-Saharan Africa, HIV testing is the largest gap in the cascade of care. This gap must be closest to meet the "90-90-90" global treatment target and eventually eradicate the epidemic.[33] We identified many associations between HIV testing uptake and other factors. For women, the strongest associations were with being married and with believing it justified for a woman to ask her husband with an STI to use a condom. These two variables may also be directly linked: a study from Zambia showed married women who knew that their husbands were either sexually promiscuous or had a sexually transmitted infection were more likely to feel justified in refusing sex or requesting he use condoms.[34] Stigma, fear and discrimination have been identified as barriers for utilizing HIV services. For men, literacy was strongly associated with HIV testing, so literacy interventions should also target men, even though they are more likely to be literate than women.

Strengths and limitations

Our study analysed the associations between many socio-behavioural variables in most sub-Saharan African countries. Other epidemiological studies have used causal graphs[35–37] but we believe we are the first to investigate detailed associations between variables related to the spread of HIV in sub-Saharan Africa. Our study was also strengthened by our use of a very large data set from the Demographic Health Surveys of almost 30 countries, which allowed us to identify commonalities and differences between countries, and between men and women.

Our study also had several limitations. Although we assumed there were no hidden variables in our analysis, we had to exclude potentially relevant variables because they were too heterogeneous or data were missing. Religion was associated with certain factors in many countries, but the diversity of religions prevented us from dichotomizing and including this variable. Other variables like male circumcision, ever paying for sex, or using condoms during the last paid intercourse were excluded because they were not collected in some countries or too many values were missing. For example, we could not include HIV status in the main analysis because too little data on HIV-positive men was available. DHS did not collect data on some factors related to geographic variability of HIV and AIDS in sub-Saharan Africa, including sex work, tuberculosis, and use of injected drugs. We had to dichotomize all variables to compute the CPDAGs with the available data, even though for some

variables it would have been better to include more categories. For example, for marital status, widowed and divorced were categorized as married. Finally, we only identified a small number of directed edges. It is possible that most factors were not causal, or it may simply demonstrate how hard it is to prove causal relationships with routine data.

We need to develop a more nuanced understanding of the association between HIV and literacy so we can devise effective interventions and limit misinformation about HIV and AIDS. Research and interventions should also focus on reshaping of social norms and behaviour to reduce stigma associated with HIV testing and condom use.

The Bayesian network approach we tested is a promising technique for extracting the structure of associations between variables from surveys and other data sources and our findings underline the importance of understanding the role of socio-behavioural and contextual factors in the spread of complex diseases like HIV. The associations with variables related to HIV vary across countries, and it is essential to understand and study further the specific situation in each country to select appropriate interventions. Literacy and urbanity were associated with several factors that are essential for HIV acquisition, and efforts should be made to improve the level of literacy across all population groups.

Contributions

ZB, OK and MM designed the study. ZB and OK reviewed and selected the variables to be included in the analysis. ZB wrote the code and performed the statistical analysis with together with JE, SM, AM and MM. SB, ZB, JE and OK reviewed the relevant literature. ZB and JE wrote a first draft of the manuscript, which was revised by OK. All authors contributed to the interpretation of the results and the final version of the manuscript.

Acknowledgement

We thank Gilles Kratzer and Reinhard Furrer for helpful discussions and Kali Tal for carefully editing the paper.

References

1. UNAIDS. Fact Sheet on HIV/AIDS. UNAIDS; 2018. http://www.unaids.org/sites/default/files/media_asset/UNAIDS_FactSheet_en.pdf. Accessed December 7, 2018.
2. UNAIDS. Miles To Go: Closing Gaps, Breaking Barriers, Righting Injustices. UNAIDS; 2018. http://www.unaids.org/sites/default/files/media_asset/miles-to-go_en.pdf. Accessed December 7, 2018.
3. Agyei-Mensah S. The HIV/AIDS epidemic in sub-Saharan Africa: Homogeneity or heterogeneity? *Nor Geogr Tidsskr - Nor J Geogr* 2005; 59(1):14–25.
4. Kharsany ABM, Karim QA. HIV Infection and AIDS in Sub-Saharan Africa: Current Status, Challenges and Opportunities. *Open AIDS J* 2016; 10(1):34–48.
5. Asamoah-Odei E, Calleja JMG, Boerma JT. HIV prevalence and trends in sub-Saharan Africa: no decline and large subregional differences. *Lancet* 2004; 364(9428):35–40.
6. ICF. *Demographic and Health Surveys (Various).* ICF; 2010. https://dhsprogram.com. Accessed March 14, 2019.
7. Cuadros DF, Sartorius B, Hall C, Akullian A, Bärnighausen T, Tanser F. Capturing the spatial variability of HIV epidemics in South Africa and Tanzania using routine healthcare facility data. *Int J Health Geogr* 2018; 17(1):27.
8. Mondal MNI, Shitan M. Factors affecting the HIV/AIDS epidemic: an ecological analysis of global data. *Afr Health Sci* 2013; 13(2):301–310.
9. Tsafack Temah C. What Drives HIV/AIDS Epidemic in Sub-Saharan Africa? *Rev Econ Dev*. 2009; 17(5):41–70.
10. Magadi MA. Understanding the gender disparity in HIV infection across countries in sub-Saharan Africa: evidence from the Demographic and Health Surveys. *Sociol Health Illn* 2011; 33(4):522–539.
11. Wamoyi J, Wight D, Plummer M, Mshana GH, Ross D. Transactional sex amongst young people in rural northern Tanzania: an ethnography of young women's motivations and negotiation. *Reprod Health* 2010; 7(1):2.
12. Singh RK, Patra S. What Factors are Responsible for Higher Prevalence of HIV Infection among Urban Women than Rural Women in Tanzania? *Ethiop J Health Sci* 2015; 25(4):321–328.
13. Hajizadeh M, Sia D, Heymann SJ, Nandi A. Socioeconomic inequalities in HIV/AIDS prevalence in sub-Saharan African countries: evidence from the Demographic Health Surveys. *Int J Equity Health* 2014; 13(1):18.
14. Johnson K, Way A. Risk Factors for HIV Infection in a National Adult Population: Evidence From the 2003 Kenya Demographic and Health Survey. *J Acquir Immune Defic Syndr*. 2006; 42(5):627–636.

15. Dunkle KL, Jewkes RK, Brown HC, Gray GE, McIntryre JA, Harlow SD. Gender-based violence, relationship power, and risk of HIV infection in women attending antenatal clinics in South Africa. *Lancet* 2004; 363(9419):1415–1421.

16. ICF. Guide to DHS Statistics. ICF; 2018. https://dhsprogram.com/data/Guide-to-DHS-Statistics/. Accessed November 12, 2018.

17. Perkovic E, Textor J, Kalisch M, Maathuis MH. A Complete Generalized Adjustment Criterion. In: Meila M, Heskes T, eds. *Proceedings of the Thirty-First Conference on Uncertainty in Artificial Intelligence (UAI 2015), July 12-16, 2015, Amsterdam, The Netherlands*. AUAI Press; 2015:682–691. http://auai.org/uai2015/proceedings/papers/155.pdf. Accessed March 14, 2019.

18. Scutari M. Learning Bayesian Networks with the bnlearnR Package. *J Stat Softw* 2010; 35(3).

19. Tsamardinos I, Aliferis CF, Statnikov A. Time and sample efficient discovery of Markov blankets and direct causal relations. In: *Proceedings of the Ninth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (KDD '03), August 24-27, 2003, Washington DC, United States*. ACM Press; 2003:673.

20. R Core Team. R: A language and environment for statistical computing. 2013. http://www.r-project.org/. Accessed March 14, 2019.

21. Day NE, Byar DP. Testing Hypotheses in Case-Control Studies-Equivalence of Mantel-Haenszel Statistics and Logit Score Tests. *Biometrics* 1979; 35(3):623.

22. The World Bank. World Bank Open Data. World Bank; 2019. https://data.worldbank.org. Accessed March 14, 2019.

23. Ciampa PJ, Vaz LME, Blevins M, *et al*. The Association among Literacy, Numeracy, HIV Knowledge and Health-Seeking Behavior: A Population-Based Survey of Women in Rural Mozambique. *PLoS One* 2012; 7(6):e39391.

24. Hegazi A, Bailey RL, Ahadzie B, Alabi A, Peterson K. Literacy, education and adherence to antiretroviral therapy in The Gambia. *AIDS Care* 2010; 22(11):1340–1345.

25. Sano Y, Antabe R, Atuoye KN, *et al*. Persistent misconceptions about HIV transmission among males and females in Malawi. *BMC Int Health Hum Rights* 2016; 16(1):16.

26. Behrman JA. The effect of increased primary schooling on adult women's HIV status in Malawi and Uganda: Universal Primary Education as a natural experiment. *Soc Sci Med* 2015; 127:108–115.

27. Fox AM. The HIV-poverty thesis re-examined: Poverty, wealth or inequality as a social determinant of HIV infection in sub-Saharan Africa? *J Biosoc Sci* 2012; 44(4):459–480.

28. Chinomona A, Mwambi HG. Estimating HIV prevalence in Zimbabwe using population-based survey data. *PLoS One* 2015; 10(12):e0140896.

29. World Health Organization (WHO). Global Heatlh Observatory data repository. WHO; 2014. http://apps.who.int/gho/data/node.main.n247?lang=en. Accessed March 14, 2019.

30. Messina JP, Emch M, Muwonga J, *et al.* Spatial and socio-behavioral patterns of HIV prevalence in the Democratic Republic of Congo. *Soc Sci Med* 2010; 71(8):1428–1435.

31. Dodoo FNA, Zulu EM, Ezec AC. Urban-rural differences in the socioeconomic deprivation-sexual behavior link in Kenya. *Soc Sci Med* 2007; 64(5):1019–1031.

32. Okoboi S, Castelnuovo B, Moore DM, *et al*. Risky sexual behavior among patients on long-term antiretroviral therapy: a prospective cohort study in urban and rural Uganda. *AIDS Res Ther* 2018; 15:15.

33. Estill J, Marsh K, Autenrieth C, Ford N. How to achieve the 90-90-90 target by 2020 in sub-Saharan Africa? *Trop Med Int Health* 2018; 23(11):1223–1230.

34. Amoyaw JA, Kuuire VZ, Boateng GO, Asare-Bediako Y, Ung M. Conundrum of Sexual Decision Making in Marital Relationships: Safer-Sex Knowledge, Behavior, and Attitudes of Married Women in Zambia. *J Sex Res* 2015; 52(8):868–877.

35. Pittavino M, Dreyfus A, Heuer C, *et al*. Comparison between generalized linear modelling and additive Bayesian network; identification of factors associated with the incidence of antibodies against Leptospira interrogans sv Pomona in meat workers in New Zealand. *Acta Trop* 2017; 173:191–199.

36. Lewis FI. Bayesian networks as a tool for epidemiological systems analysis. In: *9th International Conference on Mathematical Problems in Engineering, Aerospace and Sciences: ICNPAA 2012*, *10-14 July, 2012, Wien, Austria*. AIP Conference Proceedings; 2012: 610-617.

37. McCormick BJJ, Sanchez-Vazquez MJ, Lewis FI. Using Bayesian networks to explore the role of weather as a potential determinant of disease in pigs. *Prev Vet Med* 2013; 110(1):54–63.

Table 1: Characteristics of persons included in the analysis. The median, minimum and maximum of percentages among all countries are shown.

DHS, 2010 - 2016, countries of sub-Saharan Africa		Female median (min, max)	Male median (min, max)
Younger than 25 years	No	60% (54.7%-65.5%)	62.9% (56.1%-72.1%)
	Yes	40% (34.5%-45.3%)	37.1% (27.9%-43.9%)
Rural setting	No	38.7% (10.4%-88.5%)	40.2% (14.9%-87.1%)
	Yes	61.3% (11.5%-89.6%)	59.8% (12.9%-85.1%)
Household head female	No	72.7% (43.7%-90.8%)	86.8% (71.8%-97.1%)
	Yes	27.3% (9.2%-56.3%)	13.2% (2.9%-28.2%)
Literacy	No (Not able to read whole sentence/missing)	56.6% (9.6%-89.7%)	32% (14%-74.1%)
	Yes (Able to read whole sentence)	43.4% (10.3%-90.4%)	68% (25.9%-86%)
Media access	Less than once a week	39.5% (8%-81.7%)	25.7% (4.2%-64.8%)
	At least once a week	60.5% (18.3%-92%)	74.3% (35.2%-95.8%)
First sex before the age of 16	No	67.4% (50.5%-93.6%)	79.9% (54.6%-97.7%)
	Yes	32.6% (6.4%-49.5%)	20.1% (2.3%-45.4%)
Currently working	No	46.5% (24.8%-79.1%)	21.4% (6.9%-44%)
	Currently working / have a job, but on leave during the last 7 days	53.5% (20.9%-75.2%)	78.6% (56%-93.1%)

Married	Never in partnership	28.3% (8.6%-53.5%)	40.8% (28.7%-62.9%)
	Currently or formerly married or living with a partner	71.7% (46.5%-91.4%)	59.2% (37.1%-71.3%)
False beliefs about AIDS	No	55.5% (35.8%-88.4%)	62.3% (44.5%-85.7%)
	Yes / Does not know/ Missing	44.5% (11.6%-64.2%)	37.7% (14.3%-55.5%)
Wife beating justified	No	50.6% (20.6%-83.3%)	88.5% (66.4%-95.5%)
	Yes / Does not know/ Missing	49.4% (16.7%-79.4%)	11.5% (4.5%-33.6%)
Justified asking husband to use condom if he has a sexually transmitted disease	No / Does not know/ Missing	18.2% (2.3%-60.6%)	11.5% (1.5%-29.8%)
	Yes	81.8% (39.4%-97.7%)	88.5% (70.2%-98.5%)
Ever tested for HIV	No/ Missing	50.8% (13.8%-86.7%)	68.8% (19.1%-92.6%)
	Yes	49.2% (13.3%-86.2%)	31.2% (7.4%-80.9%)

Figure 1. Crude odds ratios for all pairs of the selected variables for women (upper panel) and men (lower panel) in the analysis without HIV status (29 countries). Each rectangle shows the odds ratios between the corresponding variables for all countries, sorted from lowest to highest.

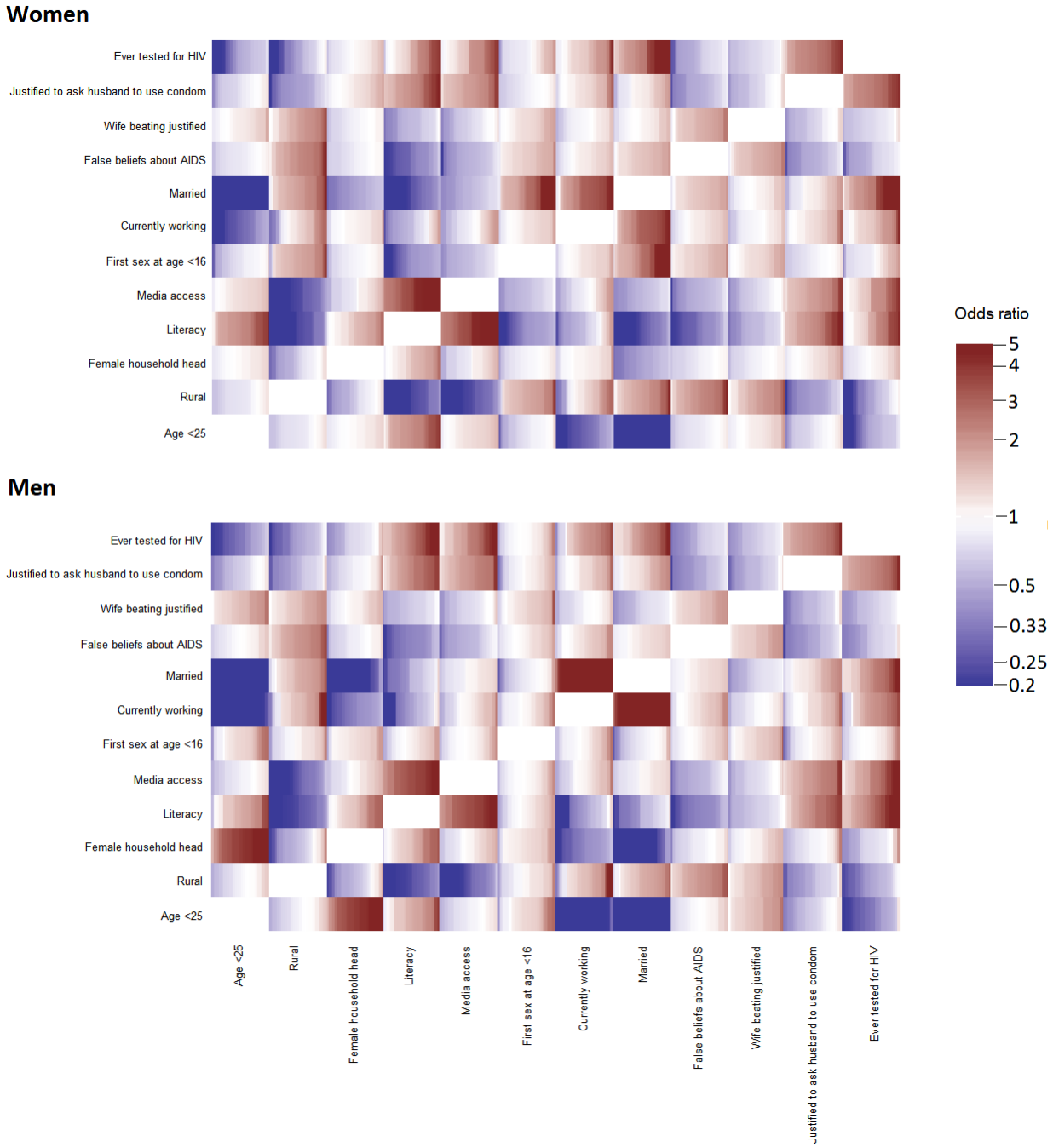
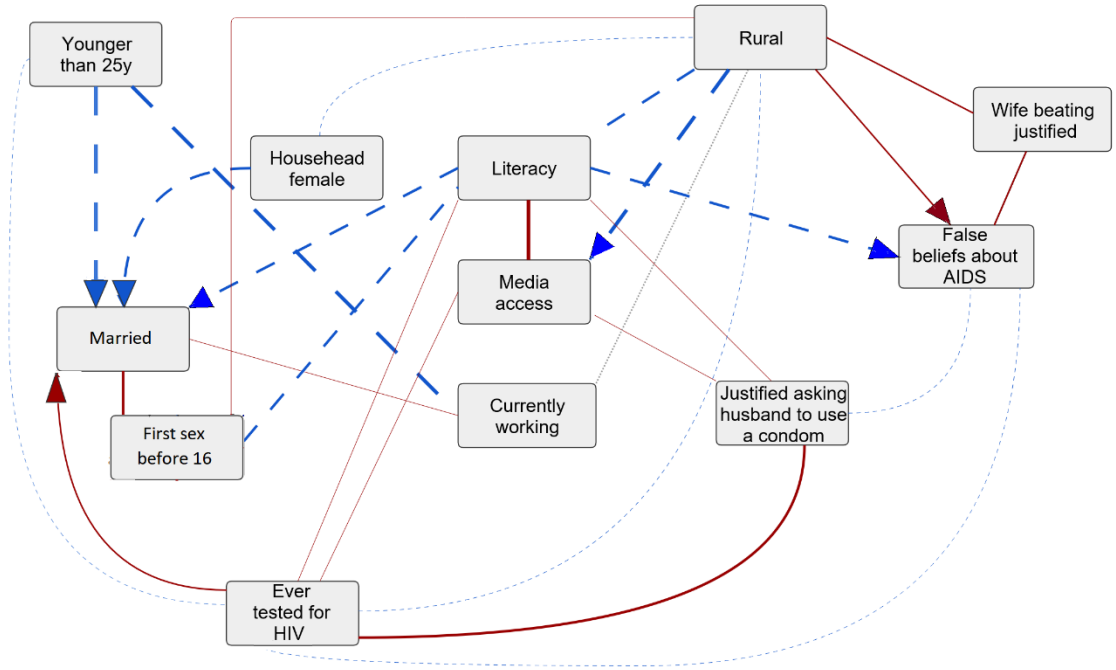


Figure 2. Summary graphs for the analysis without HIV status (29 countries) for women (upper panel) and men (lower panel). Shows associations present in at least six countries. Line thickness is proportional to the number of countries where the edge was present. The edges are oriented if the number of countries with the shown direction was at least six higher than the number of countries with the opposite direction. Blue dashed lines indicate negative conditional associations, red solid lines indicate positive conditional associations and grey dotted lines indicate that the sign of the association differed across countries.

Women



Men

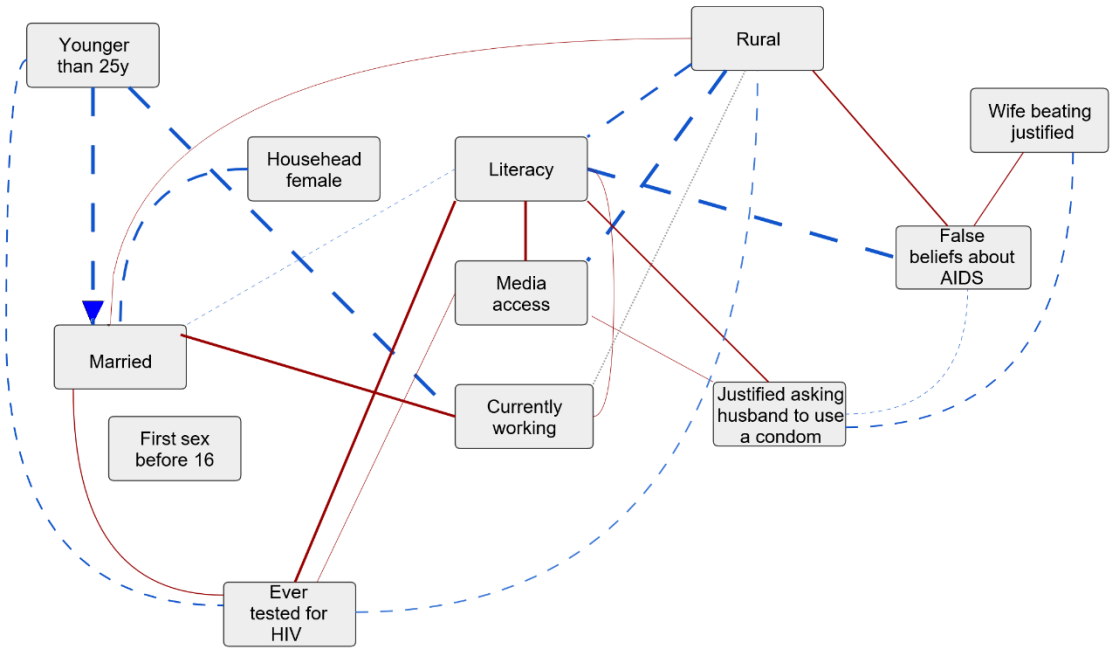


Figure 3. Crude odds ratios for all pairs of the selected variables for women (upper panel) and men (lower panel) in the analysis with HIV status (23 countries). Each rectangle shows the odds ratios between the corresponding variables for all countries, sorted from lowest to highest.

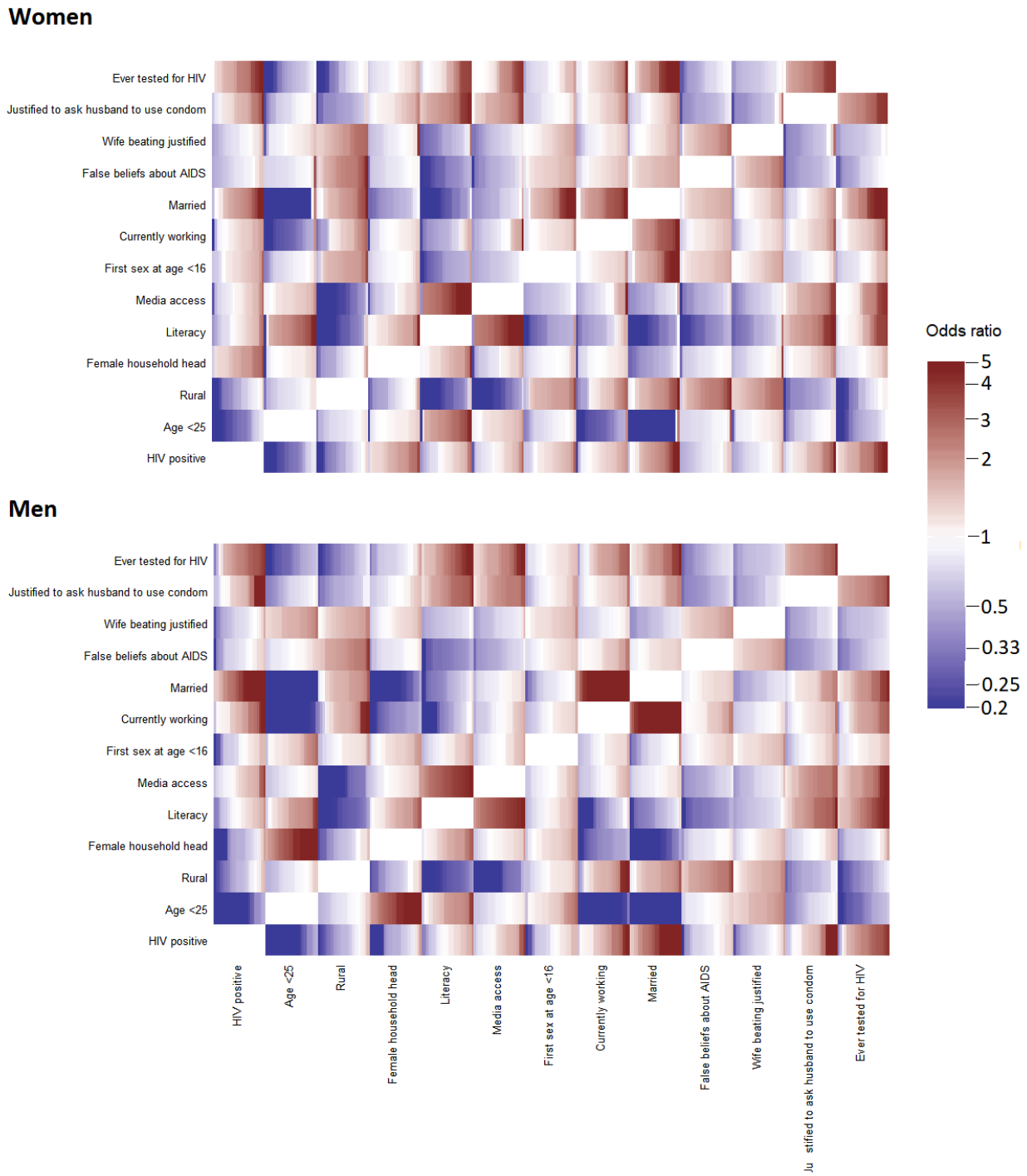
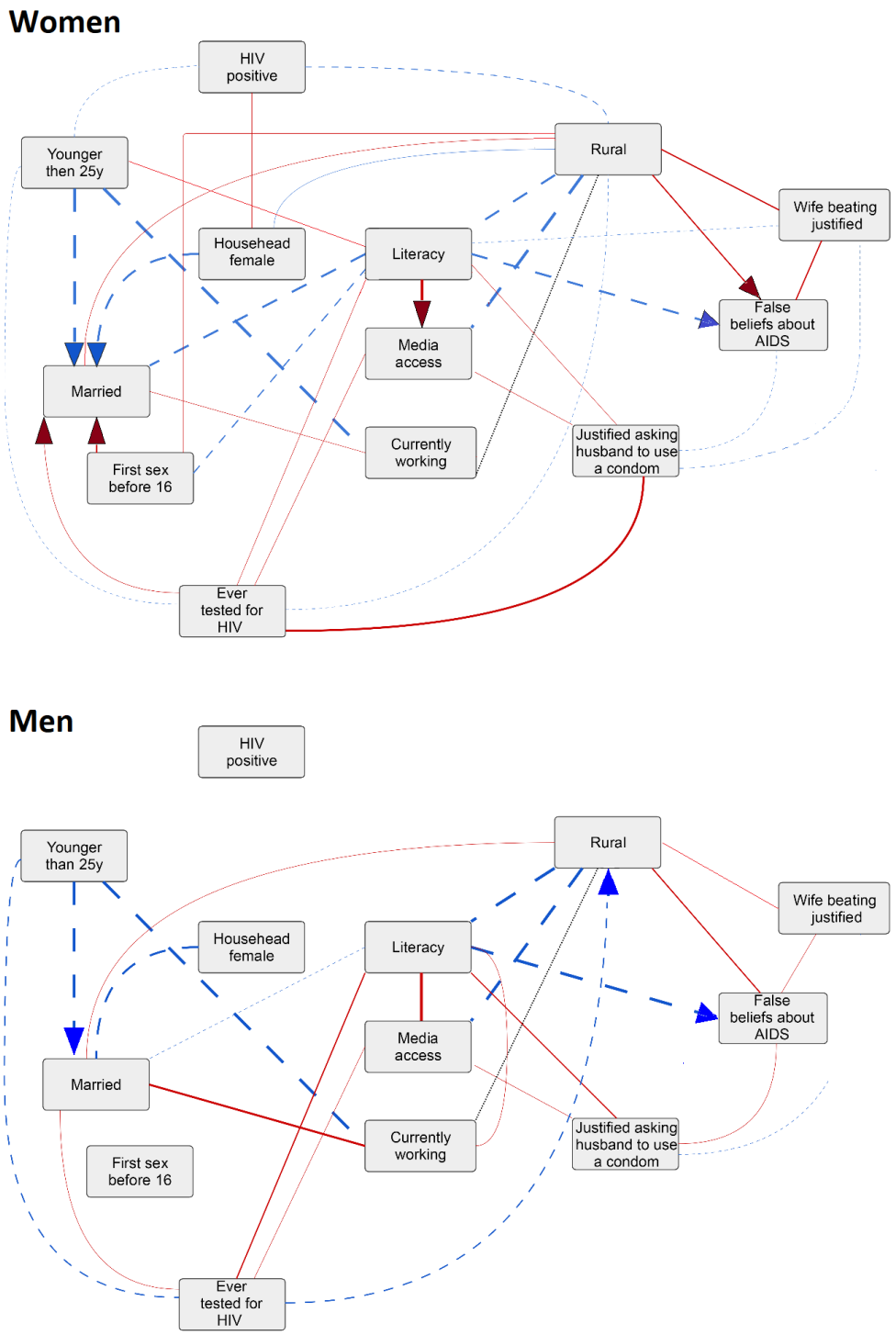



Figure 4. Summary graphs for the analysis without HIV status (23 countries) for women (upper panel) and men (lower panel). Shows associations present in at least six countries. Line thickness is proportional to the number of countries where the edge was present. The edges are oriented if the number of countries with the shown direction was at least six higher than the number of countries with the opposite direction. Blue dashed lines indicate negative conditional associations, red solid lines indicate positive conditional associations and grey dotted lines indicate that the sign of the association differed across countries.