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Undiagnosed Diabetes and Hypertension in Saudi Arabia: Triangulation of National Survey and Modelled Estimates (2019-2025) with Estimated Regional Primary-Care Case-Finding Workload

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Abstract **Objectives:** Prevalence of diabetes is one of the highest in Saudi Arabia. Yet the estimates of the number of people who are still not diagnosed and of undiagnosed hypertension conflict with one another, depending on a single survey or total numbers obtained through modelling. The recently carried out National Health Survey 2024 and Elderly Survey 2025 of General Authority for Statistics (GASTAT) now give an opportunity to compare those sources against an explicitly defined anchor of diagnosed prevalence, although neither of them assesses the currently undiagnosed fraction directly. **Methods:** We triangulated published aggregate estimates (reference years 2019-2025) by subtraction (total minus survey-reported diagnosed prevalence) and undiagnosed fractions from the sources. The prevalence of diagnosed diabetes based on the National Health Survey 2024 (households n = 73,544) was adjusted against the population of 2024 and compared with the total prevalence based on the 11th Edition of IDF Diabetes Atlas, NCD Risk Factor Collaboration (NCD-RisC), KSA World Health Survey 2019 (KSAWHS, measured blood pressure) and 2023 SHINE. The results obtained by the subtractions and the estimates of the proportion of undiagnosed in each source were synthesized equally via logit pooling (20,000 Monte Carlo draws), the proportion of self-reported hypertension was reweighted to the measured hypertension via its positive predictive value (55.2%). Estimation of the regional burden included structural and survey-calibrated models and exploratory ecological comparison of the needs of case-finding against Ministry of Health Primary Health Care (PHC) capacity in 13 regions. **Results:** There are an estimated 2.06 million of adults aged 20 to 79 years (uncertainty interval (UI) 0.85-4.97 million) with undiagnosed diabetes (proportion 48.2% (CI 27.7-69.2, PI 13.7-84.5%), as well as 2.01 million adults aged 30 to 79 years (0.90-4.59 million) with undiagnosed hypertension (67.3% (48.1-82.2%, 25.6-92.6%). Estimates from different sources varied almost twofold: subtractions based on total estimates derived from IDF- and NCD-RisC- based prevalence gave the total number of undiagnosed diabetics as 3.10 and 1.73 million respectively, while subtractions based on total estimates derived from NCD-RisC- and KSAWHS-based prevalence yielded 4.01 and 1.92 million respectively. The implied total number of patients with diagnosed diabetes (IDF - 3.01 million) was 36% higher than survey-reported (2.21 million). The proportion of undiagnosed hypertension decreases from 83.5% in 15 to 29-year-old people to 48.2% at ≥60 and 57.5 and 58.0% of adults with undiagnosed hypertension and diabetes respectively did not have a periodic check-up during last year. In the structural model, the three most populated metropolitan regions - Riyadh, Makkah and the Eastern Region had about 70% of undiagnosed cases but only 52.5% of the PHC physicians in total and were characterized by the highest value of exploratory case-finding pressure index in any of the simulations. In 13 regions, no significant correlation was found between the needs of case-finding and the physician density (Spearman $\rho = 0.17$, $p = 0.58$, limited power). **Conclusion:** About half of the adults with diabetes aged 20-79 years and 2/3 of the adults aged 30-79 years with hypertension in Saudi Arabia remained undiagnosed, taking into account adults aged 30-79, these diseases amount in total to about 3.9 million disease cases (both diseases in one person counted twice). The gap depends considerably on the chosen anchoring estimate and estimates vary between the structural and survey-based models at the regional level. Based on modelling, the gap relates mostly to working-age adults, men and non-Saudis without check-ups, as well as the three metropolitan regions with fewer MoH PHC physicians per adult.

Key Words Undiagnosed Diabetes, Hypertension, Saudi Arabia, Health Surveys, Small-Area Estimation, Primary Health Care, Mass Screening, Data Triangulation

INTRODUCTION

Undiagnosed diabetes and hypertension are parts of the population with these two highly prevalent cardiometabolic diseases that remain invisible to the public sector. In 2024, the number of people aged 20 to 79 years living with diabetes was 589 million [1,2] and according to the estimation of 2021, 44.7% (239.7 million) of the diabetic adults did not know about it [3]. According to the estimates of NCD-RisC, the number of adults with diabetes in 2022 was 828 million, including 59% of those aged 30 or more, who received no treatment [4]. The prevalence of hypertension in 2019 amounted to 1.28 billion of adults aged 30-79 years, including 59% of women and 49% of men with previous diagnosis [5]. Diabetes takes place several years before the diagnosis [6], whereas hypertension is the leading modifiable risk factor of cardiovascular disease-related mortality [7,8]. Therefore, the diagnosis is the crucial and the first step of care cascade [9,10]. Moreover, the WHO Global Diabetes Compact aimed at increasing the share of diagnosed people with diabetes in the world to 80% by 2030 [11].

Diabetes and hypertension are problems of Saudi Arabia. The age-standardized prevalence of diabetes among the adults aged 20-79 years in 2024 was estimated by IDF Diabetes Atlas to be 23.1%, resulting in the total number of 5.34 million patients, 43.6% of whom remained undiagnosed [12]. The survey of the prevalence of diabetes among Saudi Arabian adults aged 30-70 in 1995-2000 revealed 23.7%, whereas the prevalence among Saudi nationals aged 15 years old or more in 2013 was 13.4 and 57.8% of them were undiagnosed [13,14]. The national screening study of the population reported a high prevalence of glucose metabolism abnormalities [15]. The meta-analysis of the studies conducted in 2000-2020 reported the average prevalence of type 2 diabetes of 16.4% [16]. The prevalence of hypertension in 1995-2000 was 26.1% and in 2013 it was 15.2%, of which 57.8% were not diagnosed [17,18]. In addition, in 2019, the KSA World Health Survey only 34.8% of adults with hypertension were aware about it [19]. Under the framework of the program of transformation of the health sector according to the goals of Vision 2030, the delivery of care in the new Model of Care is carried out in health clusters and the prevention and early detection of diabetes and hypertension are managed by the PHC [20-22]; its capacity varies between different regions [23].

Three changes have made it possible to estimate the current situation in diabetes and hypertension and made it necessary. First, the National Health Survey of GASTAT includes the diagnosed chronic diseases by age among the resident population of Saudi Arabia [24-26]; second, the new 11th Edition of IDF Diabetes Atlas and NCD-RisC have just released their total prevalence estimates [2,4]; third, there were two national surveys, KSAWHS 2019 [19] with measured blood pressure and the (2023) SHINE [27]. Those sources are different in definition, methodological approach, covered population and time period; moreover, neither of them estimates the currently undiagnosed fraction independently. The self-reporting estimates are biased downward and incorrectly classify some people as healthy [28,29], the estimates obtained via modelling depend on the information from other countries and periods and single surveys are soon outdated in the fast-changing and growing population due to migration [30]. Therefore, the triangulation method allows to obtain the boundaries of contradiction, but not to eliminate it. The resulting consensus is not an independent estimate of undiagnosed population, but it can be used to estimate the burden indirectly, while small-area modelling helps distributing the national estimates to regions [31-33]. But the regional distribution of undiagnosed population, however, has never been compared with PHC capacity for the task. This matters because according to the Model of Care, PHC should manage early detection and thus the distribution of regional needs against PHC staff and contacts can show how large the case-finding workload will be. Previous surveys and modelled estimates could not provide a current estimate anchored to 2024 diagnosed prevalence with an explicit range of variation across sources.

Therefore, we triangulated the GASTAT survey data of 2024-2025 against IDF Diabetes Atlas 11th edition, NCD-RisC and measured survey estimates. The main objective was to estimate total, diagnosed and undiagnosed diabetes and hypertension in 2024 nationally, with propagated uncertainty and explicitly stated ranges across anchors. The secondary objectives were characterization of age structure and overlap of the gap with periodic check-ups (model-based estimates); comparison of source-specific care cascades and testing of sensitivity to anchors and assumptions (sensitivity analysis); and estimation of regional distribution of undiagnosed burden and its relationship with PHC capacity and case-finding workload (exploratory ecological comparison).

METHODS

Study Design and Data Sources

This was a secondary analysis of aggregate published data. Triangulation was defined as the double estimation of the undiagnosed burden via (i) the subtraction of the survey-reported diagnosed prevalence from the total prevalence modeled or measured and (ii) the within-source application of the undiagnosed fraction to the same diagnosed anchor, followed by pooling a pre-defined set of estimators (Section 2.4). The study was not pre-registered. Alternative estimator combinations were considered as sensitivity analyses. This study produced population-level estimates and does not identify individuals. Reporting conforms to GATHER criteria [34]. Diagnosed prevalence of chronic conditions came from the GASTAT National Health Survey 2024 (Health Status Statistics 2024, Table 4) measuring self-reported physician-diagnosed chronic diseases in residents 15 years of age or older in five age bands using the Eurostat chronic-condition module; the data was gathered with computer-assisted personal interviews in 73,544 sampled households over 37 days [24,25]. Periodic check-ups utilization by age, sex, nationality and region came from Health Status Statistics 2025; unmet needs and health-care professionals and facility utilization from Health Care Statistics 2025; obesity and smoking rates from Health Determinants Statistics 2024; and diagnosed diabetes and hypertension in residents 60 years of age or older from the

Elderly Survey 2025 [24,26,35,36]. Denominator was the GASTAT mid-2024 population estimates stratified by 5-year age groups, sex and nationality (35,300,280 residents) and regional counts from the 2022 census [30]. The total prevalence was derived from the IDF Diabetes Atlas 11th edition country estimate for 2024 [2,12]; NCD-RisC estimates from WHO Global Health Observatory for diabetes (1990-2022) and hypertension and its diagnosis, treatment and control (1990-2019) [4,5,37]; and KSAWHS 2019, a household survey with measured blood pressure in 8,266 residents aged 18 years or older [19]. SHINE 2023, a computer-assisted telephone survey of 2,650 adults with response rate of 17.1%, provides self-reported prevalence of diagnosed chronic conditions by age band and region [27]; its survey weights might not compensate the non-response or selection bias fully. The historical and concordance comparators were Saudi Health Information Survey (SHIS) 2013 [14,18] and the NCD-RisC data harmonised-series analysis [38]. PHC centers, physicians, nurses and encounters, diabetes and endocrine centers, diabetic-clinic encounters and private medical complexes came from the MoH Statistical Yearbook 2024 [39]. All the values were extracted from machine-readable sources and cross-validated against their totals. Two source anomalies were corrected: in 2020 MoH series 16.8% of PHC encounters are assigned to no region, thus the regional trends were calculated since 2022; and the GASTAT totals of diabetes and other conditions for ages 15 years or older are published specifically for the surveyed household population and were recalculated to the whole 2024 population. Thus, source reference years cover the range of 2019-2025: GASTAT 2024-2025 (diagnosed anchor, check-ups and utilisation; ≥15 y), IDF 2024 (total and undiagnosed fraction; 20-79 y), NCD-RisC 2022 for diabetes (≥18 and ≥30 y) and 2019 for hypertension (30-79 y), KSAWHS 2019 (measured blood pressure and PPV; ≥18 y) and SHINE 2023 (alternative diagnosed source; ≥18 y). Anchors were used at their reference years; assuming little change in age-specific prevalence from the sources to 2024, the linear projection of the NCD-RisC totals until 2024 changed each anchor <1 pp and the consensus ≤3% (Table 3C; Figure 3).

Harmonisation of Diagnosed Prevalence

The band-level prevalence of diagnosed chronic diseases was converted into 5-year age curves with monotone, logit-scale fit with the second difference penalty, such that each published band mean was reproduced exactly; this procedure is analogous to penalized composite-link ungrouping [40] (details are given in the analysis code) and a step function was used in sensitivity analysis. Since the curve reproduces the band means by construction, agreement with them does not serve as an independent validation. The curves were applied to the 2024 population and each target group (15 years or older, 18 years or older, 20-79, 30-79, 40-79 and 60 years or older) was formed by aggregating the corresponding 5-year age curves. Since GASTAT does not publish standard errors, each band prevalence was assigned binomial uncertainty assuming a sample allocated proportionally to population size and design effect of 2; due to dominance of variation between estimators the effect of this choice in consensus intervals is minimal. Age-standardized rates were calculated with the WHO 2000-2025 standard population [41], which reproduces the KSAWHS published estimates exactly (17.32% at 15 years or older; 22.26% at 30-79 years) [19]. SHINE and KSAWHS age-specific estimates were reweighted to the 2024 age distribution in each band; SHINE design effect of 1.56 for diabetes and 2.04 for hypertension was estimated from its published confidence intervals [27].

Total-Prevalence Anchors and Self-Report Correction

Each total was aligned to the age-range reported by its source: IDF prevalence of crude diabetes in adults 20-79 years old (5,344.6 thousand among 24,983.1 thousand, or 21.4%) [12]; NCD-RisC crude prevalence of diabetes at ages 18 and 30 and over, as well as of hypertension at ages 30-79, with credible intervals transformed into log-normal distribution [4,5,37]; and age-specific measured prevalence of hypertension in KSAWHS, defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or use of current antihypertensive medications (definition also used by NCD-RisC [5]), reweighted to the 2024 population [19]. Self-report of hypertension tends to overestimate the awareness of measured hypertension since people consider themselves hypertensive despite having normal blood pressure [28,29]. Accordingly, self-reported diagnosed hypertension was corrected multiplying it by the Positive Predictive Value (PPV), probability that the self-reported diagnosis of hypertension corresponds to measured hypertension, which was estimated from KSAWHS: among 1,049 adults with measured hypertension, 34.8% (≈365) were aware (the sensitivity of self-report), while among 7,217 normotensive adults 12.69% (≈296) reported hypertension, so PPV = 365/(365 + 296) = 55.2% (95% UI 49.7-60.5). The correction eliminates false-positive self-reports; however, the false-negatives (those with diagnosed disease, but unaware of their diagnosis) cannot be identified in aggregate data and remain in the pool of undiagnosed people. The PPV is assumed constant for age, sex, nationality, region and time and its 95% bounds were explored in sensitivity analysis. Constant false-positive self-report correction and no correction were also retained as sensitivity analyses. The self-report correction for diabetes was not applied since there is no validation study in Saudi Arabia; the false-positives would overstated and false negatives would understate the diagnosed anchor, which is varied by ±10% in sensitivity analysis. So, diagnosed diabetes prevalence is reported, not confirmed by laboratory. There was disagreement between the IDF, NCD-RisC and GASTAT total-prevalence anchors and this was regarded as structural uncertainty, not a sampling error.

Estimation and Synthesis of Gaps

Gap was defined as the difference between the total-prevalence anchor and the aware diagnosed prevalence; the gap fraction was the ratio of gap to the total for each combination of a total-prevalence anchor and a diagnosed prevalence. Impossible draws with total prevalence less than aware diagnosed prevalence were rejected and redrawn; their

proportion for each estimator is reported as a coherence test (Table 3A: 0-2.9% for primary estimators; 25.6-26.5% for NCD-RisC-SHINE diabetes pairs); rejection cuts the left tail of the distribution, so estimators with high proportions of rejection are biased to high prevalence and underestimated intervals. Within-source estimators were based on the hypothesis that the gap fraction was the same as provided by each source: IDF 43.6% [12]; NCD-RisC coverage 45.1% [37]; KSAWHS awareness 34.8% [19] and was applied to the GASTAT diagnosed anchor. Primary estimators were the subtracted IDF- and NCD-RisC-anchored and the IDF-reported gap fraction for diabetes and NCD-RisC- and KSAWHS-anchored subtracted with PPV correction and two reported fractions for hypertension. Estimators were synthesized by equally-weighted random-effects meta-analysis on logit scale with the t-based 95% confidence interval (k-1 degrees of freedom) and the 95% prediction interval [42]. Equal weighting was used because IDF total does not have uncertainty, so inverse-variance weights would depend only on the GASTAT sampling error; it considers all primary estimators as equally credible, which is a modeling decision. The primary estimators share the GASTAT diagnosed anchor and partially overlapping inputs, so they are not independent and random-effects interval underestimates uncertainty; prediction intervals for three or four estimators are unstable. DerSimonian-Laird estimation with Hartung-Knapp-Sidik-Jonkman intervals [43-45] and an equal-probability finite mixture, which pools the primary estimators' distributions, not the point estimates (Table 3B), were presented as sensitivity analyses. The uncertainty intervals were propagated through 20,000 Monte Carlo draws (seed 20261005) and summarized as medians with 95% uncertainty intervals (UI; 2.5th-97.5th percentiles of the draws) [46]; CI denotes the t-based confidence interval of the pooled mean and PI the 95% prediction interval for a new estimator. GASTAT estimates carried binomial uncertainty, NCD-RisC credible intervals were represented as log-normal distributions and IDF total was assumed to be fixed. Derived metrics were the detection multiplier (number of cases per aware case) and the Number Needed to Screen (NNS) for a new diagnosis, defined as (1-diagnosed prevalence)/undiagnosed prevalence [47].

Age Structure, Care Cascades, Trends and Sensitivity Analyses

The age-specific prevalence of hypertension gaps adjusted for PPV by GASTAT prevalence by age bands and 5-year age groups was compared in KSAWHS and the age gradient of the gap fraction was estimated by inverse-variance weighted logit-linear regression on the mid-ages of bands; PPV was assumed fixed in this regression, so its standard error does not include PPV uncertainty. Since there is no Saudi source for diabetes age-specific prevalence, the age gradient for gap fraction of diabetes was constructed applying the gradient from hypertension gap to the calibrated intercept based on the consensus estimate for 20-79 years old people and compared to the NCD-RisC total for ages 18-29 years. The assumption of borrowing gradient is rather strong: since there is agreement with the national total by construction, the age-specific estimates of diabetes are exploratory and model-based. Number of undiagnosed people not having periodic check-ups was the product of the age-specific undiagnosed prevalence count and the probability of not having check-ups, assuming independence; these are model-based estimates, not linked observations of the same individuals. Care cascades were calculated from the prevalence and stage-specific coverage provided by each source individually and applied to the 2024 population of that age-range; the cascade stages from different sources were not combined into one care cascade. The long run series of NCD-RisC prevalence were analyzed with segmented log-linear regression with up to 2 join points selected by Bayesian information criterion [48,49]; these describe the modelled NCD-RisC series, not repeated Saudi measurements and their Annual Percent change (APC) and Average Annual Percent Change (AAPC) [50] were calculated. One-way sensitivity analysis involved changing the anchor bounds, set of estimators, self-report correction, diagnosed prevalence, age harmonization, temporal alignment (projection of NCD-RisC estimates until 2024) and denominator. Overlapping coefficient, shared area under the probability densities of each estimator vs. consensus (0, no overlap; 1, identical) [51] was calculated to assess agreement between Monte-Carlo estimator distributions; the narrow distributions (e.g. IDF) represent lack of the source uncertainty rather than increased accuracy.

Small-Area Regional Estimates

The regional populations for 2024 by 5-year age groups, sex and nationality were estimated by apportionment of national strata proportionally to regional shares within stratum using the 2022 census. It was compared with the number of residents aged 60 years or older obtained from weighted Elderly Survey 2025 [26,30]; since the survey weights are likely calibrated to the same GASTAT population estimates, it is the consistency check, but not independent validation; population changes and migrations between 2022 and 2024 are not accounted for. Model A (structural) allocated proportionally the national consensus gap for each condition to regions as $N \times E \times [1 + (PR - 1) \times O]$, where N is the regional adult population, E the age-adjusted total gap and O the obesity prevalence in regions, normalized such that regions add up to the national gap; estimates from Model A are therefore constrained allocations, not independent regional estimates and their narrow variation reflects this structure; uncertainty in obesity and age structure in regions was not propagated. The ratio (PR) for obesity to be included in the model was 1.53 for diabetes (using the Zhang-Yu method: $PR = OR/[(1 - P0) + P0 \times OR]$ from the odds ratio 1.6 for the diabetes prevalence of SHINE 2023 [27]; it assumes the same baseline Prevalence (P0) in all regions [52]) and 1.72 for hypertension [19] and the diagnosed cases were apportioned proportionally to age-adjusted diagnosed prevalence. Also, Model B (survey-calibrated) was based on the application of multiplicative factors obtained by indirect standardization of prevalences and prevalence ratios (for hypertension); log-standardised ratios from KSAWHS (measured prevalence), SHINE (self-report) and prevalence and obese population for 2024 in regions, normalized with intercept-only Fay-Herriot empirical Bayes estimation

[32,53]: Each regional log standardised ratio y shrinks to the national mean μ, $\gamma y + (1 - \gamma)\mu$, where $\gamma = A/(A + \psi)$ is shrinkage parameter and ψ sampling variance of log-standardised ratio; each region's obesity or utilization of periodic check-ups then was added to this ecological model as a single covariate. Since Model B is exploratory, unconstrained and could produce inconsistent negative gap estimates, it is not feasible to construct constrained model; the agreement between the models was assessed with Spearman and Lin's concordance correlation coefficient [54]. Regional deviations from the national rate of undiagnosed cases were calculated multiplicatively as the product of age structure effect and obesity effect.

Primary-Care Sector's Capacity and Case-Finding Pressures, Software and Ethics Considerations

About 20 MoH branches were aggregated to 13 administrative regions [39]. The capacity description was done based on the indicators such as PHC centers per adult, physicians and nurses per adult, encounters per resident and physician per day (250 workdays), diabetes-endocrine centers, encounters to the diabetic clinic and private medical complexes. The workloads were the contacts needed to screen every person 30-79 years once every 3 or 5 years (scenarios related to the recommended rescreening intervals discussed in Section 4), which were obtained as adults 30-79 years ÷ (interval × 250 working days × PHC centers) and the number of new diagnoses needed to find the prevalent undiagnosed cases within 5 years. These are planning quantities assuming fixed capacity and full attendances, not actual productivity and people with both conditions are double counted. The Case-Finding Pressure Index (CFPI) is defined as the mean z-score of need and workload minus mean z-score of physician density, nurse density, encounters per resident and use of periodic check-ups, each standardized across the 13 regions (mean 0, standard deviation 1); the need is undiagnosed diabetes and hypertension per 1,000 adults 30-79 years; equal weights imply equal importance of the components. The rank intervals were calculated by recomputing ranks over 1,000 need draws with fixed capacity, so uncertainty of workforce, utilization and denominators are not taken into account; CFPI is an exploratory planning tool which has not been validated against the screening coverage or outcomes. Hierarchical clustering of regions with Ward procedure (Euclidean distance on z-scores) of 12 standardized indicators [55] was applied; four clusters were retained for description and with 13 regions the solution is exploratory and potentially unstable. The agreement of capacities with needs was calculated with need-weighted concentration curves and Gini coefficients with 95% UIs obtained with 400 need draws (Monte-Carlo stability has not been formally assessed) [56,57]; the ecological association was estimated with Spearman correlation. Maps were plotted using the administrative boundary of geoBoundaries [58]. Analysis was performed in Python 3.13 with NumPy, SciPy, pandas and Matplotlib [59-62]. Since only public aggregate data are used, no informed consent and IRB approval is necessary. Availability of data and code: all data used are published aggregate statistics obtained from the mentioned sources with their respective dates, while the extracted tables and codes are available upon request from the corresponding author.

RESULTS

Denominators, Risk Structure and History of Exposure

The resident population in 2024 consists of 35.30 million people including 27.37 million adults 15 y.o., 24.87 million adults aged 20-79 years and 17.63 million adults aged 30-79 years. 44.4% of residents are non-Saudis, 65.4% of adults are males. The allocation of national strata of the population has led to the agreement with regional distribution of the Elderly Survey 2025 (national ratio is 1.035, regional ratios 1.009 - 1.047) as well as agreement with non-Saudis' distribution among the residents of 60 years old or more (allocated 30.6%, surveyed 31.0%). Prevalence of obesity is estimated between 13.0% in Najran and 28.0% in Qassim (national 23.1%), smoking (conventional and e-smoking) is estimated between 5.2% in Najran and 20.8% in Tabuk, utilization of check-ups (GASTAT 2025 past-year item in all regions) is estimated between 27.2% in Al-Baha and 27.3% in Riyadh and 65.6% in Tabuk (national 39.2%). Citizens of Saudi Arabia tend to consult physicians on a regular basis much more often than non-Saudi residents (44.2% Vs 35.0%). The largest differences in consulting doctors on a regular basis were observed in Qassim (15.5 percentage points), Eastern Region (14.2) and Riyadh (11.1). Differences in age structure only have influence on expected prevalence of diagnosed diabetes among adults 20-79 years of age, that was estimated between 8.33% in Najran and 10.18% in Al-Baha (Table 1).

Age-Specific Diagnosed Prevalence and the Age Architecture of the Gap

The prevalence of self-reported diagnosis of diabetes increased from 2.3-43.0% (prevalence ratio 18.99) for ages 15-29 years to ages 60 years or older, hypertension from 1.6-41.0% (25.12) and high cholesterol from 1.0-15.8% (15.84). With adjustment for band rates, the published estimates for prevalence of diabetes, hypertension and high cholesterol in the population of adults aged 15 years or older (9.14, 7.91 and 3.60%), decreased to 8.65, 7.45 and 3.43%, respectively, for the adult population size in 2024, whereas the WHO age-standardized values were 13.68, 12.26 and 5.17%, respectively. For people aged 60 years or older, estimates of the Elderly Survey 2025 demonstrated a prevalence rate for diabetes as 44.8 and 44.3% for hypertension, which was comparable to the estimates from the National Health Survey. The SHINE estimate for the self-report of diabetes prevalence exceeded that of GASTAT in all ages from 1.72 to 1.20, as well as the estimates for hypertension from 4.23 to 1.20, with highest excess observed in young adult ages. Measured prevalence of hypertension (KSAWHS) increased from 5.5-43.7% for 15-29 years to 60+ years, therefore, after PPV correction 83.5% (95% UI 79.4-86.9) of prevalence of hypertension at 15-29 years and 48.2% (40.3-55.1) at 60 years or older remained undiagnosed, estimates that depend on KSAWHS measured prevalence and the assumed PPV. The model-derived NNS decreased from 21.6 to 2.8. Of 2.40 million adults aged 15 years or older with undiagnosed hypertension by this anchor, an estimated 1.38 million (57.5%) did not report periodic check-ups during the last year (assuming independence).

Table 1: Population Denominators, Cardiometabolic Risk Factors Structure and Screening Exposure by Administrative Region, Saudi Arabia, 2024-2025

	Population, ×10³					Composition (%)			Validation against the Elderly Survey 2025, residents aged ≥60 year		
Region	All ages	≥15 year	20–79 year	30–79 year	≥60 year	Non-Saudi, all ages	Men, of ≥15 year	Aged ≥40 year, of ≥15 year	Survey count, ×10³	Survey ÷ allocation	Non-Saudi, %: allocation/survey
A. Population Denominators (mid-2024) and Validation of the Regional Allocation											
Riyadh	9,507.0	7,599.7	7,017.2	4,931.4	406.9	51.2	66.9	33.8	423.5	1.041	35.3/35.9
Makkah	8,850.2	7,008.8	6,379.9	4,583.8	501.9	50.9	64.5	36.8	515.9	1.028	40.7/40.8
Madinah	2,331.1	1,756.3	1,573.5	1,105.1	117.8	39.4	64.0	34.5	122.0	1.036	26.9/27.2
Qassim	1,453.2	1,103.2	986.1	677.1	69.8	33.4	63.3	34.0	71.6	1.025	14.2/13.9
Eastern	5,634.0	4,415.1	4,072.1	2,952.9	228.1	45.3	68.8	35.5	238.0	1.044	27.4/28.2
Asir	2,194.0	1,640.6	1,449.6	1,023.2	119.2	31.2	63.4	35.2	123.0	1.032	15.6/16.1
Tabuk	956.8	699.5	620.9	430.4	37.3	30.6	64.0	32.7	39.0	1.047	22.6/23.4
Hail	808.8	602.2	537.2	376.9	40.0	31.9	63.6	34.5	40.4	1.009	17.5/15.9
Northern Borders	402.0	281.8	248.7	169.9	15.9	29.8	61.2	31.9	16.4	1.035	17.2/17.0
Jazan	1,515.0	1,102.5	959.4	669.2	88.5	30.8	60.1	34.4	91.7	1.035	20.4/21.4
Najran	641.5	455.0	402.5	274.8	26.2	36.0	63.6	31.7	27.4	1.047	24.5/25.4
Al-Baha	366.6	272.5	238.2	173.2	24.5	28.2	60.5	38.5	25.0	1.020	11.9/12.0
Al-Jouf	640.0	435.9	384.0	264.6	23.7	28.6	62.7	32.7	24.7	1.043	19.5/20.4
Saudi Arabia	35,300.3	27,373.4	24,869.2	17,632.4	1,699.7	44.4	65.4	35.0	1,758.7	1.035	30.6/31.0
	Risk factors, adults ≥15 year, (%)			Periodic check-up in the past year, (%)					Age-structure-expected prevalence, (%)		
Region	Obesity (95% CI)		Smoking, including e-cigarettes	Total	Saudi	Non-Saudi	Saudi minus non-Saudi, pp		Diagnosed DM, 20–79 year	Self-reported HTN, 30–79 year	Aware HTN, 30–79 year (PPV-corrected)
B. Risk Factors, Screening Exposure and Age-Structure-Expected Diagnosed Prevalence											
Riyadh	23.2 (22.4–24.0)		11.3	27.3	34.0	22.9	11.1		8.45	9.53	5.26
Makkah	21.5 (20.7–22.4)		13.0	46.6	48.9	44.9	4.0		9.48	10.68	5.90
Madinah	22.2 (20.5–23.9)		12.2	40.5	45.4	35.4	10.1		9.08	10.39	5.73
Qassim	28.0 (25.8–30.3)		11.3	30.5	37.0	21.5	15.5		8.90	10.34	5.71
Eastern	26.7 (25.6–27.9)		14.9	44.8	52.7	38.5	14.2		8.60	9.46	5.22
Asir	24.9 (23.1–26.7)		9.0	31.6	35.8	25.8	10.0		9.30	10.65	5.88
Tabuk	21.2 (18.6–23.8)		20.8	65.6	68.9	61.0	7.9		8.47	9.68	5.34
Hail	21.6 (18.8–24.4)		9.4	46.4	49.8	41.9	7.9		8.97	10.25	5.66
Northern Borders	20.7 (16.6–24.8)		15.2	39.5	41.9	36.1	5.8		8.42	9.77	5.39
Jazan	19.1 (17.1–21.1)		8.7	53.2	51.8	55.5	−3.7		9.47	11.03	6.09
Najran	13.0 (10.4–15.7)		5.2	43.3	43.7	42.8	0.9		8.33	9.68	5.34
Al-Baha	19.0 (15.0–23.1)		12.3	27.2	28.4	25.1	3.3		10.18	11.51	6.35
Al-Jouf	20.7 (17.4–23.9)		12.3	35.2	35.0	35.4	−0.4		8.54	9.83	5.43
Saudi Arabia	23.1 (22.6–23.5)		12.4	39.2	44.2	35.0	9.2		8.91	10.07	5.56

(Abbreviations: DM, Diabetes Mellitus; HTN, Hypertension; pp, Percentage Points; PPV, Positive Predictive value. Source: GASTAT Population Estimates 2024 and Census 2022 [30], Elderly Statistics 2025 (Table 1) [26]; Health Determinants Statistics 2024 (Tables 3 and 14) [36]; Health Status Statistics 2024 (Table 4) and 2025 (table 10) [24]. Regional denominators of population apportion the national 2024 population to 5-year age groups and nationality and sex using shares of regions within strata from the 2022 Census. The ratio of the national population and regional populations compared to estimated in the Elderly Survey 2025 (weighted method) of those ≥60 y of age is 1.035 (Spearman ρ = 1.00); difference of regional ratios from average -0.82% on average. About 95% Confidence Intervals (CI) of obesity prevalence are calculated based on binomial sampling for regional adults, assumed as representative national sample from the Health Survey with design effect of 2 (GASTAT did not publish standard errors). Expected obesity prevalence was calculated using age-specific prevalence for 2024 (smoothed mean-preserving curves) from GASTAT based on age distribution in every region. Aware HTN is defined as the product of self-reported HTN and PPV of 55.2% in KSAWHS 2019 [19])

Table 2: Diagnosed, Survey Comparator Prevalence, Modelled Prevalence Including Undiagnosed Burden of Diabetes and Hypertension by GASTAT Age Band, Saudi Arabia, 2024

	Age band, years					
Indicator	15–29	30–39	40–49	50–59	≥60	All adults ≥15 year
Population, 2024						
Residents, ×10³ (men, %)	9,573.0 (62.0)	8,229.1 (68.6)	5,269.7 (68.8)	2,601.9 (66.0)	1,699.7 (57.1)	27,373.4 (65.4)
Diagnosed, self-reported (GASTAT National Health Survey 2024)						
Diabetes, % (95% CI)	2.3 (2.0–2.5)	3.7 (3.3–4.0)	9.8 (9.1–10.5)	23.0 (21.6–24.4)	43.0 (41.0–45.1)	9.14 published; 8.65 on 2024 population; 13.68 WHO-standardised
Diabetes, diagnosed adults, ×10³	217.0	301.2	518.4	599.2	731.5	2,367.2
Diabetes, prevalence ratio vs 15–29 y	1.00	1.61	4.34	10.16	18.99	–
Hypertension, % (95% CI)	1.6 (1.4–1.9)	3.3 (3.0–3.6)	7.9 (7.3–8.6)	19.1 (17.8–20.4)	41.0 (39.0–43.0)	7.91 published; 7.45 on 2024 population; 12.26 WHO-standardised
Hypertension, diagnosed adults, ×10³	156.2	271.0	418.0	497.9	696.9	2,040.1
Hypertension, prevalence ratio vs 15–29 y	1.00	2.02	4.86	11.73	25.12	–
High cholesterol, % (95% CI)	1.0 (0.8–1.2)	2.1 (1.9–2.4)	3.8 (3.4–4.3)	7.6 (6.7–8.5)	15.8 (14.3–17.3)	3.60 published; 3.43 on 2024 population; 5.17 WHO-standardised
High cholesterol, diagnosed adults, ×10³	95.3	176.2	202.0	197.2	267.8	938.6
High cholesterol, prevalence ratio vs 15–29 y	1.00	2.15	3.85	7.62	15.84	–
Comparator surveys						
SHINE 2023 self-reported diabetes, % (ratio to GASTAT)	3.9 (1.72)	6.6 (1.79)	15.6 (1.59)	30.6 (1.33)	51.6 (1.20)	12.9 (≥18 y)
SHINE 2023 self-reported hypertension, % (ratio to GASTAT)	6.9 (4.23)	11.0 (3.35)	19.8 (2.50)	31.8 (1.66)	49.4 (1.20)	16.1 (≥18 y)
Elderly Survey 2025, diagnosed diabetes/hypertension, %	–	–	–	–	44.8/44.3	–
KSAWHS 2019 measured hypertension, % (95% UI)	5.5 (4.7–6.4)	8.1 (7.1–9.1)	16.5 (14.6–18.6)	27.7 (24.5–31.1)	43.7 (39.7–47.8)	12.9 (12.2–13.6)
Hypertension gap (KSAWHS-anchored, PPV-corrected)						
Aware of hypertension, %	0.90	1.82	4.38	10.57	22.65	4.12
Undiagnosed fraction, % (95% UI)	83.5 (79.4–86.9)	77.4 (72.8–81.4)	73.5 (68.4–77.8)	61.9 (54.8–67.9)	48.2 (40.3–55.1)	68.0 (64.2–71.7)
Undiagnosed adults, ×10³ (95% UI)	436.2 (360.2–524.4)	512.9 (431.9–603.6)	637.6 (532.2–752.7)	445.9 (355.1–540.1)	358.1 (277.2–439.2)	2,395.4 (2,170.6–2,621.1)
Undiagnosed and without periodic check-up, ×10³	292.9	309.7	367.0	246.8	160.6	1,376.9
Number needed to screen per new diagnosis	21.6	15.5	7.6	4.7	2.8	10.6
Diabetes Gap (age Gradient Borrowed from hypertension, Calibrated to the Diabetes Consensus)						
Total diabetes, % (95% UI)	7.5 (4.4–15.2)	9.1 (5.9–16.8)	20.0 (14.0–34.4)	39.5 (29.7–62.9)	61.1 (50.3–87.8)	16.8 (12.0–28.3)
Undiagnosed fraction, % (95% UI)	69.8 (48.2–85.1)	59.8 (37.8–78.2)	50.8 (29.8–71.4)	41.7 (22.6–63.4)	29.5 (14.4–51.0)	48.4 (27.8–69.4)
Undiagnosed adults, ×10³ (95% UI)	501.5 (202.1–1,234.4)	447.6 (183.2–1,081.4)	534.6 (219.9–1,293.9)	428.1 (174.7–1,036.4)	306.3 (122.7–760.3)	2,221.9 (912.7–5,377.2)

Table 2: Continued

Indicator	Age band, years					All adults ≥15 y
	15–29	30–39	40–49	50–59	≥60	
Undiagnosed and without periodic check-up, ×10³	336.8	270.2	307.7	236.9	137.4	1,289.0
Number needed to screen per new diagnosis	18.7	17.7	8.9	4.7	3.2	11.3
Screening exposure and access (GASTAT 2025)						
Periodic check-up in past year, %	32.9	39.6	42.4	44.7	55.2	39.2
Self-reported unmet health-care need in past year, %	2.6	3.0	4.6	5.3	4.0	3.5
Visited any health-care provider within 12 months, % (mean visits per adult)	–	–	–	–	–	41.7 (2.98)

(Self-reported and measured rows are survey estimates; PPV-corrected and gap rows are derived, and diabetes gap rows are model-implied. Acronyms used: CI, Confidence Interval; KSAWHS, KSA World Health Survey; OR, Odds Ratio; PPV, Positive Predictive Value; SHINE, Saudi national health InDicators survEy; UI, Monte Carlo Uncertainty Interval [20,000 draws]. Sources of data: GASTAT Health Status Statistics 2024 (Table 4) and 2025 (Table 9) [24]; Health Care Statistics 2025, Tables 4, 5 and 25 [35], applying re-weighting 5 year age groups into bands; Elderly Statistics 2025 (Table 12) [26]; SHINE 2023 [27]; KSAWHS 2019 [19]; NCD-RisC from the WHO Global Health Observatory [37]. 95% band-level CIs for GASTAT prevalence based on binomial sampling [73,544 sampled households, distributed proportionate to population size, with design effect 2]. Age-specific data from SHINE and KSAWHS re-weighted by band-specific 2024 population age structure. Aware hypertension equals self-reported hypertension multiplied by the PPV of the self-report (55.2%; 95% UI 49.7-60.5). The estimated share of undiagnosed diabetes is on the logit-linear age gradient of the hypertension prevalence (OR 0.69 per decade; slope SE 0.041); intercept in each draw is fitted to the diabetes consensus estimate for 20-79 years; according to NCD-RisC 2022 crude estimates of ≥18 y and ≥30 y total diabetes prevalence, at 18-29 y there was 4.4%, therefore the youngest band is an upper-leaning estimate. Unaware without periodic check-ups = undiagnosed prevalence * (1-band-specific check-ups uptake) assuming independence. All-adult hypertension prevalence values obtained from KSAWHS 2019 standardized to the 2024 population aged ≥15 years; GASTAT published estimates are for the surveyed population of households)

The model-implied (not measured) undiagnosed fraction of diabetes decreased from 69.8-29.5% across these bands. Among the 2.22 million adults aged 15 years or older with model-implied undiagnosed diabetes, 1.29 million (58.0%) did not report periodic check-ups during the last year. Although only 3.5% of the adults reported unmet health care needs, 58.3% did not visit any health care provider within the last year (Table 2).

Among adults with hypertension, the odds of being undiagnosed fell with age (odds ratio 0.69 per decade; logit slope −0.375, SE 0.041). The maximum number of undiagnosed hypertension cases (637,600 adults) and diabetes cases (534,600) was found among 40-49 years old individuals. Regarding the distribution of the undiagnosed population in relation to the distribution of sexes within each age group, 1.91 million of 2.50 million adults with undiagnosed hypertension (standardized to national consensus) and 1.48 million of 2.22 million adults with undiagnosed diabetes were male, reflecting the predominance of men among working-age expatriates; this split follows population structure, not independently modelled sex-specific risk. Of these males, 60.5 and 61.1% lacked periodic check-ups, compared with 51.4 and 52.1% of females (Figure 1).

National Triangulation of the Diagnosis Gap

The estimated diagnosed diabetes rate in 20-79-year-olds was 8.91% (95% UI 8.64-9.19), representing 2.21 million 20-79-year-old adults and the self-reported hypertension rate in 30-79-year-olds was 10.07% (9.73-10.43), representing 5.56% aware hypertension after adjustment for PPV. Against these benchmarks, the estimates of the undiagnosed fraction ranged quite widely. The subtraction with IDF anchor indicated that 58.4% (57.0-59.7) or 3.10 million were undiagnosed for diabetes, NCD-RisC subtraction indicated 42.6% (8.1-64.9) or 1.73 million undiagnosed and IDF-reported rate indicated 43.6% or 1.71 million. In the case of hypertension, the NCD-RisC subtraction indicated 80.4% (74.2-84.9) or 4.01 million, the KSAWHS subtraction indicated 66.3% (62.1-70.3) or 1.92 million and the gap between reported diagnosis and reported awareness was 54.9% or 65.2% of all cases. Equal weights synthesis indicated that 48.2% (95% CI 27.7-69.2; prediction interval 13.7-84.5%) for diabetes and 67.4% (48.1-82.2; 25.6-92.6%; Monte Carlo median 67.3%) for hypertension were the fractions of undiagnosed cases. This implies total prevalence of 17.2% (95% UI 12.3-28.9) and 17.0% (10.6-31.6), detection multipliers of 1.93 and 3.06, NNS of 11.0 and 7.9 and 2.06 million (0.85-4.97) and 2.01 million (0.90-4.59) undiagnosed adults for diabetes (20-79 years) and hypertension (30-79 years), respectively (Monte Carlo medians; the deterministic base cases in Figure 3 are 2.04 and 2.03 million and undiagnosed diabetes is 2.14 million at ≥18 years and 2.22 million at ≥15 years in the age-specific model). There was great heterogeneity among the estimators of undiagnosed fraction of hypertension (I^2 86.1%; Q = 21.61, $p<0.001$), whereas inverse-variance synthesis of the diabetes estimators converged on the IDF-anchored estimator (58.3%; $\tau^2 = 0$) because its interval reflects only GASTAT sampling error; finite-mixture estimates were 43.6 and 65.8% (Table 3B). Pairing the NCD-RisC totals with SHINE rather than GASTAT produced incoherent draws in 25.6-26.5% of simulations for diabetes. The number of diagnosed adults with diabetes implied by IDF anchoring (3.01 million) was 36% higher than the number reported by survey (2.21 million) despite agreement in denominators within 0.5% (neither source can be judged correct without independent validation) and the NCD-RisC-anchored diagnosed hypertension was 2.3 times the PPV-corrected level from GASTAT (5.56%), which in turn agreed with the level implied by KSAWHS measurement and awareness (5.72%), an agreement conditional on the PPV correction and the age-standardised measured prevalence (Table 3).

Crude prevalence of diabetes increased annually by 3.72% between 1990 and 1999 but decreased afterward (by -1.50% per year from 1999 to 2011 and by -0.49% from 2011 to 2022), while age-standardized series demonstrated annually decreasing trend since 2007 (by -1.33% per year). Hypertension prevalence remained almost constant (annually increasing average annual percent change: 0.08%), while its detection, management and control increased annually by 1.65, 2.49 and 5.56% per year, respectively, the highest being achieved between 1998 and 2012 (8.92%).

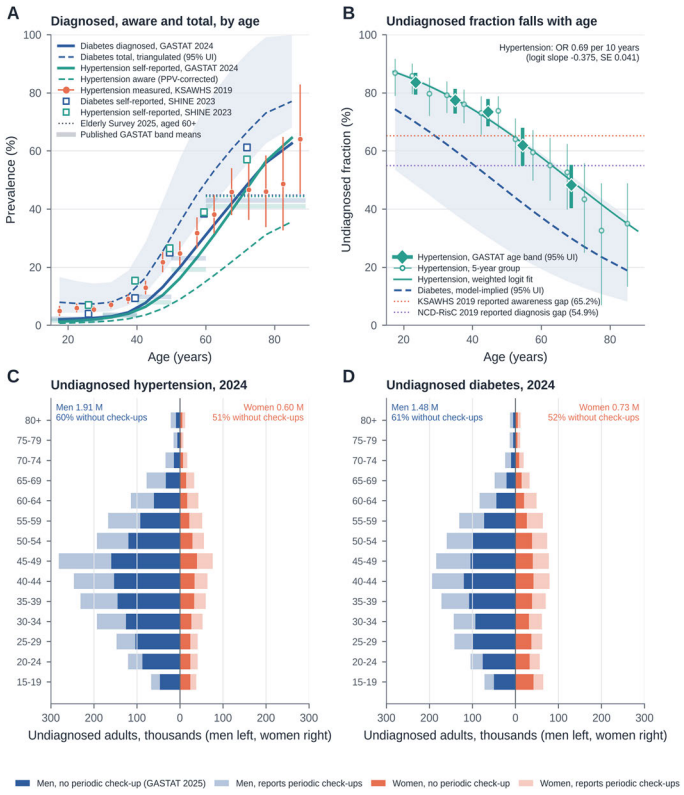


Figure 1: Age Structure of the Diagnosis Gap, 2024, (A) Prevalence by 5-Year Age Strata: GASTAT 2024 Self-Reported Diabetes and Hypertension Smoothed as Curves (Bars, Published Band Means), PPV-Adjusted Aware Hypertension, KSAWHS 2019 Measured Hypertension (95% CI), SHINE 2023 and Elderly Survey 2025 Self-Report and Model-Implied Total Diabetes Curve (95% UI). (B) Percentage Undiagnosed by Age: KSAWHS-Calibrated Hypertension Estimates for Bands and 5-Year Age Strata with the Weighted Logit-Linear Fit and the Model-Implied Diabetes Curve, which Borrows the Hypertension Age Gradient; Dashed Lines Show the Gap from KSAWHS and NCD-RisC. (C,D) Hypertension and Diabetes Undiagnosed (Thousands) by Age and Sex, Whether or not had Periodic Check-Up in Past Year; the Sex Ratio is that of 2024 Population, Owing to the Predominance of Male Expatriate Workers Rather than Modelling Bias in Risk

Table 3: Triangulation Matrix of Total, Diagnosed and Undiagnosed Diabetes and Hypertension Obtained through Cross-Source Subtraction and Within-Source Estimation, Saudi Arabia, 2024 Diagnosed Anchor

A. Estimator Matrix												
	Estimator				Prevalence			Undiagnosed				
#	Age, y	Total-prevalence source	Diagnosed source	Self-report correction	Total, % (95% UI)	Diagnosed (aware), %	Gap, pp (95% UI)	Fraction, % (95% UI)	Detection multiplier (total ÷ aware)	Adults, millions (95% UI)	NNS	Incoherent draws, %
Diabetes												
1	20–79	IDF 2024 (modelled)	GASTAT 2024	None	21.4 (fixed)	8.91	12.5 (12.2–12.8)	58.4 (57.0–59.7)	2.40	3.10 (3.03–3.17)	7.3	0.0
2	20–79	IDF 2024 (modelled)	SHINE 2023	None	21.4 (fixed)	12.98	8.4 (7.0–9.7)	39.3 (32.6–45.3)	1.65	2.09 (1.74–2.41)	10.3	0.0
3	≥18	NCD-RisC 2022 (modelled)	GASTAT 2024	None	15.7 (9.8–25.8)	9.01	6.7 (0.8–16.7)	42.6 (8.1–64.9)	1.74	1.73 (0.21–4.34)	13.6	2.9
4	≥18	NCD-RisC 2022 (modelled)	SHINE 2023	None	17.0 (12.9–26.6)	12.91	4.0 (0.2–13.6)	23.8 (1.5–51.7)	1.31	1.05 (0.05–3.54)	21.5	26.5
5	≥30	NCD-RisC 2022 (modelled)	GASTAT 2024	None	20.7 (13.1–33.0)	12.08	8.7 (1.0–20.9)	41.7 (7.6–63.5)	1.72	1.54 (0.18–3.72)	10.2	3.0
6	≥30	NCD-RisC 2022 (modelled)	SHINE 2023	None	22.4 (17.0–34.2)	17.04	5.3 (0.2–17.3)	23.8 (1.4–50.8)	1.31	0.94 (0.04–3.08)	15.7	25.6
7	20–79	IDF 2024 reported fraction (43.6%)	GASTAT 2024	None	15.8 (15.3–16.3)	8.91	6.9 (6.7–7.1)	43.6 (fixed)	1.77	1.71 (1.66–1.77)	13.2	–
8	20–79	Consensus (equal weight)	GASTAT 2024	None	17.2 (12.3–28.9)	8.91	8.3 (3.4–20.0)	48.2 (27.7–69.2)	1.93	2.06 (0.85–4.97)	11.0	–
9	≥18	Consensus (equal weight)	GASTAT 2024	None	17.3 (12.4–29.0)	9.01	8.2 (3.4–19.9)	47.8 (27.3–68.8)	1.92	2.14 (0.88–5.17)	11.0	–
10	30–79	Consensus (equal weight)	GASTAT 2024	None	21.2 (15.5–35.0)	11.60	9.6 (3.9–23.3)	45.3 (25.4–66.7)	1.83	1.69 (0.70–4.11)	9.2	–
11	≥30	Consensus (equal weight)	GASTAT 2024	None	21.7 (16.0–35.5)	12.08	9.7 (3.9–23.4)	44.4 (24.7–65.9)	1.80	1.72 (0.70–4.16)	9.1	–
12	40–79	Consensus (equal weight)	GASTAT 2024	None	31.8 (23.9–50.7)	18.55	13.2 (5.4–32.1)	41.6 (22.6–63.3)	1.71	1.24 (0.51–3.02)	6.2	–
Hypertension												
13	30–79	NCD-RisC 2019 (modelled)	GASTAT 2024	None	28.3 (21.9–35.7)	10.07	18.2 (11.8–25.7)	64.4 (54.0–71.9)	2.81	3.21 (2.09–4.53)	4.9	0.0
14	30–79	NCD-RisC 2019 (modelled)	GASTAT 2024	PPV	28.3 (21.8–35.8)	5.56	22.7 (16.3–30.3)	80.4 (74.2–84.9)	5.10	4.01 (2.87–5.34)	4.0	0.0
15	30–79	NCD-RisC 2019 (modelled)	GASTAT 2024	Constant false-positive	28.3 (21.8–35.7)	7.14	21.1 (14.9–28.3)	74.8 (68.3–79.4)	3.96	3.73 (2.63–4.99)	4.3	0.0
16	30–79	NCD-RisC 2019 (modelled)	SHINE 2023	PPV	28.2 (21.8–35.7)	11.06	17.2 (10.6–24.8)	60.9 (47.8–70.3)	2.56	3.03 (1.87–4.38)	4.7	0.0
17	30–79	KSAWHS 2019 (measured BP)	GASTAT 2024	None	16.5 (15.5–17.5)	10.07	6.4 (5.4–7.5)	38.9 (34.5–43.0)	1.64	1.13 (0.95–1.32)	14.0	0.0
18	30–79	KSAWHS 2019 (measured BP)	GASTAT 2024	PPV	16.5 (15.5–17.5)	5.56	10.9 (9.8–12.1)	66.3 (62.1–70.3)	2.96	1.92 (1.73–2.13)	8.2	0.0
19	30–79	KSAWHS 2019 (measured BP)	GASTAT 2024	Constant false-positive	16.5 (15.5–17.5)	6.66	9.8 (8.8–10.9)	59.6 (55.7–63.4)	2.48	1.73 (1.55–1.93)	9.2	0.0
20	30–79	KSAWHS 2019 (measured BP)	SHINE 2023	PPV	16.5 (15.5–17.5)	11.03	5.4 (3.5–7.3)	32.9 (21.8–42.8)	1.49	0.96 (0.62–1.28)	14.8	0.0
21	≥18	KSAWHS 2019 (measured BP)	GASTAT 2024	None	13.3 (12.6–14.0)	7.80	5.5 (4.7–6.3)	41.3 (37.4–45.0)	1.70	1.43 (1.23–1.63)	16.8	0.0
22	≥18	KSAWHS 2019 (measured BP)	GASTAT 2024	PPV	13.3 (12.6–14.0)	4.30	9.0 (8.1–9.8)	67.6 (63.7–71.3)	3.09	2.33 (2.11–2.56)	10.3	0.0
23	≥18	KSAWHS 2019 (measured BP)	SHINE 2023	PPV	13.3 (12.6–14.0)	8.92	4.4 (2.8–5.9)	32.9 (21.2–43.0)	1.49	1.14 (0.72–1.52)	19.2	0.0

Table 3: Continued

A. Estimator Matrix												
	Estimator				Prevalence			Undiagnosed				
#	Age, y	Total-prevalence source	Diagnosed source	Self-report correction	Total, % (95% UI)	Diagnosed (aware), %	Gap, pp (95% UI)	Fraction, % (95% UI)	Detection multiplier (total ÷ aware)	Adults, millions (95% UI)	NNS	Incoherent draws, %
24	30–79	NCD-RisC 2019 diagnosis coverage	GASTAT 2024	PPV	12.3 (9.4–17.1)	5.56	6.8 (4.0–11.4)	54.9 (42.0–67.1)	2.22	1.19 (0.70–2.01)	13.3	–
25	30–79	KSAWHS 2019 awareness	GASTAT 2024	PPV	16.0 (13.6–18.6)	5.56	10.4 (8.4–12.8)	65.2 (61.0–69.2)	2.87	1.83 (1.49–2.25)	8.6	–
26	30–79	Consensus (equal weight)	GASTAT 2024	PPV	17.0 (10.6–31.6)	5.56	11.4 (5.1–26.1)	67.3 (48.1–82.2)	3.06	2.01 (0.90–4.59)	7.9	–
27	≥18	Consensus (equal weight)	GASTAT 2024	PPV	13.2 (8.2–24.4)	4.30	8.8 (4.0–20.1)	67.3 (48.1–82.2)	3.06	2.29 (1.03–5.22)	10.4	–
28	40–79	Consensus (equal weight)	GASTAT 2024	PPV	27.0 (16.8–50.1)	8.83	18.2 (8.1–41.2)	67.3 (48.1–82.2)	3.06	1.71 (0.76–3.87)	4.6	–
29	20–79	Consensus (equal weight)	GASTAT 2024	PPV	12.9 (8.0–24.1)	4.23	8.7 (3.9–19.8)	67.3 (48.1–82.2)	3.06	2.16 (0.97–4.92)	10.6	–

B. Synthesis of Undiagnosed Fractions											
Synthesis	Estimators, k	Estimator undiagnosed fractions, %	Equal-weight random effects (primary)			Inverse-variance random effects (sensitivity)				Finite mixture, % (95% UI)
			Pooled, % (95% CI)	95% prediction interval, %	SD of logit estimates	Pooled, % (DL τ², HKSJ 95% CI)	τ² (logit)	I², %	Cochran Q (df; p)	
Diabetes, 20–79 y (rows 1, 3, 7)	3	58.4; 42.6; 43.6	48.2 (27.7–69.2)	13.7–84.5	0.356	58.3 (55.7–60.9)	0.000	0.0	1.68 (2; 0.432)	43.6 (16.6–60.4)
Hypertension, 30–79 y (rows 14, 18, 24, 25)	4	80.4; 66.3; 54.9; 65.2	67.4 (48.1–82.2)	25.6–92.6	0.505	67.9 (49.9–81.8)	0.103	86.1	21.61 (3; <0.001)	65.8 (46.6–83.5)

C. Cross-Source Coherence Diagnostics		
Coherence diagnostic	Value	Reading
GASTAT ≥15 y diabetes: published vs re-weighted to the 2024 population, %	9.14 Vs 8.65	Surveyed household population is older than the 2024 population (implied ≥60 y share 7.0% vs 6.2%)
GASTAT ≥15 y hypertension: published vs re-weighted, %	7.91 Vs 7.45	As above
IDF-implied diagnosed diabetes vs GASTAT diagnosed, 20–79 y, ×10³	3,014.4 Vs 2,214.9	Ratio 1.36: IDF total × (1 – 43.6%) exceeds survey-reported diagnosis
IDF 20–79 y population Vs GASTAT 2024, ratio	1.005	Denominators agree; the incoherence lies in prevalence, not population
SHINE 2023 Vs GASTAT 2024 self-reported diabetes, ≥18 y, %	12.9 Vs 9.0	Ratio 1.43 (telephone sample, 17.1% response)
SHINE 2023 Vs GASTAT 2024 self-reported hypertension, ≥18 y, %	16.1 Vs 7.8	Ratio 2.07
NCD-RisC-implied diagnosed hypertension vs GASTAT aware vs KSAWHS-implied aware, 30–79 y, %	12.76 Vs 5.56 vs 5.72	Measured (KSAWHS) and survey (GASTAT, PPV-corrected) awareness agree; the NCD-RisC diagnosed level is 2.3-fold higher
KSAWHS 2019 hypertension 30–79 y: published crude vs standardised to 2024, %	19.41 Vs 16.44	The 2024 population aged 30–79 is younger than the KSAWHS sample; re-weighting lowers the total
NCD-RisC totals projected to 2024 (linear trend), diabetes ≥18 y/hypertension 30–79 y, %	14.92/29.15	Temporal alignment moves each anchor by <1 percentage point (Figure 3)
PPV of self-reported hypertension (KSAWHS 2019), % (95% UI)	55.2 (49.7-60.5)	4.1% of measured normotensives self-report a diagnosis

(Acronyms: BP, Blood Pressure; DL, DerSimonian-Laird; HKSJ, Hartung-Knapp-Sidik-Jonkman; NNS, Number Needed to Screen; PPV, Positive Predictive value; RE, Random Effects; UI, Uncertainty Interval.) Data sources: IDF Diabetes Atlas 11th edition, reference year 2024 [12]; NCD-RisC estimates using the WHO Global Health Observatory, diabetes 2022 and hypertension 2019 [4,5,37]; GASTAT Health Status Statistics 2024 (National Health Survey) [24]; SHINE 2023 (telephone survey) [27]; KSAWHS 2019 [19]. Estimators used for subtraction: Undiagnosed = total – aware diagnosed, where awareness = self-reported diagnosed (for diabetes, without correction) or self-reported * PPV (for hypertension). Totals adjusted for age band to be consistent with 2024 population age, while diagnosed re-weighted to GASTAT age bands with mean-preserving smoothing. Fixed, IDF provides no uncertainty interval. Incoherent draws mean that in the Monte Carlo simulations, the total was found lower than the aware diagnosed prevalence; such draws were dropped and redrawn. Cases/aware cases = detection ratio, NNS is calculated assuming that undiagnosed cases have the same distribution as the population in the band. The consensus rows provide equal weighting synthesis of panel B using the GASTAT diagnosed anchor and Monte Carlo medians; they might differ from the pooled estimator of panel B at the last digit. Total estimates for the diabetes band are based on the age gradient from Table 2 (inverse-variance weighting is determined by the IDF estimator, because the only source of its uncertainty is the GASTAT sample error)

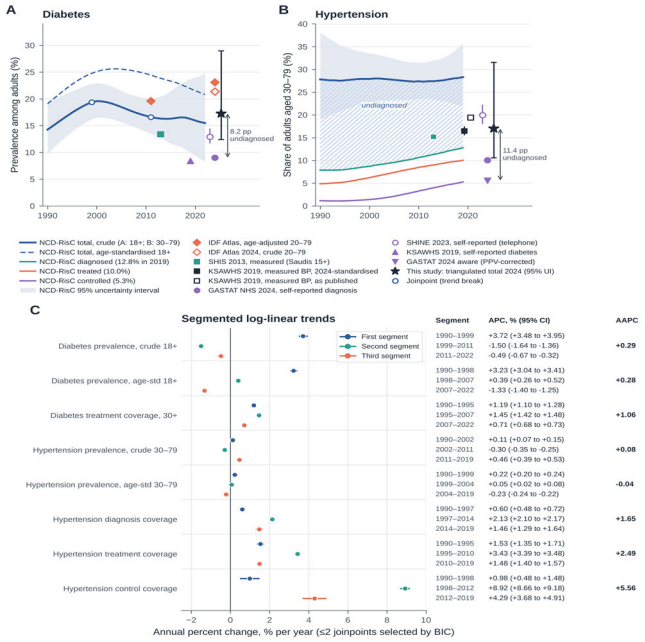


Figure 2: Trends in the Prevalence of Diabetes and Hypertension: Long Term Trend Pattern, Cross-Source Anchors and Segmented Trends in Saudi Arabia, 1990-2024. (A) Prevalence of Crude (95% Uncertain Band) and Age-Adjusted Diabetes among Adults of 18 Years and above using NCD RisC (Joinpoints, Point Anchors), IDFDIAB and SHS 2013, KSAWHS 2019, SHINE 2023 and GASTAT 2024; Star: Triangulated Prevalence Estimate 2024, Double Arrow: Undiagnosed Gap. (B) Hypertension Prevalence Rate among Adults Aged 30-79 Years using NCD RisC Segmented as Diagnosed, Treated and Controlled (Hatched Area: Undiagnosed); Measured and Survey Anchors (PPV-Corrected GASTAT). (C) Percentage Increase per Year in Segments (95% CI) and Percentage Increase Yearly in Eight NCD RisC Trends [12,14,18,19,24,27,37]. Points are Observed Survey Anchors; Lines and Bands are Modelled NCD-RisC Estimates

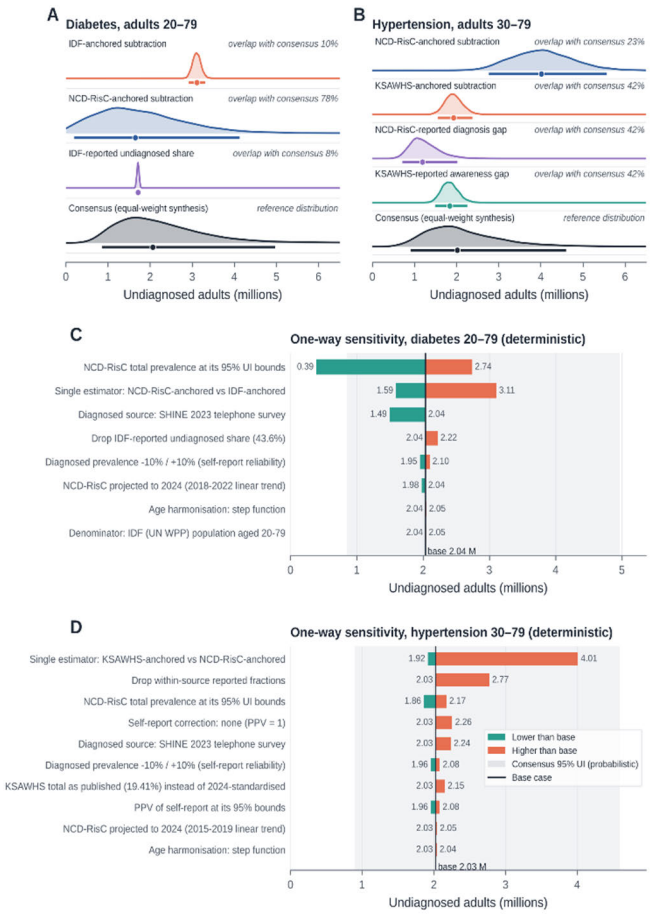


Figure 3: Uncertainty and Sensitivity Analysis for the Number of Persons Estimated to Have Undiagnosed Disease. (A,B) Probability Distribution (Monte Carlo Simulation Using 20,000 Repetitions) Of Undiagnosed Adults Based on Each Estimator and the Consensus Estimator of Diabetes (Age 20-79 Years) and Hypertension (Age 30-79 Years) Using Equal Weights, Along With their Medians, 95% Uncertainty Intervals, and the Coefficient of Overlap with the Consensus Distribution where Tall Peaks Indicate Those with No Declared Uncertainty (IDF); (C,D) Sensitivity Analysis of Consensus Estimate with Respect to Anchor Range, List of Estimators, Adjustment of Self-Report, Diagnosed Estimates, Age-Adjustment, Temporal Projections and Denominator; Grey Shaded Region Indicates the 95% Uncertainty Interval. Units: Millions of Adults

All hypertension anchor points (15.2%-19.4%) were far below the NCD-RisC trend line (28.3% in 2019) but diabetes anchor points embraced it; these segmented trends describe modelled NCD-RisC series rather than repeated Saudi measurements (Figure 2).

The major component of uncertainty originated from the choice of anchoring method. The distribution corresponded with the NCD-RisC-anchored diabetes estimator by 78%, but with the IDF-anchored and IDF-reported estimators by 10% and 8%, respectively, while with the hypertension estimators corresponded by 23-42%. The one-way sensitivity analysis revealed that with NCD-RisC credible interval, the deterministic base case for diabetes (2.04 million; Monte Carlo median 2.06 million) varied from 0.39 to 2.74 million cases and depended on any of estimators varied it from 1.59 to 3.11 million cases. As concerns hypertension, dependence on the NCD-RisC anchor varied the base case of 2.03 million to 4.01 million cases, dependence on within-source fractions varied it to 2.77 million, while excluding the self-report correction varied it to 2.26 million cases. Age harmonisation and alternative denominators affected any of those estimates by less than 1%, while projecting NCD-RisC totals up to 2024 did it by no more than 3% (Figure 3).

Care Cascades

As per NCD-RisC survey, the estimates of prevalence of hypertension for adults of 30-79 years of age in 2019 were 28.3%, of which 45.1% was diagnosed, 35.4% was treated and 18.6% controlled, meaning that their application to 2024 KSA population of the corresponding age will result in 4.99 million total cases, including 2.74 million undiagnosed cases, 0.48 million diagnosed but untreated, 0.84 million treated but uncontrolled and 0.93 million controlled. Men demonstrated relatively lower prevalence of diagnosing (40.9% Vs 54.5%) and treating (31.3% Vs 44.5%) in comparison with women. Out of treated patients, 47.5% continued being uncontrolled, while in the survey of SHIS 2013 the figure accounted for 55.0%. According to KSAWHS, the prevalence of treatment of hypertensive adults aged 30-79 years was 48.0% (41.4% in men and 57.0% in women).

Table 4: Care Cascades for Hypertension and Diabetes: Stage-Specific Coverage and Loss of Patients within the Framework of the 2024 KSA Population

				Coverage, % of all cases			Conditional coverage, %		Adults in each stage, ×10³				
Source (measurement)	Age, y	Sex	Prevalence, %	Diagnosed	Treated	Controlled	Treated, of diagnosed	Uncontrolled, of treated	Cases	Undiagnosed	Diagnosed, untreated	Treated, uncontrolled	Controlled
Hypertension													
NCD-RisC 2019 (crude)	30–79	Both	28.3	45.1	35.4	18.6	78.5	47.5	4,990.0	2,739.5	484.0	838.3	928.1
NCD-RisC 2019 (crude)	30–79	Men	31.1	40.9	31.3	16.7	76.5	46.6	3,693.1	2,182.6	354.5	539.2	616.7
NCD-RisC 2019 (crude)	30–79	Women	23.6	54.5	44.5	22.8	81.7	48.8	1,358.8	618.2	135.9	294.9	309.8
NCD-RisC 2019 (age-standardised)	30–79	Both	34.0	51.3	41.2	21.3	80.3	48.3	–	–	–	–	–
NCD-RisC 2019 (age-standardised)	30–79	Men	36.3	46.8	37.0	19.0	79.1	48.6	–	–	–	–	–
NCD-RisC 2019 (age-standardised)	30–79	Women	30.2	60.1	49.5	25.6	82.4	48.3	–	–	–	–	–
KSAWHS 2019 (measured; prevalence standardised to 2024)	30–79	Both	16.4	–	48.0	–	–	–	2,898.9	–	–	–	–
KSAWHS 2019 (measured)	30–79	Men	–	–	41.4	–	–	–	–	–	–	–	–
KSAWHS 2019 (measured)	30–79	Women	–	–	57.0	–	–	–	–	–	–	–	–
SHIS 2013 (measured; Saudi nationals)	≥15	Both	15.2	42.2	33.3	15.0	78.9	55.0	–	–	–	–	–
This study: consensus, GASTAT 2024 anchor	30–79	Both	17.0	32.7	–	–	–	–	2,995.8	2,015.1	–	–	–
Diabetes													
IDF 2024 (modelled)	20–79	Both	21.4	56.4	–	–	–	–	5,320.2	2,319.6	–	–	–
NCD-RisC 2022 (crude)	≥30	Both	20.6	–	45.9	–	–	–	3,658.2	–	–	–	–
NCD-RisC 2022 (crude)	≥30	Men	20.6	–	45.3	–	–	–	2,463.9	–	–	–	–
NCD-RisC 2022 (crude)	≥30	Women	20.4	–	47.2	–	–	–	1,194.5	–	–	–	–
NCD-RisC 2022 (age-standardised)	≥30	Both	27.6	–	51.4	–	–	–	–	–	–	–	–
NCD-RisC 2022 (age-standardised)	≥30	Men	28.0	–	51.2	–	–	–	–	–	–	–	–
NCD-RisC 2022 (age-standardised)	≥30	Women	26.7	–	51.8	–	–	–	–	–	–	–	–
SHIS 2013 (measured; Saudi nationals)	≥15	Both	13.4	42.2	36.8	16.6	87.2	54.9	–	–	–	–	–
This study: consensus, GASTAT 2024 anchor	20–79	Both	17.2	51.8	–	–	–	–	4,279.3	2,061.9	–	–	–
AlAnazi 2026 (NCD-RisC series, sex-pooled, age-standardised)	≥18 (prevalence); ≥30 (treatment)	Both	20.6	–	51.5	–	–	–	–	–	–	–	–

(Abbreviations: KSAWHS, KSA World Health Survey; PPV, Positive Predictive Value; SHIS, Saudi Health Information Survey). Sources: NCD-RisC via WHO Global Health Observatory [4,5,37]; IDF Diabetes Atlas 11th Edition [12]; KSAWHS 2019 [19]; SHIS 2013 [14,18]; AlAnazi 2026 [38]. Percentages indicate proportion of all cases. Age groups, definitions and reference years differ by source, and stages are not combined across sources. The number of patients is based on the calculation of prevalence and coverage in each respective study using the GASTAT 2024 population of the specified age [30]; age-standardized lines are not converted into numbers. Definitions for hypertension in NCD-RisC: diagnosed, previously diagnosed; treated, antihypertensive medication; controlled, treated and with blood pressure <140/90 mmHg. KSAWHS 2019 provides only the awareness (34.8%) among adults ≥18 years and treatment among 30–79 year old patients. SHIS 2013 provides statistics on Saudi citizens aged ≥15 years with either laboratory confirmed or treated diabetes mellitus and measured blood pressure. "This study" lines give the result of the triangulation of totals (Table 3) together with GASTAT 2024 diagnosed prevalence (PPV adjusted for hypertension); numbers are medians of two independently summarised quantities and may differ from Table 3 in the last digit. AlAnazi 2026 figures replicate the sex-pooled NCD-RisC age-adjusted lines (for comparison))

The GASTAT-based consensus assumes that 32.7% of adults aged 30-79 years with hypertension are informed about this problem, which figure is inferior to NCD-RisC's (45.1%) and SHIS 2013's (42.2%) findings. As far as diabetes goes, in NCD-RisC, the prevalence of treatment is 45.9% for adults aged 30 years or more (age standardized - 51.4%), while according to the consensus, 51.8% of adult KSA population aged 20-79 years with diabetes are diagnosed with the disease, which is lower than IDF's figure (56.4%) but higher than SHIS 2013's (42.2%) (Table 4); stages are source-specific and are not combined across sources and percentages may not sum to 100% because of rounding and differing age groups.

Regional Distribution of the Undiagnosed Burden

The undiagnosed diabetes and undiagnosed hypertension prevalence in model A was estimated between 72.0 and 86.7 per 1,000 adults aged 20-79 in Najran and Qassim respectively and undiagnosed hypertension between 100.7 and 121.0 per 1,000 in Najran and Qassim among those aged 30-79. Between regions coefficient of variations were 4.7% and 4.4% and all intervals overlapped because Model A distributes the total value and its interval. In Riyadh, undiagnosed diabetes prevalence was estimated at 27.6% and undiagnosed hypertension - at 27.4%, in Makkah at 26.0% and 26.3% and in Eastern Region at 16.8 and 17.0%; the top three regions combined represented 70.4% of all undiagnosed diabetes and 70.7% of all undiagnosed hypertension (shares depend on region sizes while rates per 1,000 persons are higher in Qassim and lower in Najran). Uncertainty of prevalence estimates depends on survey calibration procedure: in Model B, prevalence estimates ranged from 51.0 to 104.7 per 1,000 for undiagnosed diabetes and from 11.4 to 293.3 per 1,000 for undiagnosed hypertension (coefficient of variation 18.5% and 75.7%) which were poorly congruent to Model A (Lin's concordance 0.17 and 0.09). The actual prevalence of hypertension recorded in KSAWHS 2019 survey was in the interval of 4.7% in Najran and 4.9% in Tabuk against expected 12.6-14.7-21.0% in Madinah and 27.0% in Qassim. Heterogeneity among the actual region-level prevalences of hypertension was high (I^2 93.5%). This heterogeneity could be partially attributed to the obesity prevalence (β 10.22 per unit of obesity proportion, SE 2.62) because it reduced the residual heterogeneity component of variance τ^2 from 0.158 to 0.090. Because the actual values of totals in some draws were below survey-derived number of diagnoses in Tabuk, Jazan and Najran, the upper boundaries of uncertainty intervals in Model B extended below zero; these are not epidemiological meaning values but indicate model incoherence and ranking of Model B should not be used for prioritization (Table 5).

Age distribution contributed differently to regional estimation of the chosen variables, by between −3.0% (Najran) and +5.8% (Al-Baha) relative to the country's average, while obesity affected estimates by between −9.4% (Najran) and +4.8% (Qassim). Age recalibration reduced the share of undiagnosed disease burden by −89 and −87% in Najran and Tabuk regions, respectively, while the other two regions, Qassim and Madinah got increased percentages of +142 and +73%, respectively.

Table 5: Estimates of Undiagnosed Diabetes (20-79 year) and Hypertension (30-79 year) among Administrative Regions, 2024: Structural Model A and Survey-Calibrated Model B

A. Diabetes, Adults Aged 20–79 year												
	Model A (structural)							Model B (survey-calibrated)				SHINE 2023 self-reported DM, ≥18 year, % (n)
Region	Total (%)	Diagnosed (%)	Undiagnosed fraction (%)	Undiagnosed, ×10³ (95% UI)	Per 1,000 adults (95% UI)	Share of national (%)	Rank	Undiagnosed, ×10³ (95% UI)	Per 1,000 adults (95% UI)	Rank	
Riyadh	16.6	8.4	49.0	568.9 (239.9–1,358.6)	81.1 (34.2–193.6)	27.6	8	734.9 (404.6–1,525.8)	104.7 (57.7–217.4)	1	6.7 (577)
Makkah	17.9	9.5	47.0	535.7 (211.6–1,306.7)	84.0 (33.2–204.8)	26.0	5	486.2 (162.4–1,257.8)	76.2 (25.5–197.2)	8	15.2 (647)
Madinah	17.3	9.1	47.6	129.8 (52.4–315.2)	82.5 (33.3–200.3)	6.3	6	100.5 (23.0–285.9)	63.9 (14.6–181.7)	11	17.8 (182)
Qassim	17.6	8.9	49.3	85.5 (36.4–204.1)	86.7 (36.9–207.0)	4.1	1	81.3 (32.2–199.9)	82.5 (32.7–202.7)	3	13.1 (102)
Eastern	17.1	8.6	49.8	346.7 (149.0–822.1)	85.1 (36.6–201.9)	16.8	3	321.1 (123.4–796.5)	78.8 (30.3–195.6)	5	13.8 (440)
Asir	17.9	9.3	47.9	124.0 (50.7–299.5)	85.6 (35.0–206.6)	6.0	2	95.5 (22.1–270.9)	65.9 (15.3–186.9)	9	18.2 (211)
Tabuk	16.4	8.5	48.4	49.4 (20.4–118.3)	79.5 (32.9–190.5)	2.4	11	48.5 (19.5–117.4)	78.0 (31.4–189.1)	6	10.0 (65)
Hail	17.1	9.0	47.7	43.9 (17.7–106.6)	81.7 (33.0–198.5)	2.1	7	35.0 (8.9–97.7)	65.2 (16.6–181.9)	10	18.5 (90)
Northern Borders	16.3	8.4	48.3	19.5 (8.0–46.9)	78.5 (32.3–188.6)	0.9	12	19.1 (7.6–46.5)	76.8 (30.6–187.0)	7	8.5 (45)
Jazan	17.6	9.5	46.1	77.5 (29.7–191.5)	80.8 (31.0–199.6)	3.8	9	76.5 (28.7–190.4)	79.7 (29.9–198.5)	4	12.6 (119)
Najran	15.5	8.3	46.3	29.0 (11.2–71.4)	72.0 (27.8–177.3)	1.4	13	20.5 (2.7–62.9)	51.0 (6.6–156.3)	13	21.5 (57)
Al-Baha	18.6	10.2	45.3	20.1 (7.4–50.1)	84.2 (31.1–210.2)	1.0	4	19.9 (7.3–49.9)	83.6 (30.5–209.5)	2	12.2 (67)
Al-Jouf	16.5	8.5	48.2	30.5 (12.5–73.5)	79.5 (32.6–191.4)	1.5	10	21.9 (3.9–64.8)	57.1 (10.2–168.9)	12	22.9 (48)
Saudi Arabia	17.2	8.9	48.2	2,060.4 (848.8–4,967.7)	82.9 (34.1–199.8)	100.0	–	2,060.4 (848.8–4,967.7)	82.9 (34.1–199.8)	–	13.0 (2,650)

B. Hypertension, Adults Aged 30–79 year													
	Model A (structural)							KSAWHS 2019, ≥18 year		Model B (survey-calibrated)			SHINE 2023 self-reported HTN, ≥18 year (%)
Region	Total (%)	Aware (%)	Undiagnosed fraction (%)	Undiagnosed, ×10³ (95% UI)	Per 1,000 adults (95% UI)	Share of national (%)	Rank	Measured, % (95% CI)	Age-expected (%)	Undiagnosed, ×10³ (95% UI)	Per 1,000 adults (95% UI)	Rank	
Riyadh	16.4	5.26	68.0	551.3 (249.6–1,249.3)	111.8 (50.6–253.3)	27.4	9	11.2 (9.6–12.8)	12.8	509.4 (247.2–1,115.5)	103.3 (50.1–226.2)	5	8.6
Makkah	17.5	5.90	66.3	530.3 (232.4–1,219.6)	115.7 (50.7–266.1)	26.3	5	13.7 (11.7–15.6)	13.8	465.3 (174.8–1,138.0)	101.5 (38.1–248.3)	6	21.1
Madinah	17.2	5.73	66.6	126.5 (55.8–289.9)	114.5 (50.5–262.3)	6.3	6	21.0 (17.6–24.4)	13.4	219.1 (111.2–467.3)	198.2 (100.6–422.9)	2	19.8
Qassim	17.8	5.71	67.9	81.9 (37.2–185.3)	121.0 (54.9–273.6)	4.1	1	27.0 (22.5–31.6)	13.1	198.6 (109.7–401.6)	293.3 (162.0–593.2)	1	13.7
Eastern	16.8	5.22	68.9	341.7 (157.5–767.4)	115.7 (53.3–259.9)	17.0	4	12.5 (10.5–14.6)	13.0	320.2 (145.2–725.4)	108.4 (49.2–245.6)	4	15.4
Asir	17.7	5.88	66.8	121.0 (53.6–276.0)	118.3 (52.4–269.7)	6.0	2	19.8 (16.5–23.1)	13.6	190.5 (95.1–409.3)	186.2 (92.9–400.1)	3	19.0
Tabuk	16.4	5.34	67.4	47.5 (21.3–107.9)	110.3 (49.4–250.7)	2.4	11	4.9 (3.1–6.8)	12.7	6.2 (−5.5 to 33.1) †	14.4 (−12.8 to 77.0)	12	21.5
Hail	17.0	5.66	66.7	42.7 (18.8–97.7)	113.3 (49.9–259.1)	2.1	7	10.9 (7.6–14.1)	13.3	30.4 (11.0–75.3)	80.7 (29.1–199.9)	8	16.6
Northern Borders	16.4	5.39	67.0	18.6 (8.3–42.4)	109.7 (48.7–249.2)	0.9	12	9.8 (7.0–12.6)	12.6	11.4 (3.4–30.0)	67.3 (19.7–176.4)	10	24.5
Jazan	17.4	6.09	65.0	75.6 (32.5–175.8)	112.9 (48.5–262.7)	3.8	8	7.5 (5.1–9.9)	13.7	24.4 (−0.6 to 82.4) †	36.4 (−0.9 to 123.1)	11	19.0
Najran	15.4	5.34	65.4	27.7 (12.0–63.8)	100.7 (43.6–232.0)	1.4	13	4.7 (2.6–6.9)	12.6	3.1 (−4.1 to 19.7) †	11.4 (−14.9 to 71.6)	13	22.5
Al-Baha	18.0	6.35	64.7	20.1 (8.5–46.9)	116.2 (49.3–270.9)	1.0	3	11.0 (8.1–13.9)	14.7	12.9 (4.2–33.2)	74.7 (24.4–191.7)	9	9.0
Al-Jouf	16.5	5.43	67.1	29.3 (13.0–66.9)	110.7 (49.2–252.7)	1.5	10	11.4 (8.4–14.4)	12.7	23.1 (8.7–56.5)	87.3 (32.7–213.5)	7	21.5
Saudi Arabia	17.0	5.56	67.3	2,013.9 (900.9–4,593.4)	114.2 (51.1–260.5)	100.0	–	12.7	–	2,013.9 (900.9–4,593.4)	114.2 (51.1–260.5)	–	16.1

C. Model agreement and shrinkage diagnostics		
Diagnostic	Diabetes, 20–79 year	Hypertension, 30–79 year
Model A rate range, per 1,000 (min–max)	72.0–86.7	100.7–121.0
Model A between-region coefficient of variation (%)	4.7	4.4
Model B rate range, per 1,000 (min–max)	51.0–104.7	11.4–293.3
Model B between-region coefficient of variation (%)	18.5	75.7
Agreement of model A and model B rates: Spearman ρ	0.36	0.74
Agreement of model A and model B rates: Lin's concordance coefficient	0.17	0.09
Survey input to model B	SHINE 2023 diagnosed (self-report)	KSAWHS 2019 measured total; SHINE 2023 diagnosed
Fay–Herriot, intercept-only: I^2 of log standardised ratios (%)	48.1	KSAWHS 93.5; SHINE 40.1
Fay–Herriot with covariate: covariate (centred)	Check-up uptake	KSAWHS: obesity; SHINE: check-up uptake
Fay–Herriot with covariate: β (SE) on log ratio per unit proportion	0.74 (1.04)	KSAWHS 10.22 (2.62); SHINE 1.97 (0.76)
Fay–Herriot with covariate: residual τ^2 (I^2, %)	0.051 (48.5)	KSAWHS 0.090 (89.0); SHINE 0.005 (8.7)
KSAWHS observed vs model A total hypertension: Spearman ρ	–	0.62
Regions whose model B 95% UI crosses zero (incoherent)	None	Tabuk, Jazan, Najran

(Abbreviations: DM, Diabetes Mellitus; HTN, Hypertension; KSAWHS, KSA World Health Survey; SE, Standard Error; SHINE, Saudi National Health INdicators survEy; UI, Uncertainty Interval. Data sources: See Tables 1-3; KSAWHS 2019 regional prevalence [19]; SHINE 2023 regional weighted prevalence [27]. In model A, the national consensus estimate (See Table 3) is allocated proportionally across regions depending on the product of age-expected total prevalence and an obesity adjustment factor (prevalence ratio 1.53 for diabetes, converted from the SHINE odds ratio using the Zhang-Yu method [52], 1.72 for hypertension using KSAWHS) and age-expected diagnosed prevalence. The sum of all regional values equals the consensus estimate, therefore, intervals include all national information and regional ranks have more operational meaning than the levels. Model B further adjusts the total and diagnosed cases by indirect standardization ratio shrinkage factor (see Figure 6C) using intercept-only Fay-Herriot empirical Bayes estimation [32]. †95% UI includes negative values because in some draws, the survey-calibrated total is less than the survey-calibrated diagnosed number; such values are not epidemiologically meaningful and indicate model incoherence. Model A is a constrained structural allocation; Model B is an exploratory survey-calibrated estimate. Rank 1 = highest rate. National rows contain consensus estimates. Age-expected KSAWHS prevalence based on national age-specific prevalence in KSAWHS 2019 survey applied to regional age structure in 2022 census))

The Riyadh region had a 9.3 percentage point higher undiagnosed disease burden share than the Ministry of Health Primary Health Care physicians' share, while Eastern had 6.1 and Makkah 2.9 (Figure 4).

Capacity of the Primary Care and Case-Finding Workload

As of 2024, there were 2,172 PHC facilities (-3.8% Vs 2020), 9,693 doctors (3.54 per 10,000 adults) and 16,136 nurses (5.89 per 10,000 adults). Number of PHC visits in 2024 was 41.26 million (1.17 per resident), a decline of 19.2% since 2022. The ratio adults per PHC facility was 2,930 (Al-Baha) and 22,040 (Makkah); the ratio of physicians per adult was 2.30 (Riyadh) and 13.58 (Al-Baha). The number of PHC visits had declined in 11 out of 13 regions from -65.1% (Al-Jouf) to +17.3% (Eastern Region). Total 3.88 million (2.11-7.15) diagnosed through modelling diabetes and hypertension in 30-79-year-old adults (the adults who have both of the diseases counted twice) is equal to 400 cases per doctor of the primary care and even up to 606 in Riyadh and 622 in the Eastern Region. In order to diagnose those patients in 5 years, 357 additional diagnoses have to be made per year at PHC facility. To

examine all 30-79-year-old adults in 5 years once, 6.5 visits per day are needed (17.63 million divided by 5 * 250 * 2,172; 10.8 visits per day for 3-year cycle), 11.5 in Makkah and 1.5 in Al-Baha. Makkah (CFPI +1.94), Riyadh (+1.85) and the Eastern Region (+1.52) were top-three in all simulations and Al-Baha was in last position (−1.79; 95% interval of rank 12-13) (Table 6).

In 13 regions, need was not significantly related to physician density (Spearman's ρ = 0.17, p = 0.58), nurse density (ρ = -0.13, p = 0.67), centre density (ρ = 0.07, p = 0.82), visits per capita (ρ = 0.24, p = 0.44) and check-up uptake (ρ = -0.35, p = 0.25); these analyses for 13 regions have little power and certainly do not provide evidence of an independent distribution of capacity with respect to need. An adult population-wide screening program for all those aged 30-79 years, at an interval of 5 years will boost national PHC encounters per day to 8.5%, to 14.2% in 3 years, to 14.4% in Riyadh and 24.0% in 3 years in Riyadh and 3.1% in Al-Baha. It requires 121 and 124 new cases detected annually by PHC physicians in Riyadh and Eastern Regions, respectively, while only 21 cases in Al-Baha in 5 years (Figure 5).

Ward clustering grouped the regions into four exploratory clusters: The metropolitan regions of Riyadh, Makkah and the Eastern Region, which had higher proportions of non-Saudi population, wider catchments and low encounter rates; an older or obese group (Al-Baha, Qassim and Asir), which had high need but relatively high PHC staff density; Najran, which had the lowest need; and six regions located near the national average. The need-adjusted Gini coefficients, ecological distributional measures rather than measures of access or staffing adequacy, were 0.24 for physician and encounter ratios, 0.28 for nurse ratios, 0.31 for centre ratio and 0.39 for diabetic encounter ratio. The empirical Bayes shrinkage method reduced the SHINE ratios closer to unity (I^2 = 48.1% for diabetes and 40.1% for hypertension) but did not affect KSAWHS ratios significantly (Figure 6).

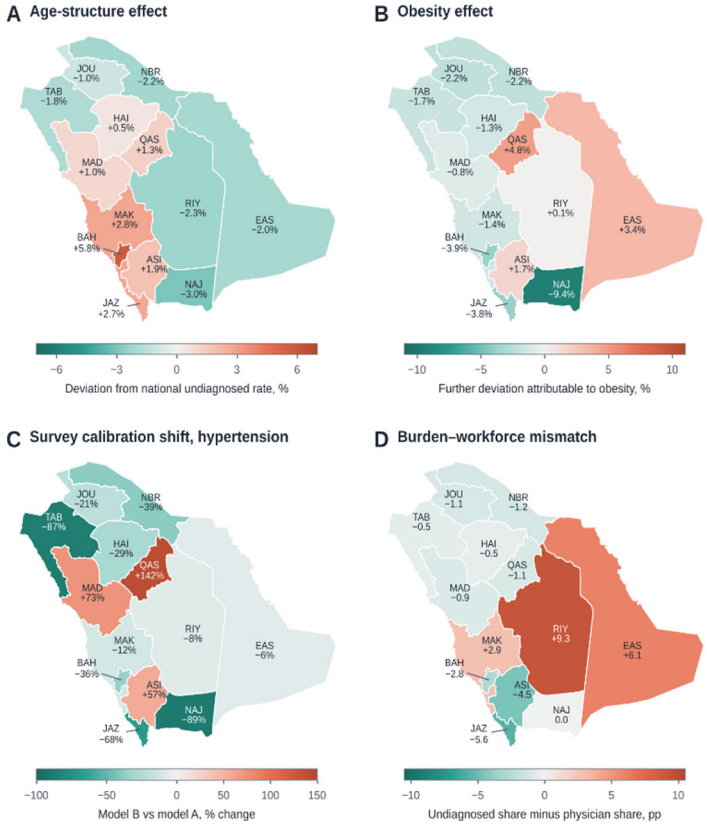


Figure 4: Undiagnosed Diabetes Burden by Regions Decomposition and Calibration and Mismatch between Undiagnosed Burden and Primary Health Care Workforce. (A) The Effect of Age Structure Composition and (B) The Effect of Obesity Composition on the Model A of the Ratio of Undiagnosed Diabetes Plus Hypertension Among Adults 30-79 Years, % Difference from the National Average Rate. (C) Effect of Model B (Survey Calibrated) of Undiagnosed Hypertension Relative To Model A, % Difference; Confidence Intervals for Tabuk, Najran And Jazan Crosses The Zero Line. (D) The Share of Undiagnosed Diabetes Burden by Regions From the National Undiagnosed Burden, Less the Share of PHC Physicians in Ministry of Health, Percent; Positive Values Mean Excess of Undiagnosed Burden over PHC Workforce. Panels A, B and D Based on Model A; Panel C Comparing Model B with Model A. Region Codes: RIY, Riyadh; MAK, Makkah; MAD, Madinah; QAS, Qassim; EAS, Eastern; ASI, Asir; TAB, Tabuk; HAI, Hail; NBR, Northern Borders; JAZ, Jazan; NAJ, Najran; BAH, Al-Baha; JOU, Al-Jouf. Boundaries are provided by geoBoundaries [58]

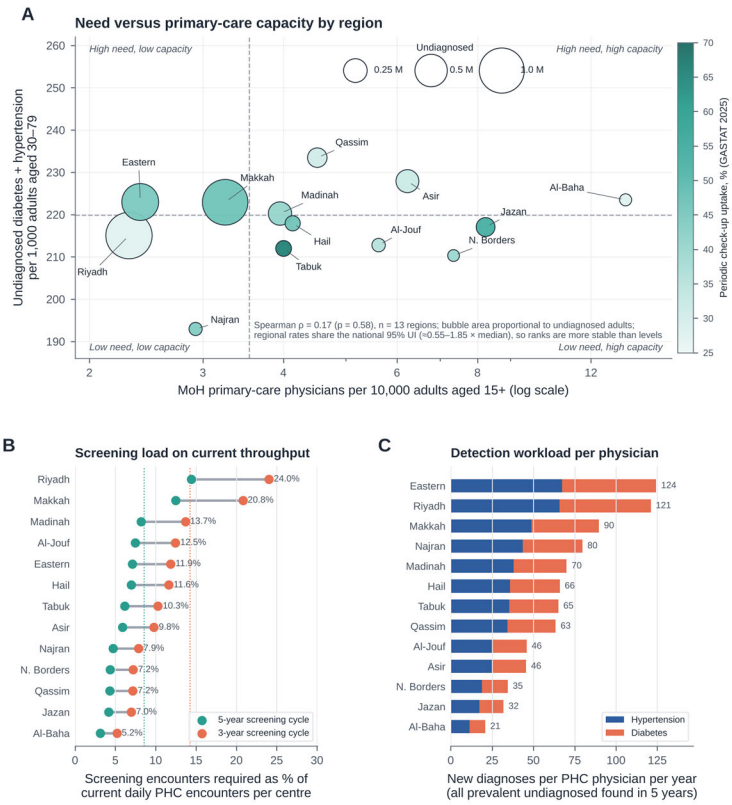


Figure 5: Need Vs Primary Care Capacity and Workload for Closing the Gap. (A) Number of Undiagnosed Cases of Diabetes and Hypertension per 1,000 Persons Aged 30-79 Years (Model A) Versus Number of MOH PHC Physicians per 10,000 Persons (Log Scale); Bubble Size Represents the Number of Undiagnosed Cases, the Color Corresponds to the Periodic Check-Ups Participation Rate and the Dashed Lines at the National Levels Define the Need-Capacity Quadrants. (B) Number of Screening Visits Necessary for Covering All Persons Aged 30-79 Years Once in 5 Years or 3 Years, Calculated as Percentage of Current Daily Visits per Center (250 Days Working Period). (C) Annual New Cases per PHC Physician to Diagnose Prevalent Undiagnosed Cases in 5 years (Table 6 Count Per Physician ÷ 5), Stratified by Disease According to its Medians [24,39]. Burden is Model-Derived (Model A) and Screening Loads Assume Fixed Intervals, Full Attendance and Current Capacity

Table 6: Capacity, Utilisation and Case-Finding Workload Required to Fill the Gap for Regions

A. Capacity and utilisation (Ministry of Health, 2024)

	Infrastructure and workforce					Utilisation			Diabetes services and private sector		
Region	PHC centres, n (Δ Vs 2020, %)	PHC physicians, n (per 10,000 adults)	PHC nurses, n (per 10,000 adults)	Nurse-to-physician ratio	Adults ≥15 y per PHC centre	PHC encounters, ×10³ (per resident)	Δ 2022→2024, %	Encounters per physician-day	Diabetes and endocrine centres, n	Diabetic-clinic encounters, ×10³ (per undiagnosed DM, 30–79 y)	Private medical complexes, n (per 100,000 adults)
Riyadh	404 (−2.7)	1,751 (2.30)	2,674 (3.52)	1.53	18,811	6,838 (0.72)	−14.2	15.6	4	71.3 (0.15)	1,171 (15.4)
Makkah	318 (−5.1)	2,277 (3.25)	2,721 (3.88)	1.19	22,040	7,343 (0.83)	−15.4	12.9	5	142.8 (0.32)	880 (12.6)
Madinah	154 (−1.3)	694 (3.95)	1,569 (8.93)	2.26	11,404	2,693 (1.16)	−11.6	15.5	2	27.5 (0.26)	182 (10.4)
Qassim	156 (0.6)	498 (4.51)	742 (6.73)	1.49	7,072	3,151 (2.17)	−36.4	25.3	3	56.3 (0.81)	146 (13.2)
Eastern	229 (−4.6)	1,059 (2.40)	2,398 (5.43)	2.26	19,280	8,297 (1.47)	17.3	31.3	3	48.2 (0.17)	476 (10.8)
Asir	281 (−11.1)	1,022 (6.23)	1,357 (8.27)	1.33	5,838	3,488 (1.59)	−38.2	13.7	3	107.2 (1.05)	255 (15.5)
Tabuk	85 (−9.6)	280 (4.00)	319 (4.56)	1.14	8,230	1,395 (1.46)	−47.3	19.9	1	16.2 (0.41)	84 (12.0)
Hail	110 (0.0)	249 (4.13)	627 (10.41)	2.52	5,475	1,081 (1.34)	−33.9	17.4	1	13.6 (0.38)	73 (12.1)
Northern Borders	42 (0.0)	207 (7.35)	375 (13.31)	1.81	6,710	785 (1.95)	−13.7	15.2	3	19.6 (1.26)	49 (17.4)
Jazan	174 (3.6)	908 (8.24)	1,601 (14.52)	1.76	6,336	3,205 (2.12)	2.2	14.1	2	53.9 (0.85)	128 (11.6)
Najran	68 (−1.4)	133 (2.92)	449 (9.87)	3.38	6,692	1,163 (1.81)	−29.8	35.0	1	21.4 (0.93)	56 (12.3)
Al-Baha	93 (−1.1)	370 (13.58)	594 (21.80)	1.61	2,930	1,112 (3.03)	−34.8	12.0	1	25.6 (1.52)	49 (18.0)
Al-Jouf	58 (−7.9)	245 (5.62)	710 (16.29)	2.90	7,516	708 (1.11)	−65.1	11.6	2	17.2 (0.70)	58 (13.3)
Saudi Arabia	2,172 (−3.8)	9,693 (3.54)	16,136 (5.89)	1.66	12,603	41,259 (1.17)	−19.2	17.0	31	620.7 (0.37)	3,607 (13.2)

B. Case-finding workload and prioritisation

	Undiagnosed DM + HTN, 30–79 y				Screening load, 3-y/5-y cycle				Prioritisation		
Region	×10³ (95% UI)	Per PHC centre	Per PHC physician	NNS, DM/HTN	Screens per centre-day	Screens per physician-day	New diagnoses per centre-year, 5-y closure	Current PHC encounters per undiagnosed adult	CFPI, z (rank; 95% rank interval)	P(top-3 rank), %	Need–capacity quadrant
Riyadh	1,060.4 (585.1–1,944.1)	2,625	606	9.5/8.1	16.3/9.8	3.76/2.25	525	6.45	1.85 (2; 1–2)	100	Low need/low capacity
Makkah	1,021.7 (547.6–1,900.8)	3,213	449	9.0/7.7	19.2/11.5	2.68/1.61	643	7.19	1.94 (1; 1–3)	100	High need/low capacity
Madinah	243.4 (131.3–450.8)	1,580	351	9.2/7.8	9.6/5.7	2.12/1.27	316	11.07	0.60 (5; 4–6)	0	High need/high capacity
Qassim	158.1 (87.1–290.7)	1,013	317	8.6/7.4	5.8/3.5	1.81/1.09	203	19.93	0.81 (4; 4–5)	0	High need/high capacity
Eastern	658.4 (367.8–1,197.9)	2,875	622	9.1/7.8	17.2/10.3	3.72/2.23	575	12.60	1.52 (3; 2–3)	100	High need/low capacity
Asir	233.2 (126.5–432.4)	830	228	8.8/7.6	4.9/2.9	1.33/0.80	166	14.96	0.42 (6; 5–6)	0	High need/high capacity
Tabuk	91.2 (49.6–168.4)	1,073	326	9.6/8.2	6.8/4.1	2.05/1.23	215	15.29	−0.62 (9; 7–9)	0	Low need/high capacity
Hail	82.1 (44.2–152.7)	747	330	9.3/7.9	4.6/2.7	2.02/1.21	149	13.16	−0.30 (7; 7–9)	0	Low need/high capacity

Table 6: Continued

Region	Undiagnosed DM + HTN, 30–79 y			NNS, DM/HTN	Screening load, 3-y/5-y cycle		New diagnoses per centre-year, 5-y closure	Current PHC encounters per undiagnosed adult	Prioritisation		
	×10³ (95% UI)	Per PHC centre	Per PHC physician		Screens per centre-day	Screens per physician-day			CFPI, z (rank; 95% rank interval)	P(top-3 rank), %	Need–capacity quadrant
Northern Borders	35.7 (19.4–66.2)	851	173	9.7/8.2	5.4/3.2	1.09/0.66	170	21.98	−1.12 (10; 9–12)	0	Low need/high capacity
Jazan	145.3 (76.5–273.7)	835	160	9.3/7.9	5.1/3.1	0.98/0.59	167	22.06	−1.32 (11; 10–12)	0	Low need/high capacity
Najran	53.0 (27.8–99.9)	780	399	10.6/9.0	5.4/3.2	2.75/1.65	156	21.93	−1.53 (12; 10–13)	0	Low need/low capacity
Al-Baha	38.7 (20.1–73.2)	416	105	9.0/7.6	2.5/1.5	0.62/0.37	83	28.74	−1.79 (13; 12–13)	0	High need/high capacity
Al-Jouf	56.3 (30.6–104.1)	971	230	9.6/8.1	6.1/3.6	1.44/0.86	194	12.58	−0.47 (8; 7–9)	0	Low need/high capacity
Saudi Arabia	3,877.3 (2,113.4–7,149.4)	1,785	400	9.2/7.9	10.8/6.5	2.43/1.46	357	10.64	–	–	–

(Abbreviations: CFPI, Case-Finding Pressure Index; DM, Diabetes Mellitus; HTN, Hypertension; NNS, Number Needed to Screen per new diagnosis; PHC, Primary Health Care (Ministry of Health facilities only); Δ, change. Sources: Ministry of Health Statistical Yearbook 2024, tables 2-4, 2-5, 2-14, 2-44, 4-7 and 4-16 [39]; GASTAT Health Status Statistics 2025 [24]; model A estimates (Table 5). The denominator of each parameter is 2024 population figures per capita from Table 1. Workload parameters are calculated assuming annual workdays 250 and one PHC visit per each person 30-79-year-old within a 5-year period. Un-diagnosed patients are defined as median of the estimated undiagnosed cases with diabetes and hypertension using model A; those having both diseases are counted twice to maximise the workload. Panel A shows administrative observed indicators and Panel B modelled planning quantities. CFPI is the difference between the average z-score of the gap (un-diagnosed per 1,000) and workload (5-year cycle), and average z-score of the physician density, nurse density, utilization of check-ups and PHC visits per resident; uncertainty rank and P(top-3) is estimated assuming uncertainty about the need since capacity is not uncertain. Quadrants are used depending on the national average need rate (per 1,000) and physician density (per 10,000), like in Figure 5A. Increase in visits is considered in 2022 instead of 2020 because in the Ministry statistics for 2020, 16.8% of PHC visits are unknown region, and national PHC visits including those of unknown region have declined from 51.1 million in 2022 to 41.3 million in 2024

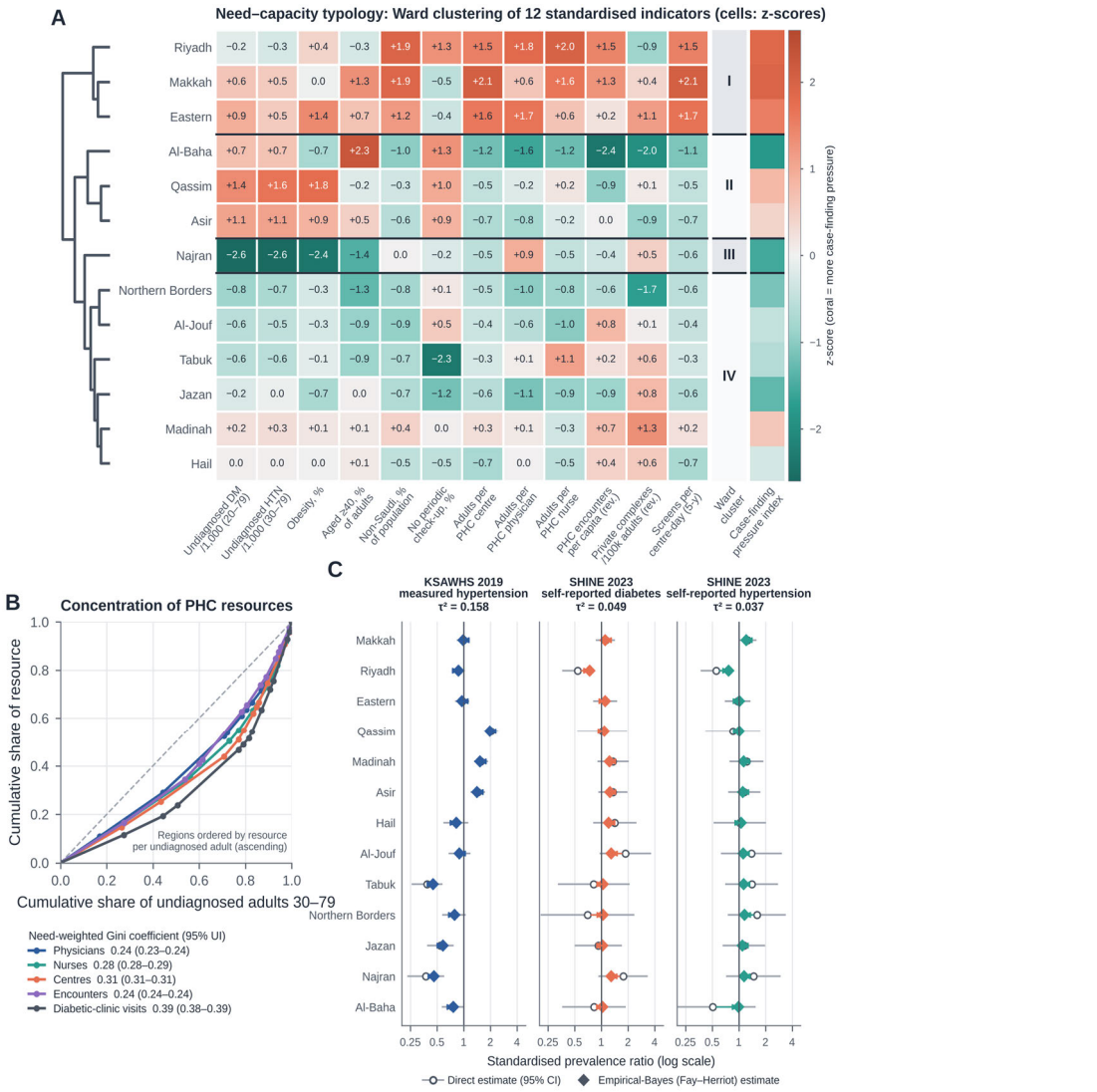


Figure 6: Need-Capacity Classification, Concentration of PHC Resources and Empirical Bayesian Shrinkage of Survey Data. (A) Ward Hierarchical Clustering of the 13 Regions on 12 Standardised Variables (z-Scores Scaled Such that Coral Represents Greater Case-Finding Pressure), along with the Case-Finding Pressure Score on the Far Right Column; Four Clusters Differentiate between the Metro Regions (I), Older and More Obese Regions (II), Najran (III) and Peripheral Regions (IV); Exploratory Analyses based on 13 Regions. (B) Need-Standardised Concentration Curves of PHC Capacity in Relation to the Number of Undiagnosed Adults Aged 30-79 Years, Along with the Gini Coefficient (95% UI). (C) Indirectly Standardised Prevalence Ratio by Region Prior (open circles, 95% CI) and Post (diamonds) Intercept-Only Fay-Herriot Shrinkage of KSAWHS 2019 Measured Hypertension and SHINE 2023 Self-Reported Diabetes and Hypertension

DISCUSSION

Based on the observed findings obtained from this analysis, we find that approximately half of adults in Saudi Arabia living with diabetes and about two-thirds with hypertension in total of 2.06 million and 2.01 million, correspondingly (aged 20-79 and 30-79 years), are undiagnosed. Restricted to the adult population aged 30-79 years, these two diseases add up to 3.9 million estimated number of undiagnosed cases of two diseases combined with overlap counted twice (Table 2). The median value is less precise than the general trends. There is the two-fold difference between single sources, each range is wide and disagreement between sources is systematic rather than random, hence the anchor-based range represents the main result. Measured and survey-based sources (KSAWHS, GASTAT) are consistent with each other and have the smallest estimates compared with modelled sources (IDF, NCD-RisC), which, in their turn, generate higher numbers of diagnosed adults compared with all surveys conducted in Saudi Arabia. Model-based estimates predict the burden of undiagnosed cases in younger adults where diagnosis is rarer (diabetes based on the borrowed age gradient) and in metropolitan areas with the smallest number of MoH PHC physicians per capita; there is disagreement between structural and survey-calibrated regional models in this issue.

The proportion of undiagnosed cases of diabetes (48.2%) falls between 43.6%, which is stated by the IDF for Saudi Arabia [12] and 57.8% of SHIS 2013 [14]; it is quite close to the global estimate of 44.7% [3]. The consensus estimate of 17.2% of adult population aged 20-79 years is lower than the crude (21.4%) and age-adjusted (23.1%) estimates stated by IDF [12] but it coincides with the pooled estimate of 16.4% of studies for 2000-2020 [16] and NCD-RisC estimate of 15.5% of adult population 18 years or older [4]. Analysis of the disagreement helps to understand its source. IDF total and fraction of undiagnosed cases of diabetes imply the number of diagnosed adults aged 20-79 years in total of 3.01 million, 36% higher than the 2.21 million provided by the national survey; the difference between the two denominators is less than 0.5%. The reason may be either that total estimated by the model for the currently younger population is higher since modelled totals are based on older surveys and age-specific extrapolation [2,4] or that households survey underestimates diagnosed cases or both. The lack of the Saudi validation study of self-reported diabetes prevents us from proving either of these assumptions. The same disagreement, i.e., the discrepancy between decreasing age-standardised series in NCD-RisC (20.62% in 2022) and the 2024 IDF anchor (23.1%) was found by AlAnazi [38]. The measurement of glucose or HbA1c from the national examination survey is required to determine the cause of disagreement, or IDF figures should be accepted as an upper bound for planning.

In the case of hypertension, the estimated KSAWHS total, adjusted to 2024 population (16.4% for age range 30-79 years), is slightly more than half of the NCD-RisC estimate of 28.3% [5,19]; the earlier examination surveys found 26.1% and 15.2%, respectively, in 1995-2000 and 2013 [17,18]. Post-test probability of diagnosed hypertension from GASTAT (5.56% in adults aged 30-79 years) is nearly identical to post-test probability implied by measurement and reported awareness from KSAWHS (5.72%); the agreement is consistent with correction but depends on it and is not a separate confirmation of the entire estimate. Self-reporting of diagnosed hypertension includes both false negatives and false positives [28,29]. The false positive rate of 4.1% among normotensive individuals in KSAWHS is especially significant in the case of low-prevalence regions and in the young population. The four times higher discrepancy between SHINE and GASTAT prevalence estimates for 15-29 years can be explained by that. Based on the 2017 GASTAT household survey 9.2% of Saudi nationals 15 years or older have self-reported hypertension, ranging from 6.0% to 10.0% [63], which is consistent with the 2024 estimate of 7.9% for the whole population of the country including the expatriates' younger population. In the contradiction with that evidence from household surveys, the NCD-RisC diagnosed value is much higher and can be considered as an outlier. A possible hypothesis, which, however, requires validation since different methods, age structure and reference years are applied, is that NCD-RisC overestimates prevalence and diagnosis coverage of the currently younger Saudi population, which explains the two times higher estimate of the NCD-RisC anchor.

The age gradient is the potentially most actionable finding, but it is adopted from the model of hypertension for diabetes. The proportion of undiagnosed cases of 73.5-83.5% for hypertension and 50.8-69.8% for diabetes for adults younger than 50 years reveal the largest pools of undiagnosed cases of hypertension and diabetes among working age population when 8-22 adults should be screened for diagnosis of one case of hypertension and fewer than 3 adults at the age of 60 years and above should be screened. Type 2 diabetes, with young onset has the higher lifetime risk of developing complications [64]; hyperglycaemia comes before diagnosis over years [6]. Only a third of adult population younger than 30 years regularly visits the doctor; an estimated proportion of 57.5 and 58.0% of adult population with undiagnosed hypertension and diabetes, respectively, have no check-ups. Men comprising 65.4% of the adult population and 77.2% of non-Saudis [30] check-up less often than women (36.0% versus 45.4%) and are diagnosed less often in NCD-RisC (40.9% versus 54.5%) [5]. Non-Saudi residents are less likely to have check-ups (35.0% versus 44.2%), among adults aged 60 years or older the share of non-Saudi visiting private doctors is 57.9% compared with 21.1% of Saudis [26]; in that case the PHC system of the Ministry of Health alone is not capable of reaching them. At present time the recommended guideline prescribes screening all adults aged 35 years and even earlier, if any risk factors are present (overweight, etc.) with rescreening at least every three years [65,66]; the blood pressure screening is recommended for all adults, every 3-5 years in low-risk individuals under 40 years and annually from 40 years [67]; the workloads from three- and five-year scenario of rescreening correspond diabetes screening and low-risk blood pressure, respectively, while the annual rescreening from 40 years would imply higher workload. In the form of the planning implication of the results of this model, workplaces and private providers of expatriate males can complement PHC screening since this study has not established the effectiveness of any approach.

Case-finding is only effective when complemented with treatment. Screening did not decrease the mortality during 10 years in the ADDITION-Cambridge trial [68]. Community program of blood pressure screening related to the primary care reduced the cardiovascular admissions [69]. Detection of high blood pressure is one of elements of the protocol-based PHC in the WHO HEARTS package [70,71]. Being 47.5% of adults with hypertension untreated, case-finding will only increase the pool of untreated patients. The attainment of the 80% WHO Compact goal of diagnosed diabetes cases [11] would add another 1.21 million adults aged 20-79 years to be diagnosed with diabetes to the currently diagnosed pool of 2.21 million. These detected patients will also need follow-up and starting treatment, which resources the present workload estimation does not cover.

The capacity analysis revealed the imbalance of resources rather than its shortage. Nationally, the screening of every adult aged 30-79 years once in 5 years will increase the PHC centres workload by 6.5 adult cases per day and 8.5% per day in total, which seems to be achievable under the assumptions made in this study. However, the workload is uneven. Under Model A Riyadh, Makkah and Eastern Regions contain 70% of the modelled undiagnosed cases (70.4% for diabetes, 70.7% for hypertension), but 52.5% of PHC physicians in them; they are populated by 18,811-22,040 adults per PHC, have the lowest rates of encounters and need PHC workload increase by 14.4% in Riyadh. The correlation between need and capacity is weak and non-significant for 13 regions, which does not indicate the PHC facilities location independent of need, although the variability of the PHC infrastructure and staff between regions has been described [23]. Diabetic clinic encounters are the most unevenly distributed resource by need (Gini 0.39); it matters since newly diagnosed cases will need follow-up, although the differences in recording and organisation may contribute. The reduction of PHC encounters by 19.2% between 2022 and 2024, which occurred simultaneously with health cluster implementation [20,22], is ecological observation which requires a careful inspection, although if it is caused by a change of reporting procedures, this is harmless, but if it is caused by fewer encounters, this removes opportunities for encountering new cases for screening. The private sector with 3,607 medical complexes and highest density in Riyadh is the natural partner for metropolitan regions.

The regional estimates have to be understood in terms of ranks and underlying factors rather than levels. Model A is consistent within −12% to +6% deviation from the national level since small discrepancies exist between regional age structure and obesity. Model B deviates by two times from the national rate for diabetes and even more than twenty times for hypertension due to huge discrepancy between regional samples in KSAWHS and SHINE. The measured total is smaller than self-reported diagnoses for Tabuk, Jazan and Najran. Empirical-Bayes shrinkage mitigates but does not solve this problem [32,53] and such discrepancy is the argument for collecting regional measured data instead of selecting models. The positive ecological association between obesity and measured hypertension in regions confirms the structural variable obesity usage.

CONCLUSION

It is estimated that 48.2% (95% CI 27.7-69.2) of adults aged 20-79 years with diabetes (2.06 million) and 67.3% (48.1-82.2) of adults aged 30-79 years with hypertension (2.01 million) in Saudi Arabia remain undiagnosed; in the 30-79 age group the two diseases combine to 3.9 million disease cases in total, the same person can be counted twice; size of the gap depends on the selected prevalence estimate; the two approaches to estimation-structural and survey-based and calibrated regional models differ in the gap; under the structural model, most burden is found among working-age adults, men, non-Saudi nationals with low number of check-ups and in Riyadh, Makkah and Eastern regions, where MoH PHC centres and physicians per adult are minimum. According to assumptions made under this study, the screening burden seems feasible for national PHC network in case of focused approach to screening, extending the screening outside PHC and linking it to therapy. A national examination survey to measure glucose, glycated hemoglobin and blood pressure and with appropriate sample size is needed.

Limitations

Diagnosed prevalence is based on self-reported data, validation of self-reported diabetes has not been performed in Saudi Arabia, PPV for hypertension was calculated separately for 2019 KSAWHS participants aged 18 or more and considered the same for any other age groups and years although potentially age-dependent self-reporting error; standard errors have not been provided by GASTAT; design effect equal to 2 is assumed, but it affects the width of intervals to a lesser extent because of predominance of between-estimator uncertainty; household survey might be missing out collective housing facilities residents which are mostly expatriate males. Total prevalence of undiagnosed is estimated for 2019, 2022 and 2024; linear interpolation of the NCD-RisC total prevalence of undiagnosed changed estimates no more than 3%, though secular trend from 2019 cannot be excluded. Uncertainty interval has not been calculated by IDF; equal weights are arbitrary choice and the result is shown in prediction intervals and sensitivity analyses. Age gradient in diabetes prevalence is borrowed from hypertension because the model replicates national consensus, but implies total of 7.5% in 15-29 year-olds which is higher than 4.4% estimate of NCD-RisC in 18-29 year-olds; the first estimate is upper-bound estimate. Modelling did not include age-specific fraction of undiagnosed people for each gender, sex distribution in Figure 1 shows population distribution only. Regional populations were estimated based on 2022 census shares, numbers of screening capacity were restricted only to MoH facilities, check-ups and undiagnosed status were considered

independent variables, adult share of burden for both diseases is double-counted; and ecological associations of 13 regions have limited statistical power. Analysis does not differentiate between under-diagnosis and underreporting; intervals show uncertainty of the model parameters, not structural uncertainty associated with the choice of the model [46]. Consensus estimates can be sensitive to the choice of data sources and models. SHINE has a 17.1% response rate and KSAWHS is 5 years prior to the target year, non-response, selection and temporal biases are possible. Models of regional estimates depend on census allocation, obesity correction, survey calibration, ecological covariates and not on direct measurements of the regional prevalence; CFPI is not validated on screening performance and results; private sector and employer-based health care that can affect accessibility and screening capacity are not included; and study does not calculate number of unique persons with undiagnosed diseases.

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