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Vision Loss in Saudi Arabia, 1990–2023, with Projections to 2050: Demographic Decomposition, Sex Differences and Comparison with Saudi Surveys Using Global Burden of Disease 2023 Estimates

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Abstract **Background:** Since 1990 or before, the population of Saudi Arabia more than doubled and became older; however, the vision loss burden remained not broken down into demographic and epidemiological components, age-standardised according to sex ratio affected by immigration, developed according to development of the country and compared with surveys' prevalence rates. **Methods:** Joinpoint regressions were performed and changes decomposed into contributions of population growth, population ageing and epidemiological change (indirect standardisation, decomposition of Das Gupta) as well as the difference by sex into contributions of age composition and rate difference in 1990–2023 according to Global Burden of Disease (GBD) 2023 vision loss prevalence and YLDs rates and UN World Population Prospects 2024 age distributions and 2022 census. Age standardisation required an assumption of eight age gradients due to lack of age-specific GBD estimates, which were tested across 81 specifications (including all gradients for all years). The exploratory single-country efficiency benchmark, comparisons of GBD estimates with seven other survey results and burden projection until 2050 under two scenarios (10,000 draws of Monte Carlo) were done. **Results:** Total prevalent cases increased by 134.7% (from 632,567 to 1,484,415 or by +15.6% crude rate), while indirectly age-standardised prevalence and YLDs rates decreased by 13.4% and 46.9% respectively. Population growth contributed to the change of the caseload by +112.0% and ageing by +46.0%, while the latter were partially mitigated by the epidemiological change of –23.3% (-57.6 to +10.7% across 81 age gradients specifications, and thus the effect varied greatly); epidemiological change decreased YLDs by 84.5% and had a negative contribution in every single specification. All 18 series of crude rate change since 2019 (+0.79% to 3.23%/yr; all 95% CIs positive) happened due to ageing of the population under the assumptions of the age gradients (2019–2023: ageing+5.6% vs. +0.4% of total change in cases of the same years). Crude female prevalence deficit of 3.0% was mainly composed, and females had excess in the age-standardised cataract prevalence and YLDs rate (female-to-male ratio 1.17 for prevalence and 1.28 for YLDs in 2023, and 1 in none of 81 age gradient specifications). By the exploratory country-level benchmarks, age-standardised YLDs rate exceeded fertility-driven frontier by 25.5% (in 2005) and its best-achieved level only in 2021–2022. Visual impairment detected in two community campaign surveys in Qassim region (prevalence pooled 33.3%) was 7.4 times higher than GBD's overall prevalence, a crude definition cross comparison rather than the underestimate of the burden; while female excess of pooled ratio 1.49 was not found in GBD estimates. At constant 2023 age-standardised rates of prevalence and YLDs, caseload would equal to 3.31 million cases (2.20–5.02 million uncertainty interval) and 153,000 YLDs in 2050; to maintain the caseload per ophthalmologist at 569 cases would require, as scenario calculations show, 5,811 ophthalmologists (4,702 if 2010-2023 trend persisted; 2.2%-3.0% annual growth of practitioners) versus 2,608 in 2023. **Conclusion:** Population growth and population ageing increased prevalence by more than double, while age-standardised prevalence rates dropped by 13.4%. Epidemiological change offset the effect of the demography on YLDs rate but not the effect on the prevalence. Prevalence increase since 2109 and the future doubling of crude cataract rate under ageing of population calls for nationally-representative survey of vision loss with age-standardised definitions.

Key Words Vision Loss, Blindness, Cataract, Global Burden of Disease, Decomposition Analysis, Sex Differences, Frontier Analysis, Projections, Saudi Arabia

INTRODUCTION

Visual impairment is one of the major contributors to the overall burden worldwide. An estimated 43.3 million people were blind, 295 million had moderate/severe, 258 million mild distance and 510 million near vision impairment in 2020 due to uncorrected presbyopia. Females made up 55% of people who were blind or had moderate/severe impairment [1]. Cataract and uncorrected refractive error are the major factors [2,3]. Worse presenting visual acuity than 6/12 raises the risk of death from all causes by 29%, while

moderate/severe impairment and blindness are estimated to cause a loss of annual productivity of $410.7 billion in purchasing power parity value [4]. If there is no acceleration, there will be 61.0 million of blind people and 474 million of people with moderate/severe impairment in 2050 [5]. World Report on vision recommended an integrated people-centred eye care [6], and in May 2021 the Seventy-fourth World Health Assembly has adopted two goals for 2030: 30% improvement in eCataract Surgical Coverage (eCSC) and 40% increase in effective refractive error coverage (eREC) [7]. These two parameters measure access along with the quality of the resulting vision [8], for which the baselines became available in more than 50 countries [9,10].

Saudi Arabia provides a special opportunity to assess the burden in the context of its health care transformation programme. Its resident population almost doubled since 1990 [11,12]. 32.2 million people recorded in 2022 census included 41.6% of immigrants and 61.2% of males, determined by the dominance of immigrant male working-age population [13,14]. Despite being a young population, it is getting older with projected percentage of population over the age of 65 increased from 2.8 in 2023 to 8.2% in 2050 [12]. Age-standardised prevalence of diabetes among the adult population aged 20-79 in 2024 is estimated as 23.1% [15], while the disease found among 19.7% of 50,464 subjects in the country's National Diabetes Registry [16]. Health Sector Transformation Program under the vision of 2030 envisages the redesign of public services in integrated clusters [17,18]. 2,608 ophthalmologists registered as of January 2023 (approximately 81 per million of census residents), including 37.7% of Saudis [19].

There are two evidential streams of the vision loss in Saudi Arabia, which do not overlap. Modelled estimates provided by the Global Burden of Disease (GBD) study showed the prevalence of 8,343.9 and YLDs rate of 464.8 per 100,000 in 2019 as the highest in North Africa and Middle East despite the greatest reduction in prevalence since 1990 and also exceeding that expected for the country's level of development [20]. GBD 2021 analysis demonstrated steady global age-standardised prevalence rate with unchanged DALY rate [21], increasing prevalence of cataract among elderly population [22], declining age-standardised rate of refraction disorders [23] and divergence of the trends under the age of 25 years [24]; while the preprint used univariate time series models for prediction of vision impairment in Gulf Cooperation Council countries till 2024 [25]. The national GBD study has not analysed vision loss in Saudi Arabia [26]. Estimates of prevalence based on RAAB among people aged 50 or older, and presenting prevalence surveys showed 2.6% and 3.3% prevalence of blindness in Taif and Jazan [27,28]; presenting visual impairment prevalence in local communities of Qassim (campaign based) and Dariyah among population aged six years or older from 24.5% to 39.9% [29–31], clinic records [32] and meta-analysis in 2025 with 16.8% prevalence among adults [33]. These estimations cannot be mutually substituted. GBD blindness category contains all severities of distance impairment and near vision loss at all ages, while surveys reported presenting distance impairment, mostly lower than 6/12, and RAAB prevalence of blindness in people aged 50 or older.

A number of unresolved questions exists. What is the proportion of increase in caseload related to population growth and ageing and what is the real trend in the risk? Do the differences between males and females really exist when the sex ratio is determined by migration? Did the country succeed in exploiting its rapid development in lowering burden? What are differences between the modelled and measured prevalence rates, and how ageing will affect the needs in eye-care practitioners? The paper describes GBD 2023 estimates for Saudi Arabia since 1990. The primary objectives are description of the levels and joinpoint trend of prevalence and YLDs rates by cause and sex and attribution of the changes to the population growth, ageing and epidemiological change (with indirect standardisation, assumptions of age gradient being applied). The exploratory objectives are decomposition of the difference between the sexes into age and rate components, benchmark against the achieved country's record and the frontier based on fertility, comparison with surveys and prediction of the burden, ophthalmologist need and mathematics of the eCSC 2030 goal to 2050.

METHODS

Study Design and Data Sources

An ecological secondary analysis of modelled and published aggregate data in line with Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) where relevant [34] was performed. The estimates for the kingdom of Saudi Arabia (Saudi Arabia) accessible from the Global Burden of Disease (GBD) Results tool [11, 35] included the prevalence, YLDs and DALYs for blindness and vision loss, and its child cause cataract, as counts and all-age crude rates per 100,000 with 95% uncertainty intervals (UI) for both sexes combined, females and males, for every year from 1990 to 2023 (2 causes × 3 measures × 3 sex groups × 2 metrics × 34 years = 1,224 records; GBD Results tool accessed 6 October 2026, location Saudi Arabia, all ages). GBD models the vision loss from population-based surveys collated by the Vision Loss Expert Group; the category includes mild, moderate and severe distance vision impairment, blindness and near vision loss caused by all underlying diseases [1,36,37]. GBD 2023 was used as the source since it represents the latest round having a full 1990–2023 series; GBD 2019 and GBD 2021 results were used only to establish the within-round benchmark ratios. DALYs equalled YLDs in all extracted records because according to the GBD cause definitions there are no deaths from blindness and vision loss; it is the feature of blindness/vision loss estimates not of all eye diseases. Glaucoma, refractive disorders, age-related macular degeneration, near vision loss and other forms of vision loss could not be separated in the extract and were thus considered as non-cataract vision loss computed as all vision loss minus cataract; it is possible since

cataract is a child of blindness and vision loss in the GBD hierarchy and these two causes have been extracted with the same criteria. Its 95% UI was estimated with the help of 20,000 Monte Carlo draws of its count assuming that each GBD count follows a two-piece log-normal distribution with the given median and 95% UI; draws for each cause are independent of the other causing a wider interval than for positively correlated causes.

The denominators were the ones in the GBD population (count ÷ rate). The age profile of the population was derived from United Nations World Population Prospects 2024 (WPP 2024) single-year estimates and projections [12] downloaded from the WPP 2024 R package, v. 1.1-3 [38]. Populations in the package are recorded at 31 December; consequently, mid-year populations were computed as the mean of the year-end stocks recreating the official time series (33,264,292 in 2023). The total population numbers from the GBD and WPP 2024 are equal in 2023 but differ before due to the downward revision of the historical population of Saudi Arabia in the WPP 2024 series (10.64 million in 1990 vs 16.25 million in GBD 2023, i.e. a 52.7% difference; 0.8% in 2023). The GBD total was kept to ensure consistency between the GBD counts and rates (population = count ÷ rate), while the WPP was used to supply the missing age profile; combining them means making an assumption about applicability of the WPP age profile to the GBD total, which makes the 1990s age profile, as well as the ageing and epidemiological components in question, uncertain. The census 2022 by nationality, sex and age was used for the analysis of nationals and contribution of migrants, as well as for the survey standardisation. The external data include published GBD 2019 and GBD 2021 results [20, 21], eCSC and eREC estimates [9, 10], WHO targets 2030 [7], the number of ophthalmologists [19] and of physicians and nurses in the Ministry of Health [39-41] and Saudi surveys (Section 2.6). Thus, sources and uses were: GBD 2023 (1990–2023; national all-age counts and rates; primary estimates), WPP 2024 (1990–2050; age profile, projections and TFR), census 2022 (sex–age–nationality profile; sex gap and survey standardisation), published GBD 2019 and GBD 2021 estimates (benchmarks), eCSC and eREC surveys (coverage benchmarks), January 2023 Registry of ophthalmologists count and Ministry of Health yearbooks (workforce), and Saudi surveys of 2012–2025 (triangulation; Table 5).

Levels and Temporal Trends

The annual percentage changes in counts and rates were stated in per cents. The estimated annual percentage change (EAPC) is the result of regression of the natural logarithm of the crude rate on year of observation with 34 observations (that is, EAPC = 100 × (exp[b] − 1) and with t-based 95% confidence intervals (CI) [42]. Joinpoint regression models the continuously piecewise linear curves with joinpoints located on observed years with at least three observations in each segment with at most four joinpoints; the number of joinpoints was chosen based on the Bayesian information criterion (BIC): $BIC(k) = \ln(SSE/n) + 2(k + 1)\ln(n)/n$, where SSE is the residual sum of squares and n = 34 [43, 44]. The annual percentage changes (APCs) and average annual percentage changes (AAPCs) in the 1990–2023, 2013–2023 and 2019–2023 periods given the selected joinpoints and their 95% CIs were calculated with n − 2(k + 1) degrees of freedom [45]; they condition on the selected joinpoints and do not show uncertainty associated with the joinpoint location. YLDs per prevalent case estimate the mean disability weight per case; being affected by the condition mix and corresponding disability weights within the aggregate category as well as severity, it is not a complete estimate of clinical severity.

Indirect Age Standardisation and Decomposition of Change

There are no age-specific or standardised estimates in the extract, so the effect of age was taken into account by the indirect standardisation procedure [46]; it means that the age-adjusted rates obtained are not directly standardised rates, but model-dependent estimates conditional on the age gradients assumed. For the year t, sex s, and cause c the count is computed with $N = P \times E \times SIR$, where P is the GBD population, $E = \Sigma w(a)R(a)$ is the crude rate expected in case of applying the age gradient R(a) to the age shares w(a) of this year and sex, and SIR is the indirectly standardised rate or the age-adjusted level. The WPP age shares were scaled to the sex-specific totals of the GBD population in the primary analysis; in the sensitivity analysis the difference between WPP and GBD totals was allocated to the age profile of non-Saudi residents in census 2022, assuming the discrepancy to be related to migrants, a sensitivity scenario rather than historical migrant population series. The age-adjusted rates are given with the SIR × E formula for the both-sexes population of Saudi Arabia in 2023, so that the crude and adjusted rates coincide in 2023; all vision loss rates are the sum of the two causes. For instance, for the cataract in the both-sexes group the crude rate of 1990 of 485.3 per 100,000 multiplied by E (2023 standard)/E(1990) = 1.605 gives the 1990 age-adjusted rate of 779.1 per 100,000 (Table 1).

The age gradient takes the shape $R(a) = \kappa$ under 40 years old and $\exp \beta(a - 40)$ thereafter. The coefficients κ and β in the age gradient for non-cataract vision loss have been calibrated on the GBD 2021 results in order to provide the maximum number of DALYs in ages 65–69 in 1990 and 2021 [21]. It holds true for β from 0.050 to 0.0625; at each particular β from this range the following inequality holds true for κ from 0.02 to 0.72. The midpoint of this range ($\kappa = 0.37$, $\beta = 0.056$) has been used. Reproduction of the peak age restricts the location of the DALY peak, but does not constrain the slope over 40 and the level under 40 years old. An exponentially increasing or logistic age gradient could not reproduce the ages of the peak prevalence of prevalent cases in 1990 and 2021 (in 1990, the peak was at ages 55-59; in 2021 - at ages 50-54); therefore, the prevalence-specific calibration was impossible, and DALY calibration was thus

applied to the prevalence too; the much smoother age gradient found in the community surveys, although for a different construct, makes the overstatement of the ageing component of prevalent cases doubtful. The cause cataract has been assigned with the steeper age gradient (κ = 0.05, β = 0.08, which corresponds to the doubling of the rate every 8.7 years since the age of 40) – it is an analyst-made assumption consistent with the predominance of the disease among older adults [22]. In the sensitivity analysis three values have been chosen for each coefficient for each cause (cataract κ = 0.01, 0.05 and 0.20, β = 0.06, 0.08 and 0.10; non-cataract κ = 0.05, 0.37 and 1.0, β = 0.03, 0.056 and 0.08); 81 gradient specifications have been obtained. Values outside the calibrated non-cataract range (β = 0.03 and 0.08; κ = 1.0) are stress tests; specifications are not equally realistic, but have been used with equal probabilities in the projection simulations.

Change between the two years has been decomposed with the help of Das Gupta's three-factor method into population growth (P), population ageing (E) and epidemiological change (SIR); the method is exact and symmetrical [47, 48]. The effect of P is ΔP × (E1 SIR1 + E2 SIR2)/3 + (E1 SIR2 + E2 SIR1)/6; the analogous formulae are for the effect of E and SIR. Their sum equals the change; this approach is widespread in separating demographic and epidemiological components of the GBD trends [49]. Decompositions have been calculated for 1990–2023, as well as for 1990–2000, 2000–2010, 2010–2019 and 2019–2023, and yearly; annual contributions were added up to produce the path of change and therefore chained total decomposition differs from exact endpoint one, whose components add up to the net change, for up to 7 percentage points of the 1990-level burden (Figure 2). As there are no GBD draws, the 81 gradient specification range is reported as a sensitivity range for the ageing and epidemiological components, but not as a 95% uncertainty interval; both components depend on assumed gradients.

Sex-Gap Analysis

The crude and age-adjusted female-to-male (F:M) rate ratios have been calculated every year; age adjustment means taking into account the gradient assumptions made. Crude female–male difference has been decomposed [50] into the age composition part (EF− EM) (SIRF + SIRM)/2, and the rate part (SIRF − SIRM)(EF + EM)/2; the latter two add up to the crude difference. The excess female cases are defined as the observed number of female cases minus the number of male cases under the male crude rate (crude basis) or male age adjusted rate (adjusted basis); negative values indicate excess of male cases. Time trends in the F:M ratios have been summarised by the EAPCs. In order to show the impact of the nationality factor on the crude comparison, the expected-rate indices have been computed for Saudi and non-Saudi males and females using the age profile in the census 2022 [14] under the primary age gradients, relative to the total population; using 2022 profile is an approximation unable to restore the 1990–2023 sex and nationality composition and any nationality-specific disease estimates have not been used.

Frontier-Efficiency Analysis and Benchmarking

The standard GBD-based frontier analysis assesses the country's burden in light of the lowest burden reached among 204 countries and territories at the same level of its Socio-demographic Index (SDI) in GBD 2023 SDI series [51,52]. The cross-national series being neither in GBD 2023 SDI series nor in the extract, two single-country benchmarks were constructed for exploratory purposes: they cannot be taken for a substitute of the cross-country SDI frontier. The first benchmark of intertemporal best-practice frontier is the lowest age-adjusted prevalence observed up to year t; the efficiency indicator is the ratio of the frontier value to the age-adjusted rate and amounts to 1 on the frontier; this indicator reacts to transient minima, to modelled estimates revisions and to the assumptions of gradients. The second benchmark is a regression of the age-adjusted prevalence on the total fertility rate (TFR) from WPP 2024 as a proxy of the fertility SDI index component excluding income and education [53]. The frontier curve is obtained in the 10th centile of quantile regressions; the curve of expected rate of development, in the median quantile. The frontier gap is calculated as a ratio of the observed prevalence to the frontier minus 1. For benchmarking purposes, age-standardised prevalence estimates of GBD 2019 [20] for Saudi Arabia, Oman, Kuwait and North Africa and the Middle East, and of GBD 2021 [21] for the world, high SDI and the region were retrieved. The differences in levels between different GBD rounds render comparison of estimates of the same round only interpretable; the number of YLDs preventable at another comparator rate is (1-1/ratio) × the number of 2023 Saudi YLDs, that is a mathematical scenario of a counterfact rather than estimation of the impact of a hypothetical intervention.

Evidence Triangulation Using Saudi Survey Results

GBD estimates were compared to measurements from two community campaign surveys of rural Qassim (Duhknah, N=929, aged 6-90; Qbah, N=587, aged 6-80) [30,31], from one community survey of Dariyah [29], from patient records of 385 patients from Qassim University Medical City (QUMC) [32], from RAAB surveys of people aged 50 years or above in Taif and Jazan [27,28] and from a meta-analysis of nine studies of the 2025 systematic review [33]. Proportions were re-calculated with Wilson Score 95% confidence interval [55] and ratios with Katz log-scale confidence interval [56]. Pooled estimates were calculated for proportions and ratios with the DerSimonian-Laird random-effect method on the logit and log scales respectively, with heterogeneity measured by the I2-statistic [57]: each pool includes two studies only (Duhknah and Qbah, Taif and Jazan), hence between-studies variance is poorly estimated. Published study frequencies were used without survey weights and without corrections for survey design, not being available. Patient record prevalence of QUMC was not pooled with community survey prevalences, but included in the meta-analysis, and may have been included in some of the analysed surveys. Age-band

prevalences in two surveys conducted in Qassim (6-10, 11-17, 18-39, 40-49, 50-59, 60+ years) [30,31] are directly age-standardised to Saudi Arabia's age structure in 2024 (WPP 2024) and to the age structure of its nationals in 2022 (population census). The ratios of survey estimates to the crude all-age estimate of GBD reflect discordance but not bias: GBD accounts for all severities throughout life, including near vision loss, whereas in community events and clinics in survey prevalences are measured at presenting distance acuity worse than 6/12.

Projections, Health Workforce Requirements and Cataract Surgical Coverage (CSCE)

Prevalent cases and YLDs were projected from 2023 to 2050 by cause and by sex using $N(t) = N(2023) \times \{P(t)/P(2023)\} \times [\{E(t)/E(2023)\} \times \{SIR(t)/SIR(2023)\}$. The population is extrapolated from the base of GBD 2023 at the medium variant rate in WPP 2024, and E(t) is derived from single-age population projection of WPP 2024. Both scenarios constitute conditional rather than forecast projections. In scenario S1, 2023 age-adjusted rates remained constant, thus separating demographic effects; in scenario S2, the log-linear trend in SIR observed in 2010-2023, that is 14 most recent years, was continued for each particular combination of sex-, cause- and measures specificities; other trend timeframes were not considered. The uncertainty was propagated using Monte Carlo simulation by 10,000 draws of GBD 2023 level uncertainty (a two-piece log-normal distribution) by a randomly selected specification of one of 81 combinations of gradients, by slope's SE and by WPP 2024 probabilistic 95% interval for total population. Projections are based on central values of the primary gradients and inputs, while the 95% uncertainty interval (UI) represents 2.5th and 97.5th percentiles of draws. WPP low- and high-fertility scenarios are applied for deterministic sensitivity analyses. The age structure independent naïve comparator for projections is an autoregressive integrated moving average (ARIMA (1,1,0)) with the drift, fitted to the logarithm of the crude rate [59]. Neither scenarios nor their comparators have been externally validated. Structural uncertainties not represented by the grid of 81 gradient specifications are not included in the interval, the heterogeneity in GBD estimates of different sex- and causes-specificity (not representable without draws), and future changes in prevention, treatment, technology or service delivery.

Ophthalmologists' numbers needed for maintenance till 2050 of the 2023 ratio of prevalent cases per one ophthalmologist (569; based on the number of 2,608 ophthalmologists who have registered with the Saudi Commission for Health Specialties in January 2023 [19]), or per person, with the implied compound annual growth rate (CAGR), are calculated. Both calculations should be interpreted as scenarios and not as the requirements for the staff; the caseload ratio takes no account of the severity, case mix, working hours and productivity of ophthalmologists, their geographical location, and shared tasks with optometrists. As to the requirement in extra surgeries needed to attain the target of effective cataract surgical coverage (eCSC), the population in need of cataract surgeries is calculated by dividing the 2030 vision loss projections from cataract in scenario S1 by (1 - baseline eCSC). The target is taken to mean that the 0.30 multiple of that population is additionally operated and reaches the good visual result. This arithmetic of the projected workload means taking the projections of cataract vision loss as unmet need, and the good outcome rate requirement as quality component of eCSC; not being a backlogged workload estimate, such an estimate would require population-based data on cataract-induced disability, surgical eligibility, previously performed surgeries and their outcomes. Since there is no national estimate of effective coverage for Saudi Arabia, the baseline was changed from 45.0% to 70.0%: the median of eCSC in high-income countries [9] is 60.5%. Thus, the +30% target implies elimination of residual cataract vision loss, at 70.0%.

Software, Verification, Ethics

Analyses have been done in Python 3.13, using libraries numpy, scipy, pandas, statsmodels, and matplotlib [60-64], with the fixed random seed (20261006). Eighteen tests automatically verified the values from the extract, the equality of DALYs and YLDs, the consistency of the populations, the additivity of each decomposition, the recalculation of survey statistics and pooled estimates, the anchoring of the projections to the year 2023 and WPP totals. Aggregate data only were used; therefore, the approval of an ethics committee and informed consent were not required. Data and software availability: GBD 2023, WPP 2024, census, workforce, survey data are available from the cited sources (access dates are mentioned in the references); extraction log, dataset derivatives, the analysis code and results of the 18 tests are available upon reasonable request.

RESULTS

Levels and Temporal Trends, 1990–2023

The number of prevalent cases of vision loss grew by 134.7% (1,484,415 {95% UI 1,332,684–1,693,179} vs 632,567 {566,351–706,486}) and crude prevalence rate by 15.6% to 4,499.8/100,000 (4,039.9–5,132.7). The number of YLDs was 46.5% higher (67,354 [48,062–93,210]), and the YLD crude rate was 27.9% lower (204.2/100,000), so the increase in cases is explained by growth of the population and its aging, but not increasing age-adjusted rates. The age-adjusted prevalence rate declined by 13.4% (from 5,193.3 to 4,499.8/100,000) and the age-adjusted YLD rate by 46.9% (from 384.7 to 204.2/100,000). The number of cataract cases grew by 68.1% (132,573), whereas the number of YLDs related to cataract dropped by 5.3% (8,965), and the YLD rate was lower by 70.9%. The proportion of vision loss caused by cataract fell from 12.5% to 8.9% among all prevalent cases, and from 20.6% to 13.3% among all YLDs. Prevalent cases increased more among men than among women (156.8% vs 105.4%), as well as YLDs (59.4% vs 29.9%) (Table 1).

Table 1: Vision Loss Burden in Saudi Arabia by Cause and Gender from 1990 to 2023: Magnitude, Uncertainty and Temporal Trends

A. Counts, crude rates per 100,000 and age-adjusted rates											
		Count (95% UI)			Crude rate per 100,000						
Cause	Sex	1990	2023	Δ 1990–2023, %	1990 (95% UI)	2010	2019	2023 (95% UI)	Δ 1990–2023, %	Δ 2019–2023, %	Age-adjusted rate, 1990 → 2023 (Δ%)
Prevalence											
All vision loss	Both	632,567 (566,351–706,486)	1,484,415 (1,332,684–1,693,179)	+134.7	3,893.0 (3,485.5–4,347.9)	4,215.0	4,246.2	4,499.8 (4,039.9–5,132.7)	+15.6	+6.0	5,193.3 → 4,499.8 (−13.4)
	Female	272,700 (242,995–306,801)	560,171 (502,003–632,805)	+105.4	3,805.3 (3,390.8–4,281.2)	4,119.9	4,215.3	4,415.9 (3,957.3–4,988.5)	+16.0	+4.8	4,986.8 → 4,470.8 (−10.3)
	Male	359,867 (320,401–400,300)	924,244 (826,543–1,058,574)	+156.8	3,962.2 (3,527.6–4,407.3)	4,287.6	4,266.8	4,552.3 (4,071.1–5,213.9)	+14.9	+6.7	5,359.8 → 4,516.2 (−15.7)
Cataract	Both	78,851 (65,622–91,757)	132,573 (112,456–155,034)	+68.1	485.3 (403.9–564.7)	384.9	362.2	401.9 (340.9–470.0)	−17.2	+10.9	779.1 → 401.9 (−48.4)
	Female	37,206 (30,651–43,830)	56,980 (48,082–66,676)	+53.1	519.2 (427.7–611.6)	408.4	405.3	449.2 (379.0–525.6)	−13.5	+10.8	789.9 → 441.3 (−44.1)
	Male	41,645 (34,983–48,357)	75,593 (64,250–89,309)	+81.5	458.5 (385.2–532.4)	367.0	333.6	372.3 (316.5–439.9)	−18.8	+11.6	769.7 → 376.5 (−51.1)
Non-cataract	Both	553,716 (486,052–628,781)	1,351,842 (1,198,780–1,561,356)	+144.1	3,407.7 (2,991.3–3,869.7)	3,830.1	3,884.0	4,098.0 (3,634.0–4,733.1)	+20.3	+5.5	4,414.2 → 4,098.0 (−7.2)
	Female	235,494 (205,313–270,209)	503,191 (444,546–576,106)	+113.7	3,286.1 (2,865.0–3,770.6)	3,711.5	3,810.0	3,966.7 (3,504.4–4,541.5)	+20.7	+4.1	4,196.9 → 4,029.5 (−4.0)
	Male	318,222 (278,863–359,512)	848,651 (750,367–984,320)	+166.7	3,503.6 (3,070.3–3,958.2)	3,920.6	3,933.2	4,180.0 (3,695.9–4,848.2)	+19.3	+6.3	4,590.1 → 4,139.6 (−9.8)
Years lived with disability											
All vision loss	Both	45,986 (32,440–62,157)	67,354 (48,062–93,210)	+46.5	283.0 (199.6–382.5)	218.4	196.9	204.2 (145.7–282.6)	−27.9	+3.7	384.7 → 204.2 (−46.9)
	Female	20,197 (14,325–27,230)	26,236 (18,805–36,079)	+29.9	281.8 (199.9–380.0)	217.0	199.5	206.8 (148.2–284.4)	−26.6	+3.7	375.2 → 209.0 (−44.3)
	Male	25,789 (18,120–34,840)	41,118 (29,224–56,582)	+59.4	283.9 (199.5–383.6)	219.5	195.2	202.5 (143.9–278.7)	−28.7	+3.8	392.3 → 201.1 (−48.7)
Cataract	Both	9,467 (6,535–12,982)	8,965 (6,227–12,525)	−5.3	58.3 (40.2–79.9)	31.7	25.7	27.2 (18.9–38.0)	−53.4	+5.6	93.5 → 27.2 (−70.9)
	Female	4,473 (3,078–6,213)	4,040 (2,797–5,574)	−9.7	62.4 (42.9–86.7)	34.6	29.8	31.8 (22.1–43.9)	−49.0	+6.9	95.0 → 31.3 (−67.1)
	Male	4,994 (3,424–6,805)	4,925 (3,394–6,932)	−1.4	55.0 (37.7–74.9)	29.5	23.0	24.3 (16.7–34.1)	−55.9	+5.3	92.3 → 24.5 (−73.4)
Non-cataract	Both	36,520 (22,625–53,062)	58,390 (39,103–84,356)	+59.9	224.8 (139.2–326.6)	186.7	171.2	177.0 (118.5–255.7)	−21.2	+3.4	291.1 → 177.0 (−39.2)
	Female	15,724 (9,558–22,827)	22,196 (14,584–31,969)	+41.2	219.4 (133.4–318.5)	182.4	169.7	175.0 (115.0–252.0)	−20.3	+3.1	280.2 → 177.7 (−36.6)
	Male	20,795 (13,052–29,875)	36,193 (23,972–51,563)	+74.0	229.0 (143.7–328.9)	190.0	172.2	178.3 (118.1–254.0)	−22.1	+3.6	300.0 → 176.5 (−41.1)

B. Trend statistics, joinpoint segments, severity per case and cause share								
Cause	Sex	EAPC, 1990–2023, % (95% CI)	AAPC, % (95% CI)			Joinpoint segments: APC, %	YLDs per prevalent case, 1990 → 2023	Share of all vision loss, 1990 → 2023, %
			1990–2023	2013–2023	2019–2023			
Prevalence								
All vision loss	Both	0.38 (0.30 to 0.47)	0.42 (0.39 to 0.45)	0.66 (0.58 to 0.74)	1.10 (0.97 to 1.22)	1990–94: −0.28*; 1994–01: 0.73*; 2001–04: 2.24*; 2004–16: −0.36*; 2016–23: 1.10*	0.0727 → 0.0454	100 → 100
	Female	0.40 (0.32 to 0.48)	0.47 (0.44 to 0.50)	0.77 (0.69 to 0.84)	1.30 (1.06 to 1.54)	1990–95: −0.07; 1995–05: 1.19*; 2005–12: −0.59*; 2012–19: 0.41*; 2019–23: 1.30*	0.0741 → 0.0468	100 → 100
	Male	0.36 (0.27 to 0.45)	0.46 (0.43 to 0.49	0.79 (0.70 to 0.88)	1.66 (1.39 to 1.92)	1990–99: 0.13*; 1999–05: 1.74*; 2005–14: −0.53*; 2014–20: 0.37*; 2020–23: 2.09*	0.0717 → 0.0445	100 → 100
Cataract	Both	−0.76 (−0.93 to −0.59)	−0.51 (−0.58 to −0.45)	1.04 (0.87 to 1.22)	3.05 (2.51 to 3.59)	1990–96: −2.12*; 1996–05: 0.57*; 2005–12: −2.73*; 2012–19: −0.27*; 2019–23: 3.05*	0.1201 → 0.0676	12.5 → 8.9
	Female	−0.70 (−0.90 to −0.50)	−0.41 (−0.47 to −0.36)	1.31 (1.16 to 1.46)	2.60 (2.21 to 2.98)	1990–95: −2.11*; 1995–05: 0.59*; 2005–11: −3.61*; 2011–18: 0.04; 2018–23: 2.60*	0.1202 → 0.0709	13.6 → 10.2
	Male	−0.75 (−0.91 to −0.60)	−0.56 (−0.63 to −0.50)	0.88 (0.68 to 1.08)	3.23 (2.61 to 3.86)	1990–97: −2.24*; 1997–05: 0.68*; 2005–13: −2.09*; 2013–19: −0.66*; 2019–23: 3.23*	0.1199 → 0.0652	11.6 → 8.2

Table 1: Continued

Cause	Sex	EAPC, 1990–2023, % (95% CI)	AAPC, % (95% CI) 1990–2023	2013–2023	2019–2023	Joinpoint segments: APC, %	YLDs per prevalent case, 1990 → 2023	Share of all vision loss, 1990 → 2023, %
B. Trend statistics, joinpoint segments, severity per case and cause share								
Non-cataract	Both	0.51 (0.43 to 0.59)	0.55 (0.53 to 0.58)	0.65 (0.59 to 0.72)	1.18 (1.06 to 1.31)	1990–94: 0.06; 1994–01: 0.85*; 2001–04: 2.27*; 2004–17: –0.13*; 2017–23: 1.18*	0.0660 → 0.0432	87.5 → 91.1
	Female	0.54 (0.47 to 0.62)	0.56 (0.54 to 0.58)	0.63 (0.58 to 0.68)	0.81 (0.74 to 0.89)	1990–93: –0.02; 1993–00: 0.92*; 2000–04: 1.76*; 2004–15: –0.11*; 2015–23: 0.81*	0.0668 → 0.0441	86.4 → 89.8
	Male	0.48 (0.39 to 0.57)	0.56 (0.54 to 0.59)	0.78 (0.70 to 0.86)	1.55 (1.32 to 1.77)	1990–99: 0.35*; 1999–05: 1.79*; 2005–14: –0.38*; 2014–20: 0.40*; 2020–23: 1.93*	0.0653 → 0.0426	88.4 → 91.8
Years lived with disability								
All vision loss	Both	−1.15 (−1.25 to −1.06)	−0.97 (−0.99 to −0.94)	−0.01 (−0.08 to 0.07)	0.99 (0.78 to 1.20)	1990–94: −1.94*; 1994–05: −0.59*; 2005–13: −2.18*; 2013–20: −0.67*; 2020–23: 1.55*	0.0727 → 0.0454	100 → 100
	Female	−1.14 (−1.24 to −1.03)	−0.92 (−0.94 to −0.90)	0.14 (0.08 to 0.21)	0.97 (0.79 to 1.15)	1990–94: −1.69*; 1994–04: −0.52*; 2004–13: −2.18*; 2013–20: −0.41*; 2020–23: 1.44*	0.0741 → 0.0468	100 → 100
	Male	−1.16 (−1.25 to −1.07)	−0.98 (−1.02 to −0.95)	−0.11 (−0.21 to −0.02)	1.02 (0.75 to 1.28)	1990–96: −1.72*; 1996–05: −0.43*; 2005–13: −2.13*; 2013–20: −0.86*; 2020–23: 1.65*	0.0717 → 0.0445	100 → 100
Cataract	Both	−2.58 (−2.77 to −2.40)	−2.25 (−2.29 to −2.21)	−0.31 (−0.41 to −0.20)	1.73 (1.38 to 2.07)	1990–94: −4.34*; 1994–03: −1.67*; 2003–14: −3.84*; 2014–19: −1.19*; 2019–23: 1.73*	0.1201 → 0.0676	20.6 → 13.3
	Female	−2.39 (−2.62 to −2.16)	−2.00 (−2.04 to −1.95)	0.41 (0.28 to 0.54)	1.75 (1.42 to 2.07)	1990–94: −4.02*; 1994–03: −1.25*; 2003–13: −4.19*; 2013–18: −0.91*; 2018–23: 1.75*	0.1202 → 0.0709	22.1 → 15.4
	Male	−2.68 (−2.84 to −2.52)	−2.41 (−2.45 to −2.38)	−0.65 (−0.74 to −0.56)	1.67 (1.36 to 1.98)	1990–94: −4.52*; 1994–05: −2.24*; 2005–14: −3.75*; 2014–19: −1.85*; 2019–23: 1.67*	0.1199 → 0.0652	19.4 → 12.0
Non-cataract	Both	−0.88 (−0.96 to −0.79)	−0.70 (−0.72 to −0.67)	−0.05 (−0.12 to 0.02)	0.93 (0.73 to 1.14)	1990–96: −1.06*; 1996–05: −0.20*; 2005–12: −1.93*; 2012–20: −0.70*; 2020–23: 1.48*	0.0660 → 0.0432	79.4 → 86.7
	Female	−0.86 (−0.95 to −0.78)	−0.68 (−0.70 to −0.66)	0.06 (0.01 to 0.11)	0.79 (0.65 to 0.94)	1990–94: −1.11*; 1994–04: −0.28*; 2004–13: −1.73*; 2013–20: −0.43*; 2020–23: 1.21*	0.0668 → 0.0441	77.9 → 84.6
	Male	−0.89 (−0.98 to −0.80)	−0.72 (−0.75 to −0.69)	−0.06 (−0.15 to 0.03)	0.94 (0.70 to 1.19)	1990–98: −1.03*; 1998–05: 0.04; 2005–13: −1.89*; 2013–20: −0.72*; 2020–23: 1.50*	0.0653 → 0.0426	80.6 → 88.0

Abbreviations: AAPC: Average Annual Percentage Change, APC: annual percentage change, CI: confidence interval, EAPC: estimated annual percentage change, GBD: Global Burden of Disease, UI: uncertainty interval, YLD: years lived with disability. Crude all-age rates per 100:000, YLDs equal disability-adjusted life-years for vision loss in every record of the extract (GBD attributes no deaths to vision loss). Non-cataract = all vision loss – cataract (glaucoma, refraction disorders, age-related macular degeneration, presbyopia and other vision loss combined), its UIs are derived from 20,000 Monte Carlo draws of the two-piece log-normal marginals assuming independence. EAPC from ordinary least squares regression of ln(rate) on year using 34 annual observations [42]. Joinpoint: piecewise log-linear regression with up to four joinpoints, at least three observations in each segment and number of joinpoints selected by the Bayesian information criterion [43,44], joinpoint years are inclusive at both ends, *APC $p < 0.05$. AAPC conditional on the selected joinpoints [45]. Rates adjusted for age are indirectly standardized to the 2023 Saudi Arabia population using assumed reference age gradients (Section 2.3), they are derived, model-dependent estimates, not directly standardised rates. YLDs per prevalent case = mean disability weight per case. Source: GBD 2023 [11].

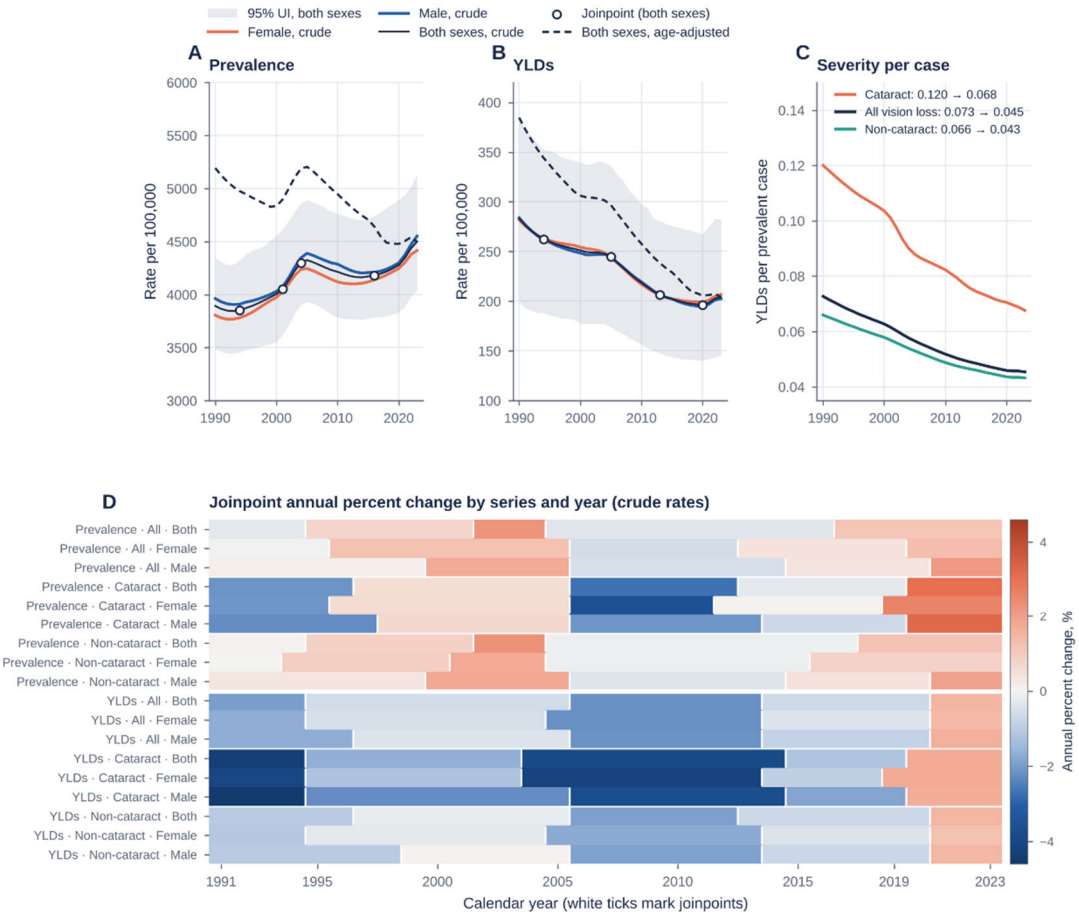


Figure 1: Temporal Structure of the Burden of Vision Loss in Saudi Arabia, 1990-2023

(A) Crude prevalence per 100,000 females and males, crude incidence rates for both genders with 95% confidence intervals and joinpoints, and age-adjusted rates for both genders; (B) the above for the years lived with disability (YLDs); (C) The years lived with disability per prevalent cases, disability weight, among all vision loss, cataracts and non-cataract vision loss; (D) Annual percentage changes per joinpoint analysis for every one of all 18 time series in every year (crude rates), where white tick marks indicate the joinpoints, blue coloration indicates a decrease, and corals indicate an increase. Data source: GBD 2023 [1]; crude rates are from GBD while age adjusted rates are through indirect standardization with age effects (Table 2)

The crude annual prevalence rate of all causes increased by 0.38% annually (the estimated annual percentage change (EAPC); 95% CI 0.30 to 0.47), while the YLD crude rate decreased annually by 1.15% (−1.25 to −1.06). The sharpest declines took place in the cases when YLDs were related to cataract (−2.58%, −2.77 to −2.40 in both sexes; −2.68% in males). For every series the permitted maximum of four joinpoints was selected, so the segments describe the shape of the modelled GBD series, but not independently substantiated structural breaks. Crude prevalence rose the fastest during the period 2001-2004 (annual percentage change (APC) 2.24%) and was decreasing during the period 2004-2016 (−0.36%), while the crude YLD rate was declining in all segments except that ending in 2020; the biggest decrease in YLD rate took place in 2005-2013 (−2.18%). Each of the studied series included positively growing APC ($p < 0.05$, conditional on the selected joinpoints) in its last segment despite small number (4-9) of annual observations. The average annual percentage changes (AAPC) during 2019-2023 for studied indicators varied between 0.79% (non-cataract YLDs among females) and 3.23% (cataract prevalence among males), with 95% CI higher than zero for each indicator, whereas for all YLDs (2013-2023) it was −0.01% (−0.08 to 0.07). The YLDs per prevalent case decreased 38% (from 0.073 to 0.045) and among cataract patients – 44% (from 0.120 to 0.068), explaining the bigger decrease of YLD rates compared to that of prevalence rates. Since this ratio summarises the severity of all causes and disability weights, its decrease can be caused by changes in cause structure and GBD disability weights, besides in severity.

Figure 1 presents the annual trajectories underlying these estimates, including the severity index and the joinpoint segments of all 18 series.

Population Growth, Population Ageing and Epidemiological Change

While from 1990 to 2023 population growth would account for 708,431 prevalent cases (112.0% of the 1990 burden) and population ageing for 290,742 additional cases (46.0%), epidemiological change would bring about 147,325 fewer cases (-23.3%), with the demography exceeding the net

Table 2: Contribution of the Total Change in the Prevalence and YLDs to Population Growth, Population Ageing and Epidemiological Changes, 1990–2023

A. Whole period, by Cause And Sex, with Sensitivity to the Age Gradient and to the Source of Age Structure										
		Count			Contribution, n (% of 1990)			Sensitivity, % of 1990		
Cause	Sex	1990	2023	Net change, N (% of 1990)	Population Growth	Population Ageing	Epidemiological Change	Ageing: Range Over 81 Gradients	Epidemiological: Range Over 81 Gradients	Migrant-Allocated Structure: Ageing / Epidemiological
Prevalence										
All vision loss	Both	632,567	1,484,415	851,848 (+134.7)	708,431 (+112.0)	290,742 (+46.0)	−147,325 (−23.3)	+12.7 to +78.2	−57.6 to +10.7	+33.0 / −9.7
	Female	272,700	560,171	287,471 (+105.4)	228,336 (+83.7)	103,533 (+38.0)	−44,398 (−16.3)	+10.8 to +66.8	−46.4 to +11.2	+32.2 / −10.3
	Male	359,867	924,244	564,377 (+156.8)	482,635 (+134.1)	188,665 (+52.4)	−106,923 (−29.7)	+14.1 to +88.9	−69.1 to +9.6	+33.1 / −9.4
Cataract	Both	78,851	132,573	53,722 (+68.1)	78,221 (+99.2)	52,841 (+67.0)	−77,340 (−98.1)	+48.8 to +73.4	−105.3 to −77.8	+49.6 / −78.7
	Female	37,206	56,980	19,774 (+53.1)	27,879 (+74.9)	21,460 (+57.7)	−29,566 (−79.5)	+40.4 to +66.4	−89.0 to −60.7	+50.3 / −71.5
	Male	41,645	75,593	33,948 (+81.5)	49,501 (+118.9)	31,655 (+76.0)	−47,209 (−113.4)	+55.8 to +82.1	−120.3 to −90.4	+49.3 / −83.2
Non-cataract	Both	553,716	1,351,842	798,126 (+144.1)	630,211 (+113.8)	237,900 (+43.0)	−69,985 (−12.6)	+7.5 to +78.9	−50.8 to +23.3	+30.6 / +0.1
	Female	235,494	503,191	267,697 (+113.7)	200,457 (+85.1)	82,073 (+34.9)	−14,832 (−6.3)	+6.2 to +66.8	−39.7 to +22.6	+29.3 / −0.6
	Male	318,222	848,651	530,429 (+166.7)	433,134 (+136.1)	157,010 (+49.3)	−59,714 (−18.8)	+8.7 to +89.8	−62.4 to +22.7	+31.0 / +0.2
Years lived with disability										
All vision loss	Both	45,986	67,354	21,368 (+46.5)	42,200 (+91.8)	18,031 (+39.2)	−38,863 (−84.5)	+13.0 to +64.8	−112.9 to −56.3	+28.0 / −72.1
	Female	20,197	26,236	6,039 (+29.9)	13,886 (+68.8)	6,637 (+32.9)	−14,484 (−71.7)	+11.2 to +55.9	−96.7 to −48.8	+27.8 / −66.3
	Male	25,789	41,118	15,329 (+59.4)	28,358 (+110.0)	11,467 (+44.5)	−24,496 (−95.0)	+14.3 to +73.5	−127.8 to −62.2	+27.8 / −76.4
Cataract	Both	9,467	8,965	−502 (−5.3)	7,849 (+82.9)	5,255 (+55.5)	−13,606 (−143.7)	+39.8 to +61.2	−150.4 to −125.5	+40.4 / −126.2
	Female	4,473	4,040	−433 (−9.7)	2,812 (+62.9)	2,154 (+48.2)	−5,400 (−120.7)	+33.2 to +55.9	−129.4 to −104.0	+41.8 / −113.5
	Male	4,994	4,925	−69 (−1.4)	4,943 (+99.0)	3,125 (+62.6)	−8,137 (−162.9)	+45.1 to +67.9	−169.3 to −142.1	+39.7 / −135.7
Non-cataract	Both	36,520	58,390	21,870 (+59.9)	34,351 (+94.1)	12,776 (+35.0)	−25,257 (−69.2)	+6.0 to +65.7	−103.2 to −38.4	+24.7 / −58.1
	Female	15,724	22,196	6,472 (+41.2)	11,073 (+70.4)	4,483 (+28.5)	−9,084 (−57.8)	+4.9 to +55.9	−87.3 to −33.1	+23.9 / −52.9
	Male	20,795	36,193	15,398 (+74.0)	23,415 (+112.6)	8,343 (+40.1)	−16,359 (−78.7)	+6.9 to +74.8	−117.8 to −43.0	+24.9 / −62.1

Table 2: Continued

B. Sub-Periods, Both Sexes								
Cause	Period	Count at Start	Net Change, N (% of Start)	Contribution, n (% of start)			Annualised Effect, N Per Year	
				Population Growth	Population Ageing	Epidemiological Change	Epidemiological	Ageing
Prevalence								
All vision loss	1990–2000	632,567	215,606 (+34.1)	194,850 (+30.8)	70,250 (+11.1)	−49,494 (−7.8)	−4,949	7,025
	2000–2010	848,173	348,249 (+41.1)	296,295 (+34.9)	25,989 (+3.1)	25,965 (+3.1)	2,597	2,599
	2010–2019	1,196,422	185,837 (+15.5)	176,662 (+14.8)	136,355 (+11.4)	−127,180 (−10.6)	−14,131	15,151
	2019–2023	1,382,259	102,156 (+7.4)	19,048 (+1.4)	77,256 (+5.6)	5,852 (+0.4)	1,463	19,314
Cataract	1990–2000	78,851	11,068 (+14.0)	22,594 (+28.7)	13,794 (+17.5)	−25,320 (−32.1)	−2,532	1,379
	2000–2010	89,919	19,335 (+21.5)	29,230 (+32.5)	6,517 (+7.2)	−16,412 (−18.3)	−1,641	652
	2010–2019	109,254	8,658 (+7.9)	15,667 (+14.3)	18,840 (+17.2)	−25,848 (−23.7)	−2,872	2,093
	2019–2023	117,912	14,660 (+12.4)	1,664 (+1.4)	10,264 (+8.7)	2,732 (+2.3)	683	2,566
Non-cataract	1990–2000	553,716	204,538 (+36.9)	172,255 (+31.1)	56,456 (+10.2)	−24,174 (−4.4)	−2,417	5,646
	2000–2010	758,254	328,914 (+43.4)	267,065 (+35.2)	19,472 (+2.6)	42,377 (+5.6)	4,238	1,947
	2010–2019	1,087,168	177,178 (+16.3)	160,995 (+14.8)	117,515 (+10.8)	−101,331 (−9.3)	−11,259	13,057
	2019–2023	1,264,347	87,496 (+6.9)	17,385 (+1.4)	66,991 (+5.3)	3,120 (+0.2)	780	16,748
Years lived with disability								
All vision loss	1990–2000	45,986	7,201 (+15.7)	13,215 (+28.7)	5,043 (+11.0)	−11,058 (−24.0)	−1,106	504
	2000–2010	53,187	8,805 (+16.6)	16,942 (+31.9)	1,640 (+3.1)	−9,777 (−18.4)	−978	164
	2010–2019	61,992	2,107 (+3.4)	8,691 (+14.0)	6,913 (+11.2)	−13,497 (−21.8)	−1,500	768
	2019–2023	64,099	3,256 (+5.1)	874 (+1.4)	3,634 (+5.7)	−1,252 (−2.0)	−313	909
Cataract	1990–2000	9,467	−152 (−1.6)	2,549 (+26.9)	1,554 (+16.4)	−4,255 (−45.0)	−426	155
	2000–2010	9,314	−323 (−3.5)	2,739 (+29.4)	608 (+6.5)	−3,670 (−39.4)	−367	61
	2010–2019	8,991	−617 (−6.9)	1,209 (+13.4)	1,454 (+16.2)	−3,279 (−36.5)	−364	162
	2019–2023	8,375	590 (+7.0)	115 (+1.4)	711 (+8.5)	−237 (−2.8)	−59	178
Non-cataract	1990–2000	36,520	7,353 (+20.1)	10,667 (+29.2)	3,489 (+9.6)	−6,803 (−18.6)	−680	349
	2000–2010	43,873	9,128 (+20.8)	14,204 (+32.4)	1,032 (+2.4)	−6,107 (−13.9)	−611	103
	2010–2019	53,000	2,724 (+5.1)	7,482 (+14.1)	5,460 (+10.3)	−10,218 (−19.3)	−1,135	607
	2019–2023	55,724	2,666 (+4.8)	758 (+1.4)	2,923 (+5.2)	−1,016 (−1.8)	−254	731

Abbreviations: GBD: Global Burden of Disease, WPP: World Population Prospects, YLD: year lived with disability. Three-factor Das Gupta decomposition of N = P × E × SIR: exact and symmetric: such that the sum of the three factors equals the net change [47:48]. P: GBD 2023 population (count / rate), E: expected crude rate: Σ w(a)R(a): using the UN WPP 2024 mid-year single-age structure normalized to GBD totals [12], SIR: observed crude rate / E. Reference gradient R(a) = κ below 40 years and exp [β(a – 40)] above 40 years: non-cataract κ 0.37: β 0.056 (midpoints of the gradient producing the GBD 2021 global maximum DALY age group: 65–69 years: in 1990 and 2021 [21]), cataract κ 0.05, β 0.08. The "All-vision-loss" lines are totals of the cause lines. The ranges represent 81 gradient combinations (cataract κ 0.01–0.20, β 0.06-0.10, non-cataract κ 0.05-1.0, β 0.03-0.08). Allocation scheme for migrants: the difference between the GBD and WPP populations by the distribution of the 2022 census age profile [14]. Since there is no draw-level information in the extract, the gradient-based range, not an uncertainty interval, expresses the uncertainty in the ageing and epidemiological parts. Panel B percentages relate to the counts at the beginning of each period. Sources: GBD 2023 [11], UN WPP 2024 [12]

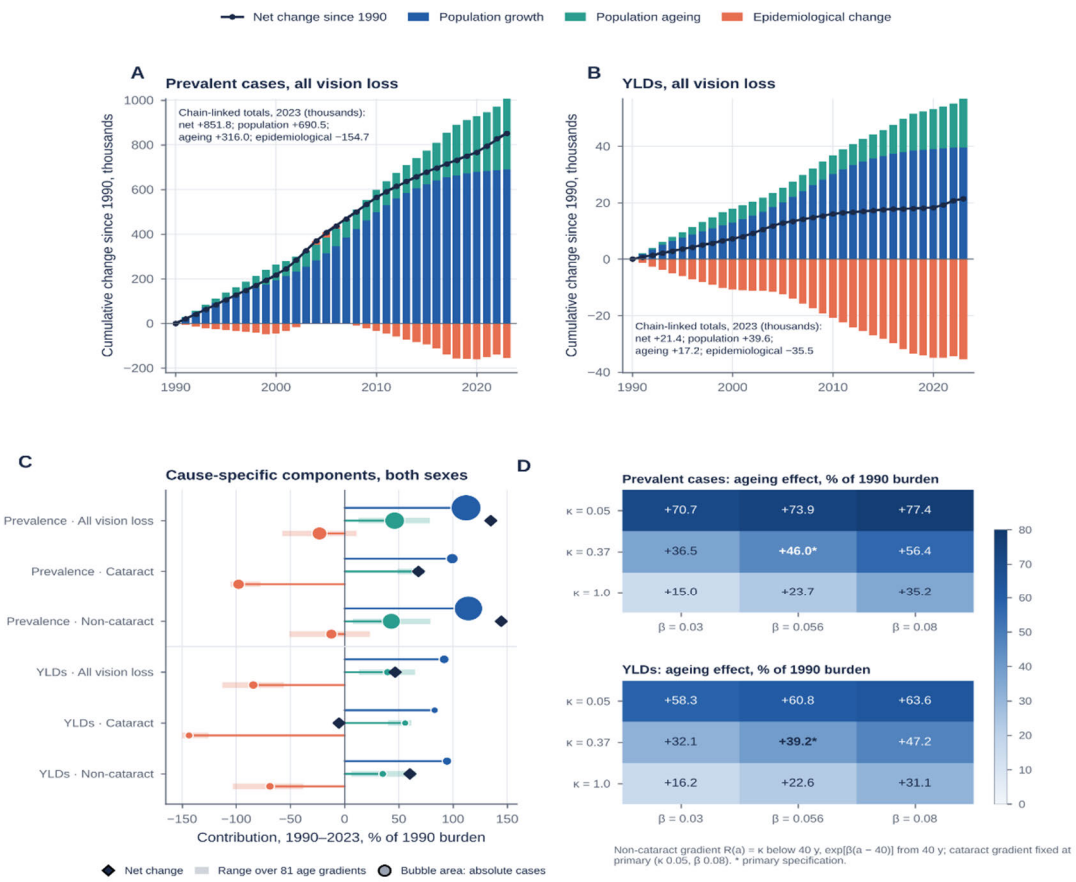


Figure 2: Factors of Vision Loss Burden Shift: Population Increase, Population Aging and Epidemiological Transition, 1990-2023

(A, B) Chain-linked Das Gupta decomposition for prevalence and YLDs from 1990 to net change, the values of which differ from endpoint Das Gupta decomposition in Table 2 up to 7 percentage points of the 1990 burden since annual change is decomposed; (C) Cause decomposition of prevalence and YLDs as percentages of the 1990 burden, where bubble area reflects the number of the burden, while grey area depicts the sensitivity range (range across 81 gradient specifications) and diamond – net change; (D) Impact of aging on all vision loss, where nine gradients without cataract and one with cataract are shown and asterisk indicates the main value of the gradients

growth (134.7%) because of the counterbalancing effect of epidemiology. Concerning the YLDs, epidemiological change decreased their burden by 84.5% (-38,863 YLDs), with increases of 91.8% owing to population growth and 39.2% owing to population ageing. For the prevalence burden, the epidemiology of cataract had the greatest influence, decreasing the number of cases by 98.1% of the 1990 caseload and 143.7% of the 1990 YLDs, whereas that of non-cataract prevalence the lowest one (by -12.6%). For all 81 gradient specifications used (a sensitivity range rather than uncertainty interval) the ageing effect was 12.7-78.2% of the 1990 burden, epidemiological one -57.6%-10.7% (with the sign of the latter effect non-robust); whereas for YLDs, both effects kept their sign in all specification sets (aging 13.0%-64.8%, epidemiological -112.9%-56.3%). With migrants being allocated according to the age structure implied by the GBD-WPP population gap, the ageing effect on prevalence became 33.0% and the epidemiological one -9.7%. The importance of the three determinants fluctuated over the years. Population growth provided 30.8% and 34.9% of the caseload increase during 1990-2000 and 2000-2010 periods, respectively, but just 1.4% for 2019-2023, while the yearly ageing effect on prevalence rose from 7,025 cases annually in the 1990s to 19,314 in 2019-2023 period. While epidemiological change in prevalence had been unfavourable in 2000-2010 (+3.1% of the 2000 caseload) and in 2019-2023 (+0.4% of all cases and +2.3% of cataract cases) which corresponded to the rising crude rates, it continued reducing YLDs in 2019-2023 (-2.0%) (Table 2).

Figure 2 traces the cumulative contribution of each driver year by year and the dependence of the ageing effect on the assumed gradient.

Sex Gap

Crude all-cause prevalence rate was 3.0% lower in females than in males (4,415.9 vs 4,552.3 per 100,000), whereas crude cataract YLD rate was 31.3% higher (31.84 vs 24.26). Females were 38.5% of population and 37.7% of prevalent cases, but 43.0% of cataract cases and 45.1% of cataract YLDs. After adjustments for age, F:M ratio of all-cause prevalence for 2023 was close to parity (prevalence ratio of 0.990, variation across specification of 0.917–1.102; YLDs

Table 3: Sex Gap Analysis: Crude and Age-Adjusted Female:Male Ratios, Kitagawa Components and Nationality Composition

A. Selected years												
		Crude rate per 100,000			F:M ratio		Kitagawa components of the gap		Female share, %		Excess female cases	
Cause	Year	Female	Male	Gap F − M	Crude	Age-adjusted [range]	Age composition	Rate	Cases	Population	Crude basis	Age-adjusted basis
Prevalence												
All vision loss	1990	3,805.3	3,962.2	−156.8	0.960	0.930 [0.863–0.979]	134.5	−291.4	43.1	44.1	−11,238	−21,112
	2000	3,974.0	4,030.8	−56.8	0.986	0.990 [0.943–1.061]	−4.9	−51.9	44.4	44.8	−5,386	−4,765
	2010	4,119.9	4,287.6	−167.7	0.961	0.934 [0.861–1.009]	122.9	−290.6	42.3	43.3	−20,600	−36,081
	2019	4,215.3	4,266.8	−51.5	0.988	1.038 [0.958–1.172]	−206.9	155.4	39.6	39.9	−6,697	19,852
	2023	4,415.9	4,552.3	−136.4	0.970	0.990 [0.917–1.102]	−91.6	−44.8	37.7	38.5	−17,305	−5,391
Cataract	1990	519.2	458.5	60.7	1.132	1.026 [0.957–1.093]	48.0	12.7	47.2	44.1	4,347	952
	2000	471.1	387.0	84.1	1.217	1.172 [1.095–1.244]	16.3	67.8	49.6	44.8	7,969	6,546
	2010	408.4	367.0	41.4	1.113	1.005 [0.923–1.082]	39.5	1.8	45.9	43.3	5,084	239
	2019	405.3	333.6	71.7	1.215	1.236 [1.129–1.348]	−6.5	78.1	44.7	39.9	9,314	10,066
	2023	449.2	372.3	76.9	1.206	1.172 [1.066–1.275]	11.9	64.9	43.0	38.5	9,749	8,356
Non-cataract	1990	3,286.1	3,503.6	−217.5	0.938	0.914 [0.850–0.964]	86.5	−304.0	42.5	44.1	−15,586	−22,065
	2000	3,502.9	3,643.8	−140.9	0.961	0.967 [0.925–1.040]	−21.2	−119.7	43.8	44.8	−13,354	−11,311
	2010	3,711.5	3,920.6	−209.1	0.947	0.926 [0.855–1.002]	83.4	−292.5	41.9	43.3	−25,684	−36,319
	2019	3,810.0	3,933.2	−123.2	0.969	1.020 [0.943–1.157]	−200.5	77.3	39.2	39.9	−16,012	9,786
	2023	3,966.7	4,180.0	−213.3	0.949	0.973 [0.903–1.086]	−103.5	−109.8	37.2	38.5	−27,054	−13,747
Years lived with disability												
All vision loss	1990	281.84	283.94	−2.10	0.993	0.957 [0.887–1.006]	11.48	−13.58	43.9	44.1	−151	−981
	2000	254.45	248.50	5.95	1.024	1.026 [0.975–1.098]	0.46	5.49	45.3	44.8	564	535
	2010	217.00	219.47	−2.47	0.989	0.957 [0.882–1.034]	7.33	−9.80	43.0	43.3	−304	−1,208
	2019	199.51	195.18	4.33	1.022	1.072 [0.989–1.209]	−9.32	13.64	40.5	39.9	562	1,743
	2023	206.82	202.53	4.29	1.021	1.040 [0.962–1.156]	−3.68	7.97	39.0	38.5	545	1,022
Cataract	1990	62.42	54.98	7.44	1.135	1.029 [0.960–1.096]	5.76	1.67	47.2	44.1	533	126
	2000	49.13	39.82	9.31	1.234	1.188 [1.110–1.260]	1.69	7.62	50.0	44.8	882	736
	2010	34.59	29.45	5.14	1.175	1.061 [0.975–1.142]	3.26	1.88	47.3	43.3	631	243
	2019	29.78	23.03	6.75	1.293	1.316 [1.202–1.435]	−0.46	7.21	46.2	39.9	878	930
	2023	31.84	24.26	7.59	1.313	1.275 [1.161–1.388]	0.81	6.77	45.1	38.5	962	872
Non-cataract	1990	219.42	228.96	−9.54	0.958	0.934 [0.869–0.985]	5.71	−15.25	43.1	44.1	−683	−1,107
	2000	205.33	208.68	−3.36	0.984	0.990 [0.947–1.064]	−1.23	−2.13	44.4	44.8	−318	−201
	2010	182.40	190.02	−7.61	0.960	0.939 [0.867–1.016]	4.07	−11.68	42.3	43.3	−935	−1,451
	2019	169.72	172.15	−2.43	0.986	1.038 [0.959–1.178]	−8.85	6.43	39.6	39.9	−315	814
	2023	174.98	178.27	−3.29	0.982	1.007 [0.934–1.123]	−4.49	1.20	38.0	38.5	−418	150

Table 3: Continued

B. Trends in the sex gap, 1990–2023								
	Crude F:M ratio		Age-adjusted F:M ratio				Cumulative excess female burden, 1990–2023, age-adjusted basis (case-years or YLDs)	Mean composition share of crude gap, %
Cause	EAPC, % (95% CI)	p	EAPC, % (95% CI)	p	Mean (min–max), 1990–2023	Years with ratio > 1, n/34		
Prevalence								
All vision loss	0.04 (0.01 to 0.07)	0.019	0.23 (0.11 to 0.34)	<0.001	0.973 (0.926–1.058)	6/34	−391,725	39.3
Cataract	0.05 (−0.05 to 0.16)	0.302	0.29 (0.08 to 0.51)	0.008	1.114 (1.005–1.261)	34/34	162,981	42.9
Non-cataract	0.06 (0.04 to 0.09)	<0.001	0.25 (0.14 to 0.36)	<0.001	0.957 (0.912–1.040)	6/34	−554,706	33.0
Years lived with disability								
All vision loss	0.02 (−0.02 to 0.06)	0.313	0.22 (0.09 to 0.34)	0.002	1.004 (0.950–1.088)	17/34	865	45.7
Cataract	0.30 (0.20 to 0.40)	<0.001	0.54 (0.34 to 0.74)	<0.001	1.154 (1.029–1.332)	34/34	18,407	35.8
Non-cataract	0.03 (−0.01 to 0.06)	0.121	0.21 (0.10 to 0.33)	<0.001	0.976 (0.926–1.054)	8/34	−17,542	40.2

C. Age–sex–nationality composition (census 2022) and expected-rate indices								
			Age distribution, %				Expected-rate index	
Group	Population	Share of total, %	0–14 y	25–49 y	≥50 y	≥65 y	Cataract	Non-cataract
Saudi male	9,434,131	29.3	35.2	34.2	11.4	3.44	1.095	1.005
Saudi female	9,358,131	29.1	34.3	34.4	12.4	3.59	1.155	1.043
Non-Saudi male	10,244,464	31.8	6.8	71.4	13.3	1.42	0.841	0.989
Non-Saudi female	3,138,498	9.8	21.0	57.8	9.6	1.81	0.770	0.890
All males	19,678,595	61.2	20.4	53.6	12.4	2.39	0.963	0.997
All females	12,496,629	38.8	31.0	40.3	11.7	3.14	1.059	1.005
Total	32,175,224	100.0	24.5	48.4	12.1	2.68	1.000	1.000

Abbreviations: EAPC: Estimated Annual Percentage Change, F: Female, M: Male, SIR: Indirectly Standardized Ratio of the Observed to the Expected Crude Rate, YLD: Year Lived with Disability. Rate/100:000. Age-Adjusted F:M = Ratio of Sex-Specific SIRs (see Table 2 footnote), Bracketed Range = Minimum–Maximum of 81 combinations on the gradients). In Kitagawa decomposition of the difference between the crude rates: F - M: into the Age Composition Component: (EF - EM)(SIRF + SIRM)/2: and Rate Component: (SIRF - SIRM)(EF + EM)/2: These Two Components Sum Up to the Difference [50]. Female Excess = Female Cases – Male Cases at Female Crude Rate (crude method) or Female Cases at Male SIR Depending on Female Age Distribution (age-adjusted method), negative numbers indicate male excess. EAPC = estimated annual percentage change of the ratio from log-linear regression over 34 years. Expected-rate index = expected crude rate of the group according to the primary gradients relative to the national population (1.000). Women comprise 55% of people: suffering from either blindness or visual impairment worldwide in 2020 [1]: there is a female excess in cataracts based on the GBD 2021 estimations [22]. Data sources: GBD 2023 [11], UN WPP 2024 [12], census 2022 [13:14]

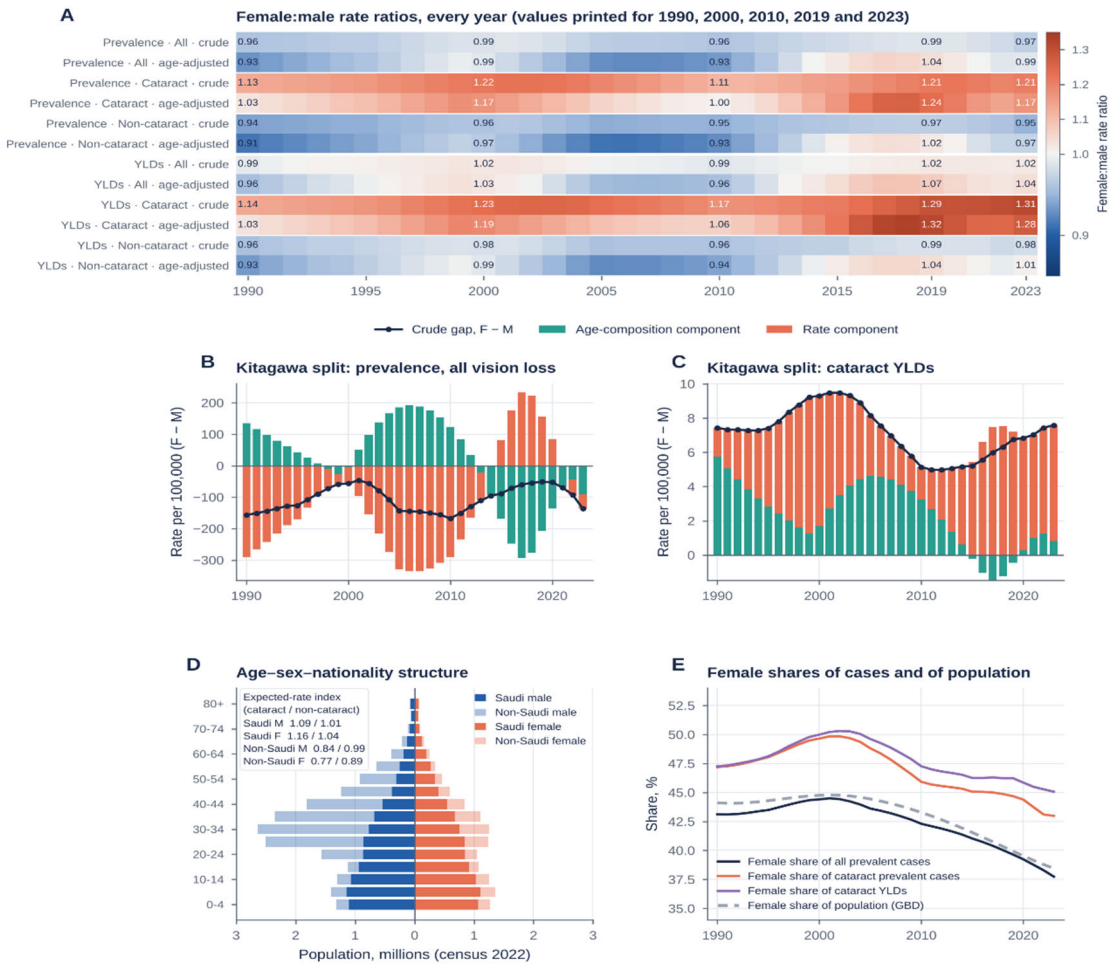


Figure 3: Mechanisms Underlying the Sex Gap and Demographics

(A) Age-adjusted and non-age adjusted rates' sex ratios of six measure-cause groups in each year, where the values are given for 1990, 2000, 2010, 2019, and 2023; (B,C) Kitagawa decomposition of crude female/male rate ratio for the age composition and age-specific prevalence or prevalence ratios of overall and cataract YLD; (D) Census 2022 distribution of population according to age, sex, and nationality with the indices of expected rates [14]; (E) The proportion of women amongst the prevalent and the cataract YLD case group in relation to the proportion of women in GBD's population

– 1.040, 0.962–1.156), but F:M ratio of cataract was above 1.0 in each gradient (prevalence of 1.172, range of 1.066–1.275; YLDs - 1.275, 1.161–1.388). In age-adjusted data, the F:M cataract ratios exceed 1.0 for each measure in all 34 years, each ratio converges to higher female proportion by 0.21% to 0.54% yearly ($p < 0.01$). The components of the all-cause prevalence gap act in the opposite direction in 26 out of 34 years, covering more serious differences inside the overall slight difference; in 2023 both components are negative (-91.6 and -44.8 per 100,000, giving overall crude difference of -136.4), where composition contributes two-thirds of difference. Instead, the cataract YLD difference is mostly driven by cataract rates in 2023 (6.77 out of 7.59 per 100,000). Based on the age-adjustment, females have 162,981 extra cataract case-years and 18,407 extra cataract YLDs versus 391,725 extra all-causes prevalence case-years in males. The composition effect is driven by the age structure: non-Saudi men, 31.8% of population, concentrate in ages 25-49 years (71.4%), while the expected cataract rate index relative to population is 0.963 in all men and 1.059 in females, ranging from 0.770 in non-Saudi women, 0.841 in non-Saudi men, and 1.155 in Saudi women (Table 3).

Figure 3 shows the annual ratios, the Kitagawa components and the age–sex–nationality structure that produces them.

Frontier Efficiency and Benchmarks

Whereas the age-adjusted YLD rate fell from 384.7 to 204.2 per 100,000 people, and achieved its own best frontier every year with the exception of 2021 and 2022, where it was just slightly higher (0.2%) than the 2020 lowest level of 205.8 (efficiency 0.999 and 0.992, respectively), the age-adjusted prevalence was higher than its best up until then in 2000-2012 (efficiency 0.927 in 005) and in 2021-2023. Concerning fertility transition frontiers, the age-adjusted YLD rate gap from the frontier rose from 0.2% in 1990 to 25.5% in 2005, narrowed until 2017 (-2.5% in 2018), expanded to 5.8% in 2022 and dropped to 1.5% in 2023, while the cataract YLD gap was enlarged to 47.5% in 2004 and to 14.6% in 2022. Each one-child decrease of the TFR

Table 4: Frontier-Efficiency Analysis and Comparative Benchmarking

A. Intertemporal efficiency, both sexes (age-adjusted rates per 100,000)														
Year	TFR	e0, y	Prevalence					YLDs					YLD rate by cause (gap to frontier, %)	
			Rate (ISR)	Best-achieved	Efficiency	TFR Frontier	Gap to Frontier, %	Rate (ISR)	Best-achieved	Efficiency	TFR frontier	Gap to frontier, %	Cataract	Non-Cataract
1990	5.80	68.9	5,193.3	5,193.3	1.000	5,097.4	+1.9	384.7	384.7	1.000	383.9	+0.2	93.54 (+0.3)	291.1 (−0.1)
1995	4.99	70.9	4,947.7	4,947.7	1.000	4,943.3	+0.1	337.0	337.0	1.000	330.5	+2.0	71.70 (+3.5)	265.3 (+2.3)
2000	4.21	72.6	4,834.5	4,827.5	0.999	4,800.6	+0.7	306.2	306.2	1.000	286.4	+6.9	60.09 (+15.2)	246.2 (+6.1)
2005	3.16	74.4	5,205.9	4,827.5	0.927	4,616.0	+12.8	296.7	296.7	1.000	236.5	+25.5	52.39 (+46.9)	244.3 (+22.1)
2010	2.81	75.6	4,948.0	4,827.5	0.976	4,555.6	+8.6	257.7	257.7	1.000	221.7	+16.3	40.55 (+29.2)	217.2 (+14.2)
2015	2.63	77.8	4,706.7	4,706.7	1.000	4,524.9	+4.0	229.0	229.0	1.000	214.5	+6.8	32.39 (+10.2)	196.6 (+6.0)
2019	2.49	78.3	4,481.4	4,481.4	1.000	4,501.2	−0.4	208.1	208.1	1.000	209.1	−0.5	27.93 (−0.0)	180.2 (−0.9)
2020	2.27	77.6	4,478.3	4,478.3	1.000	4,464.1	+0.3	205.8	205.8	1.000	200.8	+2.5	27.72 (+7.5)	178.1 (+1.1)
2021	2.17	77.1	4,505.6	4,478.3	0.994	4,447.4	+1.3	206.1	205.8	0.999	197.2	+4.5	27.87 (+12.1)	178.3 (+2.6)
2022	2.14	77.3	4,539.9	4,478.3	0.986	4,442.4	+2.2	207.5	205.8	0.992	196.1	+5.8	28.17 (+14.6)	179.4 (+3.7)
2023	2.28	78.7	4,499.8	4,478.3	0.995	4,465.9	+0.8	204.2	204.2	1.000	201.2	+1.5	27.17 (+5.0)	177.0 (+0.3)

B. Frontier slopes and cumulative inefficiency, 1990–2023					
Cause	Change in rate per 1-child fall in TFR, %		Years > 5% above frontier, n/34	Gap to frontier, mean %		Cumulative excess over best-achieved, 1990–2023 (rate-years)
	Frontier (τ = 0.10)	Median (τ = 0.50) (95% CI)		1990–2023	2019–2023	
Prevalence						
All vision loss	−3.7	−2.5 (−4.4 to −0.6)	12/34	+3.9	+0.8	2,581.8
Cataract	−17.9	−15.3 (−18.2 to −12.4)	19/34	+9.7	+6.2	110.8
Non-cataract	−2.0	−0.6 (−2.4 to +1.2)	12/34	+3.6	+0.8	3,234.5
Years lived with disability						
All vision loss	−16.8	−14.1 (−17.1 to −11.1)	18/34	+8.2	+2.8	2.0
Cataract	−30.5	−27.2 (−31.4 to −22.7)	25/34	+15.4	+7.9	0.6
Non-cataract	−13.3	−10.9 (−13.7 to −8.0)	16/34	+7.1	+1.4	5.0

C. Published age-standardised estimates used as benchmarks			
Location	Metric (per 100,000)	Published value (95% UI)	Δ since 1990, %

Table 4: Continued

GBD 2019 [20]					
Saudi Arabia	ASPR 2019	8,343.9 (7,539.1–9,197.3)		–20.9	
Saudi Arabia	ASYR 2019	464.8 (332.0–621.9)		–42.2	
Oman	ASPR 2019	9,139.0 (8,275.2–10,048.7)			
Oman	ASYR 2019	455.0 (325.7–615.3)			
Kuwait	ASYR 2019	271.7 (191.1–373.8)			
North Africa and Middle East	ASPR 2019	7,040.0 (6,195.0–8,002.7)		–11.1	
North Africa and Middle East	ASYR 2019	314.5 (222.1–427.6)		–24.3	
GBD 2021 [21]					
Global	ASPR 2021	15,784.3 (12,761.4–19,502.3)		+26.7	
Global	ASDR 2021	342.8 (224.2–503.6)		+0.2	
High SDI	ASPR 2021	8,638.2		+6.9	
High SDI	ASDR 2021	164.3		–1.1	
North Africa and Middle East	ASPR 2021	13,748.2		+2.2	
North Africa and Middle East	ASDR 2021	386.8		–17.9	
D. Within-round rate ratios and burden avoidable at the comparator's rate					
Comparison	Basis	Rate ratio	Excess, %	Avoidable fraction, %	Saudi YLDs avoidable at comparator's rate, 2023
Saudi Arabia vs North Africa and Middle East, ASYR	GBD 2019	1.478	+47.8	32.3	21,780
Saudi Arabia vs Kuwait (lowest GCC value retrieved), ASYR	GBD 2019	1.711	+71.1	41.5	27,982
Saudi Arabia vs Oman, ASYR	GBD 2019	1.022	+2.2	2.1	1,420
Saudi Arabia vs North Africa and Middle East, ASPR	GBD 2019	1.185	+18.5	15.6	10,525
North Africa and Middle East vs High SDI, ASDR	GBD 2021	2.354	+135.4	57.5	— (regional ratio)
North Africa and Middle East vs Global, ASDR	GBD 2021	1.128	+12.8	11.4	— (regional ratio)
Saudi Arabia vs High SDI, chained (GBD 2019 x GBD 2021)	chained, cross-round	3.479	+247.9	71.3	47,994

Acronyms: ASDR: Age-Standardised DALY Rate, ASPR: Age-Standardised Prevalence Rate, ASYR: Age-Standardised YLD Rate, e0: Life Expectancy at Birth, ISR: Indirectly Standardised (Age-Adjusted) Rate, SDI: Socio-Demographic Index, TFR: Total Fertility Rate. Rates Per 100:000. Best-Achieved = Lowest Age-Adjusted Rate Ever Achieved Up Until the Indicated Year, efficiency = best-achieved/observed (1 = on the frontier). TFR frontier = 10th-centile quantile regression of ln (age-adjusted rate) on TFR [54]: a proxy for the fertility component of the SDI, gap = observed/frontier -1. TFR and e0 from UN WPP 2024 [12]. The GBD 2023 SDI series and the 204-country estimates necessary for a cross-national frontier [51:52] were not available: so Panels A and B show a single-country frontier. Panel C shows published GBD 2019 and GBD 2021 estimates, levels differ substantially between rounds (North Africa and Middle East prevalence 7:040 per 100:000 in GBD 2019 compared to 13:748 in GBD 2021): so only within-round ratios are interpretable. Avoidable fraction = 1 – 1/ratio: applied to the 2023 Saudi YLD count (67:354), the chained ratio multiplies a GBD 2019 by a GBD 2021 ratio and is indicative only

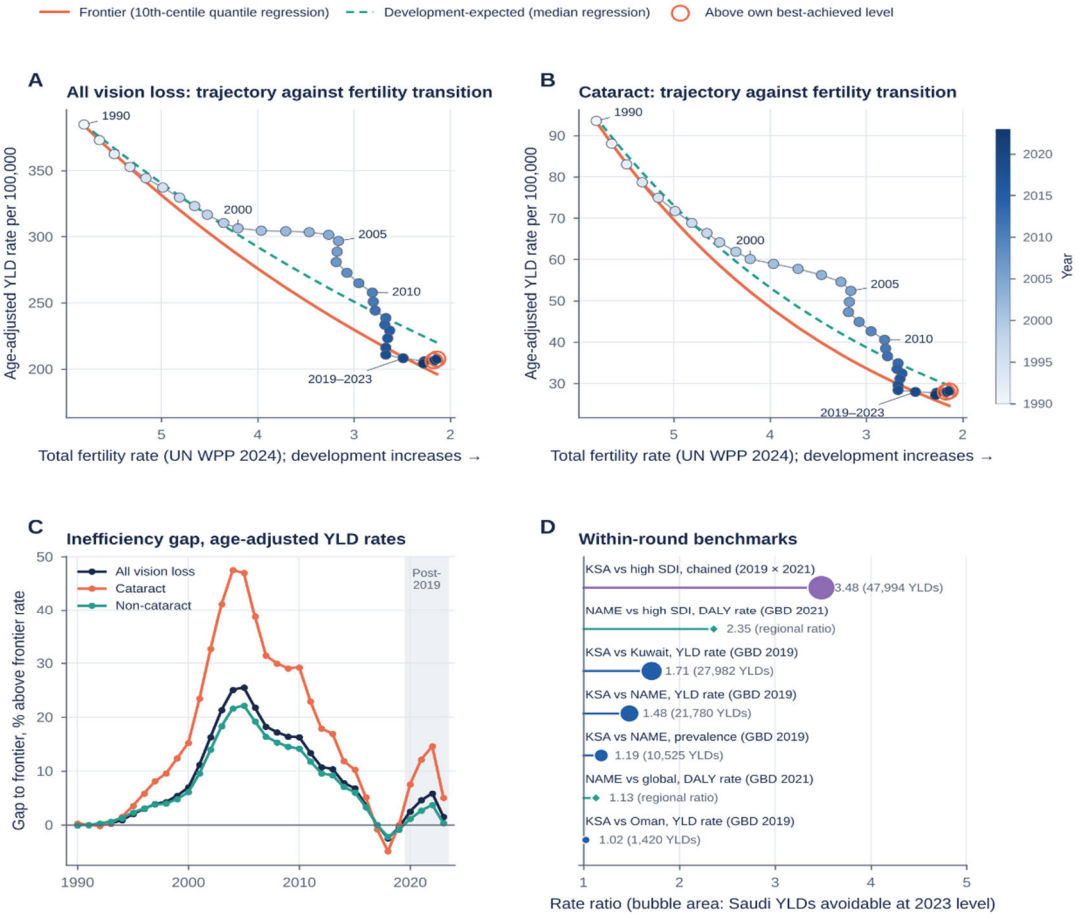


Figure 4: Efficiency Frontier and Benchmarks

(A, B) YLDs from vision loss and cataracts plotted against total fertility rate (development going right) for one point per year, with quantile regression efficiency frontier at 10th centile and median development-expectancy curve, together with rings marking out the years in which KSA exceeds its previous benchmark performance; (C) deviation from frontier by cause in %; (D) between-round ratios for the public GBD 2019 [20] and GBD 2021 [21] releases, proportional to the size of the area of the bubbles denoting the possible reduction in YLDs of KSA on adopting the comparator frontier rate in 2023; diamond ratios without a Saudi factor. KSA, Kingdom of Saudi Arabia; NAME, North Africa and the Middle East; SDI, Socio-demographic Index. Single-country exploration of the benchmarks; the position relative to the frontier is dependent on the gradients assumption

in the median regression (34 annual observations) was linked with 14.1% lower age-adjusted YLD rate (95% confidence interval 11.1–17.1), 27.2% lower cataract YLD rate (22.7–31.4) and 2.5% lower prevalence rate (0.6–4.4); these slopes and frontier gaps depend on the assumed gradients and quantile-regression specification. YLD of the cataracts exceeded the frontier by more than 5% in 25 out of 34 years. According to GBD 2019 data, the age standardised YLD rate in Saudi Arabia was 47.8% and 71.1% higher than that of North Africa and the Middle East and Kuwait, respectively, so that as a hypothetical numeric calculation, 21,780 and 27,982 YLDs (of 67,354 Saudi Arabia YLDs in 2023), respectively, were avoidable at these rates; it was only 2.2% higher than that of Oman (Table 4).

Figure 4 places the annual trajectory against the frontier and the published benchmarks.

Triangulation Against Survey Results from Saudi Arabia

All surveyed estimates of prevalence of visual impairment exceeded 4.50% (4.04–5.13) found in GBD across all age groups. The age-specific prevalence of visual impairment of more than 6/12 was 39.9% (36.8–43.1) in Duhknah and 27.1% (23.6–30.8) in Qbah that rose to 49.4% and 29.0%, respectively, after standardisation to the whole Saudi national population of at least 6 years old. The combined estimate of visual impairment of Duhknah and Qbah surveys (33.3%; 22.0–46.9; I^2 96.1%) is 7.4 times that of the GBD all age population, which can be regarded as the contrast of definitions rather than an underestimation of GBD prevalence. National meta-analyses showed prevalence of 16.8% (11.4–23.9) in adults and 10.8% (7.3–15.7) in population-based samples. Blindness prevalence in both RAABs was 2.97% (2.35–3.74) in people aged 50 years or older. Gender ratios of impairment in the community surveys were larger in female to male ratio of pooled estimates (pooled F:M 1.49; 1.13–1.96; I^2 70.1%) than adjusted in GBD (F:M 0.99). The pooled ratios in age group ≥60/age 18–39 years in the community surveys (1.85; 0.89–3.87) were extremely low compared with 21.7 using the primary non-cataract gradient, while in the flat-young version of the

Table 5: Triangulation of Gbd 2023 Estimates Against Saudi Population-Based, Raab, Clinic-Based and Pooled Estimates

A. Prevalence estimates and their ratio to GBD 2023							
Source	Design, setting, period	N	Age	Case definition	Estimate, % (95% CI)	Directly standardised to national structure, % (95% CI)	Ratio to GBD 2023 crude prevalence
GBD 2023 (this extract) [11]	Modelled, national, 2023	—	All ages	All severities incl. near vision loss	4.50 (4.04–5.13)	—	1.00
Al Khathami *et al.* SR/MA [33]	9 studies, search to July 2025	26,707	Adults ≥18	VI, any (pooled)	16.8 (11.4–23.9)	—	3.73
Al Khathami *et al.* SR/MA [33]	4 population-based studies	24,170	Adults	VI, population-based subgroup	10.8 (7.3–15.7)	—	2.40
Al Khathami *et al.* SR/MA [33]	5 clinic/campaign studies	2,537	Adults	VI, clinic/campaign subgroup	22.1 (15.4–30.7)	—	4.91
Al Khathami *et al.* SR/MA [33]	Pooled	—	Adults	Blindness	1.7 (1.0–2.8)	—	—
Al Khathami *et al.* SR/MA [33]	5 studies	7,926	Adults	Severe VI	2.1 (1.3–3.3)	—	—
Duhknah, Qassim (community, 2024) [30]	Cross-sectional community campaign	929	6–90 y	Presenting VA worse than 6/12	39.9 (36.8–43.1)	49.4 (45.1–53.6); Saudi nationals 47.0	8.87
Qbah, Qassim (community, 2024) [31]	Cross-sectional community campaign	587	6–80 y	Presenting VA worse than 6/12	27.1 (23.6–30.8)	29.0 (24.7–33.4); Saudi nationals 27.9	6.02
QUMC, Qassim (tertiary clinic records, 2023–2024) [32]	Retrospective records, tertiary centre	385	All ages (mean 43.6 y)	VA <6/18 or mild category as reported	58.2 (53.2–63.0)	—	12.93
Pooled community surveys (DerSimonian–Laird, this analysis)	Duhknah + Qbah	1,516	6–90 y	Presenting VA worse than 6/12	33.3 (22.0–46.9); I^2 96.1%	—	7.40
Alghamdi and Ovenseri-Ogbomo 2021, Dariyah [29]	Cross-sectional community	277	Not reported in abstract	VI (as reported)	24.5 (19.9–29.9)	—	5.46
Hajar *et al.* Jazan RAAB+DR [28]	Population-based	3,659	≥50 y	Blindness, better eye <3/60	3.3 (2.74–3.90)	Age–sex adjusted	—
Hajar *et al.* Jazan RAAB+DR [28]	Population-based	3,659	≥50 y	Severe VI <6/60–3/60	2.7 (2.20–3.26)	Unadjusted, as reported	—
Hajar *et al.* Jazan RAAB+DR [28]	Population-based	3,659	≥50 y	Moderate VI <6/18–6/60	14.2 (13.05–15.31)	Unadjusted, as reported	—
Al Ghamdi *et al.* Taif RAAB+DR [27]	Population-based, 66 clusters	3,052	≥50 y	Blindness, better eye <3/60	2.6 (2.0–3.2)	—	—
Pooled RAAB blindness ≥50 y (this analysis)	Taif + Jazan	6,711	≥50 y	Blindness <3/60	2.97 (2.35–3.74); I^2 60.5%	—	—

B. Sex gap, age gradient, cause composition and access to eye care		
Indicator	Source	Estimate (95% CI)
Female:male prevalence ratio	Duhknah, Qassim [30]	1.32 (1.12 to 1.54)
	Qbah, Qassim [31]	1.75 (1.35 to 2.28)
	QUMC, Qassim [32]	1.05 (0.88 to 1.24)
	Pooled, community surveys (DL)	1.49 (1.13 to 1.96); I^2 70.1%
	Pooled, all three incl. clinic records (DL; sensitivity)	1.32 (1.02 to 1.71); I^2 81.7%
	Al Khathami *et al.* subgroup (20.7% vs 12.5%) [33]	1.66
	GBD 2023, crude / age-adjusted [11]	0.970 / 0.990
Age gradient, prevalence ratio (≥60 vs 18–39 y)	Duhknah, Qassim [30]	1.28 (1.01 to 1.64)
	Qbah, Qassim [31]	2.73 (1.92 to 3.87)

Table 5: Continued

B. Sex gap, age gradient, cause composition and access to eye care		
Indicator	Source	Estimate (95% CI)
Age gradient, prevalence ratio (≥66 vs 18–35 y)	QUMC, Qassim [32]	2.68 (1.91 to 3.76)
Age gradient, prevalence ratio (≥60 vs 18–39 y)	Pooled, community surveys (DL)	1.85 (0.89 to 3.87); I^2 91.7%
	Gradient assumed in this analysis: primary non-cataract / flat-young variant	21.69 / 2.96
Cataract share of VI cases, %	Duhknah, Qassim [30]	3.2 (1.9–5.6)
	Qbah, Qassim [31]	5.7 (3.0–10.4)
	QUMC, Qassim [32]	20.8 (17.0–25.1)
	Pooled, community surveys (DL)	4.2 (2.4–7.2); I^2 39.8%
Refractive error share of VI cases, % (as reported)	Duhknah, Qassim [30]	81.4
	Qbah, Qassim [31]	83.0
Cataract share of blindness, %	Jazan RAAB 2015 / Taif RAAB 2012 [27,28]	58.6 / 41.0
Cataract share of moderate VI, %	Jazan RAAB 2015 (refractive error 55.1%) [28]	30.8
Cataract share, %	GBD 2023: of prevalent cases / of YLDs [11]	8.9 / 13.3
Never had an eye examination, %	Duhknah, Qassim [30]	72.2 (69.3–75.0)
	Qbah, Qassim [31]	65.8 (61.8–69.5)
Spectacle use among refractive error, % (proxy for refractive coverage)	Duhknah (121 spectacle users / 657 with refractive error) [30]	18.4 (15.6–21.6)
Effective refractive error coverage, distance, %	North Africa and Middle East / high-income, 2021 [10]	62.1 (54.7–68.8) / 79.1 (72.4–85.0)
Effective refractive error coverage, near, %	Global, 2021 [10]	20.5 (17.8–24.4)
Known diabetes with prior eye examination, %	Jazan RAAB+DR [28]	37.2

Abbreviations: DL: DerSimonian–Laird, QUMC: Qassim University Medical City, RAAB+DR: Rapid Assessment of Avoidable Blindness with Diabetic Retinopathy Module, SR/MA: Systematic Review and Meta-Analysis, VA: Visual Acuity, VI: Visual Impairment. Proportions and 95% CIs recalculated based on published frequencies using the Wilson method [55]: ratios with Katz log scale CIs [56], pooled estimates by DL random effects [57] with I^2 [58]. Standardised estimates use age band prevalence from the surveys (6–10: 11–17: 18–39: 40–49: 50–59 and ≥60 years) applied to the Saudi population ≥6 years old (UN WPP 2024: mid-2024 [12], to Saudi citizens (2022 census [14]). The Duhknah age band number of cases total 371 cases vs. 370 reported, the former numbers are used. The published CI for prevalence of severe VI with blindness in Qbah (0.30-0.21) is logically impossible, the recalculated Wilson CI for 5/587 cases is 0.36-1.98%. The QUMC VI definitions include mild impairment in both grades 0 and VI, this estimate is shown as reported. GBD prevalence is for all severities: including near vision loss: across all ages, the survey measured VA distance acuity in selected locations, thus ratios against GBD prevalence show the discrepancy. Refractive coverage proxy = spectacle wearers ÷ participants with refractive error

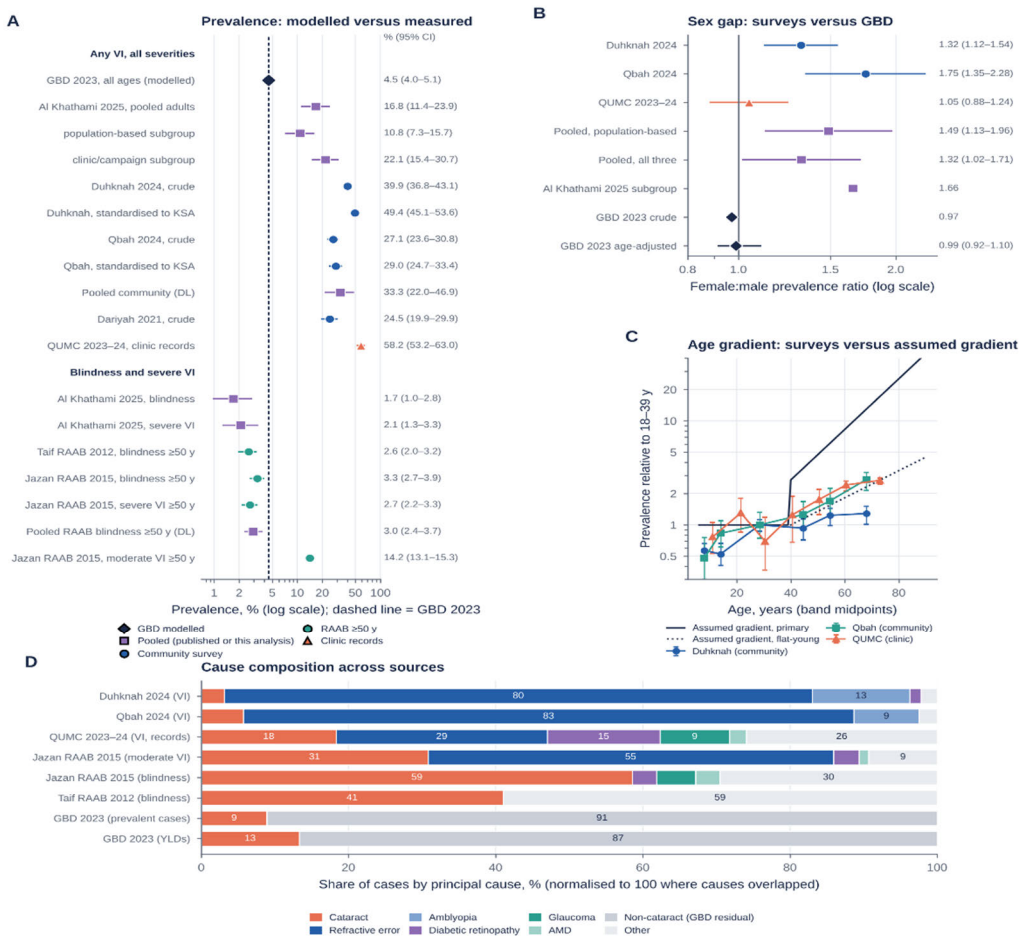


Figure 5: Triangulation of GBD 2023 Estimates Using Survey Data from Saudi Arabia
(A) Prevalence by source on log scale with 95% CIs compared with GBD 2023 prevalence (dashed line), separated by case definition, different from the GBD 2023 category, so ratios show discrepancy; (B) female to male prevalence ratios in surveys, estimated pooled value and GBD 2023 estimate (unadjusted and age-adjusted with sensitivity range); (C) prevalence compared with ages 18-39 years in community surveys in Qassim and QUMC, and the primary and flat-young gradients used for age adjustment; (D) major causes by source, presented as percents standardized to 100%, if the causes were similar across the sources. Sources: [27-33]. AMD, age-related macular degeneration; DL, DerSimonian-Laird; QUMC, Qassim University Medical City; RAAB, rapid assessment of avoidable blindness; VI, visual impairment

age gradient this ratio is similar (2.96). Cataract was responsible for 4.2% (2.4–7.2) of visual impairment in the community surveys and up to 41.0% and 58.6% blindness in the RAABs. Meanwhile refractive error was contributing approximately four out of five of visual impairment cases in the community population surveys (81.4% in Duhknah and 83.0% in Qbah). Never undergone eye exam proportion ranged between 65.8 and 72.2% in the community surveys, and only 18.4% (15.6–21.6) of refractive error subjects in Duhknah wore glasses (Table 5).

Figure 5 compares the sources on a common scale and sets their sex ratios, age gradients and cause composition against GBD.

Projections to 2050 and Service Needs

Projecting GBD 2023 WPP 2024 growth leads to 2050 population growing from 33.0 million in 2023 to 47.2 million in 2050 (95% probabilistic interval 36.8-58.5 million). As per the WPP 2024, the proportion of those aged 65+ increases from 2.82% to 8.20%, the number of those aged 80+ from 139,078 to 750,613, the old age dependency ratio from 3.86 to 11.43 per 100, so only due to ageing the expected increase in the prevalence of cataract will be 2.05 times and non-cataract 1.51 times. Holding the 2023 age-adjusted rates constant (S1) results in 1.85 million (1.55-2.23) prevalent cases in 2030 and 3.31 million (2.20-5.02) in 2050 (122.8% growth) and 152,982 (87,829-257,050) YLDs (growth by 127.1%); the cataract cases will triple to 395,100 (268,140-554,201). Cases will grow faster for females than for males (by 164.6% vs. 97.5%), increasing females share of cases from 37.7% to 44.8%. Projecting the 2010-2023 trend (S2) reduced the 2050 projection to 2.68 million cases (1.76-4.08) and 93,413 YLDs (52,895-158,369). Naive ARIMA comparator predicted 2.58 million cases but 87,703 YLDs, i.e. a 30.2% growth compared to 3-fold S1 growth. Changes in fertility in the WPP 2024 modified the S1 projections to 2050 slightly, from 3.25 million cases to 3.37 million. Holding the 2023 cases per ophthalmologist ratio

Table 6: Projections to 2050, Health System Capacity Requirements and Who 2030 Eye Care Targets

A. Demographic Inputs (UN WPP 2024)								
Indicator			2023	2030		2040		2050
Population, GBD 2023 base × WPP 2024 index (WPP 95% PI)			32,988,209	37,121,803 (33,846,426–40,284,355)		42,207,639 (34,996,120–49,266,189)		47,248,254 (36,812,714–58,513,990)
Population, WPP 2024 medium (low–high fertility variant)			33,264,292	37,443,752 (36,975,902–37,911,583)		42,592,206 (40,808,840–44,374,794)		47,693,910 (44,314,448–51,092,530)
Aged ≥50 y, n (% of population)			4,225,016 (12.7)	5,565,276 (14.9)		8,068,172 (18.9)		10,080,120 (21.1)
Aged ≥65 y, n (% of population)			937,888 (2.82)	1,382,130 (3.69)		2,273,044 (5.34)		3,909,534 (8.20)
Aged ≥80 y, n			139,078	200,990		361,406		750,613
Old-age dependency ratio (65+/15–64), per 100			3.86	5.02		7.31		11.43
Median age, y			30.2	30.7		31.7		33.0
Sex ratio, males per 100 females			154.2	149.1		142.0		137.2
Expected-rate index vs 2023 (primary gradients): cataract / non-cataract			1.000 / 1.000	1.179 / 1.100		1.533 / 1.274		2.055 / 1.507
Life expectancy at birth, both sexes, y			78.7	80.3		82.3		84.0
Total fertility rate			2.28	2.17		1.98		1.88
B. Projected Prevalent Cases and YLDs								
Cause	Scenario	Sex	2023	Projection (95% UI)			Crude rate per 100,000, 2050	Δ count 2023–2050, %
				2030	2040	2050		
Prevalence								
All vision loss	S1 constant age-adjusted rates	Both	1,484,415	1,849,572 (1,551,750–2,231,501)	2,463,772 (1,850,273–3,299,005)	3,307,527 (2,197,806–5,020,886)	7,000.3	+122.8
	S2 2010–2023 trend continued	Both	1,484,415	1,748,198 (1,467,426–2,109,443)	2,153,292 (1,611,165–2,886,878)	2,676,464 (1,761,441–4,084,606)	5,664.7	+80.3
	S1 constant age-adjusted rates	Female	560,171	728,732 (605,785–877,586)	1,046,534 (760,674–1,418,013)	1,482,165 (943,994–2,273,845)	7,604.2	+164.6
	S1 constant age-adjusted rates	Male	924,244	1,120,840 (946,162–1,354,347)	1,417,238 (1,086,059–1,883,633)	1,825,362 (1,250,269–2,744,832)	6,576.2	+97.5
	S2 2010–2023 trend continued	Female	560,171	702,543 (583,987–846,041)	956,807 (696,264–1,301,495)	1,283,841 (814,945–1,979,055)	6,586.7	+129.2
	S2 2010–2023 trend continued	Male	924,244	1,045,655 (881,757–1,260,916)	1,196,485 (912,760–1,599,081)	1,392,623 (940,719–2,116,722)	5,017.2	+50.7
	Comparator: ARIMA(1,1,0)+drift on crude rate (no age structure)	Both	1,484,415	1,802,060 (1,674,857–1,938,923)	2,190,448 (1,817,695–2,639,640)	2,575,840 (1,947,151–3,407,517)	5,451.7	+73.5
Cataract	S1 constant age-adjusted rates	Both	132,573	176,483 (144,708–212,134)	262,369 (197,112–337,302)	395,100 (268,140–554,201)	836.2	+198.0
	S2 2010–2023 trend continued	Both	132,573	158,114 (129,476–190,679)	203,124 (151,634–262,503)	266,620 (179,559–379,290)	564.3	+101.1
Non-cataract	S1 constant age-adjusted rates	Both	1,351,842	1,673,089 (1,403,280–2,022,348)	2,201,403 (1,632,121–2,986,402)	2,912,427 (1,880,927–4,534,323)	6,164.1	+115.4
	S2 2010–2023 trend continued	Both	1,351,842	1,590,084 (1,332,453–1,922,423)	1,950,168 (1,441,167–2,644,701)	2,409,844 (1,550,376–3,758,037)	5,100.4	+78.3

Table 6: Continued

Cause	Scenario	Sex	2023	Projection (95% UI) 2030	2040	2050	Crude rate per 100,000, 2050	Δ count 2023–2050, %
Years Lived With Disability								
All vision loss	S1 constant age-adjusted rates	Both	67,354	84,258 (54,906–122,286)	113,057 (69,966–175,106)	152,982 (87,829–257,050)	323.8	+127.1
	S2 2010–2023 trend continued	Both	67,354	73,997 (48,192–107,463)	82,725 (50,845–128,911)	93,413 (52,895–158,369)	197.7	+38.7
	S1 constant age-adjusted rates	Female	26,236	34,273 (22,218–50,121)	49,581 (30,152–77,558)	70,777 (39,416–120,689)	363.1	+169.8
	S1 constant age-adjusted rates	Male	41,118	49,985 (32,732–72,274)	63,476 (39,701–97,388)	82,205 (48,107–136,912)	296.2	+99.9
	S2 2010–2023 trend continued	Female	26,236	30,862 (20,006–45,134)	38,373 (23,262–60,215)	46,983 (25,956–80,460)	241.0	+79.1
	S2 2010–2023 trend continued	Male	41,118	43,134 (28,208–62,445)	44,352 (27,533–68,407)	46,430 (26,716–78,650)	167.3	+12.9
	Comparator: ARIMA(1,1,0)+drift on crude rate (no age structure)	Both	67,354	77,112 (70,261–84,631)	84,242 (65,703–108,014)	87,703 (59,730–128,776)	185.6	+30.2
Cataract	S1 constant age-adjusted rates	Both	8,965	11,954 (8,106–16,803)	17,826 (11,425–26,134)	26,899 (15,977–42,030)	56.9	+200.1
	S2 2010–2023 trend continued	Both	8,965	9,714 (6,575–13,686)	10,922 (7,006–16,109)	12,563 (7,445–19,747)	26.6	+40.1
Non-cataract	S1 constant age-adjusted rates	Both	58,390	72,304 (46,729–105,877)	95,230 (57,862–150,235)	126,083 (69,590–219,495)	266.9	+115.9
	S2 2010–2023 trend continued	Both	58,390	64,282 (41,493–94,113)	71,803 (43,429–113,480)	80,850 (44,444–140,394)	171.1	+38.5

C1. Ophthalmology Workforce Requirements

Indicator	2023	2030	2040	2050
Registered ophthalmologists (Jan 2023); per million [19]	2,608; 79.1 (81.06 on census 2022)			
Prevalent vision-loss cases per ophthalmologist if 2023 stock is frozen (S1 / S2)	569	709 / 670	945 / 826	1,268 / 1,026
Ophthalmologists to hold 2023 cases per ophthalmologist, S1 (CAGR from 2023, %)	2,608	3,250 (+3.19)	4,329 (+3.03)	5,811 (+3.01)
Ophthalmologists to hold 2023 cases per ophthalmologist, S2 (CAGR from 2023, %)	2,608	3,071 (+2.36)	3,783 (+2.21)	4,702 (+2.21)
Ophthalmologists to hold 2023 ophthalmologists per capita (CAGR, %)	2,608	2,935 (+1.70)	3,337 (+1.46)	3,735 (+1.34)
Physicians, all sectors (2023 / 2024); nurses (2023 / 2024) [39–41]	113,300 / 129,772; 213,110 / 243,336			
Ophthalmologists as % of physicians; Saudi share of ophthalmologists [19]	2.30%; 37.7% (983/2,608)			

C2. Arithmetic of the WHO effective cataract surgical coverage target, 2030

Assumed Baseline eCSC, %	Persons needing surgery, 2030 (S1)	Additional persons effectively operated on for +30 pp	Residual cataract vision loss, 2030	Change vs S1 cataract vision loss, 2030, %	Additional effective operations per ophthalmologist-year, 2024–2030
45.0 (illustrative middle-income level)	320,878	96,263	80,220	−54.5	5.3
55.0	392,184	117,655	58,828	−66.7	6.4
60.5 (high-income median, McCormick 2022)	446,792	134,038	42,445	−75.9	7.3
70.0 (upper high-income range)	588,277	176,483	0	−100.0	9.7

C3. Coverage benchmarks and targets

Indicator	Value	Source
WHO 2030 targets (WHA74, May 2021)	+30 pp eCSC; +40 pp eREC	WHO [7]
eCSC, high-income countries, median (IQR)	60.5% (55.6–65.4)	McCormick et al. 2022, 55 countries [9]
eCSC, low-income countries, median	14.8%	McCormick et al. 2022 [9]
eCSC men vs women, pooled risk ratio (95% CI)	1.20 (1.15–1.25)	McCormick et al. 2022 [9]
Projected eCSC gain 2020–2030 at current pace	+8.4 pp (target +30 pp)	McCormick et al. 2022 [9]
Distance eREC 2021, North Africa and Middle East / high-income	62.1% (54.7–68.8) / 79.1% (72.4–85.0)	Bourne et al. 2022, 61 countries [10]
Near eREC 2021, global	20.5% (17.8–24.4)	Bourne et al. 2022 [10]
Implied 2030 eREC target from regional proxy: distance / near	100% (capped) / 60.5%	This analysis

CAGR: Compound Annual Growth Rate, eCSC: Effective Cataract Surgical Coverage, eREC: Effective Refractive Error Coverage, PI: Probabilistic Interval, pp: Percentage Points, S1: Constant 2023 Age-Adjusted Rates, S2: Continuation of the 2010-2023 Log-Linear Trend in Age-Adjusted Rates, UI: Uncertainty Interval. Projections Use UN WPP 2024 medium-variant growth applied to GBD 2023 population by sex and single-age structure of the WPP to the reference gradients (see Table 2 footnotes) [12]. 95% uncertainty intervals from 10,000 Monte Carlo simulations based on GBD 2023 level uncertainty, the 81-gradient grid, standard errors of trend slope and the WPP 2024 95% probabilistic interval for total population. The ARIMA (1,1,0)-with-drift comparator [59] projects log crude rate without age structure. WPP 2024 mid-year totals match the published series (33,264,292 in 2023), the GBD 2023 population is 0.8% smaller in 2023 but 52.7% greater in 1990. Ophthalmologists: registered in January 2023 [19], physicians and nurses: Ministry of Health Statistical Yearbooks [39–41]; eCSC arithmetic: persons needing surgery = projected cataract vision loss / (1 - baseline eCSC), the +30pp goal implies an extra 0.30 x that amount of people have good surgery outcome by 2030 [7], there is no published Saudi Arabia national eCSC baseline, so the baseline is varied. Workforce and eCSC values are planning scenarios, not validated requirements or backlog estimates

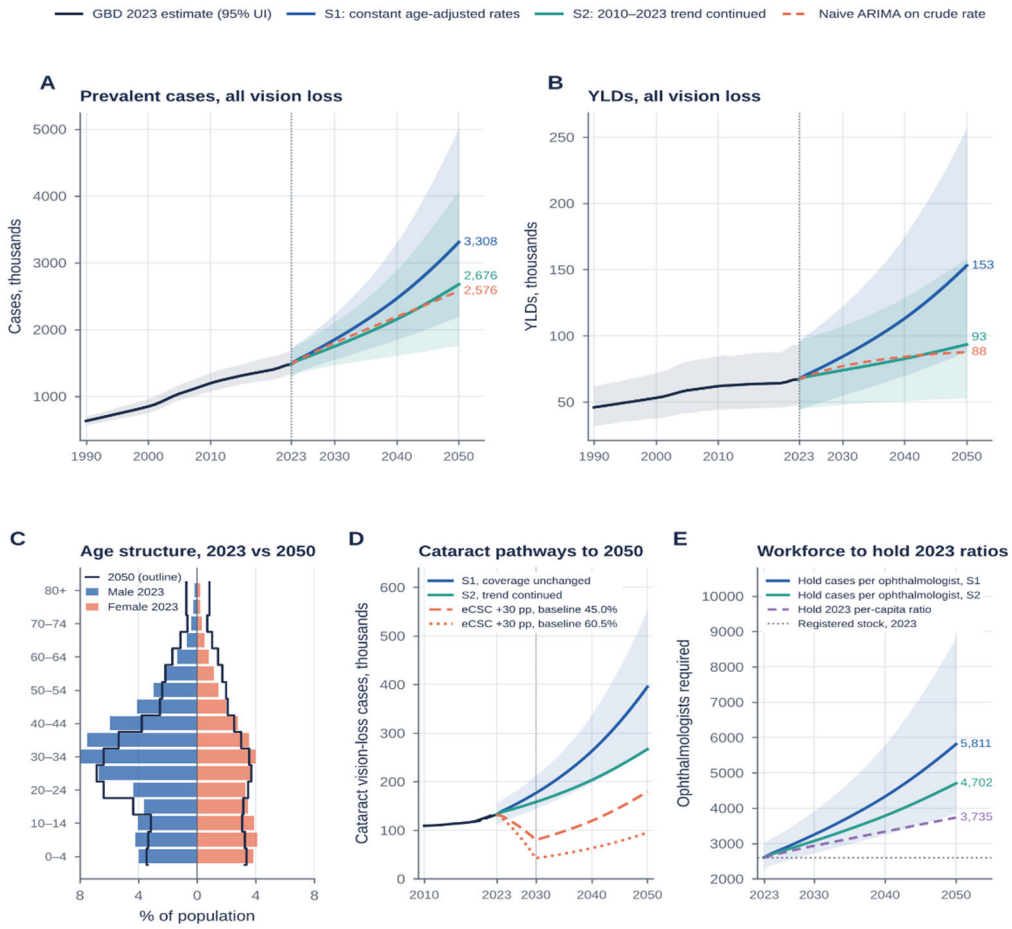


Figure 6: Estimates and Projections of the Burden and Needs for Services Due to Vision Loss till 2050
(A, B) Projections derived using the estimates of the GBD 2023 between 1990 and 2023 with 95% uncertainty intervals along with projections till 2050 derived under scenarios S1 (rates for 2023) and S2 (trends for 2010 to 2023 extrapolated) with 95% intervals, and naive ARIMA comparator; (C) Population by five-year age groups and gender as proportions of the total for 2023 (bars) and 2050 (outlines)[12]; (D) Cataract Vision Loss Pathways under S1 and S2 scenarios and trends consistent with the 30 percentage point increase in effective cataract surgical coverage (eCSC) by 2030 starting from baseline of 45.0% and 60.5%; (E) Ophthalmologists needed to maintain the 2023 case rate (under S1 scenario with 95% interval; S2 scenario), or 2023 per capita ratio, compared with the 2,608 registered in January 2023[19]

constant requires 3,071-3,250 ophthalmologists in 2030 and 4,702-5,811 in 2050 (compound annual growth rate 2.21-3.01%) beginning with 2,608 in 2023 as compared to 3,735 (CAGR 1.34%) required to hold the per-capita ratio; this is a scenario calculation, not an estimation of health workforce requirements. If the baseline eCSC was 45.0-60.5%, the WHO target requires 96,263-134,038 good outcomes per year (5.3-7.3 per ophthalmologist-year) in 2030 and reduces cataract vision loss by 54.5-75.9% relative to S1; at a baseline eCSC of 70.0%, it requires 176,483 surgeries (9.7 per ophthalmologist-year) and eliminates residual cataract vision loss. These are planning scenarios, not an estimation of the national backlog (Table 6).

DISCUSSION

From 1990 to 2023, Saudi Arabia saw more than doubling in numbers of prevalent vision-loss cases despite the decreases in age-adjusted rates because the effects of ageing and population growth dominated over the assumed epidemiological decline in our simulations; the former are robust, while the split between ageing and epidemiological change is assumption-dependent. As a result of the decline in age-adjusted rates and rise in caseloads, the age-adjusted YLD rate and cataract YLD rate decreased by 46.9% and 70.9%, correspondingly, and the age-adjusted prevalence rate decreased by 13.4%. Three other insights that might be important for policy include the following. After 2019, all crude rates increased; the crude rates of females had a deficit relative to crude all-cause rates that are mainly a consequence of the influx of males, whereas there exists a persistent female excess in age-adjusted cataract rates; and measuring visual impairment in the surveys conducted in the Saudi community revealed values several times higher than GBD's estimates with sex differences not being reproduced in GBD. Ageing will be the key driving factor in the coming decades: the caseload and YLD would almost triple by 2050, under the assumption of constant age-adjusted rates.

The trends are in line with GBD 2019 findings according to which the largest declines in prevalence (20.9%) and age-standardized YLD rate (42.2%) of all Saudi

causes took place during 1990-2019 [20], as opposed to our indirectly adjusted declines of 13.4% and 46.9% for 1990-2023. While GBD 2021 reported the increase in the age-standardized prevalence together with the stable DALY rate [21] globally. The Saudi combination of large reduction in age-adjusted severity together with the modest decrease in age-adjusted prevalence fits the trend of the DALY rate of refraction disorders globally [23]; according to GBD 2021, cataracts' burden is among the most important causes of health loss among older adults [22]. The age-adjusted rate component analysis follows the global experience of the age-adjusted mortality rates: the impact of ageing grew 2.7 times from the 1990s to 2019-2023 in Saudi Arabia (from 7,025 to 19,314 cases per year), but the growth component fell down to 1.4% of the 2019 caseload for 2019-2023. For our methodology, it means that the only available forecasting model for the Gulf countries used univariate time series for GBD 2019 data [25]; our model that did not consider the age-structure of the population predicted 25% of the future increase in S1 YLD to 2050; crude time series could not forecast the ageing transition that has not happened yet, but no approach has been externally validated so far.

The increasing trend in the crude rates of all 18 series starting from 2019, especially strong for the prevalence of cataract (AAPC 3.05%), in the presence of the assumed gradients, was mainly attributable to ageing that added 5.6% to the all-cause caseload (8.7% for cataract) in 4 years. However, it was not a pure demographic effect: the epidemiological change in cataract prevalence was unfavorable in 2019-2023 (+2.3% of 2019 caseload), as the only period of epidemiological change; the age-adjusted YLD rate has increased slightly above its minimum value recorded in 2020 to its next peak in 2021 and 2022 and then dropped to a new minimum in 2023. Due to the COVID-19 pandemic, elective cataract surgery experienced significant disruption in the national tertiary eye care hospital in Riyadh, where 71 (0.73%) of 9,701 patients operated on between November 2018 and January 2022 were treated for cataract during the pandemic phase, and their monthly rate has not returned back by then [65]; the 2 years after the surgery suspension have been expected to result in the backlog of 1.1-1.6 million procedures among Medicare beneficiaries in the United States [66]. Thus, the recent estimates depend highly on modelled covariates, and the increasing trend cannot be explained with the pandemic effects alone; however, it corresponds with it and with the fact that the age-adjusted prevalence rate in 2023 is still above its 2019 value, thus, the backlog should be monitored using the measures of the use of services, not GBD.

The gap analysis for sexes illustrates how misleading it can be to compare crude rates in the Gulf countries' populations. Two-thirds of the crude female deficit of all-cause prevalence in 2023 were due to the composition of the population consisting of males and non-Saudi males of working age and a female population with a greater proportion of children; the all-cause sex ratio, adjusted for age, is almost the same for the two sexes. On the other hand, the cataract excess existed in all years and increased by 0.29-0.54% per year: in 2023, it exceeded 1 in all 81 specifications, mostly rate effects. Females compose 55% of people blind or having moderate to severe visual impairment worldwide [1], cataract surgical coverage is lower in women [67], and the ratio of the coverage of cataract surgery estimated is 1.20 times higher for men than women [9]. The cataract excess corresponds to the access gap rather than to some demographic effect; however, this can be checked only with the individual-level or nationality-specific estimates. According to two Qassim community surveys, the prevalence of presenting visual impairment is 1.49 times higher in females, and this is a difference not seen in the GBD all-cause estimates. Differences in the age distribution, sampling, definition and the population composition might be responsible for this; the national statistics of eye care should report separately the use of services by sex, and the sex gap in eCSC should be estimated.

Our frontier analysis has revealed that the decrease in burden followed the fertility transition in an inconsistent way. During 2000-2010, when the total fertility has decreased from 4.2 to 2.8 children per women, the age-adjusted YLD rate decreased much slower, forming a 25.5% gap in 2005; the gap reached 47.5% for cataract YLD in 2004 and stayed wide until 2017. According to GBD 2019, the age-standardized YLD rate in Saudi Arabia was the highest in the region, 71% higher than that of Kuwait [20]; the region as a whole had 2.35 times the age-standardized DALY rate compared to the high-SDI countries in GBD 2021 [21]. While each comparison is rather coarse either spanning over the model rounds or being single-country-based, and differences in the age structure, migration, availability of surveys, access and data quality might affect these estimates, all comparisons put the Saudi burden above these benchmarks. Cataract YLD rate shows the steepest association with the fertility transition (-27% for one-child decrease in fertility); the gap is not a measure of the avoidable burden or policy failures.

Through the process of triangulation, another gap in the GBD estimates appeared. Community campaign surveys conducted in Qassim revealed the prevalence of presenting visual impairment at 27-40%, and the GBD all-age prevalence estimates showed crude cross-definition difference of about seven times lower. The constructs are different: while GBD includes all severities and all ages, surveys in Qassim assessed the presenting distance acuity among campaign attendees for whom uncorrected refractive error causes most of visual impairment. Definition alone cannot fully account for the difference: national meta-analysis has pooled the population-based studies' prevalence of 10.8%, twice higher than the GBD's estimate; already in GBD 2019, Saudi Arabia belonged to the countries with higher-than-expected YLD rates [20]. Selecting campaign attendees and using the clinic-based ascertainment, in addition to the possible overlap between the meta-analysis results and the surveyed samples, may contribute to the difference, so these ratios are not validation statistics. The

surveys also provide the main need for the services: two-thirds or even more of participants (65.8-72.2%) never had an eye examination, and only one in five of the ones with the refractive error among Duhknah residents wears glasses that is a very rough measure being significantly lower than the regional distance eREC 62.1% among adults 50 years or older [10]. Refractive care services, including the school screening of young population affected with myopic epidemic [68] and the near-vision correction for presbyopia [69] are as important as cataract surgery.

Ageing will change the need. While the expected age-65 population increases 4 times, and the expected prevalence of cataract increases twice, thus the number of cataract cases would almost triple at constant age-adjusted rates. Under the scenario with maintaining of the current caseload to ophthalmologist ratio at 2023 level, the workforce would need to increase by 2.2-3.0% per year, i.e. to 4,702-5,811 ophthalmologists, and not 3,735 (1.3% annually) to cope with the population increase; but because this ratio does not take into consideration the severity, case-mix, productivity, distribution of the ophthalmologists, optometrists, refractive services and capacity, it is just the planning benchmark. Under our assumption, the target of 80% coverage of cataract in the elderly population set by WHO would require about 5 to 7 additional successful operations per ophthalmologist-year (9.7 at 70% baseline); but this is only an estimate that cannot be verified because Saudi Arabia has neither the population-based eCSC nor eREC estimate; the last RAABs in it have taken place in 2012 and 2015 [7,27,28]. A nationally representative survey with standardized visual-acuity definitions such as RAAB with the eCSC and eREC modules for the population 50 years or older plus assessment of refractive errors for all ages stratified by age, sex and nationality would provide the baseline for the targets set for 2030, help close the gap between modelled and measured prevalence and give GBD data needed; the monitoring should include eCSC, eREC, waiting times, visual outcomes and the distribution of services. Diabetes in Saudi Arabia with the age-standardized prevalence of 23.1% among adults [15] and retinopathy of one-fifth of patients in registry [16] will increase the need in retinal screening and treatment that cannot be covered by vision loss prevalence projections.

Limitations

The GBD data extracted included only all-age crude estimates for the Kingdom of Saudi Arabia in two causes. Thus, age adjustments rely on user-defined age gradients based on global results – an important source of structural uncertainty affecting decomposition, sex-gap, frontier and projections analysis. Ageing contribution to prevalence burden has been found to vary from 13% to 78% of 1990 burden, while age gradient in the surveys is smaller than the main gradient, therefore, only decomposition of YLD burden, whose contributions retain their sign in every specification, can be considered robust; the sign of the contribution of epidemiological component to prevalent cases has proved not to be robust and does not allow for valid conclusion about progress in epidemiology. GBD age-specific estimates could eliminate this assumption. Non-Cataract diseases could not be disaggregated, and the uncertainty of the residual part is independent among causes. Neither SDI nor cross-country estimates have been available, and therefore, efficiency is assessed relative to the trajectory of Saudi Arabia and fertility proxy; the external benchmarking is based on earlier rounds of GBD which have very different levels compared to those of GBD 2023. The revision in the WPP 2024 of historical population of Saudi Arabia has been downward. The GBD burden estimates have been summed up using the WPP age structure and a migratory allocation has been performed, but the age structure of population in 1990s remains uncertain. The survey data is regional, campaign-based or clinic-based, heterogeneous and by definition differs from the GBD data; they cannot constitute validation of the GBD all-vision loss category, and the ratio to GBD measures discordance, not bias. Projections hold the rate or trend constant and do not consider potential future changes in the diabetes, myopia, prevention, treatment, technology, service delivery or migration policy, and the UIs are measures of parameter uncertainty only. Single-country frontiers are not comparable to cross-country SDI frontiers and, therefore, cannot measure the lowest possible burden. Workforce estimation does not reflect service capacity, and registered ophthalmologists do not equal active clinical full-time equivalent.

CONCLUSION

In Saudi Arabia, prevalent cases of vision loss have more than doubled between 1990 and 2023 mainly due to the population growth and ageing, while age-adjusted prevalence and YLD rates have decreased; sizes of the ageing and epidemiological effects depend on assumptions made regarding age gradients, and sign of the contribution of epidemiological factor to prevalent cases proves not to be robust. Decline was greatest for YLD burden and cataracts, while crude rate increased for all 18 GBD categories since 2019; that is the observed trend in the modelled categories to which ageing and adverse epidemiology changes for cataract burden contributed; the age-adjusted rate in 2023 was still above 2019 level. Excess female rate in cataract prevalence is age-adjusted and the crude shortfall of females in overall prevalence burden is compositional in nature, and measured survey presenting visual impairment rate, a different indicator, is several times higher than the GBD prevalence rate, which shows discrepancy between sources, not the quantifiable GBD underestimation. With doubling of the expected crude cataract rate just due to ageing alone by 2050, the priority is conducting of the nationally representative survey with standardized definitions and stratification by age, gender and nationality, as well as measurement of eCSC and eREC; recovery of the pandemic surgery backlog and expansion of refractive services and ophthalmologist numbers are recommended scenarios of planning, not as proven national requirements.

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