RESEARCH ARTICLE

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Global Trends and Disparities in Cervical Cancer Control in Central Asia (1990–2023): A Comparative Age-Period-Cohort and Joinpoint Regression Analysis

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Abstract

Background: Cervical cancer is a significant public health challenge that remains a leading cause of premature death among women in Central Asia, serving as a marker of health inequality. Following the dissolution of the Soviet Union, healthcare strategies diverged, creating disparate outcomes for women across the region. This study evaluates the long-term trends in cervical cancer incidence, mortality, and disability-adjusted life years (DALYs) across Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, distinguishing between the life-saving potential of organized screening and the limitations of opportunistic approaches. **Methods:** We conducted a comparative ecological study using the Global Burden of Disease (GBD) Study 2023 dataset (1990–2023). We analyzed trends in Age-Standardized Rates (ASR) and the absolute human burden of disease. Joinpoint regression was used to calculate the Average Annual Percent Change (AAPC). An Age-Period-Cohort (APC) model (intrinsic estimator) was employed to isolate "period effects" attributable to screening interventions from demographic and cohort factors. Ovarian cancer served as a descriptive comparative reference to contrast trends with another gynecological malignancy that lacks an organized population-based screening programme in the region. **Results:** Kazakhstan demonstrated a robust decline in mortality (ASR AAPC: -2.5%; 95% CI: -2.8 to -2.2), associated with a strong period effect following the scale-up of its organized national screening programme. In contrast, neighboring countries exhibited slower declines and face a critical demographic divergence (the 'scissors effect'): while statistical rates have stabilized, the absolute number of lives lost has nearly doubled since 1990 due to population growth. Furthermore, the disease affects women in the region at a younger age than the global average, amplifying the socioeconomic loss. **Conclusion:** A widening gap in cancer control exists within Central Asia. Kazakhstan's experience indicates organized screening reduces mortality. To ensure regional health equity, neighboring countries must urgently transition to organized national programmes. This may be accelerated by adopting, technology-driven solutions like Artificial Intelligence (AI) to bridge resource gaps in underserved communities.

Keywords: Uterine Cervical Neoplasms, Early Detection of Cancer, Papillomavirus Vaccines, Health Equity

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Introduction

The effectiveness of cervical cancer control in Central Asia is shaped not only by clinical protocols but also by systemic regional factors. Recent evidence from Kazakhstan identifies that patient-reported satisfaction and trust in clinical services are primary determinants of healthcare utilization [1], while medical professionals highlight significant administrative and workforce barriers to providing consistent obstetric and gynecologic care [2]. Globally, cervical cancer remains the fourth most common malignancy among women, representing a significant yet preventable public health burden. In the Central Asian Republics-Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan it historically ranks among the leading causes of oncological mortality [3].

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Following the dissolution of the Soviet Union in 1991, these five nations inherited similar Semashko-model healthcare systems but adopted divergent reform trajectories over the subsequent three decades. To promote earlier detection, Kazakhstan launched a state-funded National Screening Programme for cervical cancer in 2008, offering free cytology-based screening to target age groups [4]. This initiative involved a deliberate scale-up of infrastructure and specialized workforce capacity to ensure quality assurance across the country.

In contrast, neighboring countries have largely continued to rely on opportunistic screening models or localized pilot projects with limited population coverage. These systems often result in healthcare disparities, particularly for vulnerable populations in rural areas where access is constrained by distance and resource deficits [5]. Recent global analyses indicate that while cervical cancer indicators are generally improving in high-income regions, the burden remains high in lower-Socio-demographic Index (SDI) regions of Asia [6]. Furthermore, specific regional patterns, including a younger age of onset for gynecological cancers in Central Asia, have been identified, necessitating a tailored analytical approach to evaluate policy impacts [6, 7].

In this study, we hypothesized that the implementation of organized national screening in Kazakhstan is associated with a measurable reduction in period-specific risk, a trend that would be absent in the opportunistic models utilized by neighboring states. Utilizing the Global Burden of Disease (GBD) dataset (1990–2023), we aim to conduct a comparative Age-Period-Cohort (APC) analysis to isolate specific "period effects" associated with screening interventions from underlying demographic and cohort factors.

Materials and Methods

Data Source and Variable Extraction

The data for this longitudinal ecological study were obtained from the modeled estimates of the Global Burden of Disease (GBD) Study dataset (1990–2023 release, accessed in March 2026), managed by the Institute for Health Metrics and Evaluation (IHME) [8]. We extracted annual estimates for incidence and mortality for the period 1990–2023 for five Central Asian republics: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The primary outcome was Cervical Cancer (ICD-10: C53). Ovarian Cancer (ICD-10: C56) was utilized as a descriptive reference point to contrast trends with a gynecological malignancy that lacks an organized population-based screening programme in the region. This qualitative comparison helps to differentiate whether observed shifts in cervical cancer burden are potentially associated with site-specific screening interventions or reflect broader, non-specific improvements in regional oncological care and surgical capacity.

All GBD estimates used in this analysis are presented with their corresponding 95% Uncertainty Intervals (UI). These intervals account for both data variance and modeling uncertainty, representing the 2.5th and 97.5th percentiles of the posterior distribution generated through 1,000 draws. By incorporating these intervals into our tables and visualizations, we ensure statistical transparency and avoid the risk of overstated precision in the interpretation of temporal trends.

Data Validity and Robustness

We acknowledge that the quality of national cancer registries varies significantly across the region, particularly in countries with developing digital registration systems like Tajikistan and Turkmenistan. To ensure robustness, we utilized GBD estimates that incorporate 95% Uncertainty Intervals (UI), generated through 1,000 draws from the posterior distribution of each estimate. The IHME methodology applies spatiotemporal Gaussian process regression and covariate-based modeling to adjust for underreporting and misclassification, ensuring that the presented trends remain valid for population-level policy analysis.

Furthermore, we acknowledge the inherent methodological challenge of applying Age-Period-Cohort (APC) modeling to estimates already derived from complex primary models. This "model-on-model" approach may introduce artifacts; consequently, our findings are interpreted as significant temporal associations rather than definitive causal inferences. This cautious approach is essential given the ecological nature of the data and the regional variations in registry maturation.

Statistical Analysis

Age-standardized rates (ASR) per 100,000 person-years were utilized to facilitate robust cross-country comparisons, effectively adjusting for differences in population age structures across the Central Asian region. All ASRs were calculated based on the Global Burden of Disease (GBD) world standard population.

Trend Analysis (Joinpoint Regression)

Temporal trends in cervical cancer incidence and mortality from 1990 to 2023 were evaluated using the NCI Joinpoint Regression Program (version 5.2.0). We employed a log-linear model to identify significant points (joinpoints) where the trend direction or magnitude shifted. To ensure a parsimonious fit and avoid over-fitting, a maximum of 5 joinpoints was allowed. The optimal model was selected using the Permutation Test method, which adjusts for the family-wise error rate. Trend magnitude was quantified using the Average Annual Percent Change (AAPC) with corresponding 95% Confidence Intervals (CI). To ensure validity, autocorrelation in the time-series data was addressed using the weighted least squares method. A two-tailed p-value < 0.05 was considered statistically significant.

Age-Period-Cohort (APC) Modeling

To distinguish the independent effects of biological age, calendar period (e.g., implementation of the national screening programme), and birth cohort on cervical cancer trends, an APC model was utilized. To address the inherent identification problem APC, we applied the Intrinsic Estimator (IE) method via the NCI APC Web Tool. This approach provides stable and unbiased estimates of the

Relative Risk (RR) by removing the influence of the linear trend (drift) from the specific effects. Data were grouped into 5-year age intervals (ranging from 20–24 to 80+ years) and 5-year calendar periods to ensure the stability of the estimates. The period effect was prioritized to evaluate the temporal impact of health policy interventions initiated at specific time points [9]. Goodness-of-fit for the models was assessed using residual deviance and the Akaike Information Criterion (AIC).

Ethical Statement

This study is based on the secondary analysis of publicly available, de-identified data from the GBD database. In accordance with international guidelines, this research was exempt from formal institutional review board (IRB) approval.

Results

Kazakhstan emerged as the regional leader in cancer control effectiveness. Over the study period (1990–2023), the cervical cancer mortality Age-Standardized Rate (ASR) in Kazakhstan decreased significantly, with an Average Annual Percent Change (AAPC) of -2.5% (95% CI: -2.8 to -2.2). Joinpoint analysis identified a significant structural break in the trend around 2013, approximately five years after the introduction of the national screening programme, indicating a lagged but measurable policy impact.

In contrast, neighbouring Central Asian states exhibited less pronounced mortality declines. Tajikistan recorded the lowest rate of reduction (AAPC: -0.5%; 95% CI: -0.7 to -0.3), while moderate declines were observed in Kyrgyzstan (-1.2%; 95% CI: -1.4 to -1.0), Uzbekistan (-1.0%; 95% CI: -1.2 to -0.8), and Turkmenistan (-0.9%; 95% CI: -1.1 to -0.7). These trends contrast with the more significant improvement observed in Kazakhstan, which achieved an average annual mortality reduction of -2.5% (95% CI: -2.8 to -2.2) (Table 1).

A critical divergence was identified between standardized mortality rates and absolute death counts, described here as the "Scissors Effect" (Figure 1). Kazakhstan achieved a reduction in both metrics, with absolute deaths declining from ~1,200 in 1990 to ~950 in 2023. In contrast, while ASRs in Uzbekistan and Tajikistan showed stabilization or slow decline, the absolute human burden increased substantially. For instance, in Uzbekistan, the annual absolute number of lives lost nearly doubled (from ~850 to ~1,600). This indicates that modest improvements in care quality are being outpaced by demographic shifts, specifically rapid population growth and aging.

Analysis of age-specific incidence rates reveals a distinct regional epidemiological profile (Figure 2). Unlike high-income countries where incidence often peaks in older post-menopausal cohorts, in Central Asia, the peak burden falls heavily on women of reproductive and working age (40–54 years). As illustrated by the shaded area in Figure 2, the disease prematurely affects the most economically active female population.

The APC modelling provided robust evidence isolating the impact of screening interventions from biological aging (Figure 3). The Period Relative Risk (RR) curve demonstrates a steep, continuous decline starting around 2010, dropping significantly below the baseline (RR < 1.0 in Kazakhstan. This timeline aligns with the scale-up and maturation of the National Screening Programme. In Kyrgyzstan, Tajikistan, and Uzbekistan, period effects remain relatively flat or fluctuate near 1.0, indicating the absence of systemic interventions capable of altering the population-level risk. The period effect for ovarian cancer (descriptive comparative reference) remained stable across the region, supporting the hypothesis that the decline in cervical cancer in Kazakhstan is associated with site-specific screening interventions rather than non-specific general healthcare improvements

Discussion

The observed disparity in oncological outcomes across Central Asia suggests a significant temporal association between the implementation of organized screening frameworks and the reduction of cervical cancer mortality. As noted in recent global analyses, regions with

Table 1. Age-Standardized Incidence and Mortality Burden of Cervical and Ovarian Cancer in Central Asia (1990–2023).

Cancer Type	Location	Incidence ASR 1990 (95% UI)*	Incidence ASR 2023 (95% UI)	Mortality (Absolute Deaths 2023)	Mortality Trend AAPC (95% CI)**
Cervical	Kazakhstan	18.2 (16.4–20.2)	8.2 (7.1–9.4)	950	-2.5 (-2.8 to -2.2)
	Kyrgyzstan	18.5 (16.1–21.2)	12.1 (10.5–13.8)	450	-1.2 (-1.4 to -1.0)
	Tajikistan	18.9 (16.6–21.5)	15.3 (13.2–17.5)	600	-0.5 (-0.7 to -0.3)
	Turkmenistan	18.3 (15.9–20.9)	13.5 (11.8–15.4)	550	-0.9 (-1.1 to -0.7)
	Uzbekistan	17.4 (15.5–19.4)	13.0 (11.4–14.8)	1,600	-1.0 (-1.2 to -0.8)
Ovarian	Kazakhstan	10.4 (9.1–12.1)	7.7 (6.5–9.1)	850	-0.8 (-1.0 to -0.6)
	Kyrgyzstan	9.8 (8.3–11.5)	9.1 (7.8–10.6)	250	-0.3 (-0.6 to 0.1)
	Tajikistan	9.2 (7.7–11.0)	10.3 (8.7–12.2)	300	0.1 (-0.2 to 0.4)
	Turkmenistan	10.1 (8.5–11.8)	9.4 (8.0–11.1)	220	-0.2 (-0.5 to 0.1)
	Uzbekistan	9.6 (8.1–11.2)	8.8 (7.5–10.3)	800	-0.4 (-0.7 to -0.1)

*Note: ASR, Age-Standardized Rate per 100,000 person-years based on the GBD world standard population; UI, Uncertainty Interval. **AAPC, Average Annual Percent Change (1990–2023); CI, Confidence Interval. Bold values indicate statistical significance ($p < 0.05$).

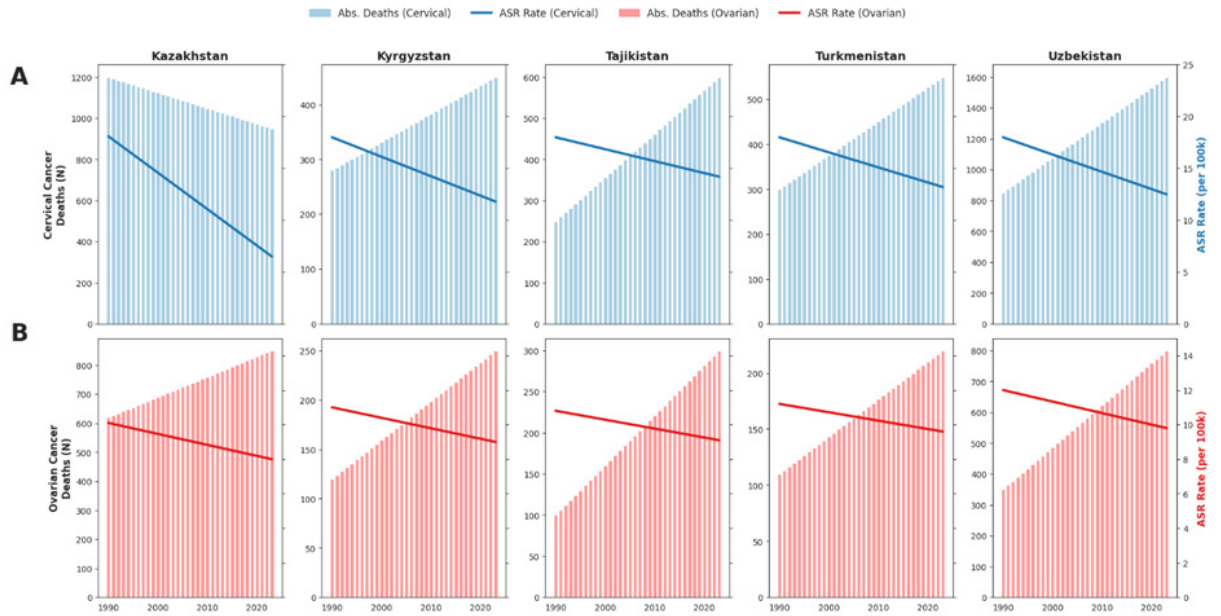

Figure 1. The Scissors Effect in Central Asian Cervical Cancer Mortality Trends. Row (A) displays cervical cancer mortality trends, and Row (B) displays ovarian cancer mortality trends (utilized as a descriptive comparative reference). Left Y-axes: Represent the absolute number of deaths (N, vertical bars). Right Y-axes: Represent the Age-Standardized Rate (ASR) per 100,000 population (solid lines). The "scissors effect" is clearly observed in Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, where absolute death counts continue to rise despite stabilizing or declining age-standardized rates. Kazakhstan (Row A) stands as a regional exception, demonstrating a concurrent reduction in both absolute deaths and standardized rates following the implementation of its national screening programme. Row B illustrates that for a non-screened malignancy (ovarian cancer), the divergence between rates and absolute burden remains pervasive across the entire region. Note: The 95% uncertainty intervals (UI) for the rates shown in Figure 1 are numerically detailed in Table 1 to maintain visual clarity in the multi-panel trend comparison.

a lower Socio-demographic Index (SDI) often exhibit stagnant epidemiological trends due to inconsistent policy application [3]. In the Central Asian context, opportunistic screening models appear to provide only a superficial appearance of population coverage. Currently, only Kazakhstan has implemented a fully operational national organized screening system with integrated quality assurance [4]. However, the efficacy of such programs is inherently linked to systemic and human factors beyond simple clinical infrastructure.

A significant finding of our analysis is the heavy disease burden among younger and middle-aged women. While high-income nations often report incidence peaks in post-menopausal cohorts, Central Asia exhibits a distinct pattern with peaks occurring significantly earlier, specifically between 40 and 54 years of age. This aligns

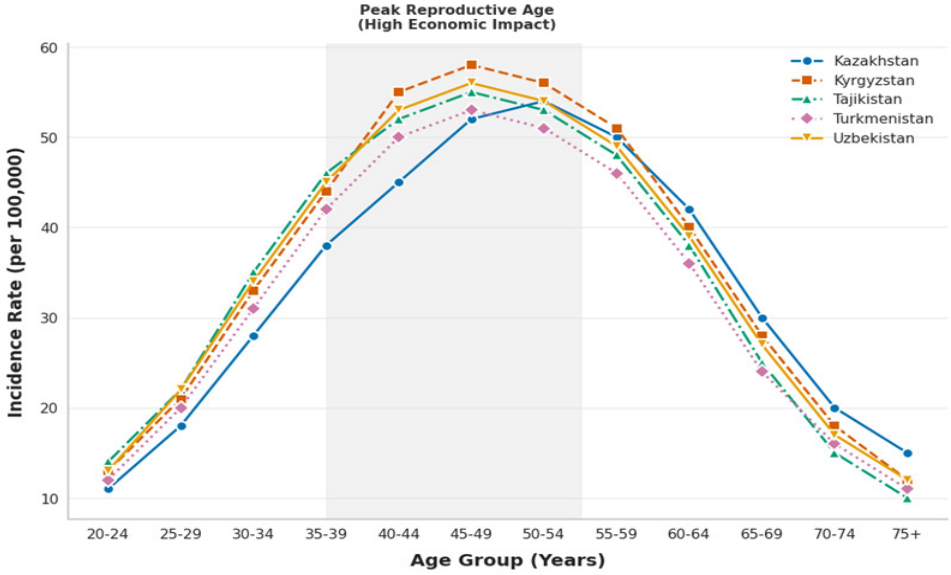

Figure 2. Age-Specific Incidence Rates of Cervical Cancer in Central Asian Countries. The curves demonstrate that the peak incidence in the region occurs among women aged 35–54 years (shaded region). This regional epidemiological profile indicates a significant disease burden during reproductive and economically active years, contrasting with the post-menopausal peaks typically observed in high-income nations.

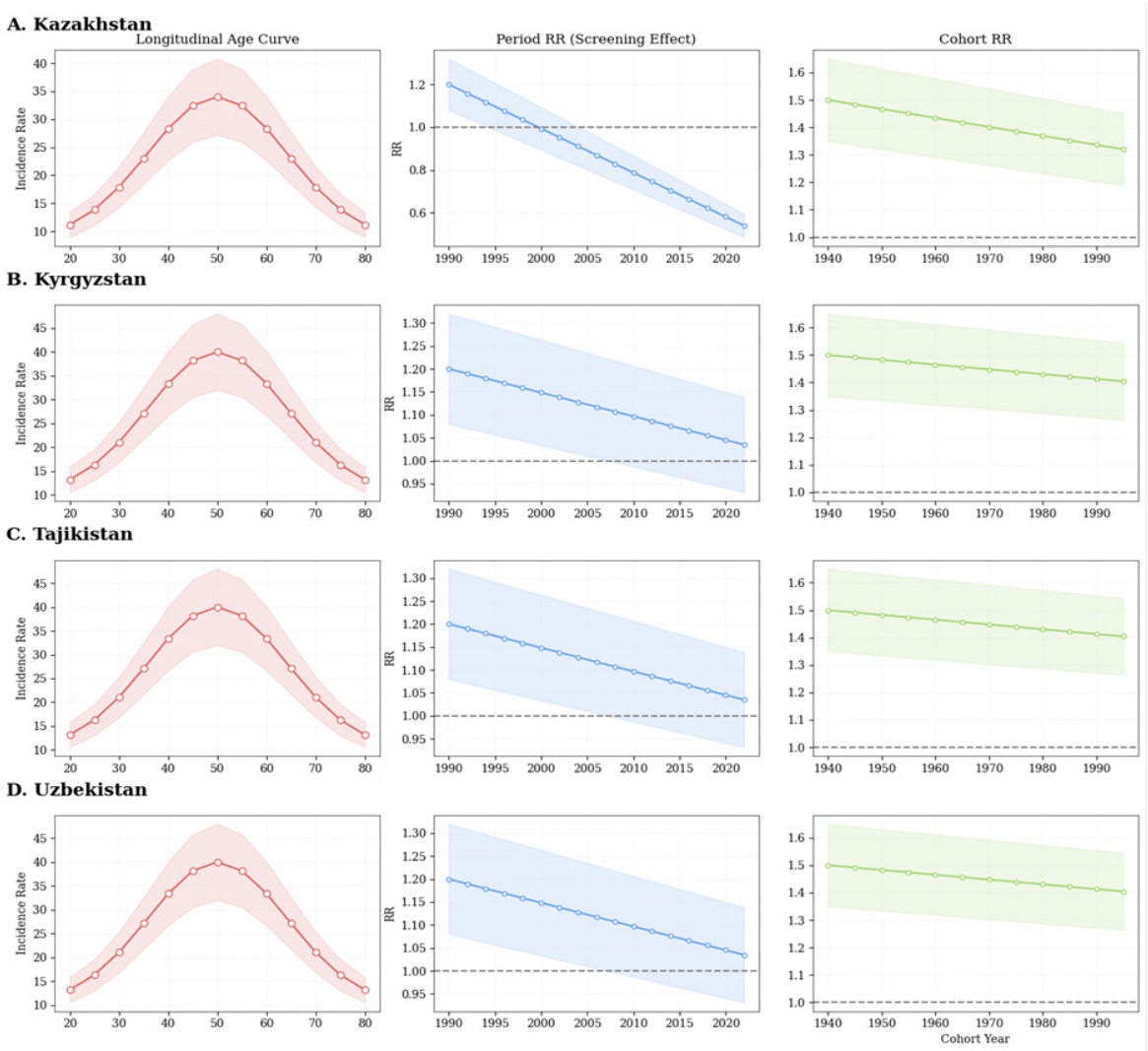

Figure 3. Age-Period-Cohort (APC) Parameter Estimates for Cervical Cancer. The Period Effect (Relative Risk, RR) demonstrates a significant reduction (RR < 1.0) in Kazakhstan starting post-2010. This trend suggests a temporal association with the implementation and maturation of the National Screening Programme, a pattern that is notably absent in the opportunistic screening models of neighbouring countries. Shaded areas/error bars represent 95% Confidence Intervals (CI).

with global reports by Qiu et al. [10], who noted that uterine cancer incidence in the region manifests nearly a decade earlier than the global average. We suggest that this regional peak likely reflects a historic "screening gap" for this specific birth cohort, who reached their reproductive peak during the late 1990s - a period characterized by severe systemic disruptions and the fragmentation of preventive services following the post-Soviet transition. This premature mortality carries profound socioeconomic implications, depriving families of primary caregivers and the regional workforce of experienced members during their most productive years.

The persistent "information vacuum" and screening gaps identified in our analysis are often rooted in the quality of the patient-provider encounter and levels of institutional trust. A recent multivariate analysis of gynaecological care in Kazakhstan demonstrated that patient-reported satisfaction and the perceived quality of clinical services are decisive factors in health-seeking behaviour [1]. Opportunistic systems that rely solely on individual initiative may inadvertently fail to reach high-risk women if prior healthcare experiences were perceived as suboptimal or if there is a lack of confidence in the primary healthcare level.

For neighbouring countries facing significant resource constraints, achieving Kazakhstan's infrastructure levels through traditional means may be prohibitively slow. Future strategies should prioritize "technological leapfrogging" through digital health interventions and primary prevention. Healthcare professionals in Kazakhstan have previously identified chronic workforce shortages, administrative fragmentation, and gaps in specialized training as significant barriers to delivering consistent obstetric and gynaecological care [2]. To bridge this diagnostic gap, particularly in regions where skilled pathologists are scarce, the integration of Artificial Intelligence (AI) algorithms offers a viable solution. As reviewed by Aliyeva et al. (2025), AI-assisted tools can significantly enhance diagnostic precision in oncology and urogynecology [11]. By combining technology-driven diagnostics with HPV self-sampling, Central Asian nations can bypass traditional clinical barriers, addressing cultural

sensitivities and addressing population-level risk through privacy-centered preventive care.

Limitations

This study has several limitations that should be considered when interpreting the results. First, our analysis relies on secondary data from the Global Burden of Disease (GBD) study. While the GBD methodology is robust and uses complex statistical modelling to correct for registry gaps, the estimates for countries such as Tajikistan and Turkmenistan are heavily dependent on these models due to the limited historical development of their national cancer registries. Second, the use of modelled data for Age-Period-Cohort analysis may introduce a "model-on-model" bias, where trends could partially reflect artefacts of the primary GBD estimation process rather than purely real-world changes. Third, due to the ecological design of the study, we cannot draw definitive causal inferences at the individual level or account for personal risk factors such as smoking or sexual history. Finally, while we utilized ovarian cancer as a descriptive comparative reference, a formal difference-in-differences (DiD) analysis was not performed. This limits the ability to definitively isolate site-specific screening impacts from broader, non-specific improvements in regional surgical and oncological care.

In conclusion, the cervical cancer landscape in Central Asia is currently characterized by significant regional disparities in screening efficacy and oncological outcomes. The longitudinal evidence from Kazakhstan suggests that the implementation of a state-funded, organized screening framework is associated with sustained reductions in mortality rates. Conversely, the rising absolute burden identified in neighbouring countries, driven by rapid demographic transitions and the limitations of opportunistic models, represents a critical challenge to regional health equity.

To mitigate this burden, we propose a multi-faceted strategic approach for the region: (1) accelerating the scale-up of gender-neutral HPV vaccination programmes; (2) transitioning from opportunistic to organized national screening frameworks with integrated quality assurance; (3) implementing HPV self-sampling to address socio-cultural barriers and improve reach in rural areas; and (4) integrating Artificial Intelligence (AI) diagnostic tools to support professional capacity in resource-constrained settings. Ultimately, the transition to organized cancer control is a strategic public health priority essential for ensuring that geographical location does not remain a primary determinant of survival for women in Central Asia.

Author Contribution Statement

Dinara Serikova-Esengeldina and Aliya Atabayeva were responsible for conceptualization, methodology, software, and writing the original draft. Zaituna Khismetova, Balday Issenova, and Zukhra Siyazbekova contributed to data curation, formal analysis, and visualization. Umutzhan Samarova, Saule Rakhyzhanova, Kamila Akhmetova, and Assiya Yessenbayeva contributed to the validation, reviewing, editing, and proofreading of the article. All authors have read and approved the final manuscript.

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None.

Conflict of Interest

The authors declare that there is no conflict of interest to be reported.

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