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ORIGINAL ARTICLE

Global and Site-Specific Osteoarthritis Burden, 1990–2021, and Rehabilitation Capacity Modeling for Indonesia: A Spatiotemporal Analysis

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ABSTRACT

Background: Osteoarthritis is a major and growing cause of disability, but prevalence does not directly measure clinically assessed rehabilitation need, demand, utilization, or unmet need.

Objective: We quantified global, regional, national, and joint-site burden and linked rehabilitation-amenable prevalence to transparent capacity scenarios for Indonesia.

Methods: We integrated annual WHO/IHME rehabilitation-amenable osteoarthritis estimates for 195 countries (1990–2021), published GBD 2019 site-specific prevalence, published GBD 2021 incidence and years lived with disability, and WHO rehabilitation specifications. EAPC was calculated from annual posterior-mean age-standardized rates using log-linear regression; published joinpoint AAPC retained its original name. Deterministic scenarios converted Indonesia's 2021 prevalence into direct-contact hours and multidisciplinary FTE-year equivalents.

Results: In 2021, 371.6 million people globally and 9.08 million in Indonesia had osteoarthritis-related functioning problems for which rehabilitation could be beneficial. From 1990 to 2021, prevalence increased by 137.7% globally and 199.8% in Indonesia. Prevalence EAPC was 0.34% annually globally and 0.55% in Indonesia. Knee osteoarthritis had the highest site-specific rate, whereas hand incidence and YLDs had the fastest published AAPCs in several middle-SDI settings. Indonesia's foundational, scale-up, and comprehensive scenarios produced 5,673, 29,223, and 93,914 direct-contact FTE-year equivalents.

Conclusion: Rehabilitation-amenable osteoarthritis burden increased faster in Indonesia than globally and varied by joint site and development level. Scenario outputs are model-based decision quantities, not national staffing requirements or workforce gaps, and require stakeholder validation with local severity, capacity, delivery, referral, adherence, and workforce data.

1. Introduction

Osteoarthritis (OA) is a whole-joint disorder characterized by pain, stiffness, impaired mobility, and limitations in activity and participation. It affects articular cartilage, subchondral bone, synovium, ligaments, periarticular muscle, and the broader movement system rather than representing a simple consequence of "wear and tear." Symptoms and structural findings are imperfectly correlated, and individual trajectories can fluctuate rather than progress uniformly. Nevertheless, OA commonly restricts walking, stair negotiation, hand use, work, caregiving, and social participation. The condition therefore sits at the intersection of rheumatology, rehabilitation medicine, primary care, orthopaedics, healthy ageing, and health-system planning[1].

The epidemiological scale is already substantial. The Global Burden of Disease (GBD) 2021 osteoarthritis analysis estimated 595 million people living with OA in 2020 and projected a continuing increase through 2050 as population growth, ageing, and obesity reshape exposure and survival[2]. Site-specific and contemporary burden analyses consistently identify knee OA as the largest joint-specific component while showing distinct hip and hand patterns across age, sex, geography, and development level[3–8]. Differences between published totals reflect GBD release, reference year, case definition, joint-site expansion, and aggregation rules; they should not be treated as contradictory point measurements.

Absolute case counts and age-standardized rates answer different policy questions. Counts describe the number of people who may seek or require support and therefore track the aggregate service envelope. Age-standardized rates reduce the influence of population age structure and are more informative about epidemiological change. A country may experience modest change in an age-standardized rate while its number of people living with OA rises steeply because the population is growing and ageing. Conversely, a high age-standardized rate does not by itself indicate that existing services are insufficient. Planning requires both epidemiological magnitude and information on current capacity, access, case severity, referral, adherence, treatment mix, productivity, and outcomes. The landmark WHO–IHME analysis operationalized rehabilitation amenability as the prevalence of selected conditions or sequelae for which rehabilitation could be beneficial at least once during the course of illness or injury[9]. Globally, 2.41 billion people had at least one included rehabilitation-amenable condition in 2019, with musculoskeletal disorders contributing the largest share. For OA, WHO reported that 344 million people with moderate or severe disease in 2019 could benefit from rehabilitation[10]. We use a strict terminology hierarchy: rehabilitation-amenable prevalence is the epidemiological estimand; clinically assessed need follows individual evaluation; expressed demand reflects care seeking; utilization is care received; and unmet need requires a need-versus-effective-access comparison. The 344-million estimate cannot therefore be converted directly into annual episodes, visits, referrals, or professionals.

Rehabilitation is central to OA management because pain and structural pathology are only part of the clinical problem. Recent systematic reviews and meta-analyses support structured exercise and education for knee and hip OA, while also demonstrating that effects vary with exercise content, dose, setting, and patient characteristics[11–15]. Hand OA trials and observational studies support progressive resistance exercise, app-delivered self-management, digital education, and selected orthotic approaches as components of a site-specific pathway rather than a knee-only model[16–19].

Delivery evidence is also relevant to capacity design. Randomized trials show that telerehabilitation can achieve outcomes comparable with face-to-face delivery in selected patients, while dose, weight-management integration, and cost-effectiveness depend on pathway design[20–23]. Evidence syntheses emphasize behavior-change techniques, appropriate exercise programming, long-term adherence, guideline quality, and the potential reach of telerehabilitation and mobile health[24–29]. These studies support education, progressive exercise, weight management where appropriate, assistive products, activity modification, and participation-focused strategies, but they do not define a universal annual contact frequency or national staffing ratio.

The WHO Package of Interventions for Rehabilitation (PIR) describes essential OA interventions and the workforce, equipment, consumables, and indicative session times commonly required to deliver them[30]. It provides an evidence-informed service-planning framework, not a prevalence-to-workforce conversion rule.

A second methodological problem concerns trend nomenclature. Many global burden studies estimate a single log-linear slope across an annual age-standardized series and label the transformed coefficient the estimated annual percentage change (EAPC). Joinpoint regression, in contrast, allows slopes to change at identified time points and summarizes the segment-specific annual percentage changes over a prespecified interval as an average annual percentage change (AAPC). Although both are expressed as percent per year, they are different estimands. Renaming a published joinpoint AAPC as EAPC erases information about model structure and may create false comparability across outcomes. Site-specific incidence and YLDs in the available GBD 2021 supplement were reported as joinpoint AAPC[4], whereas annual official rehabilitation-amenable prevalence and YLD series support direct EAPC estimation.

Existing OA burden studies have described incidence, prevalence, YLDs, attributable risks, inequalities, and projections[2–8], whereas the WHO rehabilitation analysis established a condition-based amenability envelope[9]. Neither body of work estimates a country's annual clinical caseload or required workforce. The contribution of the present study is therefore not another GBD burden enumeration. It is a source-separated rehabilitation synthesis that (1) preserves EAPC and joinpoint AAPC as different estimands; (2) distinguishes source UIs from regression model-fit intervals; (3) links joint-site patterns to a stepped rehabilitation pathway; and (4) demonstrates a transparent scenario calculator whose policy assumptions remain visibly separate from epidemiological inputs.

This study had four objectives. First, we described global, regional, and national rehabilitation-amenable OA burden from 1990 through 2021. Second, we characterized published knee, hip, and hand prevalence, incidence, and YLD patterns across Socio-demographic Index (SDI) quintiles without pooling GBD releases. Third, we calculated EAPC only from an official annual series and retained published joinpoint AAPC under its correct name. Fourth, we constructed a one-year rehabilitation capacity model for Indonesia. Indonesia was specified before national trend ranking because it is the investigators' policy setting, combines rapid demographic transition with an archipelagic, decentralized service context and documented regional capacity disparities, and provides a decision-relevant example of why national totals must be disaggregated[31–36]. The country was not selected because Indonesia had an extreme rank, and no global workforce requirement was estimated.

2. Methods

Study design and reporting framework

We conducted a secondary ecological spatiotemporal analysis and deterministic rehabilitation capacity modeling. The unit of analysis was a country-year or aggregate-region-year; no individual records were used. The project protocol classified annual WHO/IHME counts, ASRs, endpoint changes, and EAPC as primary; published site-specific estimates as secondary; HAC lag and period analyses as sensitivity analyses; and country classifications and the Indonesia capacity model as exploratory and applied decision support, respectively. Indonesia was specified before country results were ranked. Reporting followed the principles of transparent health-estimate reporting and relevant observational-study guidance.

Data architecture and sources

Four evidence layers were integrated rather than forced into one nominally uniform dataset. Layer 1 was the archived WHO Rehabilitation Need Estimator and public application programming interface, which exposes annual GBD 2021 prevalence and YLD estimates for OA sequelae selected as potentially benefiting from rehabilitation[5,9]. It contained both-sex estimates for 195 countries, the global aggregate, six WHO regions, and a World Bank high-income aggregate, with annual posterior means and 95% UIs for 1990–2021. Numbers were all-age counts; rates were age-standardized per 100,000 using the GBD reference population. Age- and sex-specific analyses were intentionally outside the primary scope.

Layer 2 was the supplementary appendix to Long and colleagues' GBD 2019 analysis of site-specific OA prevalence[3]. We extracted knee, hip, and hand prevalence numbers and age-standardized rates for 1990 and 2019, together with the authors' published EAPCs, for the global population, sexes, five SDI quintiles, 21 GBD regions, and 204 countries and territories. Layer 3 was the supplementary workbook to Wu and colleagues' GBD 2021 analysis[4]. We extracted site-specific incidence and YLD numbers and age-standardized rates for 1990 and 2021 and the published joinpoint AAPCs for the same broad geography.

Layer 4 consisted of the WHO PIR musculoskeletal module, which specifies essential OA rehabilitation interventions and typical session times for assessment, self-management, exercise training, muscle strengthening, activities-of-daily-living training, and reassessment[30]. The PIR does not prescribe universal annual frequencies, coverage targets, productive-time denominators, or staffing norms. Session durations were evidence-informed anchors; every frequency, coverage, and productivity value was an author-selected modeling input that has not undergone Indonesian stakeholder validation. The distinctions among sources, definitions, denominators, and permitted interpretations are detailed in Table 1.

Table 1. Source harmonization, case definitions, denominators, and estimands.

Source/construct	Definition and sites	Population/years	Uncertainty/trend	Permitted interpretation
Overall GBD OA	Symptomatic, radiographically confirmed OA; hip, knee, hand, and other non-spinal joints. Spinal symptoms are modeled under low-back or neck pain.	Release-specific	Source UI; no current-study trend	Overall disease burden; not annual service eligibility
WHO 2019 headline	Moderate/severe OA sequelae selected as rehabilitation amenable; 344 million people.	Global, 2019	GBD 2019 source estimate	Communication estimate; not visits, demand, or staff
WHO estimator, GBD 2021	Overall condition-level rehabilitation-amenable OA prevalence and YLDs; sites not summed.	195 countries; annual 1990–2021	Source UI; calculated EAPC with conditional model-fit CI	Primary epidemiological envelope
Long et al., GBD 2019	Knee, hip, and hand prevalence; people can have more than one affected site.	204 locations; endpoints 1990/2019	Published EAPC; not re-estimated	Secondary within-source site/SDI description
Wu et al., GBD 2021	Knee, hip, and hand incidence and YLDs.	204 locations; endpoints 1990/2021	Published joinpoint AAPC; not re-estimated	Secondary within-source site/SDI description
WHO PIR plus author capacity model	PIR content/durations; author-selected coverage, frequencies, delivery, and productivity.	Indonesia; one-year 2021 horizon	Deterministic prevalence-UI range	Model-based capacity equivalents only

Notes: Cross-source comparisons are descriptive only. EAPC and AAPC are not interchangeable. Multisite OA may increase clinical complexity, but site-specific counts were never summed to create the capacity denominator. YLDs, years lived with disability; PIR, Package of Interventions for Rehabilitation.

Definitions and denominators

Overall OA burden and rehabilitation-amenable OA prevalence are related but not identical. Overall burden encompasses GBD OA cases meeting release-specific site and severity definitions. Rehabilitation-amenable prevalence selects OA sequelae for which rehabilitation could be beneficial. Throughout this manuscript, "rehabilitation-amenable burden" denotes that epidemiological construct. It precedes clinically assessed need, expressed demand, utilization, and unmet need; none of those downstream constructs was observed. The capacity denominator used the overall OA condition estimate once and never summed knee, hip, hand, or other-site estimates. People may nevertheless have multisite OA or other rehabilitation-amenable conditions, which can alter treatment intensity and complicates cross-condition aggregation.

Incidence refers to new modeled OA cases in a year. Prevalence refers to people living with OA during the modeled year. YLDs equal sequela prevalence multiplied by disability weights after GBD comorbidity correction; they quantify population health loss but are not direct clinical function scores, rehabilitation intensity measures, or patient-reported outcomes. ASRs were reported per 100,000 using each source's GBD standard population. Source UIs reflect uncertainty propagated by the originating GBD analysis. EAPC confidence intervals quantify model fit conditional on annual posterior-mean ASRs and do not include GBD posterior uncertainty. These interval types were separated typographically and conceptually.

SDI is a composite measure based on lag-distributed income per capita, mean educational attainment, and total fertility rate among people younger than 25 years. We retained the five published categories—low, low-middle, middle, high-middle, and high SDI—without reassigning countries. The regional WHO rehabilitation aggregates include six geographically defined WHO regions plus a World Bank high-income group. Because the high-income group overlaps geographically with WHO regions, regional numbers were not summed to reconstruct the global total.

Data extraction and harmonization

Structured tables were parsed into tidy records containing source release, source table, extraction date, location, location level, sex, joint site, measure, metric, endpoint years, numbers, rates, intervals, and trend estimand. A source dictionary records exact URLs or DOIs, filters, location universes, limitations, and SHA-256 hashes. Country labels were standardized for visualization while source geographies were preserved across the 195-country estimator and 204-location supplements. A machine-readable audit flag records each crosswalk change and one evident printed typographical anomaly that was repaired from internally consistent neighboring fields; the original value, replacement, and justification remain in the audit trail. No interval was invented where the source supplied none.

The annual WHO file was tested for duplicate location–year–measure–metric keys, negative values, lower–mean–upper inversions, missing years, incomplete 32-year panels, and unexpected location counts. Site-specific endpoint files were tested for valid endpoints, trend labels, interval ordering where intervals were supplied, and uniqueness of location–site–measure combinations. All derived calculations were stored separately from source values. Valid comparisons were prespecified within a source, release, outcome, and trend method. Cross-source contrasts were descriptive and were not used for pooled estimation or formal tests.

Temporal trend analysis

For rehabilitation-amenable prevalence and YLDs, we fitted ordinary least-squares regression of the natural logarithm of each unrounded annual posterior-mean ASR on centered calendar year for 1990–2021:

$$\ln(ASR_t) = \alpha + \beta(t - \bar{t}) + \varepsilon_t$$

$$EAPC = 100 \times [\exp(\beta) - 1]$$

All rates were positive; no zero correction was required. Transformed 95% intervals around β are reported only as conditional model-fit CIs. They describe deviations of the annual posterior means from the fitted line and do not propagate uncertainty in GBD inputs, covariates, disability weights, model parameters, or cross-year posterior correlation. Draw-level EAPC would be preferred, but posterior draws were unavailable; marginal annual lower and upper bounds were not sampled as independent draws.

Because the annual series were serially ordered, Newey–West heteroskedasticity- and autocorrelation-consistent covariance estimates with finite-sample correction and three lags were prespecified as the principal robustness analysis; lag choices 1–5 were examined. We reported R^2, Durbin–Watson statistics, lag-one residual correlation, the endpoint annualized change, and alternative-period slopes for 1990–2019 and 2000–2021. These diagnostics evaluate whether the one-slope summary obscures curvature or autocorrelation; EAPC remained the prespecified descriptive summary even when residual dependence was evident. Country direction labels based on conditional intervals were exploratory, with no confirmatory significance claim or multiplicity inference.

For site-specific prevalence, EAPCs reported by Long et al. were reproduced without re-estimation because the supplement did not provide the full annual series[3]. For site-specific incidence and YLDs, we reproduced Wu et al.'s published joinpoint AAPCs[4]. AAPC is a weighted summary of segment-specific annual percentage changes and can differ from a single-slope EAPC. The source article identified joinpoint regression and the 1990–2021 interval but did not fully report software version, maximum joinpoints, permutation selection, weighting, or standard-error treatment in the accessible supplement; those settings cannot be reconstructed. Every AAPC is therefore labeled "published AAPC; not re-estimated," and its magnitude was not formally compared with a current-study EAPC.

Spatial analysis

National choropleths displayed 2021 age-standardized rehabilitation-amenable prevalence and 1990–2021 prevalence EAPC. Country names were converted to ISO-3 codes with country_converter 1.3.2 and passed to Plotly 6.9.0's built-in geographic layer, which uses WGS84 longitude/latitude rendering and Natural

Earth-derived public-domain boundaries. All 195 estimates received a unique ISO-3 code; no analytical row was lost, although very small states may be visually indistinct at world scale. Sequential rate colors used the full observed range without clipping; EAPC used the full range and a diverging midpoint of zero. The crosswalk and map-ready data are machine-readable. Boundaries are shown for visualization only and imply no position on territorial status.

Rehabilitation capacity modeling framework

The calculator adopted a one-year Indonesian health-system perspective for national and provincial planners deciding the approximate direct-contact capacity associated with an annual coverage policy. The target population was the overall condition-level 2021 rehabilitation-amenable OA estimate, not a sum of joint sites. For scenario s, the calculation was:

$N_s = P \times C_s$; $H_s = N_s \times B_s$; $F_s = H_s/Q_s$

Here, P is prevalence, C is annual coverage, B is direct-contact bundle hours per targeted person-year, and Q is productive direct-contact hours per FTE-year. Annual coverage is a policy convention, not evidence that each prevalent person requires a new episode every year. Costs, existing supply, travel time, non-contact workload, referral, adherence, outcomes, and workforce gaps were excluded. The calculation boundary is shown in Figure 1.

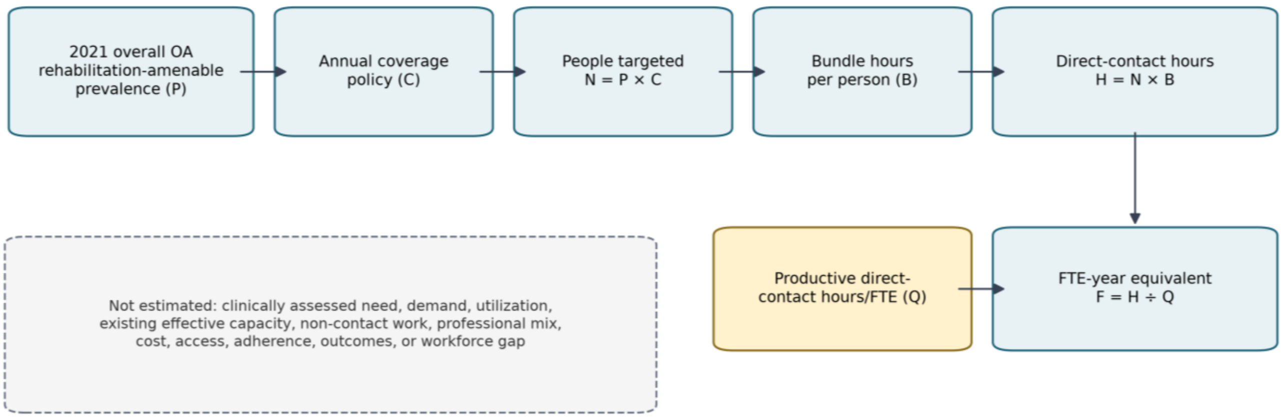

Figure 1. Structure and boundary of the rehabilitation capacity model. The diagram separates epidemiological input, author-selected policy parameters, derived contact-hour capacity, and variables excluded from the model.

The foundational scenario targeted 25% of the rehabilitation-amenable population and comprised one 30-minute pain/function assessment, one 45-minute self-management session, and four 30-minute exercise-training contacts, totaling 3.25 hours per targeted person-year. Productivity was set to 1,300 direct-contact hours per FTE-year. The scale-up scenario targeted 50% and added four 20-minute muscle-strengthening contacts, four additional exercise contacts, and one 30-minute reassessment, totaling 7.08 hours, with 1,100 productive hours. The comprehensive scenario targeted 75% and included 12 exercise contacts, eight strengthening contacts, four 30-minute activities-of-daily-living contacts, self-management, assessment, and reassessment, totaling 12.42 hours, with 900 productive hours.

Session durations were anchored to PIR specifications, but frequencies were not WHO recommendations. The calculator has no calibration target, external validation dataset, predictive-performance assessment, or completed face/content validation with Indonesian clinicians, planners, primary-care teams, or patient representatives. Its FTE unit is only a multidisciplinary volume of direct-contact time. It is not an occupational headcount, staffing norm, funded post, visit count, or workforce gap. Each assumption is designed to be replaced: coverage by an adopted policy target, bundle hours by pathway observation, productive hours by time-use data, delivery multipliers by group/telehealth workflow studies, and effective supply by a verified workforce-and-service inventory.

The scenarios were constructed to support deliberation rather than prediction. Foundational asks what contact capacity corresponds to a limited entry pathway; scale-up asks what capacity accompanies broader access to a multicomponent core; and comprehensive explores a high-coverage, higher-intensity boundary. None identifies an optimal allocation because benefits, costs, equity weights, budget constraints, and opportunity costs were not modeled. Before policy use, a structured Indonesian consensus process should specify the decision problem, agree severity and complexity strata, review every bundle component, and test feasibility across public and private primary care, hospital rehabilitation, community delivery, and remote districts. Patient representatives should assess acceptability, travel and time costs, digital exclusion, caregiver burden, and outcomes that matter beyond pain.

Clinical pathway and delivery structures

The population-level scenarios sit above a stepped clinical pathway rather than assigning one identical treatment course to every person. Low-complexity care includes function screening, education, self-management, progressive home or group exercise, activity and weight support, and planned review. Moderate-complexity care adds individualized strengthening, gait or hand-function assessment, assistive products or splints when indicated, occupational and workplace modification, and closer monitoring of adherence and response. High-complexity care includes physiatry or multidisciplinary assessment, management of frailty, falls, obesity and multimorbidity, perioperative rehabilitation, and referral for surgical opinion when appropriate. Escalation depends on function, participation, safety, goals, response, and clinical complexity rather than imaging alone. The three pathway levels are detailed in Table 2.

Delivery mode is a structural design choice rather than a cosmetic variation. Group exercise can distribute professional time across participants but requires safe screening, appropriate group size, accessible venues, and adherence monitoring. Tele-rehabilitation can reduce travel but adds technology, connectivity, privacy, and remote-safety requirements[20,21,28,29]. Asynchronous education can preserve synchronous time for individualized assessment but cannot substitute for examination when red flags, falls risk, severe limitation, or diagnostic uncertainty are present. Task sharing can expand reach only when competencies, supervision, escalation criteria, documentation, and quality assurance are defined. Consequently, professional contact hours cannot be inferred from participant contacts without observing the selected workflow.

Table 2. Stepped osteoarthritis rehabilitation pathway underlying the scenarios.

Complexity	Clinical profile	Core interventions	Joint-site emphasis	Delivery options
Low	Stable symptoms; mild–moderate activity limitation; low safety risk	Education, self-management, progressive exercise, activity/weight support, review	Knee/hip mobility and strength; hand joint protection and dexterity	Primary care, group, community, digital/asynchronous
Moderate	Persistent limitation, work/ADL impact, multisite OA, incomplete response	Individual exercise progression, gait or hand assessment, assistive products, splints, work/home adaptation	Site-specific physiotherapy and occupational therapy	Hybrid individual/group; tele-follow-up; task sharing with supervision
High	Severe disability, frailty/falls, complex multimorbidity, perioperative needs	Multidisciplinary assessment, medical coordination, intensive rehabilitation, surgical referral when indicated	Complex lower-limb mobility, hand function, participation and perioperative goals	Specialist/hub-and-spoke care with local follow-up

Uncertainty and sensitivity analysis

Deterministic scenarios were primary. Their lower and upper capacity equivalents propagated only the 95% UI of prevalence while policy assumptions remained fixed. Structural interpretation considered individual, group, supervised-community, tele-rehabilitation, asynchronous education, and task-shared delivery; these modes can change professional minutes per participant and therefore cannot be represented by one universal multiplier without workflow data.

Software, reproducibility, and quality control

Analysis used Python 3.14.3, pandas 3.0.5, NumPy 2.5.1, Plotly 6.9.0, and country_converter 1.3.2; manuscript figures added during revision used Matplotlib 3.11.1 and the document used python-docx 1.2.0. HAC covariance was implemented explicitly with a finite-sample factor $n/(n-2)$. The reproducibility package separates source, processed, and derived files; includes configuration, tests, SQLite tables, a source dictionary, crosswalk audit, map-ready data, and a completed GATHER checklist; and records extraction URLs, timestamps, licenses, and hashes. Key SHA-256 prefixes are b5f469e0 for the annual WHO file, 575f0c04 for GBD 2019 prevalence, and 527ba0e3 for GBD 2021 incidence/YLDs. Six automated tests passed.

Ethics

The study used aggregated secondary estimates and did not involve identifiable participants, tissue, or individual records; ethics approval and consent were therefore not applicable.

3. Results

Data coverage and internal validity

The annual rehabilitation-amenable OA dataset comprised 25,984 records for prevalence and YLDs, numbers and age-standardized rates, from 1990 through 2021. It included 195 countries, the global estimate, and seven regional or economic aggregates. Every country had a complete 32-year panel for each included measure–metric combination. No duplicate analytical keys, negative values, or uncertainty-order violations were identified. Endpoint files contained published site-specific prevalence for GBD 2019 and incidence and YLDs for GBD 2021. Because the source releases and geographic frames differed, comparisons were made within source and estimand rather than by pooling values.

Global rehabilitation-amenable burden

Global rehabilitation-amenable OA prevalence increased from 156.35 million (95% UI 121.84–188.00) in 1990 to 352.56 million (274.40–423.84) in 2019 and 371.61 million (288.67–446.58) in 2021, a cumulative increase of 137.7%. The ASR increased from 3,909.2 to 4,267.0 per 100,000. The EAPC was 0.34% per year; its OLS conditional model-fit CI was 0.31–0.37 and lag-3 HAC conditional interval was 0.29–0.39. These narrow intervals characterize fit to modeled annual means, not total GBD uncertainty.

Global YLDs attributable to rehabilitation-amenable OA reached 20.24 million (95% UI 9.68–40.79) in 2019 and 21.30 million (10.19–42.94) in 2021. The YLD ASR increased from 222.8 per 100,000 in 1990 to 244.5 in 2021; EAPC was 0.37%, with OLS and lag-3 HAC conditional intervals of 0.33–0.40 and 0.31–0.42. YLDs incorporate severity-weighted health loss but cannot identify an individual treatment plan. Their wide source UIs should temper apparent numerical precision. Global and Indonesian endpoint estimates are detailed in Table 3.

Table 3. Global and Indonesian rehabilitation-amenable osteoarthritis burden.

Location	Measure	1990 number	2021 number (95% source UI)	1990 ASR	2021 ASR	Calculated EAPC % (conditional model-fit CI)
Global	Prevalence	156.35 M	371.61 M (288.67–446.58)	3,909.2	4,267.0	0.34 (0.31–0.37)
Global	YLDs	—	21.30 M (10.19–42.94)	222.8	244.5	0.37 (0.33–0.40)
Indonesia	Prevalence	3.03 M	9.08 M (7.00–11.10)	2,966.4	3,516.6	0.55 (0.53–0.57)
Indonesia	YLDs	0.170 M	0.517 M (0.246–1.032)	166.2	199.4	0.60 (0.58–0.62)

Notes: M, million; YLDs, years lived with disability.

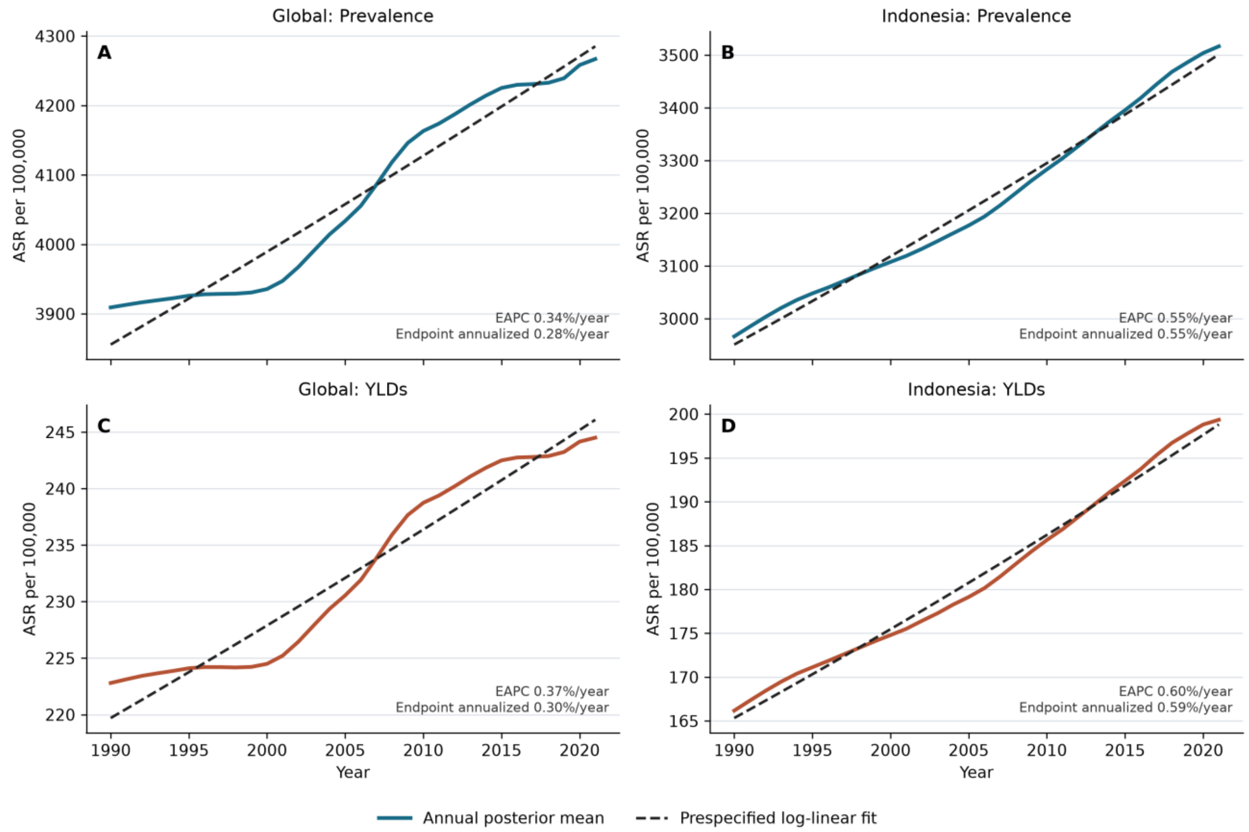

Figure 2. Annual age-standardized osteoarthritis series and prespecified log-linear fits, 1990–2021. Lines show annual posterior-mean ASRs and fitted one-slope summaries for global and Indonesian prevalence and YLDs. EAPCs and endpoint annualized changes are descriptive; neither propagates GBD posterior uncertainty.

Annual trajectories and fitted one-slope summaries are shown in Figure 2. Observed annual posterior means were smooth but not independent around the fitted line. Durbin–Watson statistics were 0.09 for both global outcomes and 0.05–0.07 for Indonesia, with lag-one residual correlations of 0.96–0.97. EAPC was therefore retained as a descriptive full-period summary rather than evidence of a constant yearly mechanism. Model diagnostics and period sensitivity analyses are detailed in Table 4.

Table 4. Trend-model diagnostics and sensitivity analyses.

Series	EAPC %	Endpoint annualized %	Lag-3 HAC conditional interval	HAC lag 1–5 interval range	R^2; Durbin–Watson	2000–2021 EAPC %
Global prevalence	0.34	0.28	0.29–0.39	0.30–0.39	0.943; 0.094	0.40
Global YLDs	0.37	0.30	0.31–0.42	0.31–0.42	0.940; 0.093	0.43
Indonesia prevalence	0.55	0.55	0.52–0.59	0.51–0.60	0.989; 0.054	0.63
Indonesia YLDs	0.60	0.59	0.56–0.63	0.56–0.64	0.990; 0.065	0.67

Regional patterns

In 2021, the largest regional rehabilitation-amenable population was in the World Bank high-income aggregate (103.67 million), followed by the Western Pacific Region (100.90 million) and South-East Asia Region (71.42 million). These categories overlap and are presented independently. The highest age-standardized prevalence rate was in the high-income aggregate at 4,798.8 per 100,000, followed by the Americas and European regions. In contrast, trend velocity was greatest in the Western Pacific Region (EAPC 0.61%) and South-East Asia Region (0.55%), while the European and high-income aggregates rose by approximately 0.26% annually. Complete regional values are detailed in Table 5.

Table 5. Regional rehabilitation-amenable prevalence in 2021 and EAPC, 1990–2021.

Aggregate	People, millions	ASR per 100,000	Calculated EAPC % (conditional model-fit CI)
African Region	20.22	3,751.7	0.36 (0.36–0.37)
Region of the Americas	30.56	4,564.5	0.38 (0.38–0.39)
South-East Asia Region	71.42	3,807.2	0.55 (0.53–0.57)
European Region	25.33	4,561.4	0.26 (0.22–0.30)
Eastern Mediterranean Region	16.44	3,680.3	0.50 (0.48–0.51)
Western Pacific Region	100.90	4,165.2	0.61 (0.54–0.68)
World Bank High Income	103.67	4,798.8	0.26 (0.21–0.30)

National spatial heterogeneity

Country analyses were descriptive and exploratory. Using the OLS conditional model-fit interval only as a classification rule, 188 of 195 countries were categorized as increasing, six as stable/uncertain, and one as decreasing for prevalence; the YLD classification had the same counts. Faster increases clustered in parts of Asia, North Africa, and the Horn of Africa, whereas several high-income settings showed slower or near-zero change. Trend patterns are shown in Figure 3, while 2021 age-standardized prevalence levels are shown in Figure 4. No false-discovery claim was made, and isolated national estimates were not treated as health-system performance rankings.

The choropleth confirms broad modeled increases but does not display source posterior uncertainty in EAPC. All 195 analytical countries were assigned unique ISO-3 codes; no estimate was unmatched, although microstates may not be visible at world scale. Countries with similar 2021 rates could have different trajectories, reinforcing the need to pair level, trend, source uncertainty, and local service evidence.

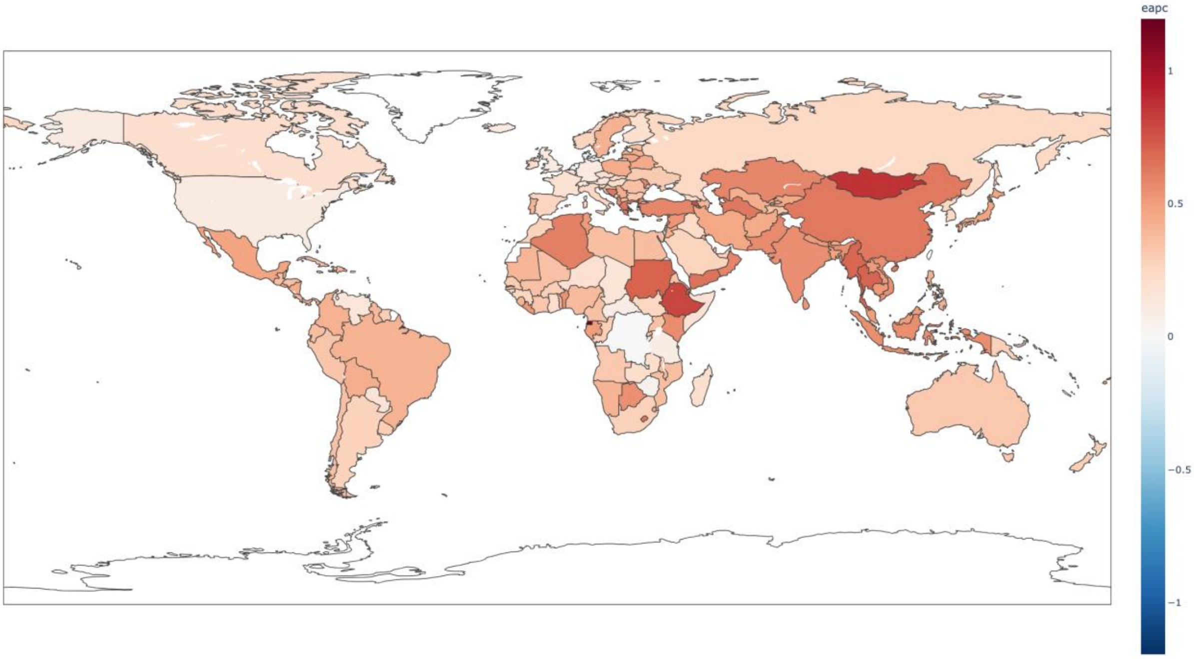

Figure 3. National EAPC in rehabilitation-amenable osteoarthritis prevalence, 1990–2021. EAPC was calculated from modeled annual posterior-mean ASRs. The map shows point estimates, not total trend uncertainty. All 195 records received ISO-3 codes; small states may be visually indistinct. Boundaries are shown for visualization only and imply no political endorsement.

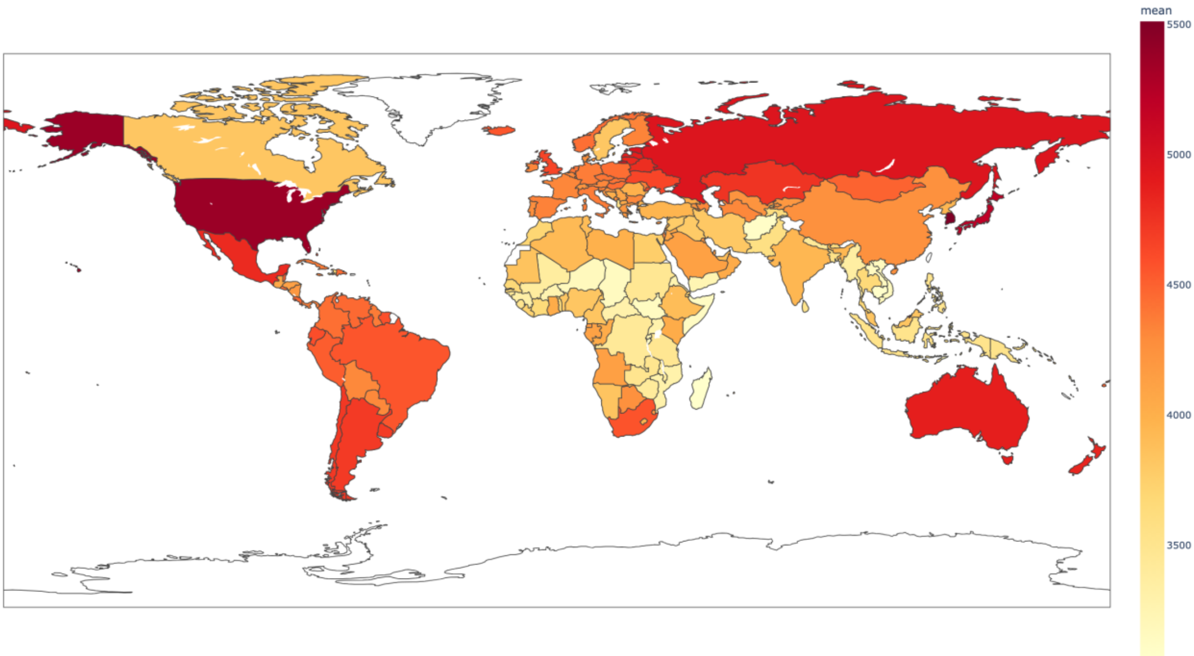

Figure 4. National age-standardized rehabilitation-amenable osteoarthritis prevalence, 2021. Modeled rates are per 100,000 and use the full observed color range without clipping. All 195 records received ISO-3 codes; small states may be visually indistinct. Boundaries are shown for visualization only and imply no political endorsement.

Site-specific burden and SDI patterns

Published GBD 2019 prevalence estimates showed knee OA as the dominant joint-specific burden. Globally in 2019, knee OA prevalence was 4,380 per 100,000 with EAPC 0.32% (95% CI 0.29–0.34), compared with hip OA at 401 per 100,000 and EAPC 0.28% (0.26–0.31), and hand OA at 1,730 per 100,000 with EAPC −0.36% (−0.38 to −0.33). These figures reflect the source's site-specific case definitions and do not sum to unique persons because an individual can have OA at multiple sites.

Published GBD 2021 joinpoint estimates similarly identified knee OA as the largest contributor to incidence and YLD rates. In 2021, global knee incidence was 353.67 per 100,000 (AAPC 0.22%) and the YLD rate was 137.59 (AAPC 0.26%). Hand incidence was

119.09 (AAPC 0.55%) and the YLD rate was 70.94 (AAPC 0.44%), while hip incidence was 20.67 (AAPC 0.22%) and the YLD rate was 13.19 (AAPC 0.18%). The faster hand AAPCs indicate a changing contribution even though knee OA remained much larger in absolute rate.

SDI patterns were not monotonic across sites. High-SDI settings had the highest 2019 rates for knee, hip, and hand prevalence, but not always the fastest trend. Hip prevalence EAPC was highest in low-middle (0.83%) and middle SDI (0.80%) settings. Knee prevalence EAPC was highest in high-middle SDI (0.47%). Hand prevalence declined markedly in high-middle SDI (−1.09%) but increased in high SDI (0.49%). For 1990–2021 incidence, hand AAPC exceeded 1% in middle SDI, whereas hip incidence rose fastest in low-middle and middle SDI. These patterns argue against a single “development gradient” for OA. Prevalence patterns are detailed in Table 6, and incidence and YLD patterns are detailed in Table 7.

Table 6. Published site-specific prevalence by SDI quintile.

SDI	Knee prevalence ASR; EAPC	Hip prevalence ASR; EAPC	Hand prevalence ASR; EAPC
Low	3,620; 0.24	279; 0.45	1,280; −0.01
Low-middle	4,170; 0.42	272; 0.83	900; 0.03
Middle	4,420; 0.39	271; 0.80	940; 0.03
High-middle	4,290; 0.47	386; 0.29	1,780; −1.09
High	4,700; 0.11	724; 0.47	3,600; 0.49

Table 7. Published site-specific incidence and YLDs by SDI quintile.

SDI	Knee inc. ASR; AAPC	Knee YLD ASR; AAPC	Hand inc. ASR; AAPC	Hand YLD ASR; AAPC	Hip inc. ASR; AAPC	Hip YLD ASR; AAPC
Low	306.06; 0.20	112.74; 0.22	85.18; 0.76	47.39; 0.84	16.63; 0.38	9.74; 0.39
Low-middle	321.83; 0.29	120.44; 0.33	101.93; 0.89	57.33; 0.96	15.51; 0.67	9.60; 0.65
Middle	359.69; 0.20	141.17; 0.23	118.77; 1.13	66.85; 1.16	16.13; 0.65	9.60; 0.63
High-middle	357.78; 0.34	138.40; 0.43	125.80; 0.30	75.73; 0.11	21.92; 0.09	13.11; 0.16
High	386.58; 0.21	149.14; 0.21	147.54; 0.25	88.47; 0.21	35.05; 0.37	21.83; 0.33

Indonesia case study

Indonesia’s rehabilitation-amenable OA population increased from 3.03 million (95% UI 2.34–3.69) in 1990 to 8.41 million (6.49–10.28) in 2019 and 9.08 million (7.00–11.10) in 2021, a 199.8% increase. The ASR increased from 2,966.4 to 3,516.6 per 100,000; EAPC was 0.55%, with OLS and lag-3 HAC conditional intervals of 0.53–0.57 and 0.52–0.59. YLDs increased from approximately 0.17 million to 0.517 million (0.246–1.032); YLD EAPC was 0.60%, with corresponding conditional intervals of 0.58–0.62 and 0.56–0.63.

Joint-specific trends in Indonesia were heterogeneous. Between 1990 and 2019, knee prevalence ASR rose from 2,942.25 to 3,268.94 (published EAPC 0.38%), hip prevalence from 216.97 to 256.62 (0.62%), and hand prevalence from 146.37 to 147.09 (0.02%). Between 1990 and 2021, knee incidence rose from 247.63 to 273.05 per 100,000 (joinpoint AAPC 0.32%), hand incidence from 82.62 to 116.55 (AAPC 1.11%), and hip incidence from 13.60 to 15.69 (AAPC 0.47%). Hand YLD AAPC was 1.22%, exceeding knee (0.35%) and hip (0.46%). These findings suggest that a knee-dominant service strategy remains necessary but would miss the fastest-changing component of upper-limb disability.

Indonesia rehabilitation capacity modeling

Applying the author-specified foundational scenario to Indonesia targeted 2.27 million people and generated 7.37 million annual direct-contact hours, equivalent to 5,673 multidisciplinary direct-contact FTE-years (prevalence-UI range 4,375–6,937). Scale-up generated 29,223 FTE-years (22,535–35,735), and comprehensive 93,914 (72,422–114,844). The approximately 17-fold span is an algebraic consequence of jointly changing coverage, bundle intensity, and productivity; it is not an uncertainty interval around one preferred staffing estimate. Inputs and outputs are detailed in Table 8 and visualized in Figure 5.

Table 8. Indonesia rehabilitation capacity modeling scenarios, 2021.

Scenario	Coverage	Bundle h/person-year	Productive h/FTE-year	People targeted	Contact hours	Direct-contact FTE equivalent (UI)
Foundational	25%	3.25	1,300	2.27 M	7.37 M	5,673 (4,375–6,937)
Scale-up	50%	7.08	1,100	4.54 M	32.15 M	29,223 (22,535–35,735)
Comprehensive	75%	12.42	900	6.81 M	84.52 M	93,914 (72,422–114,844)

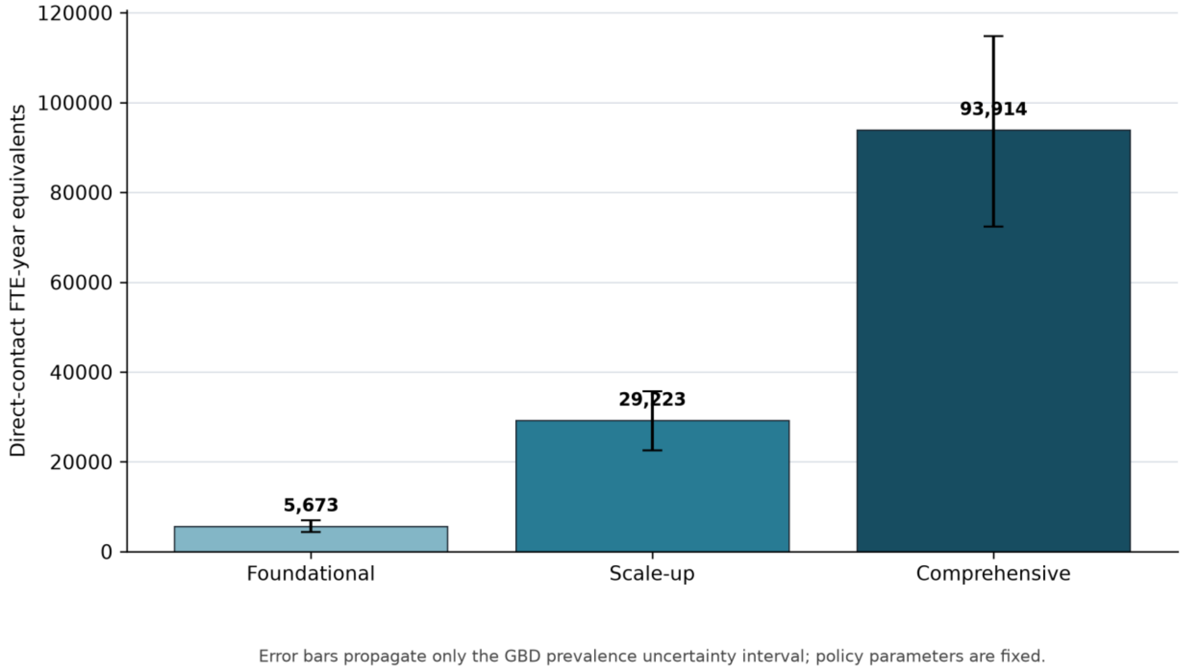

Figure 5. One-year direct-contact rehabilitation capacity modeling scenarios for Indonesia, 2021. Error bars propagate only the prevalence 95% UI while author-selected coverage, annual bundle hours, and productive contact hours remain fixed. Values are multidisciplinary direct-contact FTE-year equivalents—not headcounts, staffing recommendations, visits, or workforce gaps.

No scenario was designated a recommended national target. Group care, community delivery, tele-rehabilitation, asynchronous education, and task sharing could reduce professional minutes per participant, whereas rural travel, supervision, documentation, complex multimorbidity, and low attendance could increase effective resource requirements. Because these interactions were not observed or validated, no global FTE scenario or additional uncertainty distribution was included.

4. Discussion

Principal epidemiological findings

The global population with OA-related functioning problems for which rehabilitation could be beneficial more than doubled from 1990 to 2021, reaching 371.6 million, while the corresponding Indonesian population nearly tripled to 9.08 million. Absolute growth greatly exceeded ASR change: global prevalence increased by 137.7% but the ASR by 9.2%, and Indonesia increased by 199.8% versus 18.6%. Population growth and ageing therefore dominate the service-relevant volume, while the positive standardized trends indicate additional change in modeled age-specific burden. Counts are essential for service scale; ASRs are essential for comparing trajectories. Neither measures access.

The calculated EAPCs summarize the official annual posterior-mean series, not raw longitudinal observations. High R^2 coexisted with strong residual autocorrelation, and recent-period slopes were somewhat higher than full-period slopes. HAC lag choices did not materially alter the point estimates, but neither OLS nor HAC intervals propagated GBD posterior uncertainty. The safest interpretation is therefore descriptive: the modeled standardized trajectories increased on average, with modest nonlinearity. Draw-level EAPCs remain the preferred extension when IHME posterior draws become available.

Joint-site and SDI implications

Knee OA had the largest site-specific prevalence, incidence, and YLD rates, supporting scalable lower-limb assessment, education, strengthening, aerobic activity, weight support, mobility aids, and perioperative pathways. A knee-only strategy would nevertheless be incomplete. Hip OA can produce major gait limitation and need for timely surgical opinion, whereas hand OA affects grip, dexterity, self-care, domestic activity, and work. The rapid published hand incidence and YLD AAPCs in middle-SDI settings strengthen the case for occupational therapy, joint-protection education, splinting when indicated, and task or workplace adaptation.

SDI patterns were not monotonic, and published GBD 2019 EAPCs cannot be numerically equated with GBD 2021 joinpoint AAPCs. Differences may reflect risk exposure, diagnostic intensity, data density, model release, baseline level, and estimator. National maps are therefore hypothesis-generating. They should be combined with source uncertainty, sex and age patterns, local surveillance, service access, and subnational inequity before prioritization. Prevention and rehabilitation are complementary: injury prevention, healthy weight, occupational risk reduction, and physical activity address future OA risk, whereas rehabilitation addresses established limitations in function and participation[1–8].

Rehabilitation delivery and the Indonesia case

The central planning distinction is between an epidemiological amenability envelope and an operational care pathway. Clinically assessed need emerges only after evaluation of joint site, symptom and functional severity, frailty, obesity, multimorbidity, falls risk, work demands, surgical status, prior response, preferences, and goals. Stepped care can then match low-complexity group, community, or digital support; moderate-complexity individual and occupational interventions; and high-complexity multidisciplinary or perioperative care. Goals should emphasize participation, self-management, safety, and quality of life rather than contact completion.

The Indonesian calculator makes the policy assumptions visible. A direct-contact FTE-year equivalent is the total modeled contact-hour volume divided by an assumed productive-contact denominator. It is not professional headcount, a funded post, a visit count, a recommended staffing ratio, or the difference from current supply. The approximately 17-fold scenario span shows that coverage, intensity, and productivity choices drive the result. A real gap can be estimated only after comparing a stakeholder-validated pathway with effective current capacity across public and private sectors, professions, locations, competencies, and OA caseload.

Indonesia's decentralized archipelagic context makes province-level implementation more relevant than a single national allocation. Recent research documents workforce maldistribution, referral behavior, primary-care efficiency, financing inequities, telehealth feasibility, and the wider consequences of decentralization[31–36]. Next-stage work should combine province-specific burden with facility and workforce inventories, time-use measurement, referral, waiting time, attendance, completion, patient-reported function, travel burden, and financing. Hub-and-spoke supervision, primary-care rehabilitation, community exercise, tele-rehabilitation, and task sharing may expand reach, but access, competence, supervision, and escalation safeguards must be measured.

Strengths, limitations, and next steps

Strengths include a complete official annual WHO/IHME series; source-separated numbers, ASRs, UIs, EAPCs, and AAPCs; transparent residual and HAC sensitivity analyses; national mapping with a documented crosswalk; and a scenario calculator that exposes rather than conceals policy assumptions. The work also avoids summing joint sites, converting WHO's headline estimate into visits, or calling scenario FTE equivalents workforce gaps.

Limitations are substantial. GBD trajectories are modeled from heterogeneous evidence and borrowing across locations; annual posterior draws were unavailable, so EAPC intervals reflect conditional model fit only. The 2019 WHO headline, GBD 2021 estimator, GBD 2019 prevalence supplement, and GBD 2021 incidence/YLD supplement differ in release, geography, period, case definition, and trend method. "Could benefit" does not capture clinical eligibility, preference, demand, use, outcomes, intermittent episode periodicity, or multisite complexity. Ecological patterns cannot be interpreted as individual causal effects and may conceal age, sex, occupational, rural–urban, and provincial inequalities.

The capacity scenarios are unvalidated author selections and exclude costs, current workforce, distribution, competence, public–private mix, referral, adherence, group efficiency, telehealth workflow, non-contact work, and treatment outcomes. No patients, clinicians, primary-care representatives, or policy stakeholders participated in parameter selection. Formal Delphi or nominal-group validation, a national service-capacity inventory, and province-level implementation studies are prerequisites for policy adoption. Future epidemiological work should obtain official annual site-specific draws so a common release can support draw-level EAPCs alongside published AAPCs.

For decision makers, the practical sequence is: select a clinically defensible target population and annual coverage goal; validate a stepped bundle and delivery structure; estimate contact and non-contact resource use; measure effective existing capacity; and only then quantify an access or workforce gap. Prospective studies should compare individual, group, community, and digital pathways on function, participation, equity, adherence, cost, and safety. This sequence advances beyond multiplying prevalence by a fixed service ratio because every link is testable and replaceable with local evidence[20–30,35].

5. Conclusion

Global rehabilitation-amenable OA burden increased substantially between 1990 and 2021, with faster relative growth in Indonesia than globally. Knee OA remained the largest joint-specific burden, while hip and hand patterns varied across SDI levels and hand incidence and YLDs had rapid published AAPCs in several middle-SDI settings. EAPC calculated from annual posterior means, published GBD 2019 EAPC, and published joinpoint AAPC are different estimands and should remain source-separated.

The Indonesia calculator demonstrates how rehabilitation-amenable prevalence can be linked to policy-contingent target populations, contact hours, and FTE-year equivalents, but it does not measure actual need, demand, utilization, staffing requirements, or workforce gaps. The next step is clinical and stakeholder validation followed by integration of province-level severity, delivery mode, effective capacity, referral, adherence, cost, and outcome data.

Until then, its outputs should be interpreted only as model-based decision scenarios.

Declarations

Ethics approval and consent to participate

Not applicable. This study analyzed aggregated, publicly accessible secondary estimates and did not use identifiable individual participant data.

Consent for publication

Not applicable.

Availability of data and materials

The WHO Rehabilitation Need Estimator is available at https://viz-archive.healthdata.org/rehabilitation/. Published site-specific inputs are available with Long et al. (doi:10.1002/art.42089) and Wu et al. (doi:10.1038/s41598-025-93124-z). A blinded reproducibility package accompanying peer review contains processed analytical tables, a source dictionary, hashes, crosswalk audit, scenario configuration, plotting and analysis scripts, environment specification, tests, and a GATHER checklist. A persistent public DOI should be activated when journal policy permits unblinding; no repository identifier has been fabricated in this manuscript.

Competing interests

The author declares that there are no competing interests.

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Authors' contributions

DW is the sole author and was responsible for the study conception and design, data acquisition, analysis and interpretation of the results, and drafting and critical revision of the manuscript. The author read and approved the final version.

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Generative AI disclosure

The author declares that no generative artificial intelligence tools were used in the design, analysis, or writing of this manuscript.

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