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Global knowledge, attitudes, and practices towards antimicrobial resistance among healthcare workers: a systematic review and meta-analysis

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Abstract

Background The rising prevalence of antimicrobial resistance (AMR) poses a critical global health challenge. Healthcare workers (HCWs) play a pivotal role in combating AMR by implementing effective preventive strategies and adhering to good practices. This study aimed to evaluate the global knowledge, attitudes, and practices (KAP) of HCWs towards AMR.

Methods A comprehensive search of PubMed/MEDLINE, ScienceDirect, Scopus, Web of Science, Cochrane Library, and Google Scholar was conducted for English-language articles published up to August 2024. Inclusion criteria were observational studies reporting KAP data among HCWs related to AMR. Study quality was assessed using the Joanna Briggs Institute critical appraisal checklist. Statistical analyses, including heterogeneity (I^2 statistic, Cochran Q), were conducted using STATA version 14. Random-effects models were applied for pooled estimates, and subgroup analyses, meta-regression, and sensitivity analyses were performed. Publication bias was assessed via Egger's test and adjusted using the trim-and-fill method. Geographical distribution was analyzed with ArcGIS 10.3 software, and evidence certainty was evaluated using the GRADE framework.

Results A meta-analysis of 108 studies involving 29,433 HCWs assessed their knowledge of AMR. Additionally, 51 studies with 13,660 HCWs evaluated attitudes, and 43 studies with 10,569 HCWs examined practices regarding AMR. The pooled proportion of HCWs with good knowledge of AMR was 56.5% (95% CI: 50.4–62.6%, $I^2 = 99.5\%$), with the highest prevalence in Europe (70.3%) and the lowest in the Western Pacific (45.9%). Positive attitudes towards AMR were reported in 60.4% (95% CI: 48.5–72.3%, $I^2 = 99.8\%$), with the highest prevalence in the Eastern Mediterranean Region (64.5%) and among those with less than five years of experience (77.8%). Good practices were observed in 48.5% (95% CI: 36.5–60.5%, $I^2 = 99.7\%$), with the highest adherence in Europe (56.6%) and the lowest in Africa (39.1%). Subgroup analysis revealed that younger HCWs (under 30 years) showed better KAP scores across all domains.

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Conclusion The findings underscore the need for targeted interventions to enhance the knowledge, attitudes, and practices of HCWs regarding AMR. Priority should be given to designing and implementing robust training programs tailored to the specific needs of HCWs in resource-constrained settings. Strengthening AMR-related education and practice among HCWs is crucial for combating the global AMR crisis effectively.

Keywords Antibiotic resistance, Health personnel, Global health, Antimicrobial stewardship

Introduction

Antimicrobial resistance (AMR) has rapidly escalated into a pressing global health crisis, jeopardizing the effectiveness of one of modern medicine's most vital tools—antibiotics [1, 2]. Antibiotics are among the most frequently prescribed in both hospital and community settings, yet the alarming rise in bacterial resistance is undermining their ability to prevent and treat infections [2, 3]. This situation poses significant threats to public health, leading to increased morbidity, mortality, and economic burdens [4, 5]. Without intervention, it is projected that AMR will cause 10 million deaths annually by 2050 [6]. Given that AMR knows no geographical boundaries, it should not be viewed as an issue confined to specific countries or regions, regardless of their income level or stage of development [7]. Addressing this multifaceted challenge requires more than heightened awareness; it demands a concerted effort to transform the prescribing behaviors of healthcare providers [8, 9].

The World Health Organization (WHO) has underscored the urgency of this issue, advocating for enhanced awareness and the implementation of antimicrobial stewardship strategies to combat resistance [10]. Central to these efforts is the need to understand the knowledge, attitudes, and practices (KAP) of healthcare workers (HCWs) regarding AMR. Such understanding is crucial for developing effective interventions that promote rational antibiotic use and mitigate resistance [11].

The KAP framework serves as a valuable tool for identifying critical gaps that hinder appropriate antibiotic use. Research indicates that HCWs are more likely to modify their prescribing behaviors when their knowledge and attitudes align with strategies aimed at reducing AMR. For example, a study by Kotwani et al. in Delhi demonstrated that targeted educational interventions could significantly reduce AMR [12]. Similarly, research conducted by Srinivasan et al. at Johns Hopkins Hospital found that 96% of physicians acknowledged the severity of AMR and expressed a need for further education on antimicrobial prescribing [13].

Despite these insights, numerous studies have consistently highlighted significant gaps in the KAP of HCWs across diverse settings, emphasizing the necessity for tailored interventions [12, 14, 15]. A study by Labi et al.. in Ghana pointed out the importance of focusing educational programs on younger healthcare professionals, while Guerra et al. in Brazil reported that 99% of healthcare providers recognized AMR as a critical issue [15]. Given the limited introduction of new antimicrobial agents to counteract resistance, it is imperative to ensure that HCWs possess adequate knowledge regarding the appropriate use of existing antibiotics [16]. Antimicrobial stewardship programs (ASPs), which prioritize education, represent a promising strategy to address this challenge [17].

This study aims to conduct a global systematic review and meta-analysis to assess the KAP of HCWs concerning AMR. The findings will provide essential insights for designing effective interventions to bridge the gaps in knowledge and practices among HCWs (, ultimately contributing to the global fight against AMR.

Method

Study design and setting

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which comprise 27 criteria designed to ensure the accuracy and transparency of reporting in systematic reviews and meta-analyses. Furthermore, the study's protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) with the registration number CRD42024589791 Available from: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42024589791.

Search strategy

Search strategy a systematic search was performed in several databases including PubMed/MEDLINE, ScienceDirect, Scopus, Web of Science, Cochrane library and Google scholar. The search also included all articles published up to August 2024, regardless of years published and introduced the newest studies. Full-text articles accessible for review only were included.

The search employed the following terms and Medical Subject Headings (MeSH): ('Drug Resistances' [MeSH] OR 'Antimicrobial Drug Resistance' [MeSH] OR 'Antibiotic Resistance' [MeSH]) AND ('Health Personnel' [MeSH] OR 'HCWs' [MeSH). The search also included the terms 'medical staff' [MeSH], 'knowledge' [MeSH], 'attitude' [MeSH], 'practice' [MeSH], and 'behaviour' [MeSH], as well as 'risk factors' [MeSH] and 'prevention and control' [MeSH].

To enhance the precision of the search, the references of the identified articles were also consulted to identify any additional pertinent studies that may have been overlooked in the initial search results. As a result, 3 additional studies were included through reference checking. The titles and abstracts of the retrieved studies were evaluated independently by two researchers to ascertain their relevance to the study's focus on AMR of KAP among HCWs. Only studies closely aligned with the research objectives were included for data extraction and analysis (Fig. 1).

Inclusion and exclusion criteria

Inclusion criteria

The current review included all observational studies which reported data on KAP regarding AMR among HCWs. Inclusion criteria: studies published in English and full text available. Only HCWs-specific studies that reported on KAP regarding AMR, were included. The participants in this studies were selected using a census or random sampling approach. In addition, the included studies provided information on demographic characteristics related to the participants such as the demographic age, gender, work experience, and the study geographical area.

Exclusion criteria

We excluded studies for the following reasons: they targeted populations other than healthcare workers (HCWs), did not report on knowledge, attitudes, or practices related to AMR, employed non-random or poorly described sampling methods that limited the validity of the findings, or were review articles, meta-analyses, short reports, or case reports that lacked primary observational data. Studies were also excluded if they were duplicate publications or included overlapping data from the same study population. Additionally, studies that did not provide adequate data on essential variables, such as demographic characteristics, level of awareness, positive attitudes, or appropriate practices related to AMR prevention, were also excluded.

Risk of bias (quality) assessment

The Joanna Briggs Institute (JBI) critical appraisal checklist for analytical cross-sectional studies was employed to assess the risk of bias in the studies included in this systematic review. The checklist comprised nine criteria designed to identify potential biases related to the study design, sampling methods, and measurement tools employed. The checklist specifically examined various aspects of the studies, including the clarity of the stated objectives, the suitability of the sampling methods employed, the reliability and validity of the measurement tools used, and the appropriateness of the statistical analysis.

Each criterion on the checklist was assigned one of four ratings: Yes, No, Unclear, or Not Applicable. To guarantee comprehensive and impartial evaluations, two independent reviewers conducted the assessments. The titles of the studies and the names of the authors were accessible to the reviewers throughout the evaluation process. Any discrepancies that arose between the two reviewers were resolved through discussion. If necessary, a third reviewer was consulted to reach a decision.

In accordance with the JBI checklist scores, the studies were categorized into three distinct risk-of-bias groups: low risk of bias (scores between 8 and 9), moderate risk of bias (scores between 4 and 7), and high risk of bias (scores between 0 and 3).

Data extraction

The process of data extraction for this study was conducted with the utmost care and attention to detail, involving several key stages. At the outset of the process, any duplicates were removed using EndNote X8, following the importation of all identified articles. Subsequently, team members independently reviewed the remaining studies, evaluating their titles and abstracts to filter out those that did not meet the inclusion criteria. The criteria focused on studies utilizing descriptive, cross-sectional, and observational methods related to AMR and the KAP of HCWs.

Following the identification of relevant articles, a group consensus was reached regarding the final selections. The selected studies then underwent a qualitative assessment and systematic data extraction process. The data extracted included essential elements such as the authors' names, publication year, study design, sample size, geographic location, type of healthcare setting, and participants' levels of knowledge, attitudes, and practices regarding AMR.

Strategy for data synthesis

The meta-analysis employed STATA version 14 for the statistical analysis. The degree of heterogeneity among the studies was evaluated using inverse variance and Cochran Q statistics. Heterogeneity was categorized as low, moderate, or high based on the I^2 statistic, with I^2 values of less than 50%, between 50% and 80%, and above 80% representing low, moderate, and high heterogeneity, respectively. In cases of substantial heterogeneity, the Dersimonian and Laird random-effects model was applied to ensure the generation of more conservative estimates.

To identify the sources of heterogeneity, subgroup analyses, as well as univariate and multivariable meta-regression techniques, were conducted. Publication bias

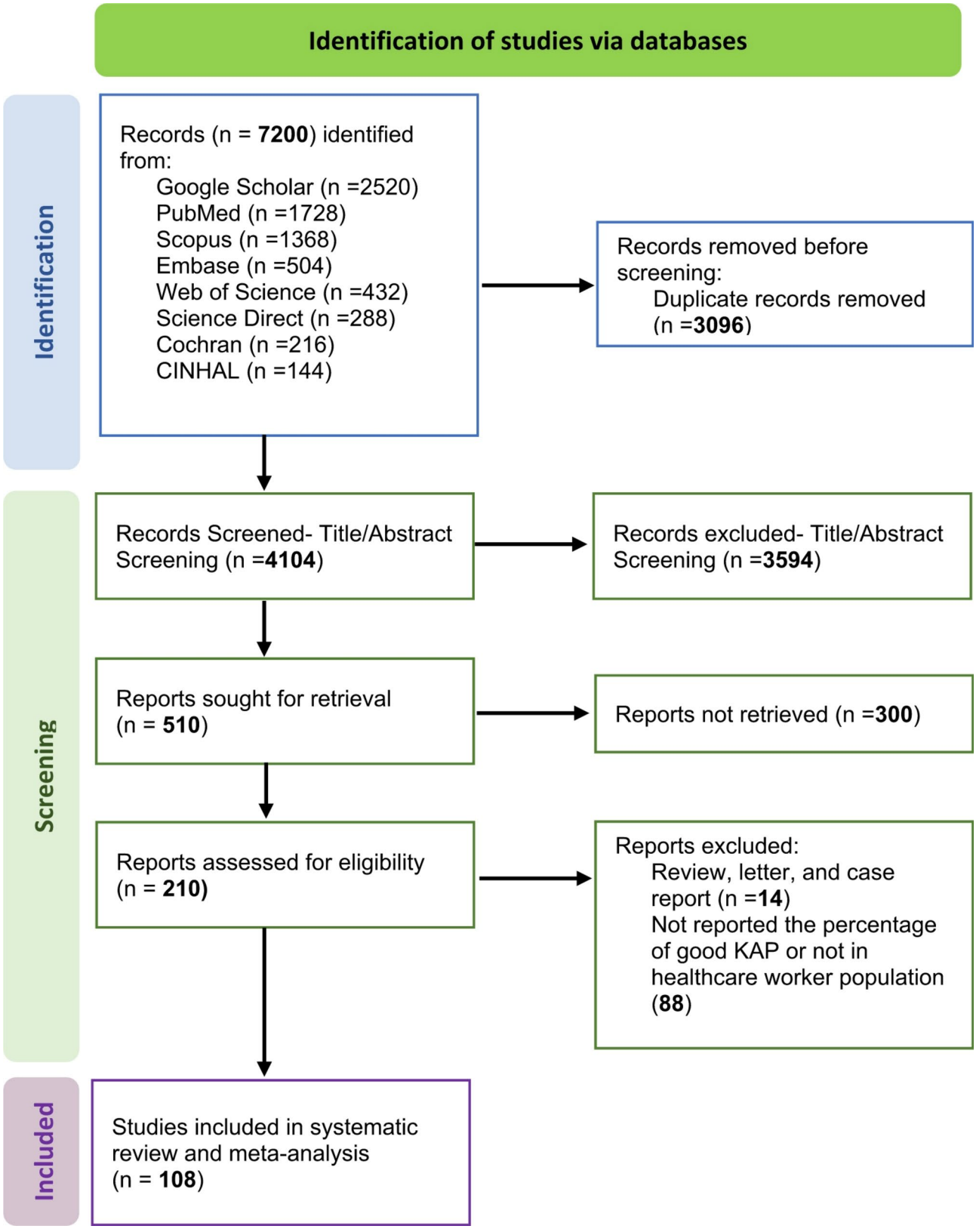

Fig. 1 The PRISMA flowchart delineates the methodology employed for the selection of studies for inclusion in this systematic review and meta-analysis

was assessed using the Egger regression test. Additionally, the trim-and-fill method was employed to adjust the overall estimates and account for any studies potentially omitted due to publication bias.

A sensitivity analysis was performed using the one-out-remove method, where each study was excluded individually to evaluate its impact on the overall results. This approach helped determine whether any single study had a significant influence on the findings of the meta-analysis. Finally, the geographic distribution of HCWs' knowledge, attitudes, and practices related to AMR was analyzed using ArcGIS 10.3 software. The data were mapped by continent and country to illustrate regional patterns in KAP concerning AMR.

Certainty assessment

In addition to adhering to the established procedures for meta-analysis, the GRADE (Grading of Recommendations Assessment, Development, and Evaluation) framework was utilized to assess the reliability of the evidence under the PRISMA 2020 guidelines. The GRADE methodology evaluated the quality of evidence across several aspects, including limitations of the studies (risk of bias), inconsistency in results, indirectness of evidence, imprecision, and potential publication bias.

The quality of the evidence was classified into four categories: very low, indicating minimal evidence with a high likelihood that the true effect might differ significantly from the estimate; low, indicating significant uncertainty and the possibility that the true effect could be substantially different; moderate, indicating sufficient evidence with some confidence that the true effect was close to the estimate; and high, representing robust evidence with a high level of confidence that the estimate accurately reflected the true effect.

Results

Characteristics of studies included

In this meta-analysis, a total of 108 studies were identified, representing a wide array of geographical regions globally, including countries from Africa, Asia, Europe, and the Middle East. These countries include Zambia, Saudi Arabia, Egypt, Bhutan, India, Nigeria, Ethiopia, Lebanon, Malaysia, Sudan, Pakistan, Uganda, Sierra Leone, Bangladesh, Thailand, Iraq, Yemen, Laos, Brunei, Jordan, Cameroon, Ghana, Palestine, the United Kingdom, Sri Lanka, Togo, Ivory Coast, the United Arab Emirates, and Kenya, among others. The populations surveyed in these studies included physicians, pharmacists, medical students, nurses, and other healthcare professionals. All included studies utilized a cross-sectional design, allowing for a comprehensive assessment of current knowledge, attitudes, and practices related to antibiotics among varied populations (Table 1; Fig. 1).

Knowledge of AMR

A comprehensive analysis of 108 studies involving 29,433 HCWs evaluated their knowledge levels concerning AMR. The findings revealed notable variations in knowledge across different regions, indicating disparities that may reflect differences in access to educational resources and training regarding antibiotics (Table 1).

Attitudes toward AMR

A comprehensive analysis of 51 studies assessing attitudes toward antibiotics revealed significant variations across regions. Zulu's study in Zambia found that 96.9% of participants held a positive attitude toward antibiotics, while El-Sokkary's research in Egypt reported only 9.4% exhibiting a similar positive outlook. These differences may be influenced by prevailing cultural and educational factors in each region, underscoring the need for targeted interventions to improve attitudes toward antibiotic use(Table 1).

Practices regarding AMR

In terms of practices, a total of 43 studies evaluated AMR prevention practices among HCWs. The prevalence of good practices related to antibiotic use varied widely, with Albalawi's study in Saudi Arabia reporting that 84.6% of participants adhered to good practices, whereas only 6% of respondents in Davwar's study from Nigeria demonstrated such adherence (Table 1).

Bias assessment and study quality

To evaluate the quality of the included studies, we employed the Joanna Briggs Institute (JBI) checklist for bias assessment. Our analysis indicated a low risk of bias across all studies, reinforcing the credibility and quality of the data collected (Table 1).

Meta-analysis

Pooled good knowledge of AMR

An extensive analysis of 108 studies, encompassing 29,433 HCWs, was performed to evaluate their knowledge levels concerning AMR. In light of the observed heterogeneity, a random-effects model was employed to calculate the pooled estimate of good knowledge.

The overall knowledge of AMR among HCWs was 56.50% (95% CI: 50.4–62.6). However, a significant level of heterogeneity was observed among the studies (I^2 = 99.5%, Q^(statistic) = 21313.74, df = 109, $p < 0.0001$, Tau-squared = 0.1052) (Fig. 2).

A comprehensive sensitivity analysis was conducted using the one-by-one study removal method. The findings indicated that no single study exerted a significant influence on the proportion of good knowledge. Consequently, no studies were identified as influential in this analysis (see Supplementary Fig. 1).

Table 1 Characteristics of included studies

N	Authors Name	Year of Pub	Study Region	Study design	Size	Good level of knowledge %	Good practice%	Positive Attitude %	Study quality	Population type
1	Tembo, N [18]	2022	Zambia	cross-sectional	263	70	64	60	Low risk	pharmacy personnel and nurses
2	Albalawi, L [19]	2023	Saudi Arabia	cross-sectional	266	76.1	84.6	61.5	Low risk	pharmacy and non-pharmacy interns
3	Nemr, N [20]	2023	Egypt	cross-sectional	350	93.7	54	79	Low risk	Healthcare Providers including physicians and dentist
4	Wangmo, K [21]	2021	Bhutan	cross-sectional	219	38.8	77	51	Low risk	veterinarians and para-veterinarians
5	Mudenda, S [22]	2020	Zambia	cross-sectional	144	93.8	25	67	Low risk	community pharmacies
6	Mudenda, S [23]	2022	Zambia	cross-sectional	172	90	64	84	Low risk	undergraduate pharmacy students
7	Lubwama, M [24]	2021	East Africa	cross-sectional	328	54	NR	NR	Low risk	final Y medical and pharmacy stu
8	Nishat, S [25]	2022	India	cross-sectional	110	60.9	37	30.4	Low risk	Clinicians
9	Zulu, A [26]	2020	Zambia	cross-sectional	260	87.3	75	96.9	Low risk	undergraduate medical students
10	El-Sokkary, R [27]	2021	Egypt	cross-sectional	500	71.6	15.6	9.4	Low risk	Physicians
11	Al Sulayyim, H [28]	2023	Saudi Arabia	cross-sectional	406	72.73	50	71.43	Low risk	HCW
12	Shrestha, L [29]	2020	Nepal	cross-sectional	216	33	43.5	78.2	Low risk	HCP
13	Abdelrahman, M [30]	2023	Somalia	cross-sectional	410	69	51.7	52.4	Low risk	pharmacists
14	Shrestha, R [31]	2019	Nepal	cross-sectional	228	17.1	17.1	50	Low risk	undergraduate medical
15	Davwar, P [32]	2023	Nigeria	cross-sectional	252	41	6	16	Low risk	Doctors
16	Sharma, S [33]	2016	India	cross-sectional	120	79.72	64	55.95	Low risk	2d y MBBS Stu
17	Tanveer, A [34]	2022	India	cross-sectional	40	40	47	58	Low risk	community pharmacies
18	Kumar Dutt. H [35]	2018	Kerala	cross-sectional	222	77.5	79.7	79.7	Low risk	Final-year students from medical, dental, and paramedical
19	Yang. C [36]	2024	China	cross-sectional	1959	7.5	20.7	3.8	Low risk	Nursing student
20	Dudhe. B [37]	2023	India	cross-sectional	344	68.02	12.5	38.95	Low risk	MBBS student
21	Kainga, H [38]	2023	Malavi	cross-sectional	68	46.7	41.6	49.2	Low risk	Veterinary drug dispensers
22	Kumar Sahu. R [39]	2021	India	cross-sectional	100	27	22	38	Low risk	Nursing professionals
23	A. Nowbuth, A [40]	2023	Zambia	cross-sectional	180	45	NR	68	Low risk	final-year medical students
24	Okedo-Alex, I [41]	2019	Nigeria	cross-sectional	184	64.7	56	NR	Low risk	pre-final and final-year medical students
25	Sadasivam, K [42]	2016	India	cross-sectional	441	82	NR	34	Low risk	paramedical staffs
26	Tafa, B [43]	2017	Ethiopia	cross-sectional	218	62.8	NR	80	Low risk	Paramedical staffs
27	Sakr, S [44]	2020	Lebanon	cross-sectional	477	78	NR	35.42	Low risk	health-related majors students
28	Rajiah, K [45]	2014	Malaysia	cross-sectional	346	84.4	NR	34.1	Low risk	final undergraduate pharmacy stu
29	N Asharani [46]	2020	India	cross-sectional	367	45.5	90	NR	Low risk	medical students and intern
30	Lin Foo, Y [47]	2021	Malaysia	cross-sectional	142	52.8	NR	76.1	Low risk	science students
31	Hamad, F [48]	2019	Sudan	cross-sectional	393	51	NR	58	Low risk	final-year students of medicine, pharmacy, and nursing
32	Bulcha, B [49]	2024	Ethiopia	cross-sectional	120	66.88	NR	66.17	Low risk	animal health professional
33	Olujide Ojo, J [50]	2024	Nigeria	cross-sectional	320	66.3	NR	39.4	Low risk	HCWs
34	S. Lalithabai, D [51]	2022	Saudi Arabia	cross-sectional	341	14.7	NR	76.7	Low risk	Nurses
35	M Sudhir [52]	2020	India	cross-sectional	30	47	66	60	Low risk	Community Pharmacists
36	Ul Mustafa, Z [53]	2022	Pakistan	cross-sectional	376	60.4	NR	NR	Low risk	Pharmacy Technicians

Table 1 (continued)

N	Authors Name	Year of Pub	Study Region	Study design	Size	Good level of knowledge %	Good practice%	Positive Attitude %	Study quality	Population type
37	Kanyike, A [54]	2022	Uganda	cross-sectional	681	87.5	NR	NR	Low risk	clinical health professions students
38	Koroma A, T [55]	2023	Sierra Leone	cross-sectional	376	68	NR	NR	Low risk	medical professionals
39	P. Reena, A [56]	2022	India	cross-sectional	354	56.2	NR	NR	Low risk	undergraduate medical students
40	Hayat, K [57]	2021	Pakistan	cross-sectional	296	31.8	NR	NR	Low risk	Pharmacy Students
41	Akande-Sholabi, W [58]	2021	Nigeria	cross-sectional	866	58.4	NR	NR	Low risk	healthcare students
42	Simegn, W [59]	2022	Ethiopia	cross-sectional	412	84.7	NR	NR	Low risk	health professionals
43	Abubakar Sani, A [60]	2023	Bangladesh	cross-sectional	20	45	55	50	Low risk	informal poultry drug prescribers
44	Netthong, R [61]	2022	Thailand	cross-sectional	387	82.69	NR	NR	Low risk	Community Pharmacists
45	Gyawali, M [62]	2024	Kyrgyzstan	cross-sectional	120	89.2	49.2	NR	Low risk	undergraduate medical students
46	Al-Attar, Z [63]	2023	Iraq	cross-sectional	365	31.2	NR	NR	Low risk	Medical Students
47	Battah, M [64]	2021	Yemen	cross-sectional	237	12.41	21.36	NR	Low risk	Medical Students
48	Sychareun, V [65]	2021	Laos,	cross-sectional	217	41	64	NR	Low risk	Healthcare Providers
49	Fetensa, G [66]	2020	Ethiopia	cross-sectional	232	68.1	NR	NR	Low risk	Health Science Students
50	E. Chukwu, E [67]	2021	Nigeria	cross-sectional	358	49.2	NR	NR	Low risk	HCWs
51	Shahpawee, N S [68]	2020	Brunei	cross-sectional	65	76	NR	NR	Low risk	Institute of Health Sciences
52	Babatola, A O [69]	2020	Nigeria	cross-sectional	326	82.7	NR	NR	Low risk	Physicians
53	Assen Seid, M [70]	2018	Ethiopia	cross-sectional	323	12.1	NR	96.3	Low risk	paramedical students
54	Suaifan, Gh [71]	2012	Jordan	cross-sectional	200	43	NR	NR	Low risk	Medical Students
55	Abera, B [72]	2014	Ethiopia	cross-sectional	385	72.2	NR	NR	Low risk	Physicians and Nurses
56	Domche Ngongang S, C [73]	2021	Cameroon	cross-sectional	98	56	NR	NR	Low risk	physicians
57	Sefah, I A [74]	2022	Ghana	cross-sectional	160	57.5	NR	NR	Low risk	final-year nursing and physician assistantship students
58	Abdelkarim, O A [75]	2024	Sudan	cross-sectional	109	70	NR	NR	Low risk	Undergraduate Pharmacy Students
59	Huang, S [76]	2023	Nigeria	cross-sectional	46	65	NR	NR	Low risk	Medical Laboratory Scientists
60	Abuawad, M [77]	2024	Palestine	Cross-sectional	384	84	NR	65.2	Low risk	Medical Students
61	El-din, M. Z [78]	2018	Egypt	cross-sectional	461	51.2	NR	NR	Low risk	community pharmacist
62	Aworh, M. K [79]	2021	Nigeria	cross-sectional	144	18.1	NR	NR	Low risk	veterinarians
63	AL-Salih, S. S [80]	2019	Iraq	cross-sectional	150	80	NR	NR	Low risk	Nursing and Dentistry Students
64	Tang, K. L [81]	2020	Malaysia	cross-sectional	295	65.3	NR	NR	Low risk	Pharmacists
65	Kulkarni, P [82]	2017	India	cross-sectional	100	39	NR	NR	Low risk	Interns
66	Saksena, R [83]	2024	India	cross-sectional	208	73.75	NR	NR	Low risk	Medical students
67	Deolekar, P [84]	2019	Nerul	cross-sectional	200	96	NR	NR	Low risk	Medical students
68	BELLO I, S [85]	2021	Nigeria	cross-sectional	576	26.4	NR	NR	Low risk	healthcare students
70	Mufwambi, W [86]	2021	Zambia	cross-sectional	304	60.4	NR	NR	Low risk	Healthcare Professionals
71	Muluye, A. B [87]	2020	Ethiopia	Cross-sectional	269	51	NR	NR	Low risk	Healthcare Professionals
72	Soré,S [88]	2022	Burkina Faso	cross-sectional	330	60	NR	NR	Low risk	human health workers and veterinarians
73	Al Harbi, A. A [89]	2023	Saudi Arabia	cross-sectional	223	16.1	NR	NR	Low risk	Physicians
74	Golding, S.E [90]	2022	UK	cross-sectional	460	58.7	NR	NR	Low risk	Veterinary students
74	Golding, S.E [90]	2022	UK	cross-sectional	113	82.3	NR	NR	Low risk	Veterinary students
75	Philip, R [91]	2023	India	cross-sectional	120	59.2	66.5	67.2	Low risk	community pharmacist

Table 1 (continued)

N	Authors Name	Year of Pub	Study Region	Study design	Size	Good level of knowledge %	Good practice%	Positive Attitude %	Study quality	Population type
76	Jamali, G. M [92]	2019	Pakistan	cross-sectional	260	51	NR	58	Low risk	Medical students
77	Agrawal, A [93]	2019	India	cross-sectional	152	56.6	NR	NR	Low risk	MBBS student
78	Hossain, J [94]	2024	Bangladesh	cross-sectional	191	8.4	43	77	Low risk	Community pharmacist
79	Sangma, Z. M [95]	2018	India	cross-sectional	167	28.1	NR	53.9	Low risk	Junior doctor
80	Okedo-Alex, I. N [96]	2019	Nigeria	cross-sectional	184	NR	NR	40.2	Low risk	Low risk
81	Chin King, L [97]	2019	Malaysia	cross-sectional	125	40.8	NR	NR	Low risk	science undergraduates
82	Jayaweerasingham, M [98]	2019	Sri Lanka	cross-sectional	199	57.8	NR	NR	Low risk	Nurses
83	Deo, S.K [99]	2020	Nepal	cross-sectional	231	45.5	99.6	96.5	Low risk	Medical students
84	GARBA, M. A [100]	2018	Kaduna	cross-sectional	74	73	NR	NR	Low risk	HCWs
85	Djuikoue, C. I [101]	2022	Cameroon	cross-sectional	100	28	31	89	Low risk	Prescribers
85	Djuikoue, C. I [101]	2022	Cameroon	cross-sectional	113	85.8	27.4	34.5	Low risk	dispensers
86	Jainlabdin, M.H [102]	2023	Malaysia	cross-sectional	312	36.7	44.1	40.6	Low risk	Medical and Science Students
87	Dayyab, F. M [103]	2021	Nigeria	cross-sectional	43	37.2	NR	NR	Low risk	nursing staff
88	Bedekelabou, A.P [104]	2022	Togo	cross-sectional	121	88	28	83	Low risk	health actors
88	Bedekelabou, A.P [104]	2022	Ivory Coast	cross-sectional	100	50	28	76	Low risk	health actors
89	Habib, K.D [105]	2022	Iraq	cross-sectional	108	28.7	26.8	89.8	Low risk	Nurses
90	Jainlabdin, M.H [106]	2021	Malaysia	cross-sectional	206	NR	88.8	98.5	Low risk	Nursing student
91	Qudah, T [107]	2024	United Arab Emirates	cross-sectional	400	43.5	34.4	42.3	Low risk	pharmacist
92	M. Sandaruwan [108]	2022	Sri Lanka	cross-sectional	102	40	41	NR	Low risk	veterinarians
93	Hakami, A.M [109]	2023	Saudi Arabia	cross-sectional	313	65.8	NR	NR	Low risk	Pharmacist
94	Sultana, R [110]	2023	Bangladesh	cross-sectional	583	34.2	NR	NR	Low risk	Physicians
95	Akande-Sholabi, W [111]	2023	Nigeria	cross-sectional	126	70.6	8.7	NR	Low risk	community pharmacists
96	Ghaffoori Kanaan, M.H [112]	2021	Iraq	cross-sectional	102	100	NR	NR	Low risk	community members, pharmacists, and healthcare providers
97	Odetokun, A.I [113]	2019	Nigeria	cross-sectional	413	40	NR	NR	Low risk	Veterinary Students
98	Kamita, M [114]	2022	Kenya	cross-sectional	240	42.9	NR	NR	Low risk	medical practitioners
99	Kamoto, A [115]	2020	Malawi	cross-sectional	72	62.5	NR	NR	Low risk	final-year medical students
100	Bazzi, R [116]	2022	Jordan	cross-sectional	115	84	NR	NR	Low risk	veterinarians
101	Rattanaumpawan, p [117]	2019	Thailand	cross-sectional	455	32	NR	NR	Low risk	Medical student
102	Rattanaumpawan, p [117]	2019	Thailand	cross-sectional	225	33	NR	NR	Low risk	Doctors in training
103	M.J. Sudha [118]	2021	India	cross-sectional	120	44.65	NR	NR	Low risk	Medical doctors
104	Tenzin, J [119]	2023	Buhtan	cross-sectional	58	100	98.2	NR	Low risk	competent persons in the community pharmacies
105	Hussain, J [120]	2023	Pakistan	cross-sectional	136	19.9	NR	NR	Low risk	Medical student
106	Dharanindra, M [121]	2023	India	Cross-sectional	389	23	NR	NR	Low risk	community pharmacies
107	Thesis/Muradyan, D [122]	2020	Yerevan	cross-sectional	291	58.3	63	67.5	Low risk	General practitioner
108	Thesis/Siltrakool, B [123]	2017	Thailand	cross-sectional	372	94	93	93.2	Low risk	Community Pharmacists

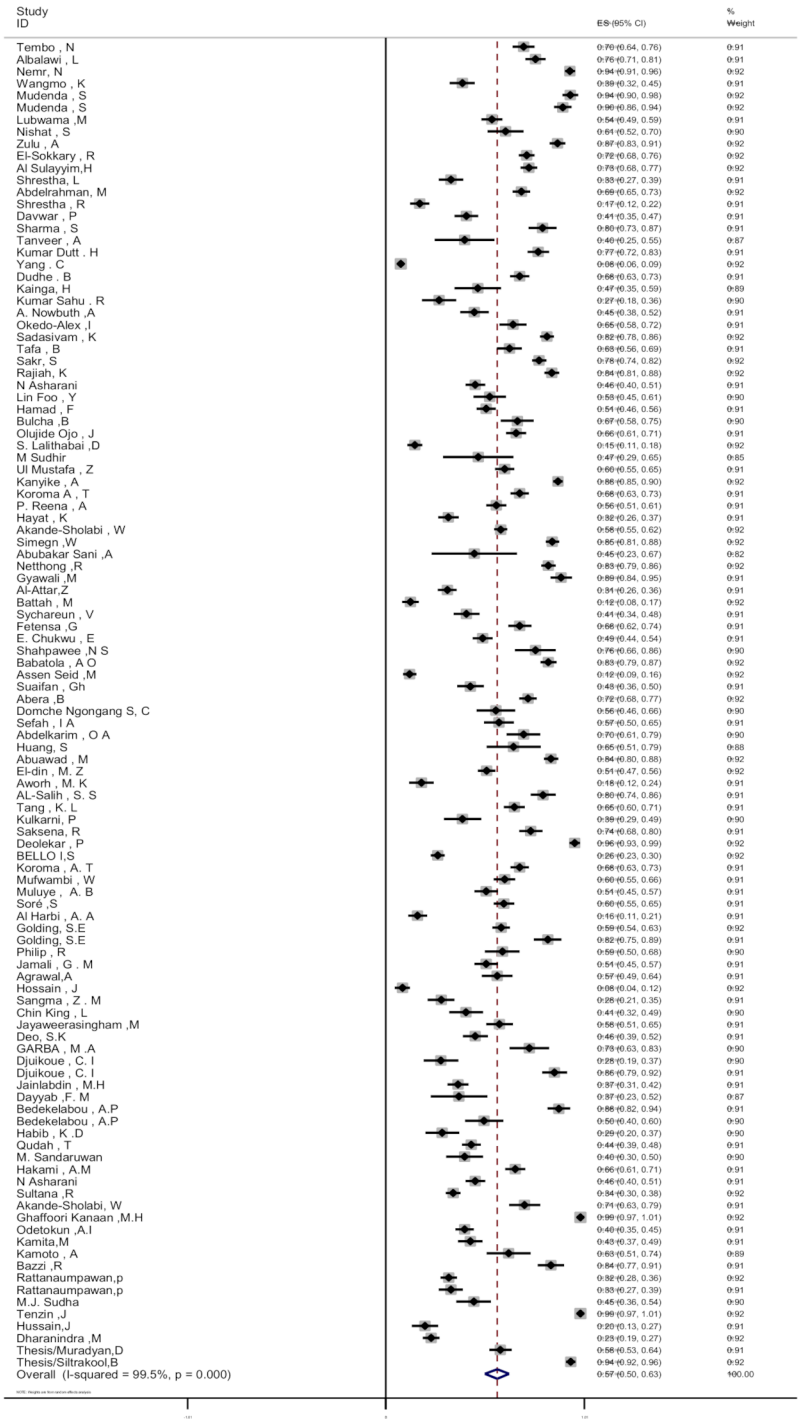

Fig. 2 The forest plot presents the results of a random-effects meta-analysis with I-V heterogeneity, providing insight into the good knowledge of AMR among HCWs

Table 2 presents the results of the univariate and multivariable meta-regression analyses aimed at identifying potential sources of heterogeneity among the studies included in the meta-analysis. The analyses examined factors such as study quality, population type, country, year of publication, sample size, and WHO region as possible causes of heterogeneity in knowledge levels.

In the univariate analysis, population type was significantly associated with heterogeneity (Coefficient = -0.0297, $p = 0.021$), indicating that variations in the

Table 2 Univariate and multivariable meta-regression to find possible causes of heterogeneity among studies included in the meta-analysis

Type	Possible cause of heterogeneity	Univariate		Multivariable	
		Coefficient (95%CI)	*p*-value	Coefficient (95%CI)	*p*-value
Knowledge	Quality of study	-0.0308(-0.0878, 0.0261)	0.285	-0.0367(-0.0935, 0.0201)	0.203
	Population Type	-0.0297(-0.0549, -0.0045)	**0.021**	-0.0304(-0.0559, -0.0050)	**0.019**
	Country	0.0012(-0.0026, 0.0050)	0.540	0.0018(-0.0021, 0.0057)	0.362
	Year	-0.0058(-0.0247, 0.0131)	0.545	-0.0049(-0.0236, 0.0137)	0.603
	Sample size	-0.0001(-0.0003, 0.00004)	0.142	-0.00013(-0.0003, 0.00006)	0.173
	WHO region	-0.0265(-0.0666, 0.0136)	0.195	-0.0247(-0.0641, 0.0147)	0.220
Attitude	Quality of study	0.0063(-0.0800, 0.0928)	0.883	-0.0198(-0.1101, 0.0705)	0.661
	Population Type	-0.0037(-0.0777, 0.0702)	0.840	0.0074(-0.0319, 0.0468)	0.705
	Country	0.0019(-0.0089, 0.0128)	0.722	0.0018(-0.0038, 0.0076)	0.516
	Year	-0.0102(-0.0377, 0.0171)	0.455	-0.0110(-0.0415, 0.0193)	0.466
	Sample size	-0.0003(-0.0005703, -0.0001)	**0.003**	-0.0003(-0.0006, – 0.000080)	**0.011**
	WHO region	-0.0308(-0.0963, 0.0345)	0.355	-0.0137(-0.0866, 0.0590)	0.705
Practice	Quality of study	-0.1611(-0.2575, -0.0647)	**0.002**	-0.1841(-0.2691, -0.0990)	**< 0.001**
	Population Type	-0.0191(-0.0599, 0.0216)	0.357	-0.0164(-0.0526, 0.0197)	0.373
	Country	-0.0070(-0.0188, 0.0046)	0.237	-0.0108(-0.0198, -0.0017)	**0.020**
	Year	-0.0463(-0.0846, -0.0080)	**0.018**	-0.0580(-0.0914, -0.0247)	**0.001**
	Sample size	-0.0001(-0.0003, 0.0001)	0.379	0.00006(-0.00014, 0.00027)	0.569
	WHO region	0.0575(-0.0074, 0.1224)	0.083	0.0535(-0.00163, 0.1088)	0.057

type of population studied contributed to differences in knowledge estimates. This association remained significant in the multivariable analysis (Coefficient = -0.0304, $p = 0.019$).

Other factors, including study quality (Univariate Coefficient = -0.0308, $p = 0.285$; Multivariable Coefficient = -0.0367, $p = 0.203$), country (Univariate Coefficient = 0.0012, $p = 0.540$; Multivariable Coefficient = 0.0018, $p = 0.362$), year of publication (Univariate Coefficient = -0.0058, $p = 0.545$; Multivariable Coefficient = -0.0049, $p = 0.603$), sample size (Univariate Coefficient = -0.0001, $p = 0.142$; Multivariable Coefficient = -0.00013, $p = 0.173$), and WHO region (Univariate Coefficient = -0.0265, $p = 0.195$; Multivariable Coefficient = -0.0247, $p = 0.220$) did not show a statistically significant association with heterogeneity in either the univariate or multivariable models (Table 2).

Table 3 shows the results of the subgroup analysis based on different WHO regions, work experience, gender, and age groups regarding HCWs' knowledge, attitudes, and practices regarding AMR. The highest frequency of knowledge was observed in the European Region (70.3%; 95% CI: 47.2–93.5%), and the lowest in the Western Pacific Region (45.9%; 95% CI: 13.9–78.0%) (Table 3, Fig. 3). Regarding work experience, health workers with less than 5 years of experience had a knowledge frequency of 60.9% (95% CI: 46.4–75.6%), which was similar to those with 5 or more years of experience (60.4%; 95% CI: 41.8–78.9%). When comparing by gender, male HCWs had a slightly higher frequency of knowledge (59.0%; 95% CI: 50.5–67.4%) compared to female workers (51.0%; 95% CI: 40.1–61.9%). Regarding age groups, health workers under 30 years of age had a knowledge frequency of 57.2% (95% CI: 48.7–65.7%), while those aged 30 years and older had a higher frequency of 65.7% (95% CI: 50.9–80.5%). The subgroup analysis based on the study population type for knowledge regarding AMR revealed notable differences. The highest level of knowledge was observed among HCWs (62.9%; 95% CI: 52.4–73.5), while the lowest was among students in health-related fields (55.3%; 95% CI: 49.7–60.9). The knowledge level among medical students (56.4%; 95% CI: 46.5–66.3) and physicians (52.4%; 95% CI: 42.3–62.6) was similar. Veterinarians and veterinary graduates had the lowest knowledge levels compared to other groups (50.1%; 95% CI: 36.4–63.8) (Table 3).

Pooled good attitudes towards AMR

A comprehensive analysis of 51 studies involving 13,660 HCWs was conducted to assess their attitude toward AMR. Given the heterogeneity observed, a random effects model was used to calculate the pooled estimate of good knowledge.

The overall attitude of AMR among HCWs was 60.4% (95% CI: 48.5–72.3) (Fig. 4). However, a significant level of heterogeneity was observed among the studies (I^2 = 99.8%, Q^ (statistic) = 24227.64, df = 51, $p < 0.0001$, Tau-squared = 0.1871) (Fig. 4).

The sensitivity analysis was performed using the one-at-a-time study removal method. The results showed that removing each study individually did not significantly change the overall estimate. This suggests that no single

Table 3 Subgroup analysis results by WHO region, work experience, sex, and age group for knowledge, attitude, and practice regarding AMR among HCWs

Type	grouping		No. studies	No. examined	Overall frequency (95%CI)	Heterogeneity			
						χ^2	*P*-value	I^2 (%)	Tau-squared
Knowledge	WHO Region	African Region	47	12,737	60.5(53.8–67.2)	3869.19	< 0.001	98.8	0.0542
		Eastern Mediterranean Region (EMRO)	22	5708	54.2(40.8–67.8)	3916.82	< 0.001	99.5	0.1031
		South-East Asia Region (SEARO)	33	7161	53.6(43.0-64.1)	4873.26	< 0.001	99.3	0.0938
		Western Pacific Region (WPRO)	6	3254	45.9(13.978.0)	1882.53	< 0.001	99.7	0.1596
		European Region (EURO)	2	573	70.3(47.2–93.5)	30.67	< 0.001	96.7	0.0269
	Work Experience	< 5 years	11	714	60.9(46.4–75.6)	226.90	< 0.001	95.6	0.0542
		≥ 5 years	11	778	60.4(41.8–78.9)	492.22	< 0.001	98.0	0.0947
	Sex	Male	25	2907	59.0(50.5–67.4)	635.63	< 0.001	96.2	0.0428
		Female	26	3033	51.0(40.1–61.9)	1326.70	< 0.001	98.1	0.0769
	Age group	< 30 years	11	1973	57.2(48.7–65.7)	136.99	< 0.001	92.7	0.0185
		≥ 30 years	11	789	65.7 (50.9–80.5)	265.30	< 0.001	96.2	0.0552
	Population type	HCWs	17	5434	62.9(52.4–73.5)	1394.78	< 0.001	98.9	0.0481
		Students in Health Field	2	302	55.3(49.7–60.9)	0.67	0.412	0	0.0000
		Medical Students	29	8065	56.4(46.5–66.3)	3114.63	< 0.001	99.1	0.0727
		Physicians and Doctor	14	3338	52.4(42.3–62.6)	598.39	< 0.001	97.8	0.0364
		Veterinarians and An	11	2120	50.1(36.4–63.8)	539.32	< 0.001	98.1%	0.0524
		Pharmacists and Phar	30	7274	62.2(51.6–72.8)	5370.87	< 0.001	99.5	0.0858
		Nurses and Nursing S	7	2900	56.5(50.4–62.6)	701.61	< 0.001	99.1	0.0685
Attitude	WHO Region	African Region	13	2277	61.8(44.8–78.9)	1497.85	< 0.001	99.2%	0.0974
		Eastern Mediterranean Region (EMRO)	14	4424	64.5(56.3–72.8)	484.66	< 0.001	97.3%	0.0240
		South-East Asia Region (SEARO)	19	3994	58.9(43.0-74.8)	4226.28	< 0.001	99.6%	0.1229
		Western Pacific Region (WPRO)	5	2965	60.4(48.5–72.3)	10186.73	< 0.001	100.0	0.3639
	Work Experience	< 5 years	7	506	77.8(65.2–90.5)	126.92	< 0.001	95.3	0.0268
		≥ 5 years	7	528	65.3(40.6–89.9)	416.00 (	< 0.001	98.6	0.1087
	Sex	Male	13	1059	59.9(42.2–77.5)	646.79	< 0.001	98.3	646.79
		Female	13	1383	64.9(49.0-80.8)	1330.32	< 0.001	99.1	0.0823
	Age group	< 30 years	7	668	68.5(50.0-87.1)	278.44	< 0.001	97.8	0.0603
		≥ 30 years	7	537	72.6(57.9–87.3)	116.96	< 0.001	94.9	0.0358
	Population type	HCWs	7	1777	66.5(53.8–79.2)	216.70	< 0.001	97.2	0.0285
		Medical Students	16	5627	51.5(28.3–74.7)	11947.37	< 0.001	99.9	0.2229
		Physicians and Doctor	1	291	67.5(62.1–72.9)	NA	NA	NA	NA
		Veterinarians and An	3	439	51.8(37.3–66.4)	19.14	< 0.001	89.5	0.0147
		Pharmacists and Phar	19	4347	63.0(54.9–74.1)	1674.93	< 0.001	98.9	0.0593
		Nurses and Nursing S	5	1179	74.4(52.5–92.4)	551.54	< 0.001	99.3	0.0620

Table 3 (continued)

Type	grouping		No. studies	No. examined	Overall frequency (95%CI)	Heterogeneity			
						χ^2	*P*-value	I^2 (%)	Tau-squared
Practice	WHO Region	African Region	13	1923	39.1(23.6–54.5)	890.39	< 0.001	98.7	0.0785
		Eastern Mediterranean Region (EMRO)	7	2267	41.0(21.2–60.8)	739.59	< 0.001	99.2	0.0710
		South-East Asia Region (SEARO)	18	3480	58.4(43.4–73.3)	4546.19	< 0.001	99.6	0.1034
		Western Pacific Region (WPRO)	3	2488	42.8(16.4–69.2)	210.84	< 0.001	99.1	0.0536
		European Region (EURO)	2	411	56.6(43.1–70.1)	6.60	0.010	84.9	0.0081
	Work Experience	< 5 years	7	506	48.8(20.9–76.7)	337.41	< 0.001	98.2	0.1379
		≥ 5 years	7	506	39.4(9.04–69.4)	451.73	< 0.001	98.7	0.1609
	Sex	Male	13	1010	46.7(28.4–65.0)	621.08	< 0.001	98.1	0.1089
		Female	13	1154	48.9(31.6–66.3)	665.71	< 0.001	98.2	0.0968
	Age group	< 30 years	7	668	56.0(33.0–79.0)	321.13	< 0.001	98.1	0.0933
		≥ 30 years	7	537	43.2(12.0-74.3)	486.52	< 0.001	98.8	0.1732
	Population type	HCWs	6	1410	44.9(34.8–55.0)	75.45	< 0.001	93.4	0.0147
		Medical Students	11	2313	55.3(31.8–78.9)	4453.01	< 0.001	99.8	0.1584
		Physicians and Doctor	4	1153	30.3(7.06–52.9)	336.30	< 0.001	99.1	0.0524
		Veterinarians and An	3	389	53.5(26.6–80.4)	57.25	< 0.001	96.5	0.0543
		Pharmacists and Phar	16	3137	53.7(38.1–69.4)	1873.70	< 0.001	99.2	0.0998
		Nurses and Nursing S	3	2167	21.0(19.3–22.8)	2.02	0.365	0.9%	0.0000

Abbreviation: NA, Not applicable

study had a significant impact on the pooled proportion of the outcome, confirming the robustness of the results. The estimates remained consistent and no influential studies were identified throughout the analysis (see Supplementary Figure).

Based on the findings from the univariate and multivariable meta-regression analyses, none of the variables except for the sample size were found to be significant sources of heterogeneity in the attitude domain. In the univariate analysis, the sample size showed a statistically significant negative association with heterogeneity (coefficient = -0.0003, 95% CI: -0.0005703 to -0.0001, $p = 0.003$). This indicates that as the sample size increases, the variation in attitude-related outcomes decreases. Similarly, in the multivariable analysis, the sample size remained a significant factor (coefficient = -0.0003, 95% CI: -0.0006 to -0.000080, $p = 0.011$), suggesting its importance as a potential source of heterogeneity even when accounting for other variables. Other variables, such as study quality, population type, country, year of study, and WHO region, did not show a significant association with heterogeneity in attitudes among the included studies (Table 2).

The subgroup analysis of attitudes toward antibiotic resistance among HCWs showed significant variation across regions and demographics. EMRO had the highest frequency of positive attitudes (64.5%, 95% CI: 56.3–72.8), while SEARO had the lowest (58.9%, 95% CI: 43.0-74.8) (Table 3; Fig. 5). Those with less than 5 years of experience reported a higher positive attitude (77.8%, 95% CI: 65.2–90.5) compared to those with more experience (65.3%, 95% CI: 40.6–89.9). Females (64.9%, 95% CI: 49.0-80.8) and those aged ≥ 30 years (72.6%, 95% CI: 57.9–87.3) had higher positive attitudes compared to males (59.9%, 95% CI: 42.2–77.5) and those under 30 (68.5%, 95% CI: 50.0-87.1). Among population types, HCWs had more positive attitudes (66.5%, 95% CI: 53.8–79.2) than medical students (51.5%, 95% CI: 28.3–74.7) (Table 3).

Pooled preventive behavior towards AMR

A comprehensive analysis of 43 studies involving 10,569 HCWs was conducted to assess their AMR prevention practices. Given the heterogeneity observed, a random effects model was used to calculate the pooled estimate of practice.

The overall practice of AMR among HCWs was 48.5% (95% CI: 36.5–60.5) (Fig. 6). However, a significant level of heterogeneity between studies was observed (I^2 = 99.7%, Q^ (statistic) = 15660.70, df = 42, $p < 0.0001$, tau-squared = 0.1602) (Fig. 4).

We used the one-at-a-time study removal method to perform a sensitivity analysis. This showed that removing each study did not significantly change the overall estimate. This confirms that no single study had a significant impact on the pooled proportion of practice. The estimates remained consistent and no influential studies were identified (see Supplementary Fig. 3).

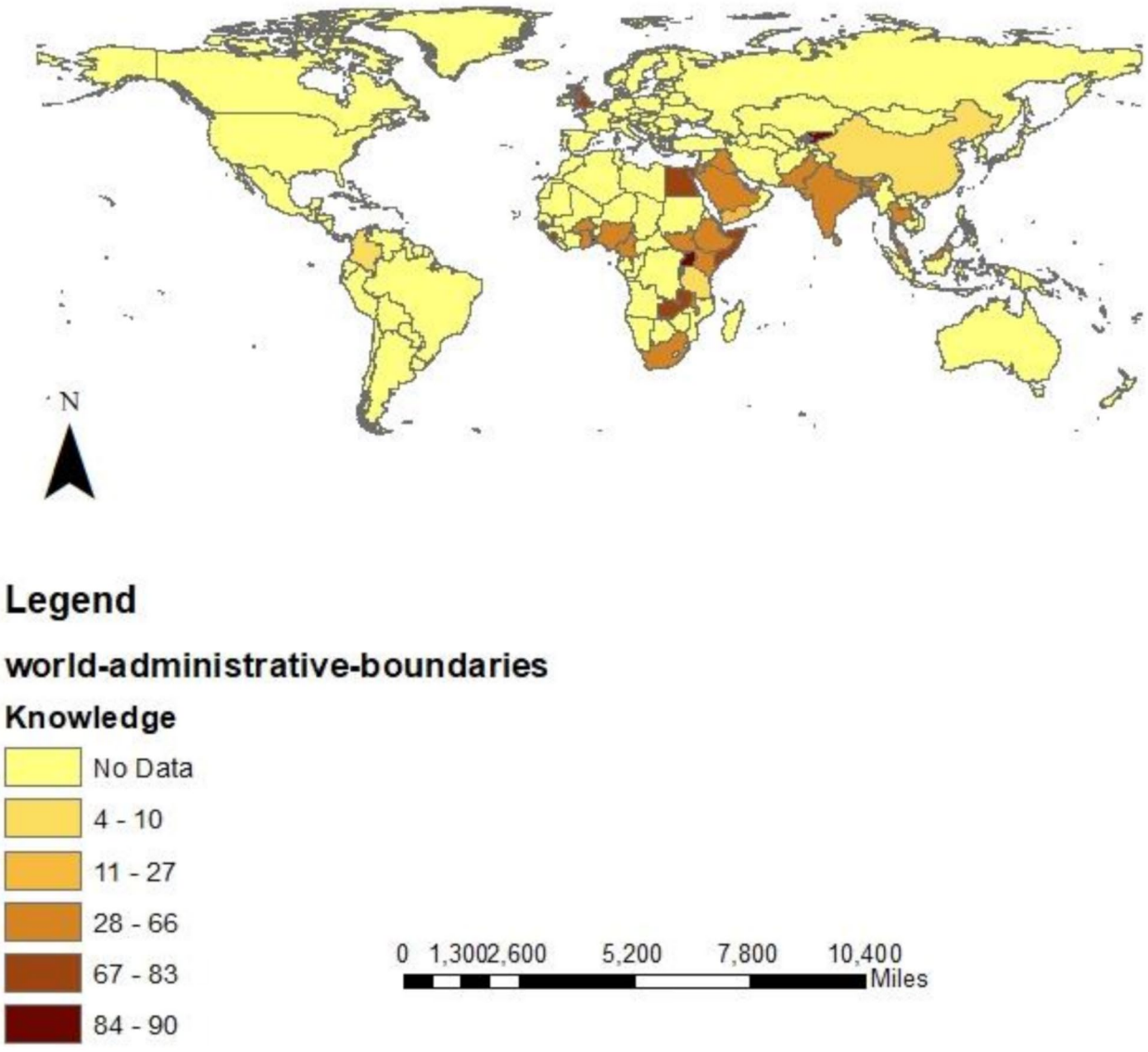

Fig. 3 Percentage of good knowledge of AMR among HCWs by country

In the meta-regression analysis for practice, quality of study, year, and country were identified as potential sources of heterogeneity. The quality of the study was significant in both univariate (Coefficient: -0.1611, $P=0.002$) and multivariable analyses (Coefficient: -0.1841, $P<0.001$). Year also showed a significant negative association in both models (Univariate: Coefficient: -0.0463, $P=0.018$; Multivariable: Coefficient: -0.0580, $P=0.001$). Additionally, the country was significant in the multivariable analysis (Coefficient: -0.0108, $P=0.020$) (Table 2).

The results of the subgroup analysis for practice regarding AMR among HCWs revealed significant variations across different World Health Organization (WHO) regions. Overall, the prevalence of appropriate practice was lowest in the African region at 39.1%, while it reached 56.6% in the European region (Fig. 7; Table 3). Additionally, HCWs with less than 5 years of experience reported a practice prevalence of 48.8%, compared to 39.4% for those with 5 or more years of experience. In terms of sex, male and female workers exhibited similar practice rates of 46.7% and 48.9%, respectively. Among age groups, workers under 30 years demonstrated a better practice rate of 56.0%, compared to 43.2% in those aged 30 years and older. Among different population types, medical students had the highest practice rate at 55.3%, while nurses reported the lowest rate at 21.0%(Table 3).

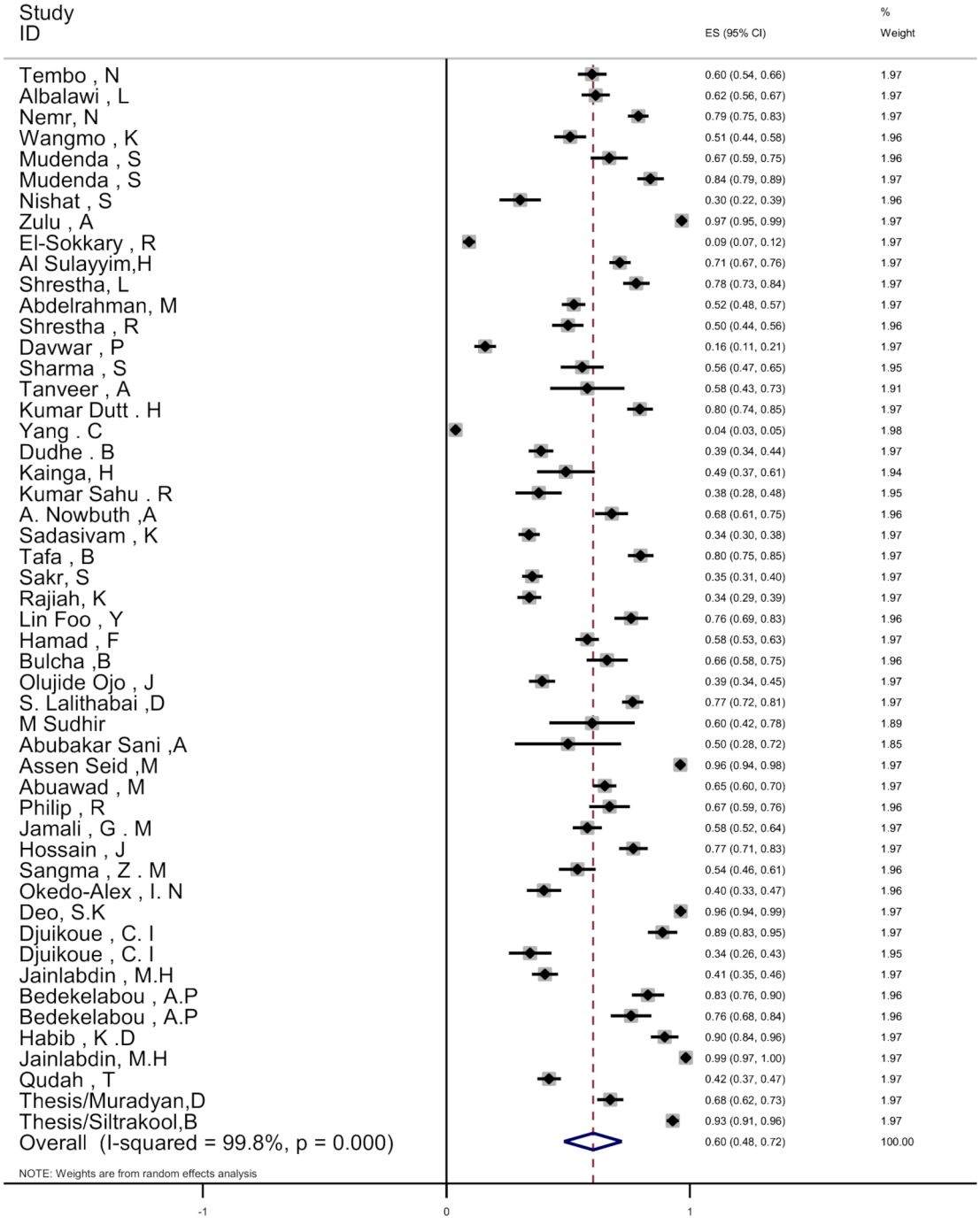

Fig. 4 The forest plot presents the results of a random-effects meta-analysis with I-V heterogeneity, providing insight into the positive attitude of AMR among HCWs

Publication Bias

Egger's test was used to check for publication bias among studies evaluating knowledge. The slope coefficient was significant ($p < 0.001$), suggesting that smaller studies might differ from larger ones in their results. However, the bias ($p = 0.765$) was not significant, indicating that any potential bias is not strong. Overall, Egger's test shows a possibility of small-study effects but does not confirm substantial publication bias (bias = 0.854, 95% CI: -4.804-6.513, $P = 0.765$)(see Fig. 8, A).

Egger's test was used to assess the potential publication bias among studies evaluating attitudes. The results

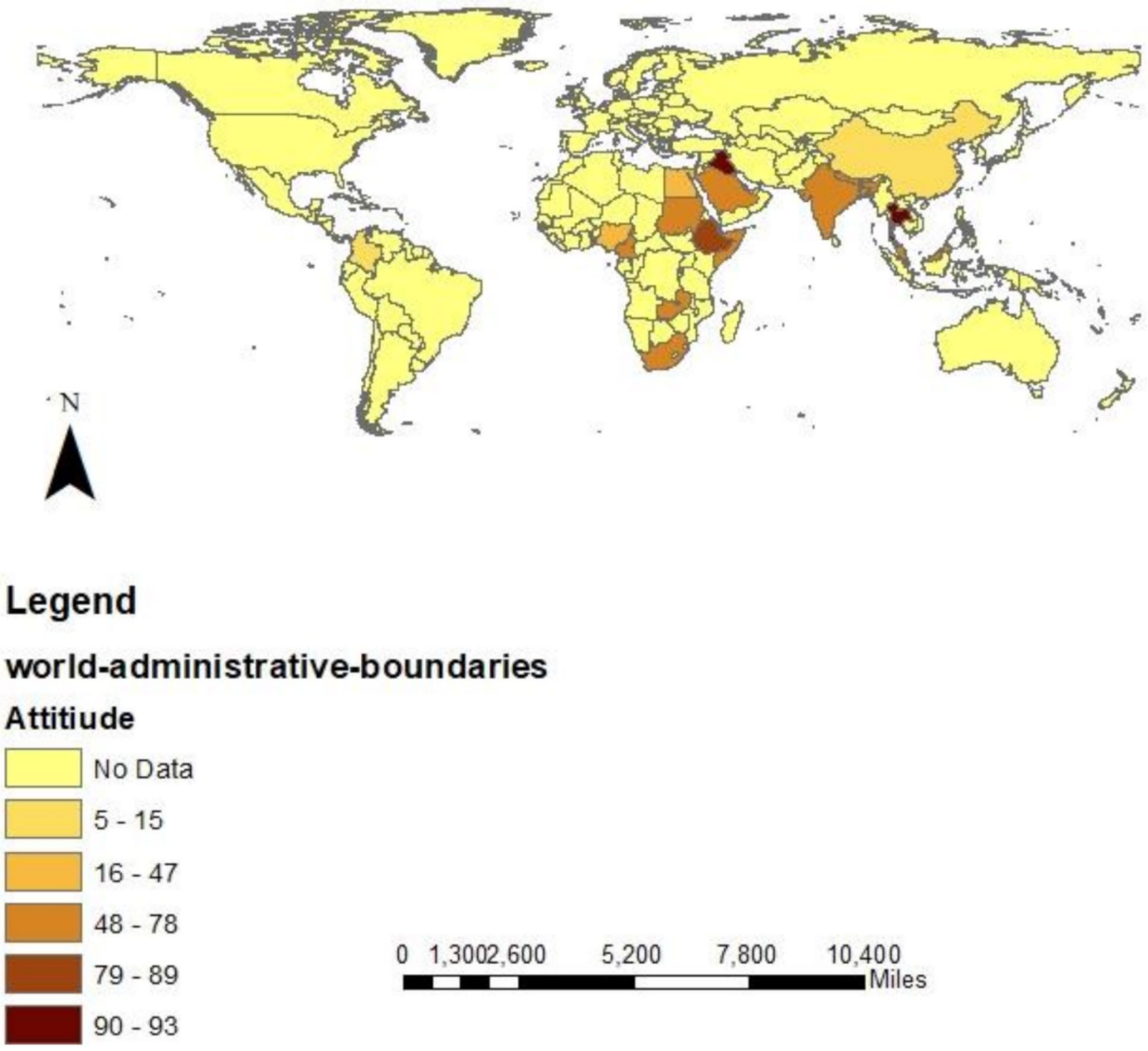

Fig. 5 Percentage of good attitude of AMR among HCWs by country

indicated a significant intercept (bias) of 11.6724 (95% CI: 2.28, 21.06; $p = 0.016$), suggesting the presence of small-study effects. The slope coefficient was 0.3181 (95% CI: 0.146, 0.490; $p = 0.001$), indicating that studies with smaller sample sizes and larger effect sizes may have a higher likelihood of being published. Additionally, the funnel plot was asymmetrical, further suggesting the presence of publication bias in the analyzed attitude studies) (see Fig. 8, B). To estimate the extent of publication bias, the trim-and-fill method was applied. This analysis identified 26 hypothetical studies that might be missing due to publication bias. The adjusted pooled estimate of attitude using the random-effects model, after accounting for the potentially missing studies, was 23.7% (95% CI: 9.7, 37.7; $p = 0.001$). The adjustment suggests that the initial pooled estimate may have been overestimated due to the presence of small-study effects.

The Egger's test for studies on good practices for AMR showed a slope of 0.907 (95% confidence interval: 0.7642 to 1.0509) with a p-value < 0.001, indicating a significant relationship between the standard errors and the effect sizes of the studies. Additionally, the bias value was − 14.648 (95% confidence interval: -22.4188 to -6.8777) with a p-value < 0.001, suggesting the presence of publication bias among the included studies. The asymmetrical shape of the funnel plot further supports this finding, implying that studies with larger effect sizes were more likely to be published(see Fig. 8, C).

The random-effects meta-analysis initially estimated a pooled practice of 48.5% (95% CI: 36.5 to 60.5,

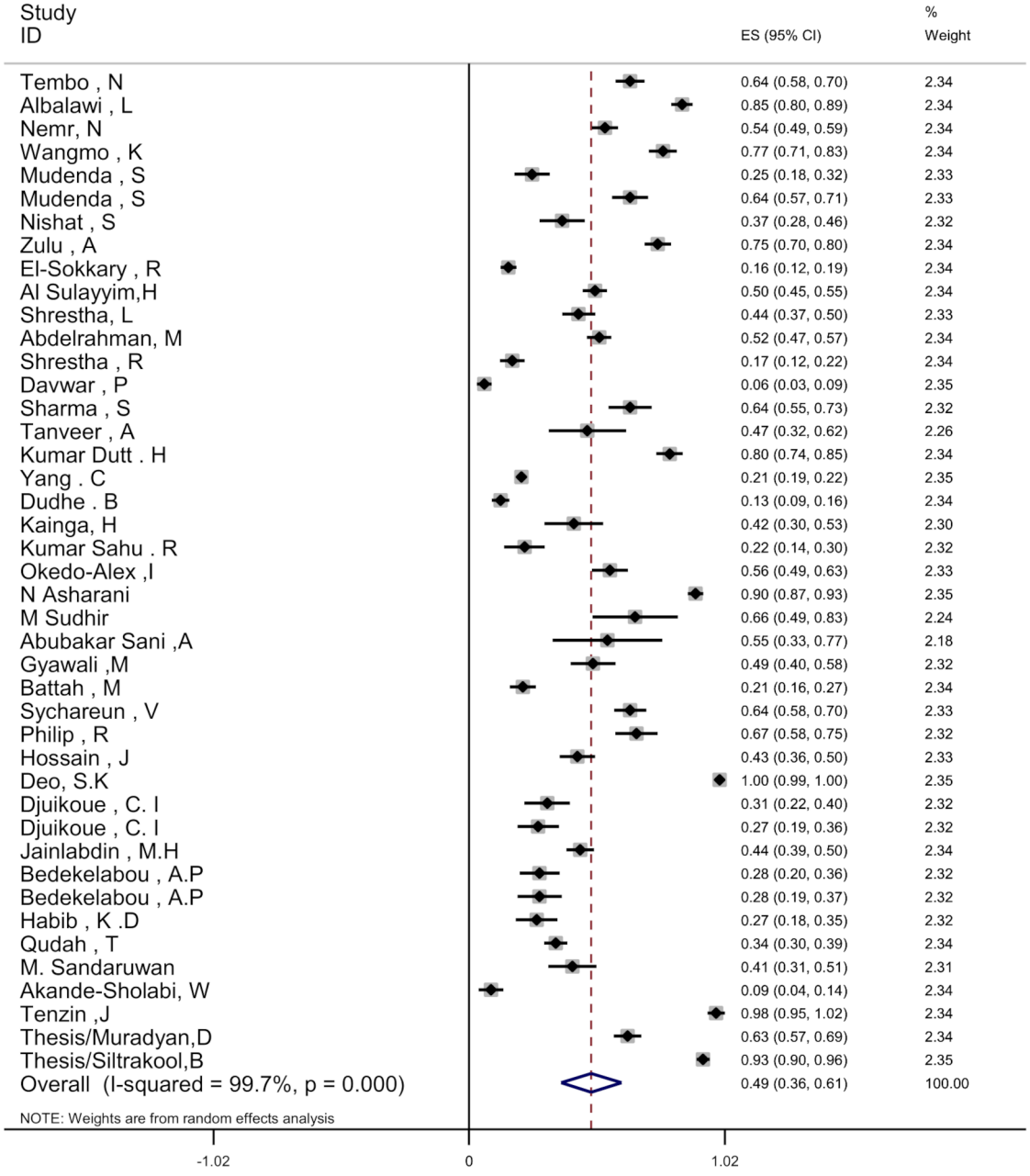

Fig. 6 The forest plot presents the results of a random-effects meta-analysis with I-V heterogeneity, providing insight into the preventive behavior of AMR among HCWs

p-value < 0.001). After trimming three studies, the pooled estimate was updated to 0.515 (95% CI: 0.403 to 0.627, *p*-value < 0.001) (Q = 16,000, $p < 0.001$).

GRADE assessment

The GRADE assessment shows that the evidence quality for knowledge, attitudes, and practices on AMR among HCWs varies. Knowledge has a "Good" rating (4/5), attitudes are "Moderate" (3/5), and practices are "Low" (2/5) (Supplementary Table 1).

Discussion

This study underscores the moderate levels of knowledge, attitudes, and practices (KAP) regarding AMR among HCWs globally. The findings reveal significant regional and demographic disparities, highlighting areas where awareness and adherence to good practices remain insufficient. These results emphasize the urgent need for targeted educational initiatives and policy reforms, particularly in regions with lower KAP scores, to combat the growing challenge of AMR effectively.

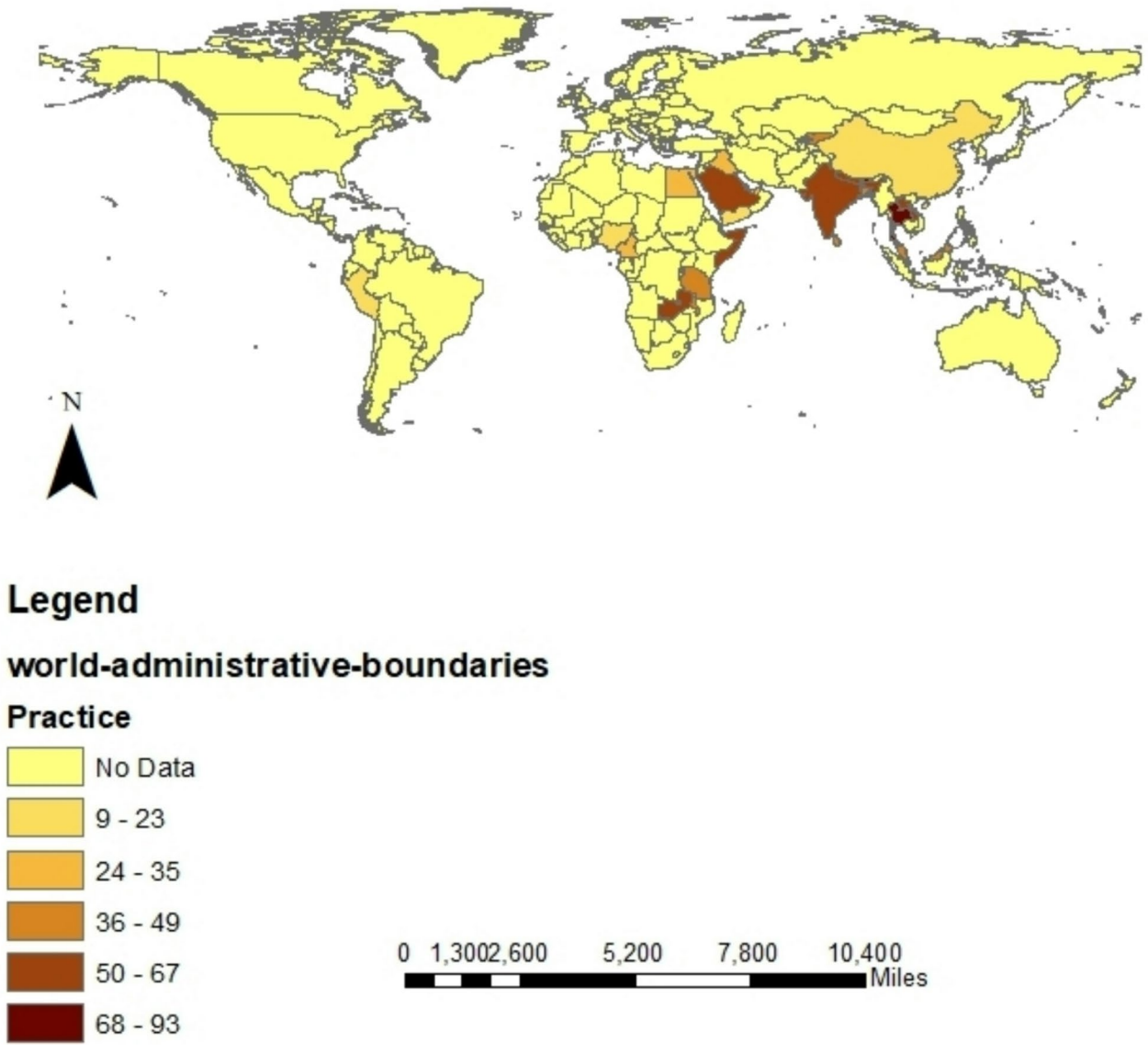

Fig. 7 Percentage of practice of AMR among HCWs by country

The results of the reviewed studies do not indicate a good state of knowledge of HCWs. The very low level of knowledge reported in some studies [31, 36, 51, 64, 70, 79, 94] highlights the need to implement urgent intervention measures for HCWs regarding AMR awareness. The knowledge of HCWs about AMR is much more important than the knowledge of the general public. HCWs play a critical role in antibiotic use, which includes educating patients and minimizing the spread of infection in healthcare settings [124, 125].

While studies provide mixed results across countries, with the highest levels of good knowledge among HCWs in Nepal and Iraq (100%) [113, 119] and the lowest levels of good knowledge among HCWs in Bangladesh (8.4) and China (7.5) [36, 94], statistically significant differences were observed across geographical regions. In particular, studies conducted in Europe and North America reported higher levels of knowledge than in lower-income countries in Africa and Southeast Asia. These disparities may be due to different educational resources and unequal access to specialized training.

AMR represents a serious health threat as well as considerable economic burden worldwide. Under a low burden scenario, AMR is projected to add $330 billion to the annual healthcare cost by 2050—under a high burden, the increase could reach up to $1.2 trillion, according to estimates by the World Bank [126].

AMR could also impose more than a 1.1% cut in global gross domestic product (GDP) by 2030, possibly above $1 trillion a year [127]. Such economic burdens are

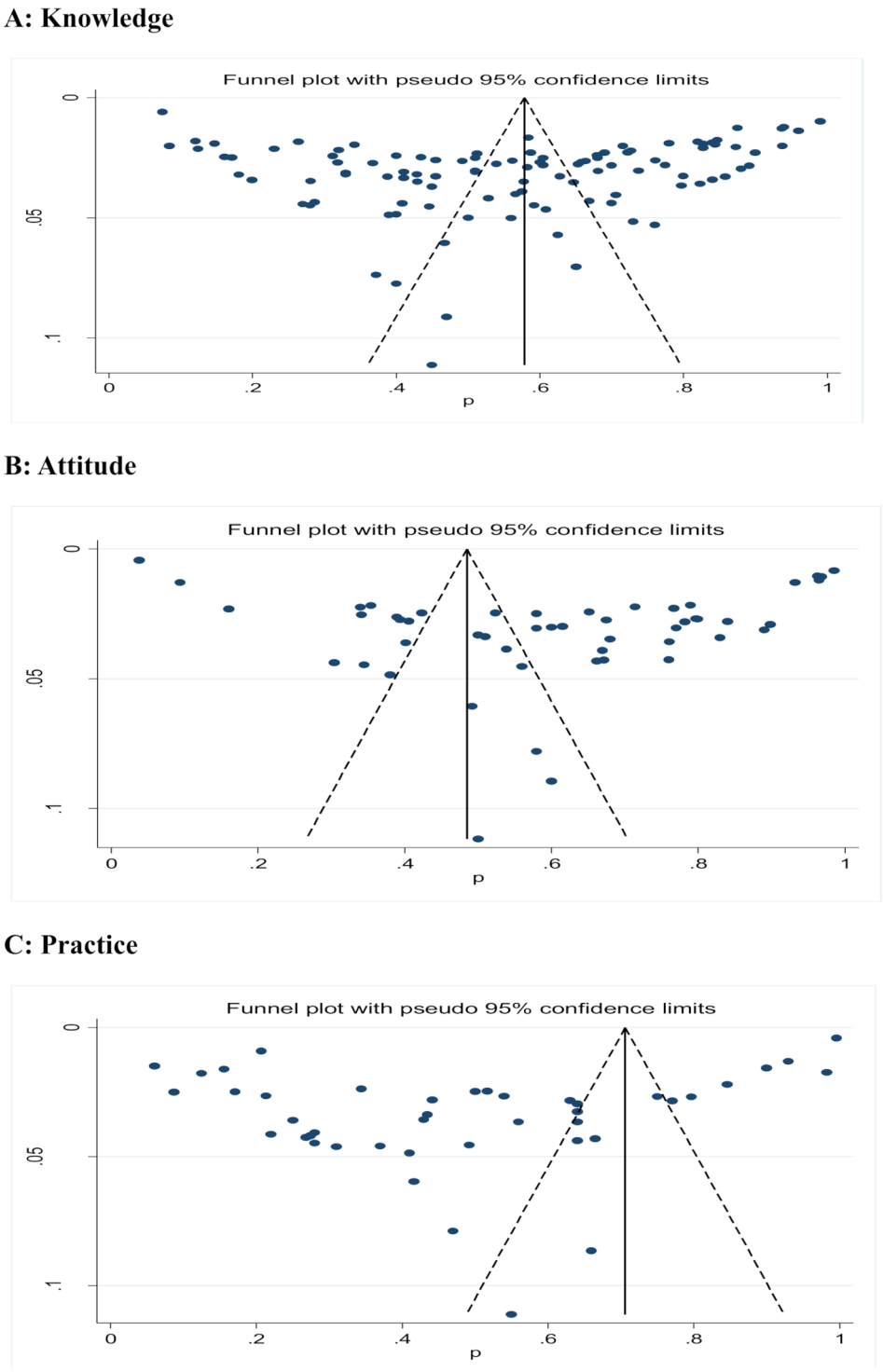

Fig. 8 Funnel plot with pseudo 95% confidence limits for detection of publication bias among included studies

related to higher healthcare costs, longer duration of hospitalizations, and newer and expensive medications treatment when common antibiotics fails. The economic implications of AMR are significant and addressing AMR through focused educational interventions for HCWs and implementing best prevention strategies is not only of vital importance for public health, but also vital for alleviating these economic impact. Such measures can be cost-effective due to reduced incidence of resistant infections and preservation of existing

antimicrobial agents. Therefore, a global commitment, centered on rich and developed countries, is needed to implement urgent interventions, especially educational interventions, in less developed countries to increase the knowledge of HCWs in these countries to prevent the spread of AMR.

According to the study findings, the attitudes of HCWs towards AMR are highly variable. This can be attributed to the complexity of measuring people's attitudes and beliefs, which can challenge the ability of research studies to measure them. However, similar to the level of good knowledge, low levels of good attitudes were observed in poor or densely populated countries [27, 32, 36]. Since intentions and attitudes are strong predictors of intention and behavior [128], implementing structured educational programs aimed at improving the attitudes of HCWs, especially in developing countries, seems essential. Of course, it should be noted that among the studies reviewed in the present study, fewer articles addressed attitude measurement compared to knowledge measurement, thus making international comparisons difficult.

Results of studies on the positive practice of HCWs towards AMR clearly show the lowest levels of positive practice in poor and less developed countries. The lowest values were found in studies conducted in Nigeria (8.7, 6) and India (12.5) [32, 37, 112]. On the other hand, studies that showed low levels of knowledge and attitude often observed an undesirable level of practice [36, 39, 64]. Also, high levels of good knowledge and attitudes have demonstrated high-level practice [99, 119, 123]. Therefore, it is essential to promote best practices regarding AMR among HCWs by enhancing their knowledge and attitudes. This is vital in less developed regions of the world. Policies are inadequate and access to educational resources seems limited, both of which are major hurdles to effective practice. Therefore, it is imperative to reinforce continuous education and enhance the availability of health. According to GRADE assessments, the overall rating for practices was low (2/5). This reflects major shortcomings in the available evidence, especially with regard to precision, inconsistency, and indirectness. These findings underscore the importance of caution when interpreting recommendations regarding practices, and they highlight the need for additional research to bolster the evidence base. Relative to this, ratings for knowledge and attitudes were determined to be good (4/5) and moderate (3/5), respectively, indicating notably stronger evidence in these aspects.

This meta-analysis found significant heterogeneity across studies, which could be related to differences in demographics, study type, and social settings. For example, in the multivariable regression analyses, gender differences, education level, and work experience of staff were identified as influential factors. These factors were associated with staff knowledge, attitudes, and practices regarding AMR.

Based on the results of this meta-analysis, it is recommended that health policymakers in each region implement specific educational and strategic programs to increase knowledge and improve the attitudes and practices of health workers toward AMR. Future research should examine and evaluate the effectiveness of educational interventions in this area. Also, a more detailed analysis of the impact of cultural, social, and economic factors on the knowledge, attitudes, and practices of health workers is needed to contribute to the reduction of AMR globally more scientifically and systematically.

Strengths and limitations

This study had several limitations. Examination of publication bias indicated that studies with more positive and valid results were likely to be more widely published, which may have biased the results. In addition, most studies were from high-income countries, which may limit the generalizability of the findings. Also, due to the cross-sectional nature of most of the studies, it is not possible to draw causal conclusions from these results. Another limitation of this study is the variation in the quality and inclusion of some studies, which could have influenced the results of the meta-analysis. Furthermore, while our study highlights the need for educational interventions to improve HCWs' knowledge, attitudes, and practices regarding AMR, the effectiveness of such interventions was not assessed, representing a gap in the current literature. Despite these limitations, this study provides a clear picture of the current state of knowledge, attitudes, and practices of HCWs towards AMR, using advanced analysis methods and a comprehensive approach.

Conclusion

This systematic review and comprehensive meta-analysis highlight significant gaps in the knowledge, attitudes, and practices of HCWs regarding AMR globally. Overall, it can be said that the level of knowledge and attitudes, and consequently the level of good practice, among HCWs, especially in less developed countries, is far from optimal. Given the devastating impact of AMR on health globally, a global commitment, especially in socio-economically and health-developed countries, to conduct international educational interventions targeting HCWs in less developed countries seems essential. The design of these interventions should be tailored to regional conditions, taking into account the observed differences between different regions. These interventions should address the cultural, economic, and structural challenges specific to each region that may be barriers to the effective implementation of antibiotic stewardship. Sustainable and targeted

educational programs are essential to reinforce and promote evidence-based practices among HCWs to reduce the inappropriate use of antibiotics, which is a major driver of drug resistance.

Abbreviations

AMR	Antimicrobial Resistance
ASPs	Antimicrobial Stewardship Programs
HCWs	Healthcare Workers
JBI	Joanna Briggs Institute
KAP	Knowledge, Attitudes and Practices
MeSH	Medical Subject Headings
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
GRADE	Grading of Recommendations Assessment Development and Evaluation
CI	Confidence Interval
EMRO	Eastern Mediterranean Region
I^2	Heterogeneity Index
SEARO	South-East Asia Region
WHO	World Health Organization
WPRO	Western Pacific Region
EURO	European Region

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions
ASJ and VR developed the study concept and design. NNAM performed the literature search and screening process. NNAS and SS were responsible for data collection. VR carried out the statistical analysis. Data interpretation was contributed by MJ, NSH, and VR. The manuscript was drafted by ASJ, VR, and NSH, with critical revisions by VR. All authors reviewed and approved the final manuscript before submission. [VR] took full responsibility for the accuracy and integrity of the data analysis and had complete access to the study's data.

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Data availability
The authors confirm that all essential data required to support the findings of this study are included in the article and its supplementary materials.

Declarations

Ethics approval and consent to participate
Ethical standards were rigorously followed in conducting this systematic review and meta-analysis. The study protocol was officially approved by the Ethics Committee of Jahrom University of Medical Sciences under the approval code: IR.JUMS.REC.1402.027.

Competing interests
The authors declare no competing interests.

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