

REVIEW

Open Access



# A meta-analysis on the prevalence of resistance of *Staphylococcus aureus* to different antibiotics in Nigeria

Christian Kelechi Ezeh<sup>1\*</sup>, Chibuzor Nwadike Eze<sup>1</sup>, Marie Esther Uju Dibua<sup>1</sup> and Stephen Chijioke Emencheta<sup>2</sup>

## Abstract

**Background** Rapid emergence of multidrug resistant *Staphylococcus aureus* has resulted to difficulty in treatment of infections caused by such strains. The aim of this meta-analysis study was to determine the pooled prevalence of resistance of *S. aureus* to different antibiotics in Nigeria.

**Methods** Literature search for studies was done using Google scholar, PubMed, Science direct, and African Journal Online. The prevalence of *S. aureus* resistance to different antibiotics was evaluated using the meta-analysis proportion command in MedCalc software version 20.0 adopting a rand effect model.  $I^2$  statistic and Egger test in MedCalc was used to evaluate the heterogeneity and the presence of publication bias among studies respectively.

**Results** A total of 40, 682 studies were retrieved through the database search of which 98 studies met the study inclusion criteria. Prevalence of resistance of *S. aureus* to different antibiotics ranges from 13 to 82%. Results showed a very high degree of resistance to penicillin G (82% [95% confidence interval (CI) 61%, 0.96%]), cloxacillin (77% [95% CI 64%, 88%]), amoxicillin (74% [95% CI 66%, 81%]), cefuroxime (69% [95% CI 51%, 85%]), ampicillin (68% [95% CI 53%, 81%]). Moderately resistance to erythromycin (47% [95% CI 40%, 53%]), chloramphenicol (47% [95% CI 37%, 56%]), methicillin (46% [95% CI 37%, 56%]), ofloxacin (24% [95% CI 18%, 31%]) and rifampicin 24% [95% CI 6%, 48%]). Low resistance was observed in vancomycin 13% (95% CI 7%, 21%). For each individual meta-analysis, high heterogeneity was observed with  $I^2$  range (79.36–98.60%) at p-values  $\leq 0.01$ ). Egger's tests for regression intercept in funnel plots indicated no evidence of publication bias.

**Conclusion** This meta-analysis study established that *S. aureus* in Nigeria has developed resistance to commonly used antibiotics such as the beta-lactam class antibiotics, sulphonamides, tetracyclines, chloramphenicol, and vancomycin. Hence it is imperative to develop programs to promote rational use of antimicrobial agents, infection prevention and control to reduce the incidence of antimicrobial resistance.

**Keywords** Antibiotic resistance, Meta-analysis, Nigeria, *Staphylococcus aureus*

## Background

*Staphylococcus aureus* (*S. aureus*) is well adapted to various environments due to their metabolic versatility and pharomic resistance ability. *S. aureus* colonize the skin and nasopharyngeal membranes as normal microbiota in healthy individuals [1]. However, they cause myriad of detrimental infections when they invade the internal tissues or enter the bloodstream. *S. aureus* is an important

\*Correspondence:

Christian Kelechi Ezeh  
ezechristian.kelechi@gmail.com

<sup>1</sup> Department of Microbiology, University of Nigeria, Nsukka, Enugu State, Nigeria

<sup>2</sup> Department of Pharmaceutical Microbiology, University of Nigeria, Nsukka, Enugu State, Nigeria



© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

pathogen involved in both hospital-acquired and community-acquired infections and causes many infectious diseases ranging from mild skin and soft tissue infections, bones and joint infections, infective endocarditis, cardiovascular disorders, osteomyelitis, bacteremia, and fatal pneumonia in both healthy and individuals with underlying diseases [2]. The high incidence of both community and nosocomial staphylococcal infections coincide with the emergence of multidrug resistant *S. aureus* which renders antibiotic treatments ineffective [3].

*S. aureus* has become resistant to various antibiotics over the past years especially to the beta-lactam class of antibiotics [4]. Emergence of methicillin resistant *S. aureus* (MRSA) and vancomycin resistant *S. aureus* (VRSA) constitutes a serious global public health problem. Currently, VRSA and MRSA strains are classified as very potent and dangerous agents that can potentially cause devastating damage worldwide in the absence of effective treatment options [5].

Various mechanisms of resistance utilized by *S. aureus* include: production of beta-lactamase enzymes to deactivate beta-lactam antibiotics, efflux pump for extruding antibiotics such as tetracyclines [6], reduced accumulation of macrolides antibiotics [7], production of aminoglycosides modifying enzymes to inactivate aminoglycoside antibiotics, alteration of DNA gyrase and topoisomerase IV expression of fluoroquinolones antibiotics, and expression of Mec genes which alters penicillin binding proteins [8].

In Nigeria, the prevalence of multi-drug resistant pathogens continue to be on the increase due to several factors such as drug misuse, self medication, lack of trained medical personnel, and poverty. As the world battles the persistent rise in antimicrobial resistance (AMR), it is pertinent that adequate data and information about AMR is known which can serve as the basic foundation for setting out effective interventions to contain the crisis of AMR. From the literature, no prior meta-analysis has been done on *S. aureus* resistance to different antibiotics routinely use in Nigeria. Due to the various infections caused by *S. aureus*, it is pertinent to determine the pooled prevalence of resistance of *S. aureus* to various routinely used antibiotics in Nigeria. This will help in improving treatment options and enlighten the populace on the menace and the possible cause of treatment failures due to the increasing rise of multidrug resistant strains. The aim of this meta-analysis was to determine the pooled prevalence of *S. aureus* resistance to various routinely used antibiotics in Nigeria.

## Methods

### Study design

Meta-analysis was adopted to evaluate the prevalence of *S. aureus* of resistance to various antibiotics in Nigeria

using the appropriate studies that rely solely on *S. aureus* from the title. The prevalence of resistance of *S. aureus* to various routinely used antibiotics in Nigeria is a country wide study as it covers studies from the six geo-political regions of Nigeria. Meta-analysis was adopted because it is a quantitative study of pooled prevalence of resistance of *S. aureus* to routinely use antibiotics in Nigeria.

### Search strategy

Electronic search engines including Google scholar, PubMed, ScienceDirect, and African Journal Online (AJOL) were used to search for available studies from 23rd March to May 2022. Relevant key words such as Staphylococcus, antibiotic resistance, antibacterial resistance, antimicrobial resistance, drug resistance, drug susceptibility, Nigeria were used during the search. These key words were used in different combinations (Staphylococcus OR *S. aureus* AND antibiotic resistance OR antibacterial resistance OR antimicrobial resistance OR drug resistance AND Nigeria) in various electronic databases using the Boolean operators. The reference lists of included articles were also check to identify studies relevant to the current study.

### Inclusion and exclusion criteria

The titles of search results of all retrieved articles were screened independently by two authors with the aim of including studies that address the research question. The articles were inserted into Zotero version 5.0.95.1 referencing application which helped in detecting duplicate articles. The title of the study which solely focused on prevalence of antimicrobial resistance of *S. aureus* was grouped as eligible for inclusion. *S. aureus* resistance in any state in Nigeria and studies only done in Nigeria represented in the title is the first criteria for inclusion. However, studies that focused on many microbial strains antimicrobial resistance were excluded.

In general, retrieved studies selected from predefined criteria were screened further using the inclusion criteria: studies that were research articles and used cross sectional design, studies that used human samples, studies that conducted antimicrobial susceptibility tests using the Clinical Laboratory Standard Institute (CLSI) guidelines, studies written in English language and studies with full text.

Exclusion criteria in this meta-analysis include: studies conducted on non-human samples, studies with isolates below 20, duplicate studies, studies that did not conduct antimicrobial susceptibility tests using the Clinical Laboratory Standard Institute (CLSI) guidelines studies not written in English, and review articles.

### Data extraction

Relevant data such as name of author (s) and publication year, study design, study place, clinical sample size, isolate source, total number of *Staphylococcus aureus* isolates tested in each research article, and total No. of isolates resistant each antibiotics. In situations where the proportion of susceptible isolates was reported, then the No. of resistant *Staphylococcus aureus* isolates was calculated by subtracting the percentage susceptibility from 100 and then dividing the result by 100 and multiplying to the total number of isolates. However, in situation where the proportion of the resistant isolates was given, then the No. of resistant *Staphylococcus aureus* isolates was calculated by dividing the proportion of the resistant isolates by 100 and multiply with the total number of isolates. The formula is given as thus:

$$\text{Prevalence of resistance(\%)} = \frac{\text{number of resistant isolates}}{\text{total number of isolates}} \times 100 \quad (1)$$

To ascertain the reporting of all relevant information in this meta-analysis, we followed the Preferred reporting Items for Systematic Review and Meta-analysis (PRISMA) [9] (Additional file 1: S1) guidelines.

### Statistical analysis procedures

In this meta-analysis, statistical analyses were performed using MedCalc statistical software version 20.0.1. The pooled prevalence of antibiotic resistance of *S. aureus* was evaluated using the meta-analysis proportion command in MedCalc. A total of 23 separate meta-analyses were carried out to evaluate the pooled prevalence of *S. aureus* resistance to 23 different antibiotics. Between 6 and 77 studies were included in the 23 different meta-analyses.  $I^2$  statistic command in MedCalc was used to evaluate the heterogeneity among the included studies. Random effect and fixed effect are two models used to estimate pooled prevalence in meta-analysis. In this study, due to the characteristically high heterogeneity of the included studies, the random effect model was used for meta-analysis at 95% CIs. Egger test was employed for assessing the presence of publication bias [10].

The Freeman-Tukey double arcsine transformation was used to ensure studies which report proportions near or at 0 and 1 were not being excluded. In addition, studies that report unusually high prevalence of resistance when compared to others, a sensitivity analysis was performed by removing the studies. If the point estimate of pooled prevalence after removing a study that reported unusually high prevalence of resistance lies within the 95% CI of the overall pooled estimate for all studies combined,

the study is considered as having no significant influence on the overall estimate and vice versa.

## Results

### Characteristics of included studies

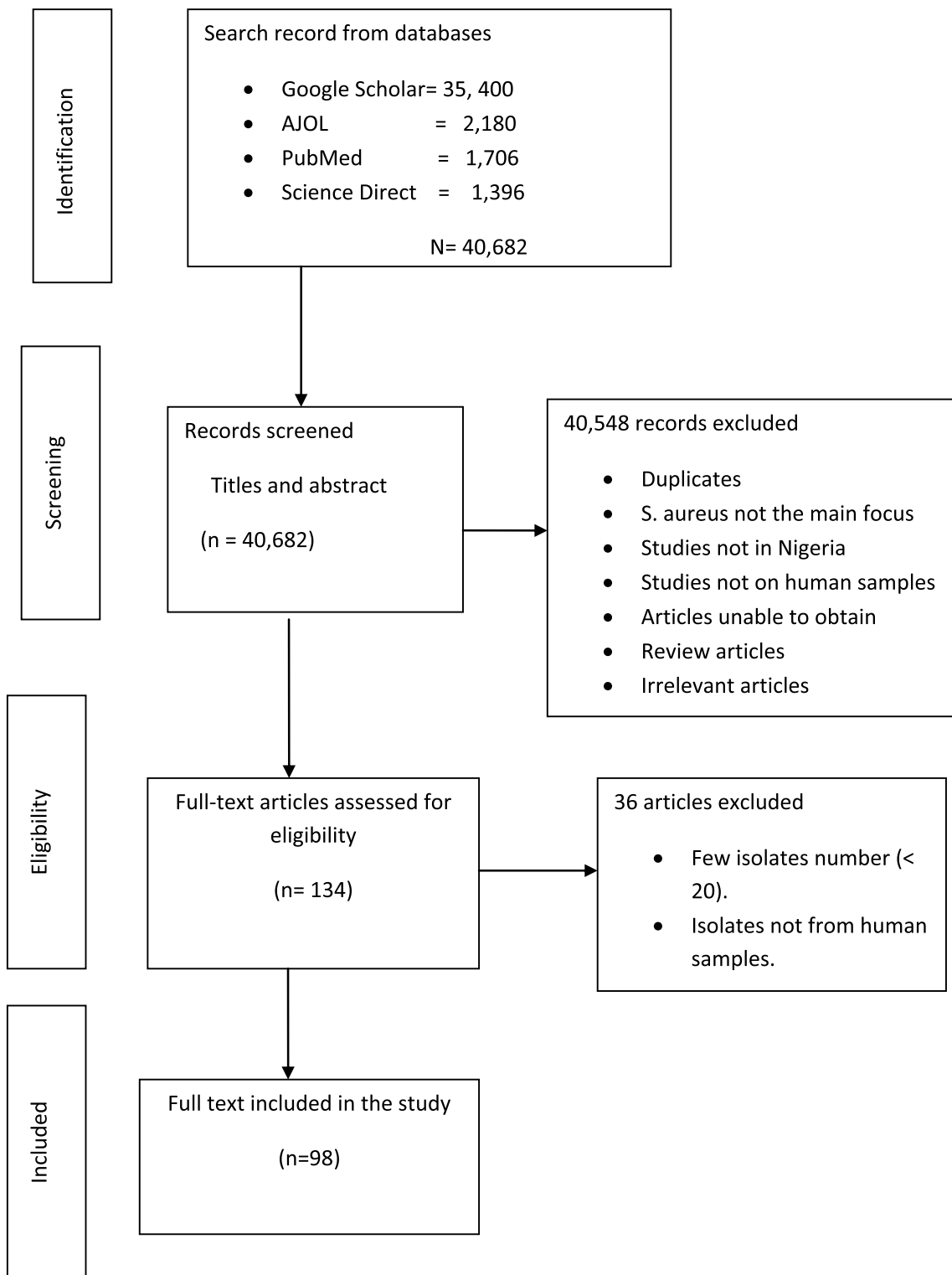
Studies search record from electronic databases yielded 40, 682 of which 35, 400, 2, 180, 1,706, and 1396 were from Google scholar, AJOL, PubMed, and Science Direct, respectively. Articles from Google Scholar gave 35,400 results comprising of many studies irrelevant or that does not fit to the study aim; hence, they were screened randomly from titles alone. Screening of the titles reduced the number of eligible articles to 134 for full text assessment. After going through the full texts, 36 articles were excluded (reported small number of isolates and isolates not from human samples). Thus, 98 studies met the

inclusion criteria of the study (Fig. 1).

About 46, 640 *S. aureus* isolates were tested against different antibiotics and 23,048 isolates were resistant to various antibiotics. Isolates sources include: nasal, blood, vaginal, ear, wound, urine, throat, pimples, hand, and mixed samples were collected from both symptomatic patients [61] and asymptomatic people [37]. Eighty six studies used primary data while twelve used records from hospitals. The characteristics of each study included is summarized Table 1.

### Heterogeneity survey and publication bias

The included studies were conducted in the six geo-political zones of Nigeria; a total of 98 studies comprising of 26 from South South, 23 South West, 20 South East, 18 North West, 8 North Central and 3 North East. Quality assessment (risk of bias) was done in line with the following criteria: studies which used CLSI guideline for antibiotic resistant assessment, studies that used more than 20 *S. aureus* isolates and studies that used adequate sample representative of the region where testing was done. Agar diffusion based method was used to determine the resistance level of *S. aureus* isolates in all included studies. High heterogeneity was observed for each of the meta-analyses performed with  $I^2$  ranging from 79.36 to 98.60%; at p-values  $\leq 0.01$ ). This is due to vast difference in sample sizes; some studies used 20 isolates while some used 400 isolates which impacted on the resistance profile of each antibiotic. Also, number of clinical samples and recovered *S. aureus* isolates differ in all studies and these disparities resulted in high heterogeneity. More studies were conducted in the Southern (South South,



**Fig. 1** PRISMA flowchart for the selection and screening of eligible studies

**Table 1** Characteristics of included studies

Reference	Study	Study place	Data type	Setting and sample source	Sample size	No of recovered isolates	Antibiotics used
[11]	Akortha and Iken-ebomeli, 2010	South south (Benin)	Primary	Hospital: Nasal	52	20	CPR, TET, CHL, ERY, AMP, OFL
[12]	Idris et al., 2018	Northwest (Kano)	Primary	Hospital: Blood		195	MET, CPR, TET, ERY, GEN, CLIN, CEF
[13]	Stanley et al., 2013	Southsouth (Portha-court)	Primary	Hospital: Vaginal swab	265	74	MET, CPR, TET, ERY, AMP, GEN
[14]	Odu and Okonkwo, 2012	Southsouth (Portha-court)	Primary	Urban:Nasal	100	32	MET, CIPRO, TET, ERY, AMP, GEN, CLIN, CXC, COT, STR
[15]	Isibor and Otabor, 2014	Southsouth (Edo)	Primary	Urban: Nasal	100	32	AMO, CTR, CRX
[16]	Nworie, 2013	Southeast (Ebonyi)	Primary	Urban: Nasal	87	20	VAN, CPR, TET, ERY, AMP, OFL, GEN, COT, CTR
[17]	Egbuobi et al., 2014	Southeast (Imo)	Primary	Hospital: Different clinical samples	200	76	MET
[18]	Olowo-Okere et al., 2017	Northwest	Primary	Hospital: Wound	38	20	CPR, ERY, AMO, GEN, NOR
[19]	Olorode et al. 2021	Southsouth (Bayelsa)	Primary	Hospital: Different clinical samples	250	25	MET, CPR, CHLERY, AMP, AMO, GEN, RIF, STR, NOR
[20]	Onanuga and Awhowho, 2012	Southsouth (Bayelsa)	Primary	Hospital: Urine	200	46	VAN, CPR, TET, CHL, AMP, OFL, GEN, COT, AUG, CRX, CEF
[21]	Ayodeji and Omoniyi, 2009	Southwest (Ogun)	Primary	Hospital; Different clinical samples	107	107	VAN, CPR, TET, ERY, AMP, AMO, GEN, CXC, COT, STR, CAZ, PEN
[22]	Onanuga and Onaolapo, 2008	Nortwest (Kaduna)	Primary	Urban: Urine	150	54	VAN, MET, CPR, AMP, OFL, GEN, CLIN
[23]	Chigbu and Ezeronye, 2003	Southeast (Abia)	Primary	Hospital: Ear and nasal	70	38	CPR, TET, CHL, ERY, AMP, AMO, GEN, RIF, CXC, PEN
[24]	Enabule et al., 2007	Southsouth	Primary	Hospital: Urine		80	CPR, TET, ERY, AMP, GEN
[25]	Yah et al., 2009	Southsouth (Benin)	Primary	Hospital: Wound	153	86	CPR, TET, CHL, ERY, GENCXC, COT
[26]	Onwubiko and Saidiq, 2011	Northwest (Kano)	Secondary	Hospital: Different clinical samples		150	CPR, TET, ERY, AMP, AMO, OFL, GENCXC, STR, PEN, CAZ
[27]	Onanuga and Teme-die, 2011	SOuthsouth	Primary	Urban: Nasal	120	40	VAN, CPR, CHL, ERY, AMP, AMO, OFL, AUG, CRX, CEF
[28]	Onanuga et al., 2005	Northcentral (Abuja)	Primary	Hospital: Urine	150	60	VAN, MET, CPR, AMP, OFL, GEN, CLIN
[29]	Akanbi and Mbe, 2013	Northcentral (Abuja)	Primary	Hospital: Different clinical samples		214	VAN, MET, ERY, AMP, OFL, GEN
[30]	Terry et al., 2011	Nortwest	Secondary	Hospital: Different clinical samples		194	MET, TET, CHL, ERY, AMP, GEN, STR, CAZ, PEN, CTR
[31]	Iroha et al., 2012	Southeast (Ebonyi)	Primary	Hospital: Nasal		105	VAN, CPR, ERY, CLIN, CXC, COT, PEN
[32]	Eke et al., 2012	Southsouth (Edo)	Primary	Urban: Nasal and ear	100	39	MET, CPR, TET, AMP, PEN
[33]	Ekundayo and Ndubuisi, 2015	Southeast (Abia)	Primary	Hospital: Different clinical samples	100	113	TET, CHL, ERY, AMP, GEN, CXC, COT, AUG, STR, PEN
[34]	Obasuyi and Akerele, 2015	Southsouth (Edo)	Secondary	Hospital: Different clinical samples		75	MET

**Table 1** (continued)

Reference	Study	Study place	Data type	Setting and sample source	Sample size	No of recovered isolates	Antibiotics used
[35]	Akerele et al., 2015	Southsouth (Edo)	Primary	Urban: Nasal	200	99	MET, CPR, ERY, AMP, AMO, GEN, STR, CTR
[36]	Badger-Emeka et al., 2014	Southeast 9Enugu)	Primary	Hospital: Wound	34	34	VAN, MET, TET, CHL, ERY, AMO, OFL, GEN, CXC, COT, AUG, STR
[37]	Ayeni et al., 2015	Southsouth (Bayelsa)	Secondary	Urban: Nasal	185	185	ERY, AMP, PEN, CTR, NOR
[38]	Torimino et al., 2012	Southwest (Oyo)	Primary	Urban: Different clinical samples	50	40	CPR, TET, CHL, ERY, AMO, OFL, GENCXC, COT, STR, CTR
[39]	Bale et al., 2019	Southwest (Kwara)	Primary	Urban: Nasal	113	42	TET, ERY, OFL, CXC, AUG, CTR, CTR
[40]	Adesoji et al., 2019	Northwest (Katsina)	Primary	Urban: Different clinical samples	120	120	ERY, OFL, GEN, CXC, AUG, CAZ, CRX, CTR
[41]	Ariom et al., 2011	Southeast (Ebonyi)	Primary	Hospital: Different clinical samples	709	84	MET, CPR, TET, GEN, CAZ, PN
[42]	Ajani et al., 2020	Southwest (Ogun)	Primary	Urban: Nasal	200	20	MET
[43]	Olonrunfemi et al., 2020	Northcentral	Primary	Urban: Urine	217	73	MET
[44]	Onanuga et al., 2021	Northeast	Primary	Urban: Nasal	262	46	TET, ERY, AMO, GENCOT
[45]	Ramalan et al., 2020	Northcentral (Nasarawa)	Primary	Hospital: Urine	202	62	CPR, CHL, ERY, AMP, AMO, GEN, STR
[46]	Udobi et al., 2013	Northwest (Kaduna)	Primary	Hospital: Skin and wound	217	69	CPR, AMO, GEN, CTR
[47]	Obasola et al., 2010	Southwest (Oyo)	Primary	Urban: Different clinical samples	50	50	TET, CHL, ERY, AMO, GENCXC, COT, AUG
[48]	Moses et al., 2017	Southsouth (Uyo)	Primary	Hospital: Nasal	130	41	VAN, CPR, TET, ERY, GENCLIN, CEF
[49]	Nsofor et al., 2015	Southeast (Imo)	Primary	Urban: Nasal	270	152	TET, CHL, ERY, GEN
[50]	Adetayo et al., 2014	Southwest (Oyo)	Primary	Hospital: Different clinical samples	150	66	VAN
[51]	Ejikeugwu et al., 2018	Southeast (Ebonyi)	Secondary	Hospital: Different clinical samples		39	ERY, GEN, CLIN, CXC, CEF
[52]	Anucha et al., 2021	Southeast (Anambra)	Primary	Hospital: Urine	236	62	VAN, TET, ERY, AMO, OFL, GEN, CRX
[53]	Agwu et al., 2010	Southsouth (Edo)	Primary	Hospital: Wound	220	66	VAN, RIF, CRX, CTR
[54]	Adesida et al., 2016	Southwest (Lagos)	Primary	Urban: Nasal	230	50	ERY, AMO, OFL, GEN, CXC, CAZ, CRX, CTR
[55]	Mofolorunsho et al., 2015	Northcentral (Kogi)	Primary	Hospital: Different clinical samples	100	22	CPR, TET, ERY, AMO, OFL, GEN, COT, STR
[56]	Osiyemi et al., 2018	Southwest (Ogun)	primary	Hospital: Different clinical samples	338	161	VAN, CPR, TET, ERY, OFL, GEN, COT, AUG, CAZ, CEF, CTR
[57]	Ibe et al., 2014	Southeast (Abia)	Primary	Hospital: Different clinical samples	84	69	MET
[58]	Onaolapo et al., 2016	Northwest(Kaduna)	Primary	Hospital: Wound and skin	65	22	VAN, CPR, ERY, AMP, AMO, CLIN, CEF, CTR
[59]	Ugwu et al., 2016	Southsouth (Delta)	Primary	Urban: Nasal	300	218	MET
[60]	Tula et al., 2016	Northeast	Primary	Hospital: Different clinical samples	100	45	CPR, AMO, OFL, GEN, CXC, CAZ, CRX, CTR
[61]	Anyanwu et al., 2013	Northwest (Kaduna)	Primary	Hospital: Skin	400	69	VAN, CHL, CAZ, CTR
[62]	Onyeagwara et al., 2014	Southsouth (Edo)	Primary	Hospital: Nasal	50	25	CPR, ERY, AMP, AMO, GENSTR, CAZ
[63]	Ngwai and Bakare, 2012	Northcentral (Nasarawa)	Primary	Urban: Urine	300	60	CHL, TET, ERY, AMO, GENCXC, STR

**Table 1** (continued)

Reference	Study	Study place	Data type	Setting and sample source	Sample size	No of recovered isolates	Antibiotics used
[64]	Umar et al., 2015	Northwest (Kaduna)	Primary	Hospital: Skin and nasal	40	34	CPR, CHL, ERY, AMO, GEN, RIF, STR
[65]	Obajuluwa et al., 2015	Northwest (Kaduna)	Primary	Hospital: Wound and skin	100	39	VAN, CPR, ERY, AMP, AMO, GENCEF, CTR
[66]	Iduh et al., 2015	Southsouth	Primary	Hospital: Wound	300	64	TET, AMP, GEN, STR
[67]	Ibanga et al., 2020	Southsouth (Akwa-lbom)	Primary	Hospital: Different clinical samples	100	28	TET, CHL, ERY, AMO, GEN, STR
[68]	Emeakaroha et al., 2017	Southeast (Imo)	Primary	Urban: Nasal and throat	54	28	CHL, ERY, AMO, AMP, COT, CRX, PEN
[69]	Bisi-Johnson et al., 2005	Southwest (Oyo)	Primary	Hospital: Different clinical samples	86	97	TET, CHL, AMP, AMO, GENCXC, STR, PEN
[70]	Ayepola et al., 2015	Southwest (Lagos)	Secondary	Hospital: Nasal		217	TET, GEN, PEN
[71]	Odogwu et al., 2019	Northcentral (Abuja)	Primary	Hospital: Different clinical samples	360	55	CPR, ERY, AMP, GEN, RIF, CLIN, STR, TRIM
[72]	Adeiza et al., 2020	Northwest (Sokoto)	Primary	Hospital: Nasal	378	33	TET, CHL, ERY, GEN, CLIN, CAZ, CEF, TRIM
[73]	Ismail et al., 2015	Northeast (Borno)	Primary	Urban: Different clinical samples	110	42	CPR, CHL, ERY, AMO, GEN, RIF, STR, NOR
[74]	Ibrahim et al., 2018	Northwest (Kano)	Primary	Hospital: Wound and ear	150	71	CPR, TET, ERY, GEN, CLIN, CEF, TRIM, CTR
[75]	Olowe et al., 2013	Southwest (Ekiti)	Primary	Hospital: Different clinical samples		208	VAN, MET, TET, ERY, GEN, PEN, CEF
[76]	Oche et al., 2021	Northwest (Kano)	Primary	Hospital: Different clinical samples	140	26	MET, CPR, TET, ERY, AM, GEN, CEF, TRIM, NOR
[77]	Onelum et al., 2015	Southwest (oyo)	Primary	Hospital: Different clinical samples	246	102	MET, CHL, GEN, CLIN, CAZ, CEF
[78]	Akinduti et al., 2021	Southwest (Ogun)	Primary	Hospital: Different clinical samples	256	68	VAN, CPR, TET, ERY, AMO, OFL, GEN, CAZ, CRX, TRIM
[79]	Oladipo et al., 2019	Southwest (Osun)	Primary	Hospital: Different clinical samples		25	MET, CPR, ERY, AMO, GEN, OFL, CXC, CEF, CRX
[80]	Ogefere et al., 2020	Southsouth (Edo)	Secondary	Urban: Different clinical samples		556	MET
[81]	Motayo et al., 2012	Southwest (Ogun)		Hospital: Different clinical samples		50	MET, TET, CHL, ERY, AMO, GEN, CTR
[82]	Onyeka et al., 2021	Southsouth (Rivers)	Primary	Urban:	150	78	ERY, OFL, GENCXC, AUG, CAZ, CRX, CTR
[83]	Ugwu et al., 2009	Southeast (Enugu)	Primary	Nasal	100	53	TET, CHL, AMO, GEN, COT, AUG
[84]	Nsofor et al., 2016	Southeast (Abia)	Primary	Hospital: Different clinical samples	424	104	CPR, TET, CHL, ERY, AMP, CAZ, PEN
[85]	Mbim et al., 2017	Southsouth (Cross river)	Primary	Hospital: Nasal	150	42	MET, CPR, CHL, ERY, AMO, GEN, RIF, CEF, NOR
[86]	Ogbolu et al., 2015	Southwest (Osun)	Secondary	Hospital: Different clinical samples		116	VAN, TET, ERY, GEN, CAZ
[87]	Osinupebi et al., 2018	Southwest (Ogun)	Primary	Hospital: Different clinical samples	338	161	VAN, CPR, TET, ERY, OFL, GEN, COT, AUG, CAZ, CEF, CTR
[88]	Ajoke et al., 2012	Northcentral (Plateau)	Primary	Urban: Nasal	200	98	TET, ERY, AMP, AMO, GEN
[89]	Onyebueke et al., 2019	Southeast (Enugu)	Primary	Hospital: Urine	818	89	CPR, ERY, AMO, GEN, STR, NOR

**Table 1** (continued)

Reference	Study	Study place	Data type	Setting and sample source	Sample size	No of recovered isolates	Antibiotics used
[90]	Adetutu et al., 2017	Southwest (Ota)	Primary	Urban: Pimple	20	20	TET, CHL, ERY, GEN, CXC, COT, AUG, STR
[91]	Bale et al., 2021	Southwest (Kwara)	Primary	Hospital: Urine	856	56	MET, CPR, TET, CHL, ERY, AMO, OFL, GEN, AUG, CEF, CTR
[92]	Nmema, 2017	Southwest (Ondo)	Primary	Urban: Skin and nasal	80	34	ERY, GEN, CXC, AUG, CAZ, CRX, CTR
[93]	Ike et al., 2016	Southeast (Anambra)	Primary	Hospital: Nasal and hand	261	142	MET
[94]	Ugwu et al., 2015	Southeast (Anambra)	Primary	Hospital: Nasal	100	68	CPR, ERY, AMP, AMO, OFL, GEN, COT, STR, CTR
[95]	Emeka- Nwabunnia et al., 2015	Southeast (Imo)	Primary	Urban:Different clinical samples		59	VAN
[96]	Alli et al., 2012	Southwest (Osun)	Secondary	hospital: different samples		116	VAN, TET, ERY, AMO, GEN, CAZ
[97]	Sadauki et al., 2022	Northwest (Kano)	Primary	Hospital: Blood	214	40	MET, CPR, GEN, PEN, CTR
[98]	O' Malley et al., 2015	Southwest (Iagos)	Primary	Hospital: Different clinical samples	73	38	TET, ERY, GEN
[99]	Emeka- Nwabunnia et al., 2019	Southeast (Anambra)	Primary	Hospital: Different clinical samples	83	25	MET
[100]	Ako-Nai et al., 2005	Southwest (Osun)	Primary	Urban: Different clinical samples		112	CPR, TET, CHL, ERY, GEN
[101]	Frank-Peterside and Mukoro, 2010	Southsouth (Rivers)	Primary	Hospital: Different clinical samples		50	VAN, MET
[102]	Yahaya et al., 2022	Northwest (Kano)	Primary	Hospital: Different clinical samples	200	31	CPR, CHL, ERY, CLIN, COT, CEF
[103]	Onanuga et al., 2019	Southsouth (Bayelsa)	Primary	Urban: Nasal	390	47	CPR, TET, ERY, AMO, GEN, COT
[104]	Ogini and Olayinka, 2021	Southwest (Oyo)	Primary	Urban: Nasal	700	223	CPR, TET, ERY, AMO, GEN
[105]	Nwankwo et al., 2010	Northwest (Kano)	Secondary	Hospital: Different clinical samples		185	MET, CPR, AMO, OFL, GEN, CAZ, CTR
[106]	Olufunmiso et al., 2017	Southwest (Ogun)	Primary	Hospital: Different clinical samples	200	200	ERY, OFL, GEN, COT, AUG, CAZ, CRX, CTR
[107]	Olajide et al., 2012	Northwest (Kano)	Secondary	Hospital: Different clinical samples		100	ERY, AMO, CRX, NOR

VAN Vancomycin; MET Meticilin; CPR Ciprofloxacin; TET Tetracycline; COT Cotrimoxazole; CHL Chloramphenicol; ERY Erythromycin; PEN Penicillin; CLIN Clindmycin; AMO Amoxicillin; AMP Ampicillin; GEN Gentamycin; CTR Ceftriaxone; AUG Amoxicillin/clavulanic acid; CAZ Ceftazidime; CRX Cefuroxime; CXC Cloxacillin; NOR Norfloxacin; RIF Rifampicin; STR Streptomycin; OFL Ofloxacin; TRIM Trimethoprim; CEF Cefoxitin

South West, and South East) part of Nigeria giving rise to high heterogeneity. Studies were done in different hospitals within these regions with different prevalence estimates. Random sampling was used in most of the studies and different clinical samples were collected. More than one clinical sample per patient was collected in 51 studies while one clinical sample was collected per patient in 47 studies. Egger's test for a regression intercept gave a p-value range of 0.06 to 0.99, indicating no evidence of publication bias (Additional file 2: S2) following Eggers'

test rule which state that 'P-value less than 0.05 indicates the presence of publication bias'.

#### Prevalence of *S. aureus* resistance to different antimicrobial agents

In this meta-analysis, the pooled prevalence of *S. aureus* resistance to twenty-three different antibiotics and the number of studies included in each meta-analysis is summarized in Table 2. Prevalence of resistance of *S. aureus* to



**Table 2** Pooled prevalence of *S. aureus* resistance to different antibiotics in Nigeria

Antibiotics	No. of studies	Total No. of isolates	No. of resistant isolates	Pooled AMR prevalence (95% CI)	I <sup>2</sup> (P-value) (P ≤ 0.01)
Vancomycin	29	2546	340	0.13 (0.7, 0.21)	96.60
Methicillin	30	3109	1445	0.46 (0.37, 0.56)	96.71
Ciprofloxacin	44	2739	838	0.31 (0.24, 0.38)	93.85
Tetracycline	43	3359	2170	0.65 (0.56, 0.76)	96.03
Cotrimoxazole	21	1293	855	0.66 (0.55, 0.76)	93.91
Chloramphenicol	32	2015	943	0.47 (0.37, 0.56)	95.03
Erythromycin	66	4969	2325	0.47 (0.40, 0.53)	95.31
Penicillin	15	1709	1396	0.82 (0.61, 0.96)	98.97
Clindamycin	12	787	275	0.35 (0.23, 0.49)	93.26
Amoxicillin	40	2167	1614	0.74 (0.66, 0.81)	94.64
Ampicillin	28	2074	1408	0.68 (0.53, 0.81)	97.91
Gentamycin	77	5470	1701	0.31 (0.25, 0.37)	95.90
Ceftriaxone	25	2144	943	0.44 (0.34, 0.54)	95.64
Amoxicillin/clavulanic acid	20	1665	1032	0.62 (0.50, 0.73)	95.76
Ceftazidim	24	2179	1329	0.61 (0.46, 0.75)	98.01
Cefuroxime	17	1035	714	0.69 (0.51, 0.85)	97.23
Cloxacillin	22	1565	1205	0.77 (0.64, 0.88)	97.13
Norfloxacin	9	491	162	0.33 (0.17, 0.52)	95.27
Rifampicin	7	302	72	0.24 (0.06, 0.48)	95.19
Streptomycin	20	1287	579	0.45 (0.34, 0.57)	94.08
Ofloxacin	25	2058	494	0.24 (0.18, 0.31)	91.63
Trimethoprim	6	291	160	0.55 (0.35, 0.74)	91.99
Cefoxitine	21	1791	770	0.43 (0.31, 0.56)	96.61

each antibiotic based on pharmacological classification is given below for antibiotics routinely used in Nigeria.

#### Prevalence of resistance *S. aureus* to rifamycins (rifampicins)

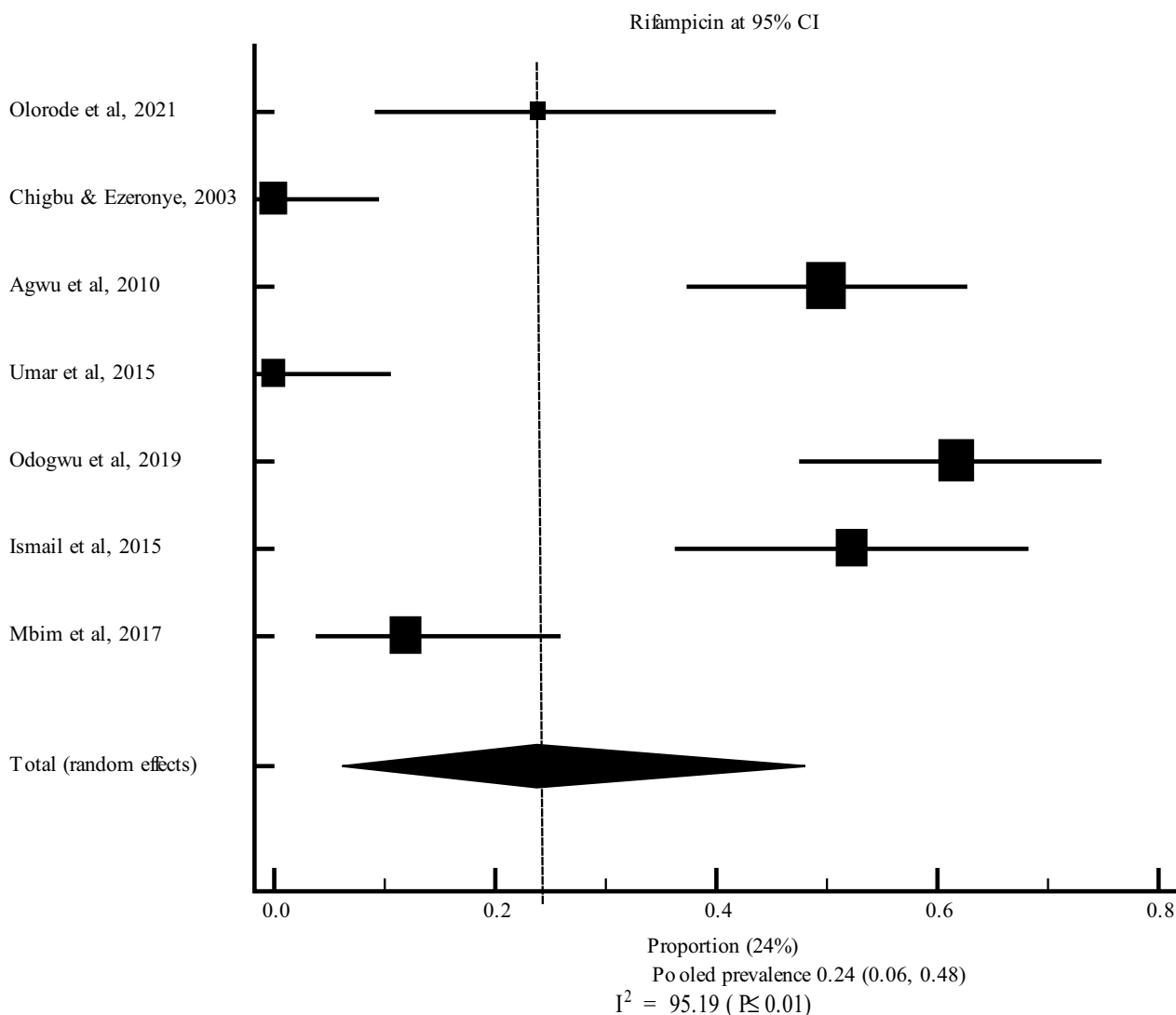
Seven studies involving the prevalence of resistance to rifampicin was analyzed. The pooled prevalence of resistance of *S. aureus* to rifampicin in Nigeria is 24% (95% confidence interval [CI] 6%, 48%). The forest plot (rifampicin) is presented in Fig. 2.

#### Prevalence of resistance of *S. aureus* to glycopeptides (vancomycin)

The pooled prevalence of *S. aureus* resistance to vancomycin is 13% (95% CI 7%, 21%) and the forest plot is presented in Fig. 3. Sensitivity results after exclusion of four studies [20, 22, 27, 36] that reported high prevalence of *S. aureus* resistant to vancomycin is 7% (95% CI 3.3%, 12%). Hence, there was significant decrease in pooled prevalence.

#### Prevalence of resistance of *S. aureus* to beta-lactams antibiotics

Estimation of the pooled prevalence of *S. aureus* resistance to penicillin antibiotics (penicillin G, methicillin, amoxicillin, cloxacillin, ampicillin, and amoxicillin/clavulanic acid) are here presented. Resistance to penicillin G, amoxicillin, cloxacillin, ampicillin, and augmentin were estimated based on 15, 40, 22, 28 and 20 studies respectively. Pooled prevalence resistance rates were highest in penicillin G at 82% (95% CI 61%, 96%). Resistance to cloxacillin [77% (95% CI 64%, 88%)], to amoxicillin [74% (95% CI 66%, 81%)], to ampicillin [68% (95% CI 53%, 81%)] and to amoxicillin/clavulanic [62% (95% CI 50%, 73%)]. However, resistance rate was moderate for methicillin [46% (95% CI 37%, 56%)]. Forest plots for antibiotics (methicillin and penicillin G) resistance are shown in Fig. 4 and 5, respectively while the forest plots for amoxicillin, ampicillin, amoxicillin/clavulanic acid and cloxacillin resistance are presented in Additional file 3: S3,



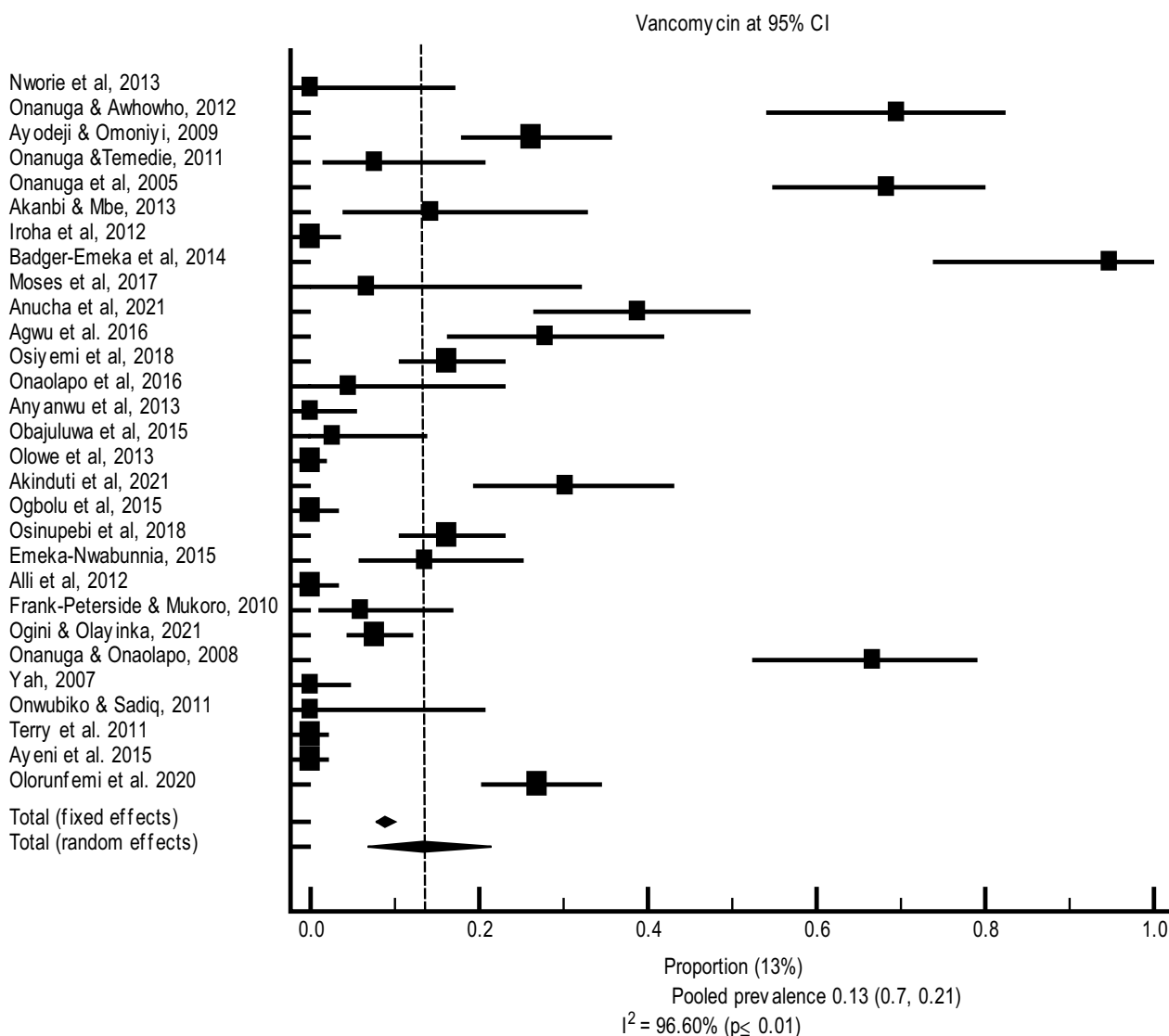
**Fig. 2** Forest plot of the prevalence of *S. aureus* resistance to rifampicin

Additional file 4: S4, Additional file 5: S5 and Additional file 6: S6 respectively.

Higher prevalence of resistance among cephalosporin antibiotic was observed in cefuroxime 69% (95% CI 51%, 85%) followed by ceftazidime 61% (95% CI 46%, 75%). Resistance to ceftriaxone is 44% (95% CI 34%, 54%) and to cefoxitine is 43% (95% CI 31%, 54%). The forest plot for ceftriaxone resistance is presented in Fig. 6 while the forest plots for cefuroxime and cefoxitine resistance are presented respectively in Additional file 7: S7 and Additional file 8: S8.

**Prevalence of resistance of *S. aureus* to fluoroquinolones**

Three antibiotics (ciprofloxacin, ofloxacin, and norfloxacin) from fluoroquinolones were included in the study. For ciprofloxacin, 44 studies were used to estimate the pooled resistance, 25 were used for ofloxacin and 9 studies were used for norfloxacin. The pooled prevalence of resistance of *S. aureus* to ciprofloxacin [31% (95% CI 24%, 38%)], ofloxacin [24% (95% CI 18%, 31%)], and to norfloxacin [33% (95% CI 17%, 52%)]. The forest plot for ofloxacin resistance is presented in Fig. 7 while the forest plot for ciprofloxacin



**Fig. 3** Forest plot of the prevalence of *S. aureus* resistance to vancomycin

and norfloxacin included in Additional file 9: S9 and Additional file 10: S10.

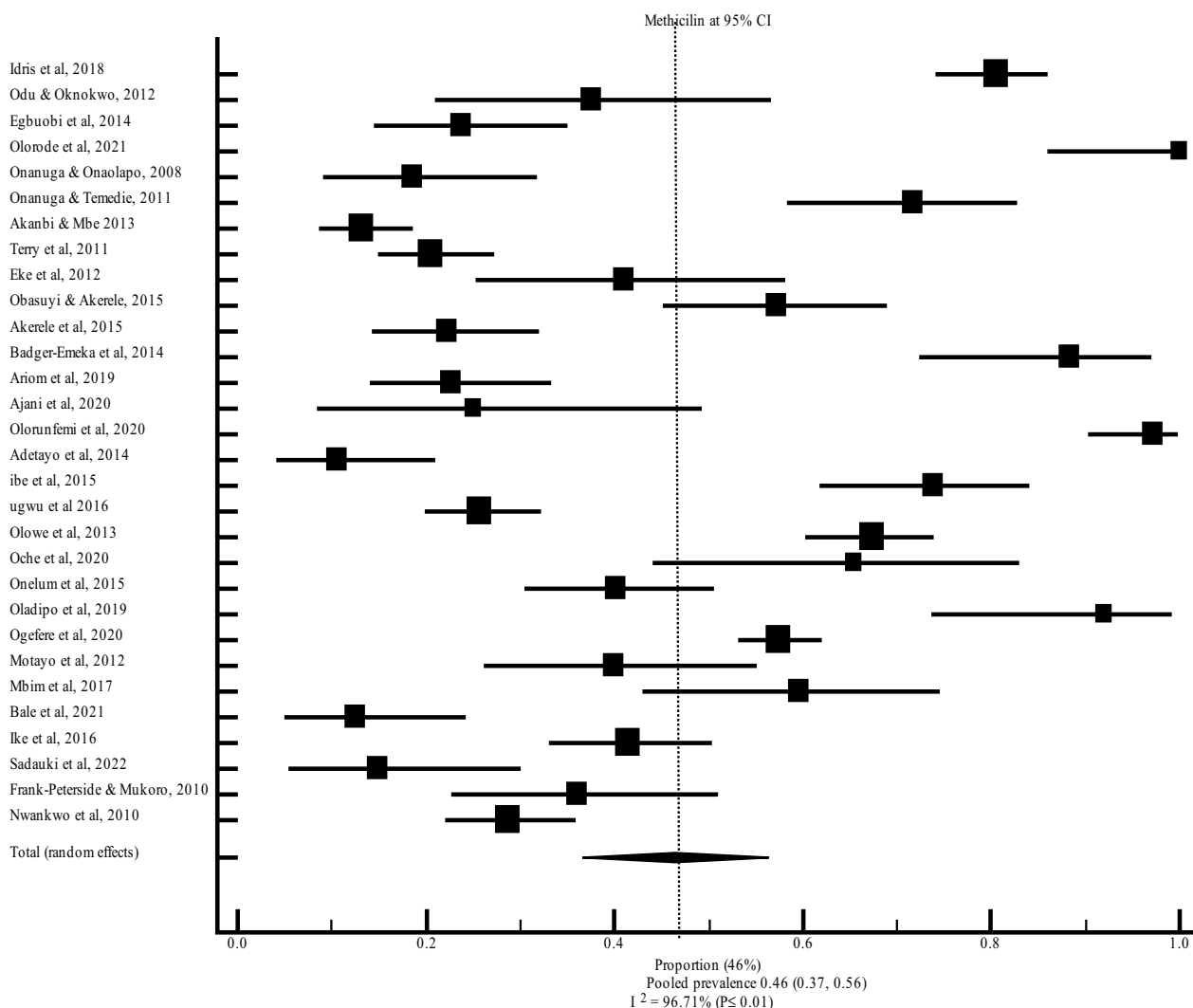
**Prevalence of resistance of *S. aureus* to protein synthesis inhibitors**

Tetracycline a reversible protein synthesis inhibitor showed the highest resistance rate [65% (95% CI 56%, 76%)] followed by erythromycin (macrolides) [47% (95% CI 40%, 53%)] and chloramphenicol [47% (95% CI 37%, 56%)], respectively. Aminoglycosides (gentamycin and streptomycin) and lincosamides (clindamycin) showed relatively lower level of resistance. The pooled prevalence of resistance to streptomycin [45% (95% CI 34%, 57%)], to clindamycin [35% (95% CI 23%, 49%)] and to gentamycin

[31% (95% CI 25%, 37%)]. The forest plot for chloramphenicol resistance is presented in Fig. 8 while the forest plots for tetracycline, erythromycin, gentamycin, streptomycin, and clindamycin resistance are presented in Additional file 11: S11, Additional file 12: S12, Additional file 13: S13, Additional file 14: S14, and Additional file 15: S15 respectively.

**Prevalence of resistance of *S. aureus* to antimetabolites**

High resistance was observed among the antimetabolites antibiotics. Pooled prevalence of *S. aureus* resistance to cotrimoxazole was found to be 66% (95% CI 55%, 76%) and to trimethoprim is 55% (95% CI 35%, 74%). The forest plot for cotrimoxazole resistance is presented in Fig. 9



**Fig. 4** Forest plot of the prevalence of *S. aureus* resistance to methicillin

while the forest plot for trimethoprim is presented in Additional file 16: S16.

**Comparison of the prevalence of *S. aureus* resistance to different antibiotics**

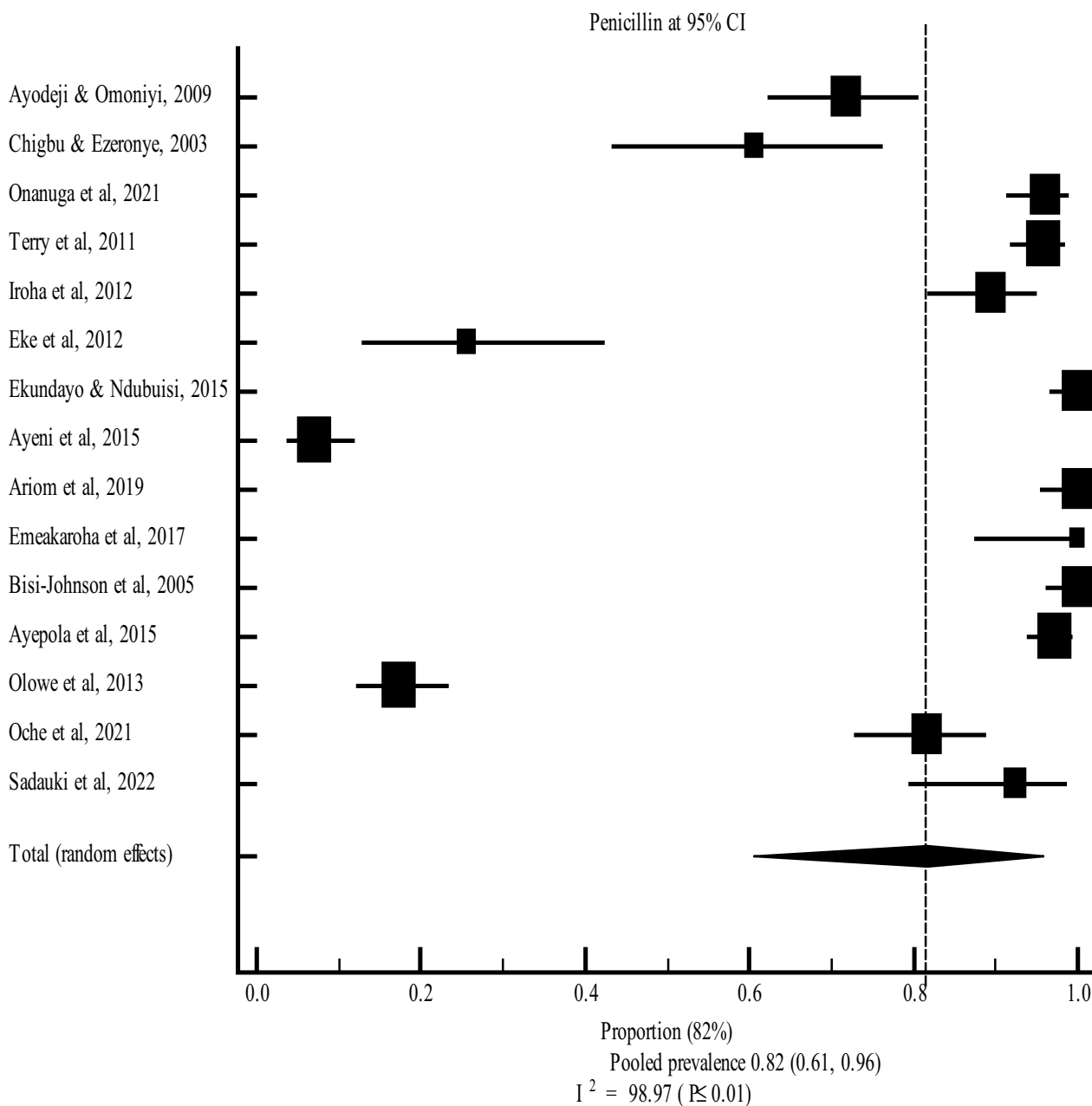
The trend of prevalence of *S. aureus* resistance to different antibiotics addressed in this meta-analysis is shown in Fig. 10. From observation, the prevalence of resistance of *S. aureus* to the different antibiotics in this study ranges from 13 (vancomycin) to 82% (penicillin G).

The order of resistance in increasing order based on the pooled prevalence of *S.aureus* resistance to different antibiotics was observed to be vancomycin, ofloxacin, rifampicin, ciprofloxacin, gentamycin, norfloxacin, clindamycin, ceftazidim, ceftriaxone, streptomycin, methicillin, chloramphenicol, erythromycin, trimethoprim, ceftazidim, amoxicillin-clavulanic acid, tetracycline, cotrimoxazole,

ampicillin, cefuroxime, amoxicilin, cloxacillin, and penicillin G.

**Discussion**

Antimicrobial resistance continues to be on the rise which constitutes a serious public health problem globally. Many microbes have developed resistance to many different antimicrobial agents over time. This meta-analysis estimated the pooled prevalence of resistance of *Staphylococcus aureus* to 23 different antibiotics routinely used in Nigeria. Ninety eight studies [98] were included in this meta-analysis study with variation in the number of studies included in each meta-analysis which ranged from 6 to 77. In general, the 98 studies evaluated the rate of *S. aureus* resistance to different antibiotics based on 46,640 isolates of which 23, 048 were resistant to various antibiotics. Prevalence of resistance of *S.*

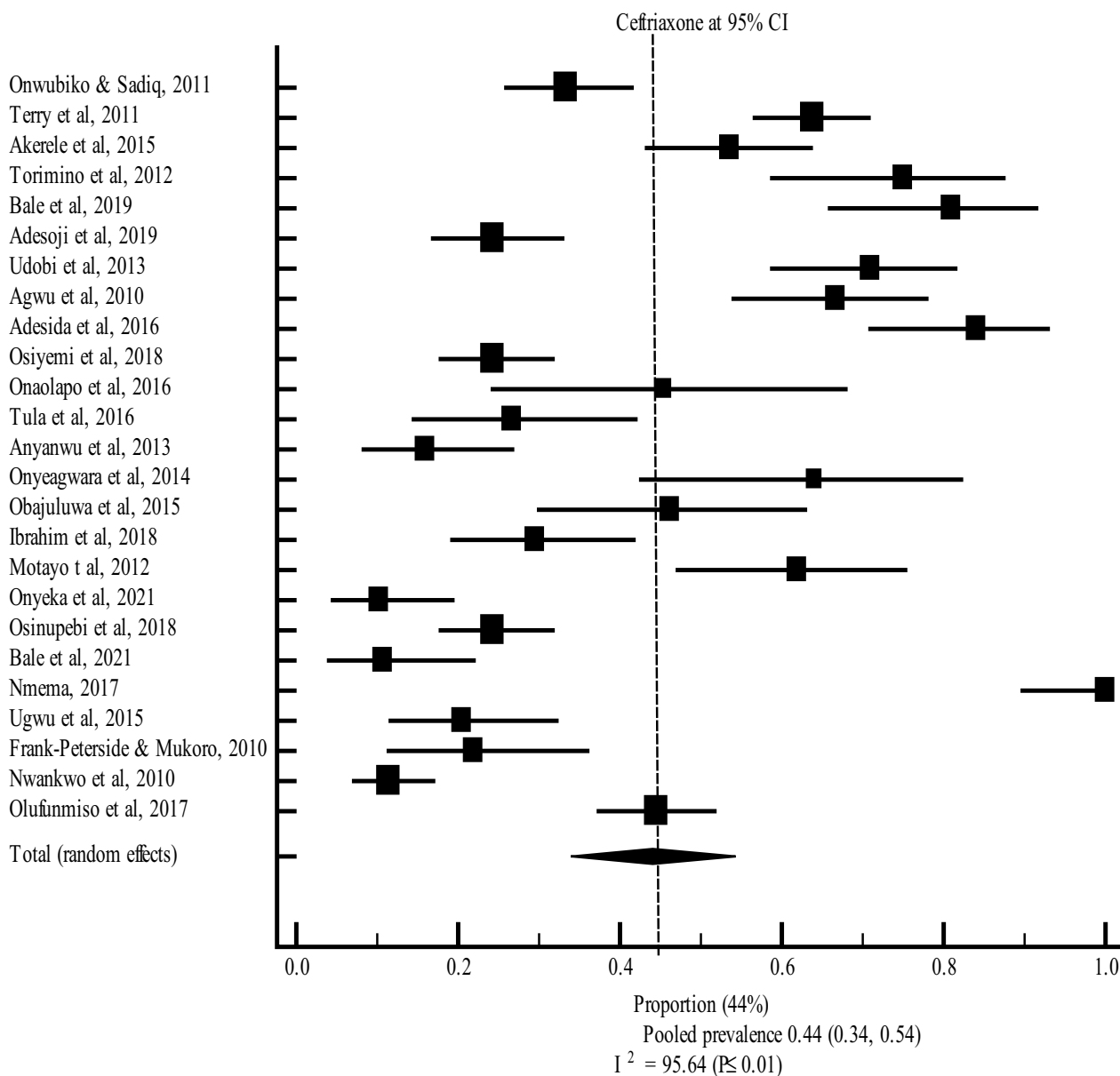


**Fig. 5** Forest plot of the prevalence of *S. aureus* resistance to penicillin G

*aureus* to different antibiotics ranges from 13 to 82%. Results from the meta-analysis showed that resistance of *S. aureus* to routinely used antibiotics in Nigeria was alarmingly high. From the studies, it was found that 82% *S. aureus* were resistant to penicillin G. However, it was observed from the studies that 24% of *S. aureus* were resistant to ofloxacin and rifampicin. In general, clinical samples (nasal, urine, wound, pimple, ear, blood, and

vaginal swab) were collected from both symptomatic patients [61] and asymptomatic people [37].

High heterogeneity was observed for each of the meta-analyses performed with  $I^2$  ranging from 79.36 to 98.90% at  $p$ -values  $\leq 0.01$ . This is because many studies used varying number of isolates/sample sizes. Some studies used 20 isolates while some used 400 isolates which impacted on the resistance profile of each antibiotic. This

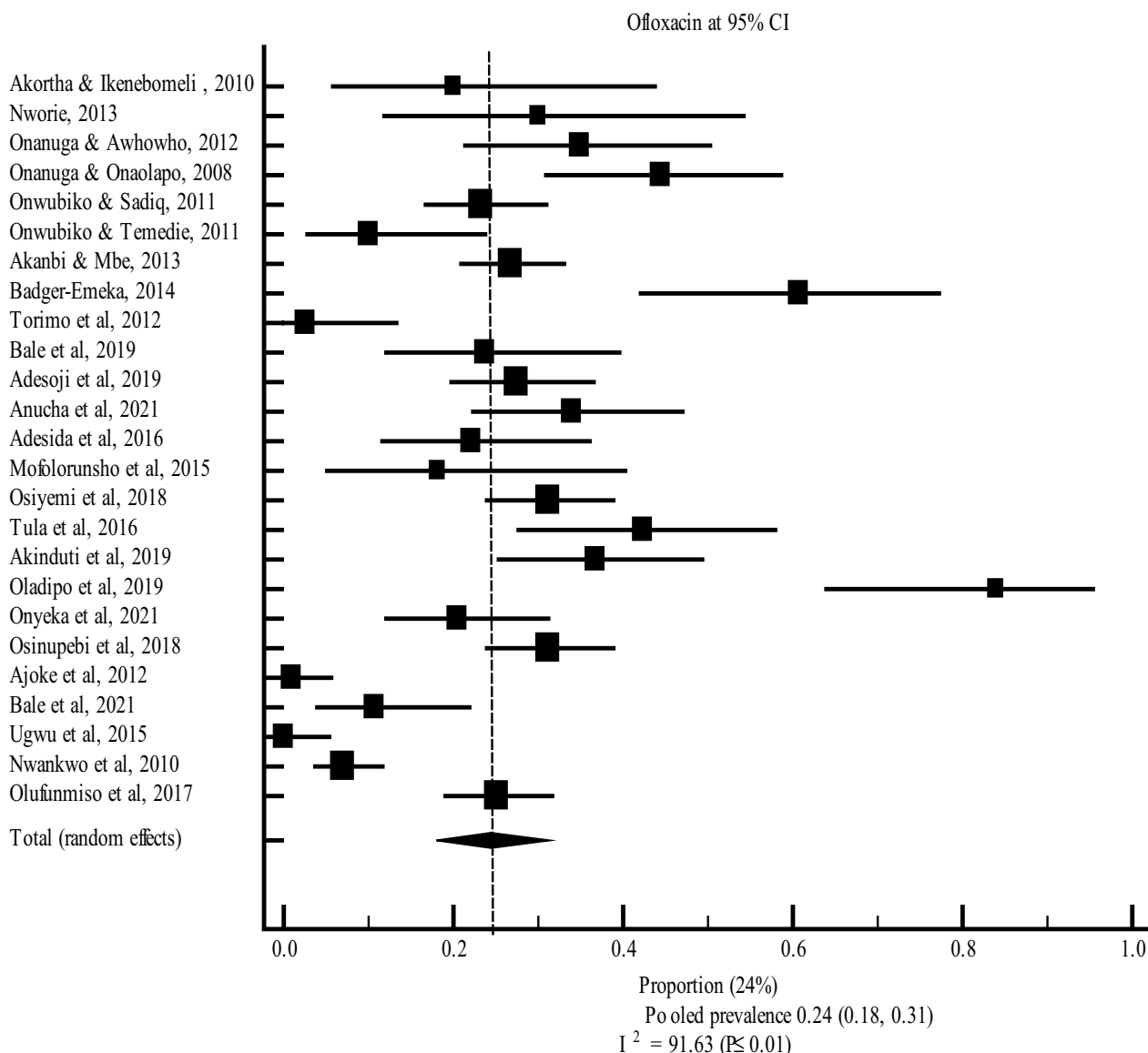


**Fig. 6** Forest plot of the prevalence of *S. aureus* resistance to ceftriaxone

can better be illustrated in the prevalence of resistance of *S. aureus* to vancomycin. Sensitivity test was carried out to by removing studies that reported very high prevalence of *S. aureus* to vancomycin and the overall pooled prevalence reduced from 13 to 7%. This showed the degree of heterogeneity among studies. Possible cause of heterogeneity is due to different number of clinical samples and number of isolates recovered which were subjected to antibiotic sensitivity tests. Also random sampling of clinical samples can also be the possible cause. Publication bias was evaluated for all meta-analysis of the 23

antibiotics and publication bias was not found. Egger test is use to estimate asymmetry of data using funnel plots. p-value less than 0.05 using Egger criteria indicate no presence of publication bias even though erythromycin had p-value of 0.017 which is below 0.05. This is because a p-value of 0.017 for the Egger test means that the results found have a 1.7% chance to occur when there is no 'small sample bias.

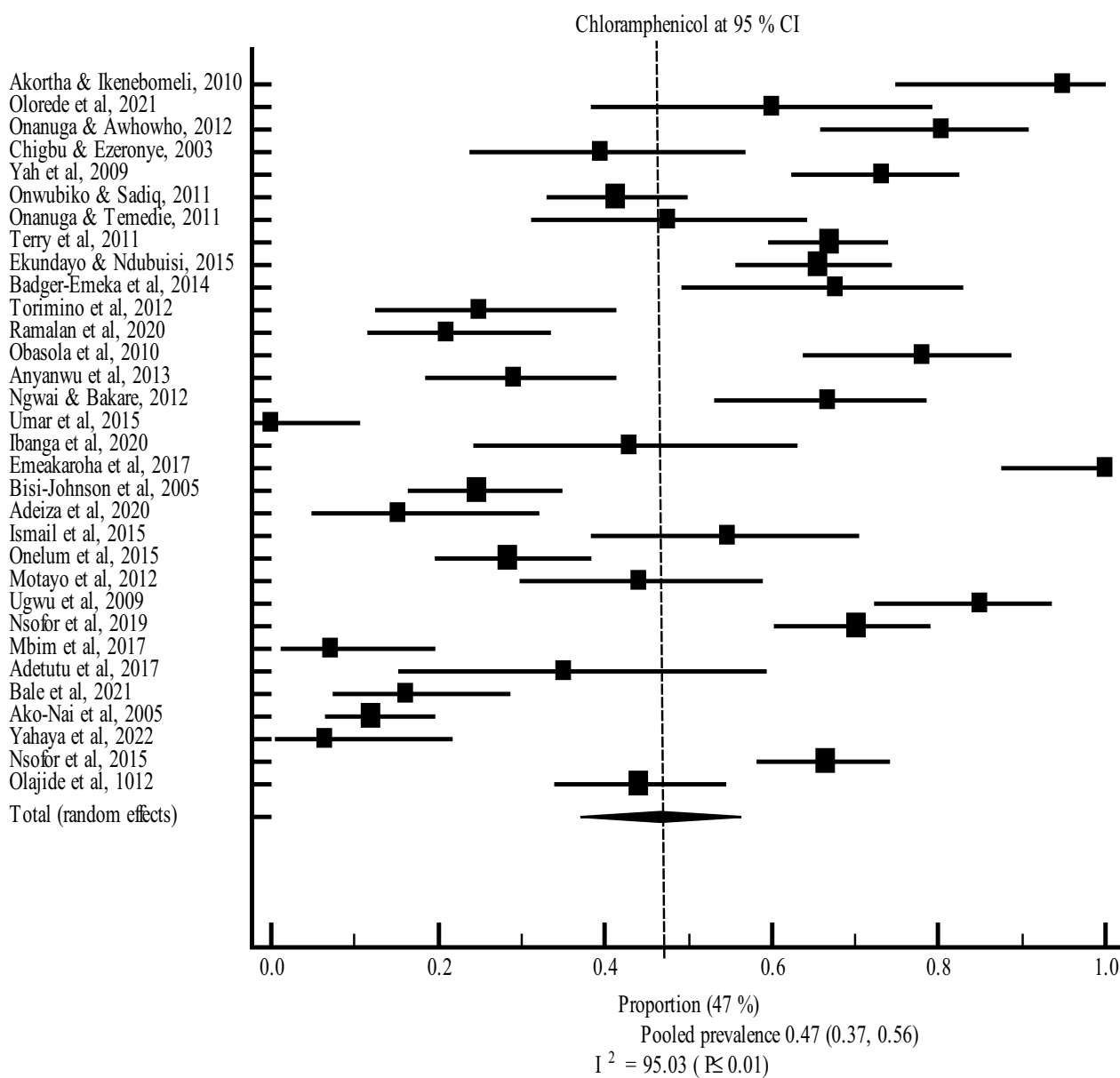
The pooled prevalence of *S. aureus* resistance to Beta-lactams class of antibiotics was extremely high especially for penicillins. *S. aureus* showed highest resistance



**Fig. 7** Forest plot of the prevalence of *S. aureus* resistance to ofloxacin

to penicillin G (82%) and 69% resistance to cefuroxime (cephalosporin). The pooled estimate of *S. aureus* resistance to penicillin G is comparable with the reported estimation of worldwide resistance of 90–95% [108]. This is not surprising due to the fact that penicillin G is the first antibiotic to be discovered. Bacteria are able to develop resistance to antibiotics due to selective pressure from antibiotics. Selective pressure from penicillin led to the production of beta-lactamase to counter the effect of beta-lactam antibiotics. Consequently, semi-synthetic beta-lactam antibiotics such as ampicillin, Amoxicillin/clavulanic acid and amoxicillin with different side chains were developed to counter such bacteria strains.

However, *S. aureus* resistance to amoxicillin and ampicillin is relatively high from our results. Lower rate of resistance was observed among beta-lactamase-resistant antibiotics (methicillin, ceftriaxone, ceftiofene). Also, lower rate of resistance to clindamycin might be attributed to infrequent use of the antibiotic. Amoxicillin-clavulanic acid was developed as a combination of an antibiotic (amoxicillin) and non-antibiotic (clavulanic acid). Clavulanic acid inhibit beta-lactamase enzyme which prolong the antibacterial activity of amoxicillin component; however, results from the meta-analysis showed high resistance of *S. aureus* to amoxicillin/clavulanic acid.

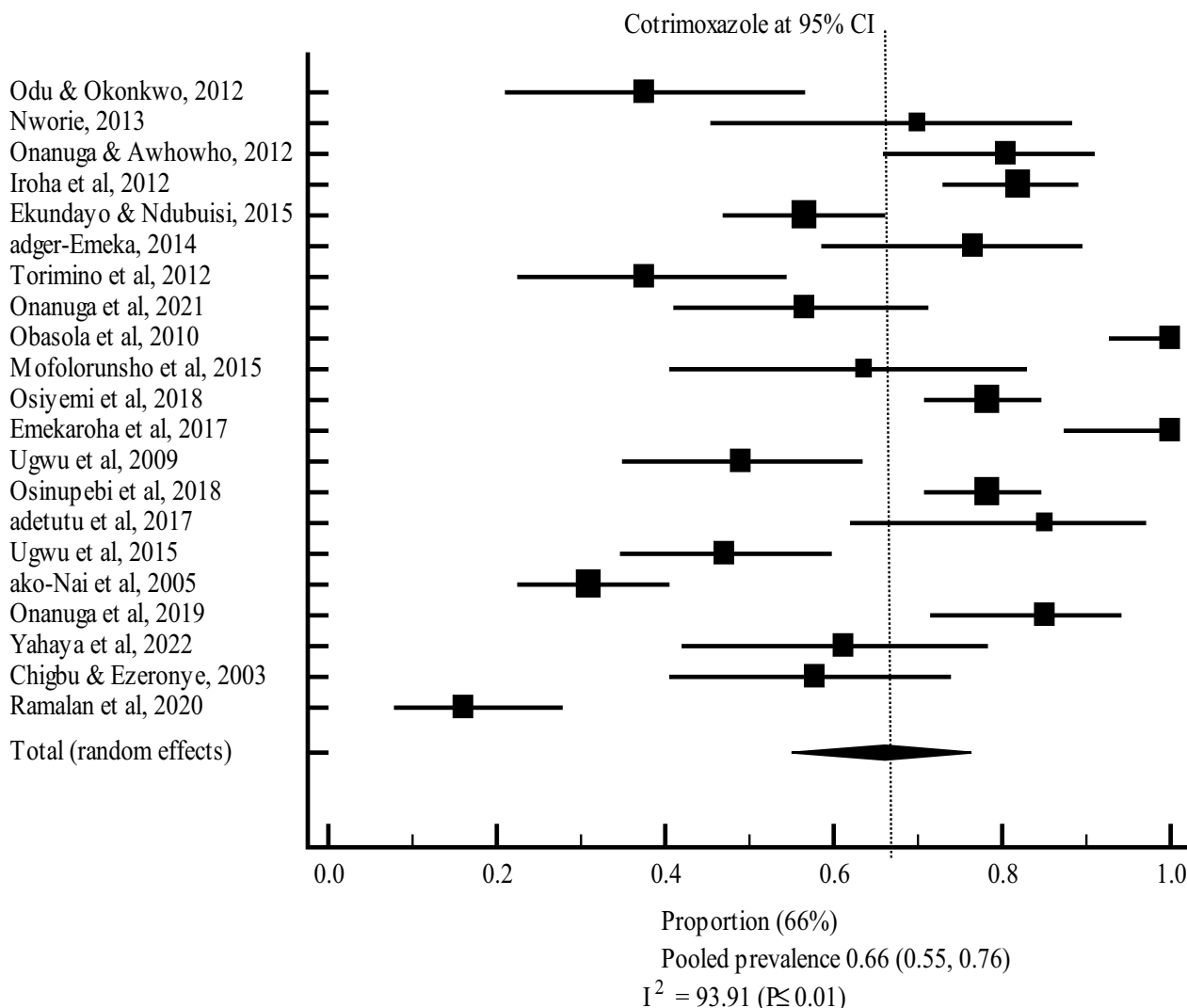


**Fig. 8** Forest plot of the prevalence of *S. aureus* resistance to chloramphenicol

Another semi-synthetic penicillin resistant antibiotic called methicillin was developed which is resistant to hydrolysis of beta-lactamase was developed. The term Methicillin Resistant Staphylococcus aureus (MRSA) is synonymous with multi-drug resistance (MDR) because MRSA are invariably resistant to different antibiotics. Acquisition of *mec A* gene that encodes penicillin binding protein confers resistance to *S. aureus* [109]. The pooled prevalence of *S. aureus* to methicillin (46% [95% CI 37%, 56%]) in Nigeria is similar to 2014 global surveillance reports of the world health organization (WHO) [110]

2014. Which depicted MRSA prevalence ranged 33–95% in Africa. Similarly, the pooled estimate of 46% in our study is also in agreement with the pooled prevalence estimate of MRSA in continents such as North America, Asia, and Europe which ranges from 23.1 to 47.4% [109]. The high pooled prevalence in our study might be due to certain factors and variables such as the inclusion of nosocomial and community acquired infections in the original studies analyzed. Generally, nosocomial infection causing pathogens are believed to possess higher resistance rate due to prolonged and higher exposure to



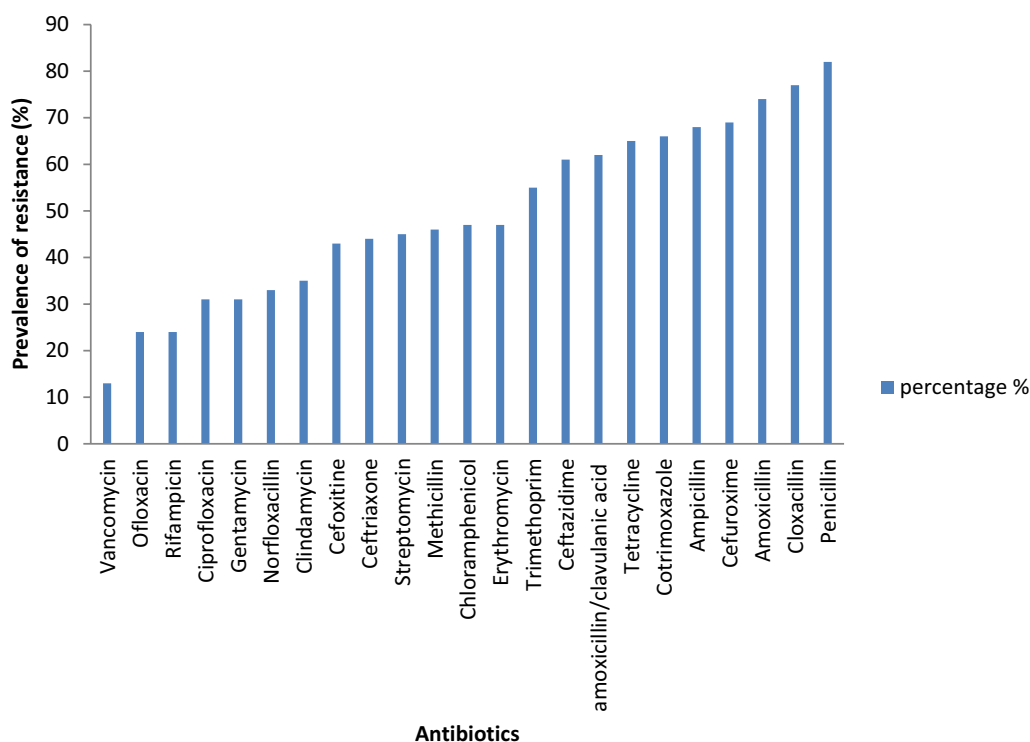


**Fig. 9** Forest plot of the prevalence of *S. aureus* resistance to cotrimoxazole

different antimicrobial agents and exchange of genetic materials. Thus, there is greater transmission of resistant genes through various means within the hospital settings [111]. The implication of infections cause by MRSA is difficulty in treatment which often requires alternative antimicrobial agents which are most times very expensive.

The pooled prevalence of *S. aureus* resistance to vancomycin (13% at 95% CI [0.7%, 21%]) in this meta-analysis is high and a cause for concern when compared to global prevalence estimate [4]. The prevalence of vancomycin resistant *S. aureus* (VRSA) in Africa was reported to be 2.5% [4]. This is quite low when compared to the result from this study which is very high (13%). With this increased resistance, the use of vancomycin to treat MRSA is becoming problematic and poses serious health challenge. The rise in VRSA might be due to the indiscriminate use of vancomycin in Nigeria. By the way, Four

studies [20, 22, 28, 36] reported a very high prevalence of VRSA; however, sensitivity analysis showed that they had high significant influence on the overall pooled prevalence estimate. Removing the three studies reduces the pooled prevalence of *S. aureus* resistance to vancomycin from 13 to 7%. Analyzing studies that depicted high prevalence of resistance of *S. aureus* to vancomycin showed that the same author conducted and published the three studies in peer reviewed journals. Urine samples were mainly used for *S. aureus* isolation by the author in the three studies of which [20, 22] were from symptomatic urinary tract infection patients who visited the hospitals and [27] from healthy volunteers. Urinary tract infection is a common infection and a reason for antibiotic use; consequently, resistant microbial strains have emerged. This reason might be attributed to the high prevalence of *S. aureus* resistant to vancomycin in



**Fig. 10** Comparison of the prevalence of *S. aureus* resistance to different antibiotics in Nigeria

the three studies. Exposure to resistant strains especially in hospital settings might have resulted in the increased resistance to vancomycin in the three studies [112, 113]. This is because in Nigeria, expired or waste antibiotics are not properly discharged. This could result in selective pressure on inhabitant microorganisms which results in development of various resistant mechanisms.

Generally, the global pattern of antimicrobial resistance varies among different geographical locations and socio-economic level [114, 115]. Variations in studies can be attributed to design, time, and population involved. Heterogeneity tests at  $p \leq 0.01$  showed significant variation among included studies in this meta-analysis. Therefore, it is reasonable to assert that the study population might be infected with the same strains of *S. aureus* within the same location at a specified period. This is because most of the studies were conducted within a specified period of time and area.

Mechanisms of resistance of *S. aureus* include: production of beta-lactamase enzymes to deactivate beta-lactam sensitive antibiotics, efflux pump for extruding antibiotics such as tetracyclines [6], reduced accumulation of macrolides antibiotics [7], production of aminoglycoside modifying enzymes to inactivate aminoglycosides antibiotics, alteration of DNA gyrase and topoisomerase IV expression for fluoroquinolones antibiotics, and

expression of Mec genes which alters penicillin binding proteins. From the results and mechanism of resistance of *S. aureus*, it can be said that *S. aureus* found in Nigeria are highly resistant to the beta-lactam class of antibiotics.

The pooled prevalence of *S. aureus* resistance to the fluoroquinolones class of antibiotics such as ciprofloxacin, ofloxacin, and norfloxacin was lower especially for ciprofloxacin which is commonly used within Nigeria. However, high pooled prevalence of *S. aureus* resistance to antimetabolites class of antibiotics (cotrimoxazole and trimethoprim) was observed.

From the meta-analysis, *S. aureus* mediated infection in Nigeria can be treated using vancomycin, fluoroquinolones, and aminoglycosides. MRSA has been a concern in Nigeria especially with the incidence of VRSA. Newer alternative antibiotics such as linezolid, telavancin, cefcaroline, tigecycline and daptomycin are rarely used in Nigeria. Various factors such as lack of infection prevention which lead to reoccurrence of infection, inappropriate use of antibiotics, poor hospital facilities, lack of routine susceptibility test before antibiotic administration, and self medication contributes to the rapid emergence and re-emergence of AMR. Tackling this factors, will go a long way in the fight against the continue rise of MDR pathogens in general.

### Study limitations

Most of the included studies share similar characteristics. The search was limited to only titles that deal with antibiotic resistance. Selection was done randomly especially in Google Scholar with had 35, 400 studies results from the search. The meta-analysis was done once for each antibiotics and sub-grouping to reduce high heterogeneity and publication bias was not done due to too many meta-analysis already done. The included studies used in-vitro antimicrobial assays which has limitations such as difficulties in interpreting data, variability of testing media (differences in cation content, acidic or alkaline), and difficulty in knowing the pharmacokinetics of an antibiotic or post effect of an antibiotic (a situation where bacteria growth is inhibited even when the antibiotic concentration falls below the MIC). Most of the studies were done in teaching hospitals and tertiary institutions in big cities; hence both symptomatic and asymptomatic individuals are involved. For symptomatic individuals, most of the studies were done in teaching hospitals were patients with chronic and recurrent infections are treated; resistance level could be overestimated.

### Conclusion

The results of this meta-analysis showed that *S. aureus* is resistant to many routinely used antibiotics in Nigeria. It is highly resistant to beta-lactams, tetracyclines, and antimetabolites antibiotics. Resistance of *S. aureus* to vancomycin remains a serious health problem due to limited treatment options. There is a lot of variation in resistance estimates between studies. High heterogeneity was observed in each meta-analysis for each antibiotic which was attributed to various factors such as different clinical sample and recovered isolates sizes, random sampling and method used for resistance investigation. Hence it is imperative to develop programs to promote rational use of antimicrobial agents, infection prevention and control to reduce the incidence of AMR. In addition, furthers researches focusing on identifying the dynamics promoting microbial resistance, infectious microbial strains and molecular/genetic basis of resistance should be encouraged.

### Abbreviations

AMR	Antimicrobial resistance
CLSI	Clinical Laboratory Standard Institute
CI	Confidence interval
MRSA	Methicillin resistant <i>Staphylococcus aureus</i>
<i>S. aureus</i>	<i>Staphylococcus aureus</i>
VRSA	Vancomycin resistant <i>Staphylococcus aureus</i>

### Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13756-023-01243-x>.

Additional file 1: S1. PRISMA 2009 Checklist

Additional file 2: S2. Egger's test of publication bias

Additional file 3: S3. Forest plot of the prevalence of *S. aureus* resistance to amoxicillin

Additional file 4: S4. Forest plot of the prevalence of *S. aureus* resistance to ampicillin

Additional file 5: S5. Forest plot of the prevalence of *S. aureus* resistance to augmentin

Additional file 6: S6. Forest plot of the prevalence of *S. aureus* resistance to cloxacillin

Additional file 7: S7. Forest plot of the prevalence of *S. aureus* resistance to cefuroxime

Additional file 8: S8. Forest plot of the prevalence of *S. aureus* resistance to ceftiofime

Additional file 9: S9. Forest plot of the prevalence of *S. aureus* resistance to ciprofloxacin

Additional file 10: S10. Forest plot of the prevalence of *S. aureus* resistance to norfloxacin

Additional file 11: S11. Forest plot of the prevalence of *S. aureus* resistance to tetracycline

Additional file 12: S12. Forest plot of the prevalence of *S. aureus* resistance to erythromycin

Additional file 13: S13. Forest plot of the prevalence of *S. aureus* resistance to gentamycin

Additional file 14: S14. Forest plot of the prevalence of *S. aureus* resistance to streptomycin

Additional file 15: S15. Forest plot of the prevalence of *S. aureus* resistance to clindamycin

Additional file 16: S16. Forest plot of the prevalence of *S. aureus* resistance to trimethoprim

### Acknowledgements

Not applicable

### Author contributions

CKE, CNE and UMED conceptualized the research idea. CKE and SCE conducted literature search, selection and data extraction. CKE performed the statistical analyses. CKE prepared the draft manuscript. All authors revised, edited and approved the final manuscript.

### Funding

No funding was received.

### Availability of data and materials

The data supporting the conclusions of this article are included within the article and its supporting information.

### Declarations

### Ethics approval and consent to participate

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

Received: 11 August 2022 Accepted: 14 April 2023

Published online: 25 April 2023

**References**

- Rasigade JP, Vandenesch F, Vandenesch S. *Staphylococcus aureus*: a pathogen with still unresolved issues. *Infect Genet Evol.* 2014;21:510–4.
- Bamigboye BT, Olowe OA, Taiwo SS. Phenotypic and molecular identification of vancomycin resistance in clinical *Staphylococcus aureus* isolates in Osogbo, Nigeria. *Eur J Microbiol Immunol.* 2018;8:25–30.
- McGuinness WA, Malachowa N, DeLeo FR. Vancomycin resistance in *Staphylococcus aureus*. *Yale J Biol Med.* 2017;90(2):269–681.
- Shariati A, Dadashi M, Moghadam MT. Global prevalence and distribution of vancomycin resistant, vancomycin intermediate and heterogeneously vancomycin intermediate *Staphylococcus aureus* clinical isolates: a systematic review and meta-analysis. *Sci Rep.* 2020;10:12689.
- Khan A, Wilson B, Gould IM. Current and future treatment options for community-associated MRSA infection. *Expert Opin Pharmacother.* 2018;19(5):457–70.
- Sompolinsky D, Zaidenzaig Y, Ziegler-Schlomowitz R, Abramova N. Mechanism of tetracycline resistance in *Staphylococcus aureus*. *J Gen Microbiol.* 1970;62(3):351–62.
- Yamagishi S, Nakajima Y, Inoue M, Oka Y. Decrease in accumulation of macrolide antibiotics as a mechanism of resistance in *Staphylococcus aureus*. *Jpn J Microbiol.* 1971;15(1):39–52.
- Li XF, Fan XJ, Guo XJ, Feng P, Lu XJ, Gao YY, et al. A study on the mechanism of drug resistance in *Staphylococcus aureus*. *Sichuan Da Xue Xue Bao Yi Xue Ban.* 2006;37(3):365–8.
- Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 2009;15(1):264–9.
- Egger M, Davey SG, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ.* 1997;315(7109):629–34.
- Akortha EE, Ikenebomeh MJ. Nasal colonization of symptomatic pneumonia patients in University of Benin Teaching Hospital, Benin City, Nigeria by multiple antibiotic resistant *Staphylococcus aureus*. *Afr J Microbiol Res.* 2010;4(11):1071–5.
- Idris MA, Kumurya AS, Mohammed Y. Detection of methicillin-resistant *Staphylococcus aureus* among bacterial isolated from children aged 0–5 years with septicaemia in Kano, north western, Nigeria. *FUDMA J Microbiol.* 2018;1(1):51–7.
- Stanley CN, Ugbooma HAA, Ibezim EC, Attama AA. Prevalence and antibiotic susceptibility of *Staphylococcus aureus* and other staphylococcal infections in pregnant women attending antenatal clinic in a tertiary hospital in port Harcourt, Nigeria. *Infect Dis Ther.* 2013;2(1):1–6.
- Odu NN, Okonko IO. Nasal carriage and antibiotics susceptibility of *Staphylococcus aureus* in healthy students of University of Port Harcourt, Rivers State, Nigeria. *N Y Sci J.* 2012;5(7):56–63.
- Isibor JO, Otabor E. Asymptomatic carriage of plasmid-mediated multidrug-resistant *Staphylococcus aureus* in nasal tracts of persons in a semi-urban area of Nigeria. *Am J Life Sci.* 2014;2(4):200–4.
- Nworie A. Nasal carriage of methicillin resistant *Staphylococcus aureus* amongst meat sellers in Abakaliki Metropolis, Ebonyi State, Nigeria. *Microbiol Res Int.* 2013;1(3):48–53.
- Egbuobi RC, Wachuku CK, Dike-Ndudim JN, Ogamaka AI, Okorie HM, Nwagbaraocha MA, et al. Evaluation of antibacterial profile of methicillin resistant *Staphylococcus aureus* (MRSA) isolated from hospitals in Imo state, Nigeria. *Int J Med Med Sci.* 2014;6(2):69–74.
- Olowo-Okere A, Atana RF, Abass A, Shuaibu AS, Yahya UH, Tanko N. Incidence and antibiotic susceptibility profile of *Staphylococcus aureus* isolates from wounds of patients at specialist hospital, Sokoto, Nigeria. *J Med Bacteriol.* 2017;6(4):44–50.
- Olorode OA, Ogba OM, Nanighe SO. Molecular detection of methicillin resistance genes (Mec A; Pvl) in methicillin resistant *Staphylococcus aureus* isolates from Federal Medical Centre, Yenagoa, Bayelsa State, Nigeria. *J Curr Med Res Opin.* 2021;4(10):1035–41.
- Onanuga A, Awhowho GO. Antimicrobial resistance of *Staphylococcus aureus* strains from patients with urinary tract infections in Yenagoa, Nigeria. *J Pharm Bioallied Sci.* 2012;4(3):226–30.
- Ayodeji AA, Omoniyi AK. Multi-drug resistant *Staphylococcus aureus* in clinical cases in Ile-Ife, Southwest Nigeria. *Int J Med Med Sci.* 2009;1(3):68–72.
- Onanuga A, Onaolapo AJ. Antimicrobial Susceptibility of Community-associated *Staphylococcus aureus* Isolates from Healthy Women in Zaria, Nigeria. *Trop J Pharm Res.* 2008;7(1):929–34.
- Chigbu C, Ezeronye OU. Antibiotic resistant *Staphylococcus aureus* in Abia State of Nigeria. *Afr J Biotechnol.* 2013;2(10):374–8.
- Yah SC, Enabule OI, Eggafona NO. The screening of multidrug resistance (MDR) susceptibilities of *Staphylococcus aureus* and *Staphylococcus epidermidis* to methicillin and vancomycin in teaching hospitals in Nigeria. *Int J Biol Chem Sci.* 2007;2(4):257–61.
- Yah SC, Yusuf EO, Haruna T. Patterns of antibiotics susceptibility of isolates and plasmid analysis of *Staphylococcus* from surgical site infections in Nigeria. *Sudan JMS.* 2009;3(4):810–8.
- Onwubiko NE, Sadiq NM. Antibiotic sensitivity pattern of *Staphylococcus aureus* from clinical isolates in a tertiary health institution in Kano, Northwestern Nigeria. *Pan Afr Med J.* 2011;8(4):1–7.
- Onanuga A, Temedie TC. Nasal carriage of multi-drug resistant *Staphylococcus aureus* in healthy inhabitants of Amassoma in Niger delta region of Nigeria. *Afr Health Sci.* 2011;11(2):176–81.
- Onanuga A, Avosuahi RO, Onaolapo JA. Prevalence and susceptibility pattern of methicillin-resistant *Staphylococcus aureus* isolates among healthy women in Zaria, Nigeria. *Afr J Biotechnol.* 2005;4(11):1321–4.
- Akanbi RO, Mbe JU. Occurrence of methicillin and vancomycin resistant *Staphylococcus aureus* in University of Abuja teaching hospital, Abuja, Nigeria. *Afr J Clin Exp Microbiol.* 2013;14(1):10–3.
- Alli OAT, Ogbolu DO, Akorele E, Onemu OM, Okanlawon BM. Distribution of mecA gene amongst *Staphylococcus aureus* isolates from Southwestern Nigeria. *Afr J Biomed Res.* 2011;14:9–14.
- Iroha IR, Okoye E, Osigwe CA, Moses IB, Ejikeyigwu CP, Nwakaeze AE. Isolation, Phenotypic characterization and prevalence of ESBL-producing *Escherichia coli* and *Klebsiella* species from orthopedic wounds in National Orthopedic Hospital Enugu (NOHE), South East Nigeria. *J Pharm Care Health Syst.* 2017;4(4):1000184.
- Eke S, Abdulkadiri S, Okoro CJ, Ekoh SN, Mbachi NG. The prevalence and resistivity pattern of *Staphylococcus aureus* Isolates from apparently healthy university students in Ekpoma, Edo, Nigeria. *Int J Basic Appl Innov Res.* 2012;1(4):183–7.
- Ekundayo EO, Ndubuisi RN. In-vitro antimicrobial susceptibility pattern of *Staphylococcus aureus* isolates in Umuahia, Abia state, Nigeria. *Afr J Clin Exp Microbiol.* 2015;16(3):62–6.
- Obasuyi O, Akerele JO. High incidence of multidrug-resistant strains of methicillin-resistant *Staphylococcus aureus* isolated from clinical samples in Benin-city, Nigeria. *Afr J Clin Exp Microbiol.* 2015;16(3):124–7.
- Akerele JO, Obasuyi O, Omede D. Prevalence of methicillin-resistant *Staphylococcus aureus* among healthy residents of Ekosodin community in Benin-City, Nigeria. *Trop J Pharm Res.* 2015;14(8):1495–9.
- Badger-Emeka LI, Emeka PM, Dibua UME. Plasmid profile of multi antibiotic resistant *Staphylococcus aureus* isolated from diabetic wounds from patients at Nsukka, South eastern, Nigeria. *Afr J Biotechnol.* 2014;13(43):4148–54.
- Ayeni FA, Gbarabon T, Andersen C, Nørskov-Lauritsen N. Comparison of identification and antimicrobial resistance pattern of *Staphylococcus aureus* isolated from Amassoma, Bayelsa state, Nigeria. *Afr Health Sci.* 2015;15(4):1282–8.
- Torimiro N, Torimiro SEA. Antibiotic resistance profile in community-associated *Staphylococcus aureus* strains isolated from a Nigerian peri-urban community. *Afr J Biotechnol.* 2012;11(94):16071–6.
- Bale M, Babatunde SK, Adedayo MR, Ajiboye AE, Ajao AT. Characterization of methicillin-resistant *Staphylococcus aureus* isolates from apparently healthy individuals in Maleta, Kwara state, Nigeria. *Afr J Clin Exp Microbiol.* 2019;20(1):17–24.

40. Adesoji AT, Onuh JT, Bagu J, Itohan SA. Prevalence and antibiogram study of *Staphylococcus aureus* isolated from clinical and selected drinking water of Dutsin-Ma, Katsina state, Nigeria. *Afr Health Sci*. 2019;19(1):1385–92.
41. Ariom TO, Iroha TR, Moses IB, Iroha CS, Ude UT, Kalu AC. Detection and phenotypic characterization of methicillin-resistant *Staphylococcus aureus* from clinical and community samples in Abakaliki, Ebonyi State, Nigeria. *Afr Health Sci*. 2019;19(2):2026–36.
42. Ajani TA, Elikwu CJ, Nwadike V, Babatunde T, Anaedobe CG, Shonekan O, et al. Nasal carriage of methicillin resistant *Staphylococcus aureus* among medical students of a private institution in Ilishan-Remo, Ogun State, Nigeria. *Afr J Clin Exp Microbiol*. 2020;21(4):311–7.
43. Olorunfemi PO, Onaolapo JA, Ibrahim YKE. Prevalence and antibiotic susceptibility of community acquired methicillin resistant *Staphylococcus aureus* from healthy students of University of Jos. *J Pharm Bioresour*. 2020;17(2):131–41.
44. Onanuga A, Adamu OJ, Odetoyin B, Hamza JA. Nasal carriage of multi-drug resistant panton valentine leukocidin positive *Staphylococcus aureus* in healthy individuals of Tudun-Wada, Gombe State, Nigeria. *Afr J Infect Dis*. 2021;15(1):24–33.
45. Ramalan AS, Joseph FN, Owoseni MC, Ya'aba Y, Chuku A. Prevalence and antibiotic resistance profile of *Staphylococcus aureus* and *Escherichia coli* among patients attending urology Clinic of Dalhatu Araf specialist hospital (dash) Lafia, Nasarawa state, Nigeria. *Bayero J Pure Appl Sci*. 2020;13(1):80–9.
46. Udobi CE, Obajuluwa AF, Onaolapo AJ. Prevalence and Antibiotic resistance pattern of methicillin-resistant *Staphylococcus aureus* from an Orthopaedic Hospital in Nigeria. *BioMed Res Int*. 2013;4.
47. Obasola EF, Ezeamagu CO, Oyelade AA, Adeniyi AO. Comparative study of antibiotic resistance of *Staphylococcus* species isolated from clinical and environmental samples. *AU J Tech*. 2010;13(3):165–9.
48. Moses AE, Ohagim IP, Inyang UC. Nasal methicillin-resistant *Staphylococcus aureus* carriage in pre and post-operative patients in a tertiary health facility in Uyo, South-south, Nigeria. *World J Pharm Res*. 2017;6(5):160–71.
49. Nsofor CA, Nwokenkwo VN, Nwaokpa C. Nasal carriage of *Staphylococcus aureus* among apparently Healthy School Children in Owerri Metropolis, Nigeria. *Basic Res J Microbiol*. 2015;2(3):34–8.
50. Adetayo TO, Deji-Agboola AM, Popoola MY, Atoyebi TJ, Egberongbe KJ. Prevalence of methicillin resistant *Staphylococcus aureus* from clinical specimens in Ibadan, Nigeria. *Int J Eng Sci*. 2014;3(9):1–11.
51. Ejikegwu C, Nwezeagu FJ, Edeh C, Eze P. Detection of constitutive and inducible-clindamycin-resistance in clinical isolates of *Staphylococcus aureus* from a Federal Teaching Hospital in Abakaliki, Nigeria. *J Bacteriol Infect Dis*. 2018;2(1):31–4.
52. Anucha JC, Morikwe UC, Ikegbunam MN, Ezejiegu CK, Ugwu MC. Age and gender-based antibiotic susceptibility patterns of *Staphylococcus aureus* among HIV patients in some selected hospitals in Anambra Central, Nigeria. *Gen Mol Med*. 2021;3(2):1–5.
53. Agwu E, Ihongbe J, Inyang N. Prevalence of quinolone-susceptible *Pseudomonas aeruginosa* and *Staphylococcus aureus* in delayed-healing diabetic foot ulcers in Ekpoma, Nigeria. *Cell Tis Prod*. 2010;22(4):100–5.
54. Adesida AS, Okeyide AO, Abioye A, Omolopo I, Egwuatu TO, Amisu KO, et al. Nasal carriage of methicillin-resistant *Staphylococcus aureus* among elderly people in Lagos, Nigeria. *Avicenna J Clin Microb Infect*. 2016;3(4):e39272.
55. Mofolorunsho CK, Ocheni M, Omatola CO, Agieni AG. *Staphylococcus aureus* prevalence and antibiotic susceptibility profile in Anyigba, North-Central Nigeria. *Am J Infect Dis*. 2015;11(4):93–7.
56. Osiyemi JA, Osinupebi OA, Akinduti PA, Ejilude O, Makanjuola SO, Sunmola NO, et al. Antibiotic resistance profile of methicillin-resistant *Staphylococcus aureus* in Abeokuta, Nigeria. *J Adv Microbiol*. 2018;9(2):1–9.
57. Ibe C, Onyeagba RA, Ugochukwu SC. Antibiotic resistance patterns and plasmid profiles of methicillin resistant *Staphylococcus aureus* isolates from human samples. *Br Microbiol Res J*. 2014;4(2):185–94.
58. Onaolapo JA, Olayinka BO, Adeshina GO, Igwe JC, Obajuluwa AF. Antimicrobial susceptibility pattern of *Staphylococcus aureus* isolates from orthopaedic patients in Abuth Zaria. *J Food Indust Microbiol*. 2016;2(1):1–6.
59. Ugwu MC, Anie CO, Ibezim EC, Esimone CO. Antimicrobial evaluation of methicillin-resistant *Staphylococcus aureus* nasal carriage amongst healthy students in Agbor, Delta State, Nigeria. *Arch Clin Microbiol*. 2016;7(2):13.
60. Tula MY, Okoro AJ, Okojie RO, Iyoha O. Antimicrobial susceptibility pattern and plasmid-mediated antibacterial resistance in *Staphylococcus aureus* and coagulase-negative staphylococci. *Highl Med Res J*. 2016;16(2):80–6.
61. Anyanwu NC, Abdullahi IO, Ameh JB, Ella EE. Molecular detection of PVL, msaA genes and antibiotic susceptibility pattern of *Staphylococcus aureus* from skin and soft tissue infections in Zaria, Nigeria. *Sci J Microbiol*. 2013;2(2):43–52.
62. Onyeagwara N, Obasuy O, Otthi I, Akerele JO. Nasal carriage of methicillin-resistant *Staphylococcus aureus* among hospitalized otorhinolaryngological patients in Benin City of Nigeria. *Arch Int Surg*. 2014;4(2):99–103.
63. Ngwai YB, Bakare OR. Asymptomatic bacteriuria and antimicrobial susceptibility of *Staphylococcus aureus* from university students in Keffi, Nigeria. *Int J Microbiol Bioinform*. 2012;2(1):6–8.
64. Umar M, Abdulkarim IM, Yaya A, Bello HI, Yusuf G, Mathias ML. Biochemical characterization and antibiotic susceptibility profile of *Staphylococcus aureus* isolated from patients attending Barau Dikko Specialist Hospital, Kaduna State, Nigeria. *Int J Novel Res Life Sci*. 2015;2(6):1–9.
65. Obajuluwa AF, Olayinka BO, Adeshina JA, Afolabi-Balogun NB. Plasmid profile of *Staphylococcus aureus* from orthopaedic patients in Ahmadu Bello University Teaching Hospital Zaria, Nigeria. *Afr J Microbiol Res*. 2015;9(33):1941–6.
66. Iduh UM, Chollom CS, Nuhu A, Spencer THI, Nura MB, Ashcroft OF, et al. Nosocomial infections in post-operative wounds due to *Staphylococcus aureus* and *Pseudomonas aeruginosa* in Benue State Nigeria. *Afr J Microbiol Res*. 2015;9(36):1989–96.
67. Ibanga IA, Akan OD, Iyanga FZ, Mantu EC, Asuquo M. Multi-drug resistance pattern of *Staphylococcus aureus* from pediatric ward, General Hospital, Ikot-Ekpaw, Mkpata Enin LGA, Akwa-Ibom State, Nigeria. *Arch Clin Microbiol*. 2020;11(105):1–4.
68. Emeakaroha MC, Nkwocha IG, Adieze NC, Adieze IE. Antimicrobial susceptibility pattern of *Staphylococcus aureus*, and their nasal and throat carriage among food handlers at the Federal University of Technology, Owerri Nigeria. *Int J Biomol Biomed*. 2017;6(3):1–7.
69. Bisi-Johnson MA, Kolawole DO, Shittu OA. Epidemiological analysis of clinical isolates of *Staphylococcus aureus* in Ile-Ife, Nigeria. *Pak J Bio Sci*. 2005;8(7):1016–20.
70. Ayepola OO, Nurudeen AO, Egwari LO, Becke K, Schaumburg F. Molecular characterization and antimicrobial susceptibility of *Staphylococcus aureus* isolates from clinical infection and asymptomatic carriers in Southwest Nigeria. *PLoS ONE*. 2015;10(9):e0137531.
71. Odogwu DA, Kadarko PS, Muazu JS, Bassey BE, Abimiku RH, Nkene IH, et al. Antimicrobial resistance profile and molecular detection of MecaA gene in methicillin resistant *Staphylococcus aureus* from patients in selected general hospitals in Abuja municipal, Nigeria. *GSC Biol Pharm Sci*. 2019;7(3):93–106.
72. Adeiza SS, Onaolapo JA, Olayinka BO. Prevalence, risk-factors, and antimicrobial susceptibility profile of methicillin-resistant *Staphylococcus aureus* (MRSA) obtained from nares of patients and staff of Sokoto state-owned hospitals in Nigeria. *GMS Hyg Infect Control*. 2020;15:1–17.
73. Ismail HY, Bello HS, Mustafa A, Adamu A. Multidrug resistance pattern of *Staphylococcus aureus* isolates in Maiduguri metropolis. *Sci Rev*. 2015;1(2):16–20.
74. Ibrahim S, Adam SA, Alero AA, Umar S. Prevalence and antibiotic sensitivity pattern of *Staphylococcus aureus* isolated from wound and otitis media among patients attending Aminu Kano Teaching Hospital, Kano, Nigeria. *Microbiol Res J Int*. 2018;25(2):1–9.
75. Olowe OA, Kukoyi OO, Taiwo SS, Ojuronbe O, Opaleye OO, Bolaji OS, et al. Phenotypic and molecular characteristics of methicillin-resistant *Staphylococcus aureus* isolates from Ekiti State, Nigeria. *Infect Drug Res*. 2013;6:87–92.
76. Oche AD, Oyegoke PI, Akpudo MO, Olayinka BO. Antibiotics resistance pattern of *Staphylococcus aureus* isolated from in-patients of an Orthopaedic Hospital in North-Western Nigeria. *Int J Epidemiol Res*. 2021;8(4):160–6.

77. Onelum B, Odetoyin B, Onipede A, Oyelese A. The role of methicillin-resistant *Staphylococcus aureus* in clinical infections in Obafemi Awolowo University Teaching Hospitals Complex, Ile-Ife, South Western Nigeria. *J Microbiol Exp*. 2015;2(2):00041.
78. Akindut AP, Osiyemi JA, Banjo TT, Ejilude O, El-Ashke M, Adeyemi AG, et al. Clonal diversity and spatial dissemination of multi-antibiotics resistant *Staphylococcus aureus* pathotypes in Southwest Nigeria. *PLoS ONE*. 2021;16(2):e0247013.
79. Oladipo AO, Oladipo OG, Bezuidenhout CC. Multi-drug resistance traits of methicillin-resistant *Staphylococcus aureus* and other Staphylococcal species from clinical and environmental sources. *J Water Health*. 2019;17(6):932–43.
80. Ogefero HO, Umaru G, Ibadin EE, Omoregie R. Prevalence of methicillin-resistant staphylococci among apparently healthy students attending a tertiary institution in Benin City, Nigeria. *Niger J Basic Appl Sci*. 2019;27(1):114–21.
81. Motayo BO, Akinduti PA, Okerentugba PO, Innocent-Adiele HC, Onoh CC, Nwanze JC, et al. Methicillin resistance and beta-lactamase production in *Staphylococcus aureus* isolated from different clinical samples in Abeokuta, Nigeria. *Acad Arena*. 2012;4(6):25–8.
82. Onyeka FI, Nwobodo DC, Umenna IC, Atada EE, Ojukwu CA, Aniekwe MA, et al. Antibiotic resistance pattern of *Staphylococcus aureus* isolated from nostrils of healthy undergraduates of Madonna University Elele Campus, Rivers State, Nigeria. *Microbes Infect Dis*. 2021;2(2):280–5.
83. Ugwu CM, Odimegwu DC, Ibezim EC, Esimone CO. Antibiotic Resistance patterns of *Staphylococcus aureus* isolated from nostrils of healthy human subjects in a Southeastern Nigeria Locality. *Maced J Med Sci*. 2009;2(4):294–300.
84. Nsofor CA, Nwokenkwo VN, Ohale CU. Prevalence and antibiotic susceptibility pattern of *Staphylococcus aureus* isolated from various clinical specimens in South East Nigeria. *MOJ Cell Sci Rep*. 2016;3(2):00054.
85. Mbim EN, Mboto CI, Edet UO, Umego CF, George UE, Temidayo L. Comparative evaluation of methicillin-resistant *Staphylococcus aureus* (MRSA) isolates from hospital and community settings in Nigeria. *J Adv Microbiol*. 2017;4(4):1–9.
86. Ogbolu DO, Alli TOA, Bello LA, Ibrahim AO. Emergence of vancomycin intermediate *Staphylococcus aureus* (VISA) in clinical isolates of methicillin resistant *S. aureus* from South Western Region of Nigeria. *Int J Trop Dis Health*. 2015;10(4):1–5.
87. Osinupebi OA, Osiyemi JA, Deji-Agboola AM, Akinduti PA, Ejilude O, Makanjuola SO, et al. Prevalence of methicillin-resistant *Staphylococcus aureus* in Abeokuta, Nigeria. *South Asian J Res Microbiol*. 2018;1(1):1–8.
88. Ajoke OI, Okeke OI, Odeyemi OA, Okwori AEJ. Prevalence of methicillin-resistant *Staphylococcus aureus* from healthy community individuals volunteers in Jos south, Nigeria. *J Microbiol Biotechnol Food Sci*. 2012;1(6):1389–405.
89. Onyebueke EA, Onyemelukwe NF, Oladeji DS. Antibiotic susceptibility pattern of *Staphylococcus aureus* species implicated in urinary tract infection in Enugu state Nigeria. *Pharm OnLine*. 2019;1:166–76.
90. Adetutu AA, Oritsewihinmi B, Khiwili OM, Moradeke AO, Odochi AS, Adeola OE. Studies on *Staphylococcus aureus* isolated from pimples. *Pak J Biol Sci*. 2017;20:350–4.
91. Bale MI, Babatunde SK, Awe S. prevalence of methicillin resistant *Staphylococcus aureus* bacteriuria among pregnant women attending secondary health hospitals in LLorin, Nigeria. *J Adv Microbiol*. 2021;21(9):2456–7116.
92. Nmema EE. Risk factors for infection of *Staphylococcus aureus*: nasal carriage, skin carriage and multi-antibiotic resistance in healthy individuals. *Br J Med Med Res*. 2017;21(9):1–8.
93. Ike B, Ugwu MC, Ikegbunam MN, Nwobodo D, Ejikeugwu C, Gugu T, et al. Prevalence, antibiogram and molecular characterization of community-acquired methicillin-resistant *Staphylococcus aureus* in AWKA, Anambra Nigeria. *Open Microbiol J*. 2016;10:211–21.
94. Ugwu MC, Mokwe NM, Ejikeugwu P, Enemor EC, Eze CO, Ugwu BC, et al. Antibiogram of *Staphylococcus aureus* from healthy school pupils in Agulu, Southeastern Nigeria. *Int J Res Pharm Biosci*. 2015;2(4):5–9.
95. Emeka-Nwabunnia I, Chiegboka NA, Udensi UJ, Nwaokorie FO. Vancomycin-resistant *Staphylococcus aureus* isolates from HIV positive patients in Imo State, Nigeria. *Sci J Public Health*. 2015;3(5):1–7.
96. Alli OAT, Ogbolu DO, Mustapha JO, Akinbami R, Ajayi AO. The non-association of Panton-valentine leukocidin and *mecA* genes in the genome of *Staphylococcus aureus* from hospitals in South Western Nigeria. *Indian J Med Microbiol*. 2012;30(2):159–64.
97. Sadauki AH, Olorukooba AA, Balogun MS, Dalhat MM, Waziri H, Abdulaziz MM, et al. Nasal carriage of methicillin-resistant *Staphylococcus aureus* among children living with HIV attending infectious diseases clinics in Kano, Nigeria. *Infect Prev Pract*. 2022;4:1–8.
98. O'Malley SM, Emele FE, Nwaokorie FO, Idika N, Umeizudike AK, Emeka-Nwabunnia I, et al. Molecular typing of antibiotic-resistant *Staphylococcus aureus* in Nigeria. *J Infect Public Health*. 2015;8:187–93.
99. Emeka-Nwabunnia I, Ejigeme K, Oguoma OI. Antibiotic resistance pattern of methicillin-resistant *Staphylococcus aureus* isolated from children under the age of five years in Anambra State. *Niger J Biotechnol*. 2019;36(1):213–21.
100. Ako-Nai AK, Adeyemi FM, Aboderin OA, Kassim OO. Antibiotic resistance profile of staphylococci from clinical sources recovered from infants. *Afr J Biotechnol*. 2015;4(6):816–22.
101. Frank-Peterside N, Mukoro M. The current susceptibility pattern of methicillin resistant *Staphylococcus aureus* to antibiotics in Port Harcourt. *Global J Pure Appl Sci*. 2010;16(4):375–9.
102. Yahaya H, Ahmad AS, Ibrahim A, Abdullahi AS. Phenotypic Detection of Macrolide, Lincosamide and Streptogramin B resistance among *Staphylococcus aureus* clinical isolates in A Northern Nigeria Tertiary Hospital. *Alq J Med App Sci*. 2022;5(1):193–8.
103. Onanuga A, Eboh DD, Okou GT. Antibiogram and virulence characteristics of multi-drug resistant *Staphylococcus aureus* from nasal cavity of healthy students of Niger Delta University, Amassoma, Bayelsa State, Nigeria. *J Clin Diagn Res*. 2019;13(7):24–9.
104. Oginni IO, Olayinka AA. Distribution and antibiotics resistance pattern of community-acquired methicillin-resistance *Staphylococcus aureus* in Southwestern Nigeria. *Adv Exp Med Biol*. 2022;1369:81–91.
105. Nwankwo EOK, Sale A, Magagi A, Ihesiulor G. Methicillin resistant *S. aureus* (MRSA) and their antibiotic sensitivity pattern in Kano, Nigeria. *Afr J Clin Exp Microbiol*. 2010;11(1):129–36.
106. Olufunmiso C, Tolulope I, Roger C. Multidrug and vancomycin resistance among clinical isolates of *Staphylococcus aureus* from different teaching hospitals in Nigeria. *Afr Health Sci*. 2017;17(3):798–806.
107. Olajide RA, Ameh JA, Simon MK. Antibiotic resistance and susceptibility pattern/profile of *Staphylococcus aureus* and *Klebsiella* species to popularly—used and readily available antibiotics in Zaria, Nigeria. *J Phytother Pharm*. 2012;1:16–21.
108. Hemaiswarya S, Kruthiventi AK, Doble M. Synergism between natural products and antibiotics against infectious diseases. *Phytomedicine*. 2008;15(8):639–52.
109. Li S, Li J, Qiao Y, Ning X, Zeng T, Shen X. Prevalence and invasiveness of community-acquired methicillin-resistant *Staphylococcus aureus*: a metaanalysis. *Indian J Pathol Microbiol*. 2014;57(3):418–22.
110. WHO. Antimicrobial resistance: global report on surveillance. 2014.
111. Struelens MJ. The epidemiology of antimicrobial resistance in hospital acquired infections: problems and possible solutions. *BMJ*. 1998;317(7159):652–4.
112. Guta M, Aragaw K, Merid Y. Bacteria from infected surgical wounds and their antimicrobial resistance in Hawassa University referral teaching hospital, southern Ethiopia. *Afr J Microbiol Res*. 2014;8(11):1118–24.
113. Dessalegn L, Shimelis T, Tadesse E, Gebre-selassie S. Aerobic bacterial isolates from post-surgical wound and their antimicrobial susceptibility pattern: a hospital based cross-sectional study. *J Med Res*. 2014;3(2):18–23.
114. DACA. Antimicrobials use, resistance and containment baseline survey: syntheses of findings. In: 2009th ed. Addis Ababa; 2009.
115. Falagas ME, Karageorgopoulos DE, Leptidis J, Korbila IP. MRSA in Africa: filling the global map of antimicrobial resistance. *PLoS ONE*. 2013;8(7):e68024.

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.