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Global mapping of cholera *Vibrio* and outbreaks in the Pre-Millennium Development Goals (MDG)/Sustainable Development Goals (SDG) and MDGs/SDGs era of 1990–2019

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**ABSTRACT**

*Vibrio* species and cholera outbreak yet remain a frequent health emergency despite progress made in integrated implementation of the MDGs/SDGs/WASH worldwide. Hence, this study aimed at appraising the impacts of MDGs/SDGs/WASH campaigns on the mitigation of cholera outbreak and associated consequences. The study mapped scientific production related to *Vibrio* outbreak from 1990 to 2019, identified trend, institutional/international concerted efforts toward outbreak research/response and gaps for future preparedness. Relevant documents were identified from the Web of Science database using an optimised title-field specific search Boolean that accommodated all pre-set inclusion criteria for the study. A total of 901 documents were identified including 869 available abstracts were retrieved for content-review of human incidence cases, mortality, culprit *Vibrio* species, strains, and biotypes. Explanatory analysis showed that the trend of outbreak documents approximately increased in 6th order quadratic relationship \(R^2 = 0.7948\) from 1990 to 2019 with an annual growth rate of 3.21% and a mean value of 30.0 ± 18.0 per year. Other details revealed an increased and undulating case report/mortality rate of cholera outbreaks especially in the MDGs/SDGs era. Decadal comparison of *Vibrio* outbreak during the period showed significant variation in documents distribution \(p = 0.00077\). based on countries’ efforts, the USA, ranked first in terms of article numbers (191), publication frequency (24.6%) and total citations (5962). Four prevailing conceptual frameworks were identified in the outbreak documents with global community interest revealed as the largest topical coverage. All conceptual frameworks consisted in *Vibrio* characterisation, methodology-related, intervention-related, geographic-related concepts and some replete with health and climate-change depicting concepts. Also, the study observed high mortality in *Vibrio* outbreaks during 1990–1999 (29080 deaths), and 2010–2019 (386606 deaths) compared to 2000–2009 (7705 deaths) \(p < 0.05\). High number of outbreaks due to *V. cholerae* and *V. parahaemolyticus* and a limited outbreaks attributed to emerging strains. In conclusion, vibrio outbreak has not lived up to various investment put into its control from various programme evolutions. The broad spectrum *Vibrio* vaccines that could cater for outbreak caused by common and emerging strains is inevitable and a significant thrust for future research.

1. Introduction

*Vibrio* species, cholera and other waterborne diseases outbreaks are usually consequences of inaccessibility to improved drinking water supplies and sanitations from time immemorial. Meanwhile, among the primary priorities of the United Nations e.g., the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) for some decades include access to enough safe drinking water and sanitation, which has gained widespread attentions from one-health perspectives. While the United Nations’ efforts on global safe drinking water targets can be traced early to 1959 [1,2], since then, five phases of programmes could be recognised namely, 1959–1980, 1981–1990, 1991–2000, 2001–2015 (MDGs) and 2016–2030 SDGs periods [3]. The 1959–1980 had its target to achieve 'reasonable access and safe water supply' [1], while the 1981–1990 period aimed at 'providing all people with water of safe quality, adequate quantity and basic

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sanitary facilities by 1990 [4,5]; the 1991–2000 hinged on ‘safe drinking water coverage at a convenient distance from the user’s dwelling’ [6,7]; the 2001–2015 (MDG) focused at ‘reducing to half, the percentage of individuals who lack safe water’ by 2015 and ‘safe water for everyone’ by 2025 [8]; and the SDGs centred at ‘achieving universal and equitable access to safe and affordable drinking water for all’ by 2030 [9]. Both the MDGs and SDGs goals especially SDGs 3 “ensure healthy lives and promote well-being for all at all ages”, and 6 “Clean water and sanitation”. It is therefore hypothesised that they could meritioriously support possible reduction in disease outbreaks if a level of progress in their implementation is achieved.

Fortunately, all the aforementioned phases, have witnessed some progresses towards safe water supply and sanitation against their respective baselines. For instance, the World Health Organization/United Nation International Children’s Emergency Fund (WHO/UNICEF) Joint Monitoring Programme for Water Supply and Sanitation (JMP) in 2012 declared that ‘halving the proportion of those have-nots connected with safe drinking water’ was achieved in 2010 [10]. Also, that the rural population without access to drinking water reduced by $6.33 \times 10^8$ [11] in the same periods. In similar manner, the period 1990–2015 witnessed $9.79 \times 10^6$ and $1.48 \times 10^6$ increases in rural and urban populations with access to improved water sources, respectively, excluding developed nations; and $6.03 \times 10^6$ deceased in the population that relied on unimproved water ([WHO/UNICEF JMP (https://washdata.org/)]. Similarly, the JMP in 2017, revealed on global population scale that 92% used ‘improved water sources’ in 2015 during the MDG and 71% of which used ‘safely managed drinking water services’, situated on the premises or available at will and without priority chemical and faecal contaminants [12]. The most notable progress related to safe water supply was recorded in India involving $3.84 \times 10^4$ increase and $1.68 \times 10^4$ decrease in rural population with and without access to improved water respectively, notwithstanding a total increase of $2.16 \times 10^8$ in India’s rural populations during the period [3].

Despite these progresses, it is unknown whether the achievements recorded in the MDGs/SDGs are related to improved water and sanitation access, which is translated to reduced outbreaks of cholera/Vibrio globally or not. It is against this backdrop that this study assessed contributions of the MDGs/SDGs activities on water and sanitation targets to reducing cholera outbreaks. There exist no formal analysis or study related to contributory impacts of MDG/SDG campaigns towards the mitigation of global Vibrio/cholera outbreaks. This study investigated whether MDGs/SDGs progress translated to reduced cholera outbreaks or not. The approach involved mapping of scientific production related to Vibrio outbreak from 1990 to 2019 as an indirect source-track of cholera outbreaks during the period. This investigation also identified outbreak trend, institutional/international concerted efforts toward outbreak research/response, topical concerns and gaps for future outbreak preparedness.

2. Methods

2.1. Retrieval of outbreak documents

Published peer-reviewed article, proceedings paper, editorial material letter, meeting abstract, news item, and note on Vibrio outbreaks globally were searched on the Web of Science (WoS) core collection database on 23/05/2019; 12:08 GMT +2). The study adopted title-specific search with the Boolean “(Vibrio* AND epidemic*) OR (Vibrio* AND outbreak$) OR (choler* AND outbreak$) OR (choler* AND epidemic*)” to retrieved all available Vibrio outbreak information from 1990 to 2019 (23/05/2019). This was done to enhance specificity, maximum recovery and as well minimized loss compared to a topical search [13]. The adoption of WoS database is pre-informed by the availability of news items. News item is normally unavailable in other databases; meanwhile news constituted the first outlet for outbreak information to enhance prevention or halt further spread. The wildcard * and $ ensured inclusion of words such as “Vibrio spp”, “Vibrios”, “Vibrio cholerae”, “Vibrio para-haemolyticus”, “Vibrio vulnificus”, “Vibrio anguillarum”, “Vibrio alginolyticus”, “epidemic(s)” and “outbreak(s)” as the case may be. The search result was further refined by excluding document types such as correction addition, review, book review, biographical item, book chapter, correction, avian cholera, book and reprint, as they do not constitute primary sources of outbreak information and/or are synthesis of primary articles. All documents that meet the inclusion criteria were downloaded in the BibTeX file format. In addition, the documents’ titles and abstracts were retrieved in PDF file format for extraction of bacterial strain, number of human, and death cases involved. SDGs (2016 jan).

2.2. Data analytics

2.2.1. Data pre-processing and descriptive analysis

The retrieved data were pre-processed for quality control. Data fields related to authors’ names, affiliation, country, document source, keywords and other bibliometric variables were extracted for normalization. All relevant fields including authors’ names and keywords were extracted by two investigators (IBE and ETC) and checked for spelling errors. Further analysis was based on agreement between data normalized by the two investigators. Keywords with similar meanings or multiple occurrences in a document were grouped together and regarded as one word respectively (e.g., “Cholera”, “Cholera epidemic”, and “Cholera Outbreak”, or “India” and “Calcutta”).

The standardised data was analysed for descriptive indices and rates for topmost 10 productive authors, top productive countries, total citations per country and 10 topmost relevant sources.

2.2.2. Outbreak trend analysis

Time series of annual scientific production related to Vibrio outbreak was generated in terms of documents. The time series data was further grouped into 3 decadal periods (1990–1999, 2000–2009, and 2010–2019) for comparison of distribution of outbreak related documents in pre-MDGs/SDGs and MDGs/SDGs period. The study achieved the decadal comparison via non-parametric ANOVA test (Kruskal-Wallis H test) visualized as composite violin-boxplots. The study further modelled/predict future trend of authors’ productivity or publication frequency in terms of Lotka’s inverse square law [15].

2.2.3. Determination of the prevalence/incidence of cases, mortality, culprit Vibrio species, strains and biotypes

The study also performed content-review of 869 available abstracts for records of incidence of human cases, mortality, culprit Vibrio species, strains and biotypes. Decadal analysis as mentioned in the previous section was carried out in addition and visualized using pie graphs.

2.2.4. Topical concerns in Vibrio outbreaks

The study also assessed topical concerns associated with Vibrio outbreaks via Co-Word analysis [16,17]. Co-Word analysis was performed by K-means clustering via metric multidimensional scaling (MDS) of 517 individuals described by 183 variables/keywords. Where necessary, inflectional words were regulated to their root form using Porter’s stemming algorithm [18]. The study visualized trending topics in outbreak using dendrogram based on average Euclidean distance technique.

2.2.5. Assessment of concerted action on outbreak response and mitigation

The study considered concerted action or collaboration on Vibrio outbreak response/mitigation in terms of joint effort from authors’, institutional and country/international point of views. Different matrix (Documents × Authors, Documents × Countries, and Documents × Institutions) was built from the retrieved bibliographic data for corresponding joint effort or collaboration network. A
collaboration (joint effort) network has its nodes representing authors/ institutions/countries and the corresponding links relationships/joint actions. Country collaboration network, authors’ collaboration network, universities collaboration networks, keyword co-occurrence network, and co-occurrences network were built based on 92 countries, 3538 authors, 961 institutions, 1095 keywords, and 9935 items involved in the documents, respectively. All networks were normalized via the Jaccard’s similarity index and graphed using Fruchterman force-directed algorithms.

2.2.6. Software
All analysis was performed using an excel 2016 and Rstudio versions 3.4.4 & 3.6.0 [14,19] with ggpubr version 0.2 package [20] https://CRAN.R-project.org/package=ggpubr and the bibliometrix R-package [16,20].

3. Results and discussions
3.1. Characteristics of Vibrio outbreak documents
A total of 901 Vibrio outbreak documents were identified during the study period (Table 1). The documents were primarily from 307 journal sources and altogether contained 1063 author’s keywords and 1117 keywords plus. Average citations per the retrieved documents was 17.58. The articles were authored by 3544 authors with a total of 5255 keywords plus. Average citations per the retrieved documents was 17.58 Meeting Abstract 66(7.3%). The documents were primarily from 307 journal sources and altogether contained 1063 author’s keywords and 1117 keywords plus. Average citations per the retrieved documents was 17.58 Meeting Abstract 66(7.3%).

Table 2 lists 10 top productive authors related to Vibrio outbreaks. These authors included Nair GB (32, 3.6), Ramamurthy T (24, 2.7), Tauxe RV (22, 2.4), Luquero FJ (21, 2.3), Azman AS (18, 2.0), Sack RB (18, 2.0), Bhattacharya SK (17, 1.9), Faruque SM (17, 1.9), Mintz ED (17, 1.9), and Sack DA (16, 1.8). They were majorly affiliated with institutions from India (n = 3), USA (n = 4), France (n = 1) and Bangladesh (n = 2). The thrust and interest of these 10 top productive authors can be as an attempt geared toward providing solutions to the menace of the cholera Vibrio in their countries (e.g., India and Bangladesh) and/or collaborative effort to combat spread of outbreak in other countries (e.g., USA and France). Major reports from India and Bangladesh were reports of outbreak surveillance studies. French authors also reported food associated cholera cases after outbreaks. The authors’ h-index ranged from 6 (Azman AS) to 20 (Nair GB), and average total citation from 135 (Azman AS) to 1762 (Nair GB), and average total citations from 7.5 (Azman AS) to 77.7 (Faruque SM). The domination of Nair GB both in terms of h-index and total citations is instructive of the author’s productivity and jointly pointing to endemicity of Vibrio outbreaks in the author’s country India. Faruque SM from Bangladesh had the highest average total citations (77.7) among the authors. This revealed that Faruque’s work received more recognition in term of the number of citations.

The 10 topmost productive countries related to Vibrio outbreak research is listed in Table 3. The USA ranked first with a total number of 191 articles followed by India (n = 111), France (46), Bangladesh (n = 25), UK (n = 22), and Japan (n = 21). Others were China (n = 19), Brazil (n = 18), Canada (n = 17) and Switzerland (n = 16). The USA and India possessed higher frequency of production of 24.7% and 14.3% respectively; while others have <5.9%. Based on multi-country publication ratio, Switzerland ranked 1st with 100% multiple country publication ratio, followed by Bangladesh (80%), France (69.6), Japan (66.7%) and the least were India (16.2) and China (15.8%). The 100% publications from Switzerland as multiple country publication ratio probably suggests that Vibrio outbreak might not be endemic in Switzerland and showed that the country has strong collaboration network or play supportive roles to other countries that experienced Vibrio epidemics. The China and India ranked low based on multi-country publication ratio among the countries due to their large population, and large number of institutions that probably encouraged intra-national collaborations compared to international ones. While the USA and India retained their 1st and 2nd position based on country

| Rank | Authors | Articles (%) of 901 | h-index | TC | ATC | Country |
|------|---------|-------------------|--------|----|-----|---------|
| 1    | Nair GB | 32 (3.6)          | 20     | 1762| 55.1 | India   |
| 2    | Ramamurthy T | 24 (2.7)  | 11     | 949 | 39.5 | India   |
| 3    | Tauxe RV | 22 (2.4)          | 16     | 835 | 38.0 | USA     |
| 4    | Luquero FJ | 21 (2.7)  | 10     | 835 | 15.5 | France  |
| 5    | Azman AS | 18 (2.0)          | 6      | 135 | 7.5  | USA     |
| 5    | Sack RB | 18 (2.0)          | 14     | 1087| 60.4 | USA     |
| 6    | Bhattacharya SK | 17 (1.9) | 11     | 863 | 50.8 | India   |
| 6    | Faruque SM | 17 (1.9)  | 14     | 1321| 77.7 | Bangladesh |
| 6    | Mintz ED | 17 (1.9)          | 13     | 678 | 39.9 | USA     |
| 7    | Sack DA | 16 (1.8)          | 11     | 608 | 38.0 | Bangladesh |

Vibrio epidemics. The China and India ranked low based on multi-country publication ratio among the countries due to their large population, and large number of institutions that probably encouraged intra-national collaborations compared to international ones. While the USA and India retained their 1st and 2nd position based on country

Table 1: Characteristics of Vibrio outbreak documents.

| Variable | Count/rate | Variable | Article (%) |
|----------|------------|----------|-------------|
| Documents | 901 | Document Types | Article |
| Sources (Journals) | 307 | 656 (72.8) |
| Keywords Plus (ID) | 1085 | Proceedings Article | 18 (2.0) |
| Author’s Keywords (DE) | 989 | Editorial Material | 48 (5.3) |
| Period | 1990-2019 | Letter | 53 (5.9) |
| Average citations/documents | 17.58 | Meeting Abstract | 66 (7.3) |
| Authors | 3538 | News Item | 42 (4.7) |
| Author Appearances | 5255 | Note | 18 (2.0) |
| Authors of single-authored documents | 118 | Language | 15 (1.8) |
| Authors of multi-authored documents | 3420 | English | 854 (93.9) |
| Single-authored documents | 146 | French | 542 (2.8) |
| Documents per Author | 0.255 | German | 40 (4) |
| Authors per Document | 3.93 | Korean and Dutch | 1 (0.1) each |
| Co-Authors per Documents | 5.83 | Portuguese and Russian | 1 (0.1) each |
| Collaboration Index | 4.53 | Spanish | 2 (0.0) |

ATC: average total citations; TC: total citations.
total citations with 5962 and 1606 citations respectively, France lost her 3rd position to Bangladesh (1137). Countries such as Denmark, Netherlands and Taiwan made the 5th, 6th and 7th with a total citation of 591, 415 and 398 respectively. Also, Denmark, Netherlands and Taiwan possesses average article citation of 42.21, 41.5 and 39.8 to be ahead of other countries except Bangladesh with 45.48 average article citations. Hence, it is noteworthy that Vibrio outbreak publication from the 3 countries receive greater credit and attention in term of the total citations obtained. However, the drop off of UK, Canada and China from the 10 topmost positions based on total citation might be showing lack of recognition and quality coverage of their institutional production in Vibrio outbreak research.

Table 4 presents 10 topmost productive Journal sources that published Vibrio outbreak documents during the study period. Among these sources, American Journal of Tropical Medicine and Hygiene ranked 1st by publishing 42% of the outbreak documents, followed by Emerging Infectious Diseases (36%), Journal of Clinical Microbiology (27%), Epidemiology and Infection (26%). These journals have the reputation of publishing articles related to infectious diseases except Plos one that deals in publishing multidisciplinary research. The impact factor of these journals according to InCites Journal Citation Reports (2018) range from 1.251 (Indian Journal of Medical Research) to 7.185 (Emerging Infectious Diseases) with Lancet having exceptionally high impact factor of 59.102. The sources further attest to the importance of Vibrio outbreaks both at infectious diseases perspectives and a need for multidisciplinary responses/actions in combating its menace.

3.2. Vibrio outbreak trend from 1990 to 2019

The trend of Vibrio outbreak documents approximately increased in 6th order quadratic relationship ($R^2 = 0.7948$) from 1990 to 2019 with an annual growth rate of 3.21% and a mean value of 30.0 ± 18.0 per year (Fig. 1a). This annual growth is an indicator of outbreak trend overtime and subsequent Vibrio outbreaks in the future. Also, the distribution of Vibrio outbreak document varied significantly on a decadal scale during the survey period (Kruskal-Wallis, $p = 0.0058$) (Fig. 1b). While there was no significant difference between article distribution in 1990–1999 and 2000–2009 ($p = 0.31$), distribution between the period 1990–1999 and 2010–2019/2000–2009 and 2010–2019 was significantly different ($0.001 \leq p \leq 0.0028$). Summarily, Vibrio outbreak article distribution had its 75th percentile (mean, maximum [year]) in 1990–1999, 2000–2009 and 2010–2019 as 22.5 (18.1, 28.0 [1994]), 23.75 (21.90, 34.00 [2009]) and 62.75 (50.1, 71.0 [2011]) respectively.

The observed increase in outbreak documents in the study period might denote more occurrence or incidence of Vibrio outbreaks despite decades of United Nations’ programme for safe water supply and sanitation campaign (MDGs and first-five years of SDGs). Control of global cholera outbreak yet remains a menace as concerted efforts and diverse novel strategies are being employed by researchers and public health related non-governmental organizations for the achievement of MDGs/SDGs/WASH. From our bibliometric mapping of choler outbreaks, it is observed that the level/trend of outbreak reports in the last decade (2010–2019) have increased in diverse endemic area of the world. For a period, greater than three decades, the non-governmental organization and research based strategies have been employed yet the situation remain a dilemma of unending result. Although, various steps employed in some outbreak situations have yielded short-lived results as depicted from the study, the succession on subsequent outbreak report in such area are quite alarming.

The annual growth rate was 3.21%. A decadal comparison of outbreak documents varied in distribution (Kruskal-Wallis, $P = 0.00077$). In the composite violin and box plots, violin area shows the distribution including mild and extreme outliers. Central line in box plot represents median, and its edges the 25% and 75% percentiles. The p-values for comparison of the 3 decadal outbreak documents is showed on the lines above the bins.

Decadal human cases of infection documented in Vibrio outbreaks was 871119, 324323 and 6364070 persons in 1990–1999, 2000–2009, and 2010–2019 respectively (Fig. 2a). High number of cases in 2010–2019 which included the first 5 years of SDGs might connote more detailed report of outbreaks compared to other periods as many non-documentation of the number of people affected were noticed in the article abstracts in other periods. Also, it might connote increase in number of human affected during the late MDGs and the first 5 years of SDGs (2010–2019) periods in comparison to the pre-MDGs and the early MDGs periods (1990–1999, 2000–2009). This in part, can be linked to global warming. Some authors have showed increasing and positive correlation of cholera/Vibrio outbreaks with global warming [30,31]. Similarly, the investigation observed high mortality in Vibrio outbreaks during 1990–1999 (29080 deaths), and 2010–2019 (386606 deaths) compared to 2000–2009 (7705 deaths), (Kruskal-Wallis, $p < 0.05$) (Fig. 2b). This suggests that progress has been made in combating mortality due to outbreaks as many intervention options are available than the previous decades. This occurrence may be
attributable to non-evaluation, unreported/unpublished, limited investigation, or surveillance of cholera vibrio cases within the decadal boundaries. It could also be primarily linked to difference in the impact of meteorological events or environmental factors such as rainfall, precipitation, drought, temperature and any other natural disaster in the compared periods. On the contrariwise, abstracts in most cases cannot provide comprehensive outbreak information. The underline factors responsible for high mortality during 1990–1999 and MDGs/
early SDGs year compared to other period is not clear. However, the mortality rate and case fatality reports from these recorded cases are reduced when a comparative rule is accessed between the first decade reports (1990–1999) and last decade reports based on volume of articles. The outbreak trend may probably continue to increase in SDGs era as indicated by annual growth rates and comparative decadal analysis (Fig. 1a and 1b).

3.3. Infection cases, mortality, and prevalent Vibrio species, strains and biotypes in outbreak

Table 5 shows the prevalence of Vibrio species, serogroup and bioype responsible for outbreaks from 1990 to 2019. V. cholerae and V. parahaemolyticus were responsible for 783(90.0%) and 45(5.2%) outbreaks in the period respectively. Outbreaks jointly caused by divalent (two) strains include V. alginolyticus and V. parahaemolyticus (3; 0.3%), V. cholerae and V. parahaemolyticus (1; 0.1%), V. fluvialis and other enteric pathogens (3; 0.3%), V. harveyi (1; 0.1%), V. mimicus (4; 0.5%), V. mimicus and V. cholerae (1; 0.1%), V. neptunius (1; 0.1%), V. parahaemolyticus (45; 5.2%), V. Pelagius (1; 0.1%), V. rotiferanuis (1; 0.1%), V. salmonicida (1; 0.1%), V. vulnificus (4; 0.5%), Vibrio (10; 1.2%).

Table 5a

| Species prevalence |
|--------------------|
| ND | 6 (0.7) |
| V. alginolyticus | 1(0.1) |
| V. alginolyticus and V. parahaemolyticus | 3(0.3) |
| V. anguillarum | 1(0.1) |
| V. campbellii | 1(0.1) |
| V. cholerae | 783(90.0) |
| V. cholerae and V. parahaemolyticus | 1(0.1) |
| V. fluvialis and other enteric pathogens | 3(0.3) |
| V. harveyi | 1(0.1) |
| V. mimicus | 4(0.5) |
| V. mimicus and V. cholerae | 1(0.1) |
| V. neptunius | 1(0.1) |
| V. parahaemolyticus | 45(5.2) |
| V. Pelagius | 1(0.1) |
| V. rotiferanuis | 1(0.1) |
| V. salmonicida | 1(0.1) |
| V. vulnificus | 4(0.5) |
| Total | 869(100) |

Table 5b

| Strain Frequency(%) |
|---------------------|
| Altered El Tor | 1(0.1) |
| Atypical O1 | 1(0.1) |
| Inaba O1 | 2(0.2) |
| ND | 643(74) |
| Non-endemic strain | 20(2) |
| non-O1/non-O139 and O1 Ogawa | 22(2.5) |
| O:K | 1(0.1) |
| O1 | 17(2) |
| O1 Ogawa | 114(13.1) |
| O1/O139 | 51(5.8) |
| O139 and O1 Ogawa | 20(2) |
| O141 | 1(0.1) |
| O3:K59 | 1(0.1) |
| O3:K6 | 7(0.8) |
| O37 and O1 | 1(0.1) |
| O5:K15, O4:K8, O3:K29, O1:K56 | 1(0.1) |
| O75 | 1(0.1) |
| W07 | 1(0.1) |
| Total | 869(100) |
implicated in cross-infections as well as confer cross immunity against multiple biotypes and serogroups, an area that may be a significant thrust for future research. About 643(74%) of the articles failed to provide information on *Vibrio* serotypes or biotypes responsible for outbreaks, some yet provided were associated with avian cholera. However, the common serotypes/biotypes encountered in most outbreaks spanned from non-O1/non-O139 and O1 Ogawa (22, 2.5%), O1 (17, 2%), O1 Ogawa (114, 13.1%), O1/O139 (51, 5.8%) to O3:K6 (7, 0.8%) among others. A multivalent vaccine composed of non-O1/non-O139, O1 Ogawa and O1/O139 might be ideal and necessary for outbreak prophylactic measures in a cholera endemic region (see Table 6).

### 3.4. Conceptual framework and trending topics related to *Vibrio* outbreaks

MCA performed on 300 individuals described by 50 variables identified four distinct conceptual frameworks (CF) (Fig. 3). The first framework (purple) includes terms related to characterisation of *Vibrio* such as genetic diversity, pathogenicity, island, pandemic strains, ctx-phi, evolution, sequences, serotype inaba/Ogawa or O1 strain. The methodology-related concepts in the purple CF were molecular analysis and field gel electrophoresis. Geographical pointers found in the purple CF were western-hemisphere. The second framework (green CF) includes identification, polymerase-chain-reaction, DNA, molecular characterisation, comparative genomics, molecular epidemiology. ctx, ctx prophage, toxin, reg, plasmid, thermostable direct hemolysin, colonization factor, virulence, toxigenic *Vibrio cholerae*, pathogen, and pathogenesis were pathogenidentity concept found in the red CF. Antibiotic-resistance, resistance, and integrons were concept-marker for the problem of antimicrobial resistance in *Vibrio* outbreaks. The agency of risk-factors/vehicle for transmission such as immunity, antibodies, drinking-water, environment, water, waters, sanitation, spread, and storage, in outbreak became evident in the CF. The role of rainfall, natural disasters and global climate in *Vibrio* outbreak had imprint in the CF. *Vibrio* strain-defining terms in the CF include El Tor strains, non-O1, O1 strains, O139 bengal, *parahaemolyticus*, *Vibrio cholerae*, inaba, and*Vibrio*-cholerae-O1, and O139. Outbreak consequences had it footprints described as burden, diarrhoea, emergence, mortality, impact, infectious-diseases. Health concepts varied from public health, health education, health behaviour, health service, and health policy in *Vibrio* outbreaks.

#### Table 6
Most Relevant Keywords accessed during study.

| s/n | Author Keywords | Articles | Keywords-Plus | Articles |
|-----|----------------|---------|---------------|---------|
| 1   | CHOLERA        | 166     | VIBRIO CHOLERAIE | 103     |
| 2   | VIBRIO CHOLERAIE | 68     | STRAINS       | 76      |
| 3   | OUTBREAK       | 34      | BANGLADESH    | 75      |
| 4   | EPIDEMIC       | 22      | TRANSMISSION  | 71      |
| 5   | EPIDEMIOLOGY   | 22      | EMERGENCE     | 47      |
| 6   | EPIDEMICS      | 18      | AFRICA        | 44      |
| 7   | PASTEURELLA MULTOCIDA | 16 | DYNAMICS     | 43      |
| 8   | VIBRIO         | 16      | O1           | 43      |
| 9   | DISEASE OUTBREAKS | 13    | EPIDEMIC     | 42      |
| 10  | AVIAN CHOLERA  | 11      | INDIA        | 37      |
| 11  | INDIA          | 11      | OUTBREAK     | 37      |
| 12  | VIRULENCE      | 11      | HAITI        | 36      |
| 13  | CHOLERA OUTBREAK | 10    | IDENTIFICATION | 33     |
| 14  | HAITI          | 10      | TOXIN        | 31      |
| 15  | GLOBAL STABILITY | 8      | PCR          | 26      |
| 16  | VIBRIO CHOLERAIE O1 | 8     | BIOTYPE      | 24      |
| 17  | DIARRHOEA      | 7       | POLYMERASE CHAIN | 24     |
| 18  | DIARRHOEA      | 7       | WATER        | 24      |
| 19  | FOWL CHOLERA   | 7       | GENE         | 23      |
| 20  | SANITATION     | 7       | DISEASE      | 22      |
| 21  | V CHOLERA      | 7       | EL TOR       | 21      |
| 22  | CHOLERA EPIDEMIC | 6     | INFECTIOUS DISEASE | 21     |
| 23  | GASTROENTERITIS | 6      | EPIDEMIOLOGY  | 20      |
| 24  | HYGIENE        | 6       | UNITED STATES | 19      |
| 25  | MORTALITY      | 6       | CALCUTTA     | 18      |

Conceptual themes associated with *Vibrio cholerae* outbreak studies.

\[
\begin{align*}
\beta &= 2.45, \beta &= 0.52, s_R^2 = 0.96, s_p, \text{value} = 0.10 \text{ (Kolmogorov-Smirnoff goodness-of-fit of 0.96) (P = 0.10, two-sample t-test).)}
\end{align*}
\]

3.5. Cooperative action and response in *Vibrio* outbreak mitigation

Fig. 4a–c shows conjunctive responses and actions in *Vibrio* outbreaks mitigations. While the network size, density, transitivity, diameter, degree centralization, and average path length of various authors’ joint efforts/cooperative response (ACCN) was 3538, 0.003, 0.574, 13, 0.04 and 4.587, respectively (Fig. 4a), that of University/ institutional joint efforts (UCC) was 961, 0.004, 0.348, 12, 0.059 and 4.333 respectively (Fig. 4b). In ACCN 5 major academic collaboration clusters can be seen. Most clusters and subclusters coordination centred on Sack DA, Nair R, Narra R, Ramamurthy T, Malama K and Azman AZ (Fig. 4a). Central players in UCN include John Hopkins Bloomberg School of Public Health, University of Maryland, Centre for Disease Control and Prevention, National Institute for Cholera and Enteric Diseases, International Institute for Diarrheal Diseases and Research, London School of Hygiene and Tropical Diseases and Pasteur Institutes. It is evident to note that many of the institutions are saddled with responsibility related to infectious diseases mitigation and research. This might influence their central roles in *Vibrio* outbreak as it is known as one of the deadliest infectious diseases. Collaborative effort in term of country’s joint cooperative responses (CCN) has it statistics as 92, 0.092, 0.393, 5, 0.546 and 2.204 for network size, density, transitivity, diameter, degree centralization, and average path length respectively (Fig. 4c). The USA, United Kingdom, France and Switzerland ranked 1st, 2nd, 3rd and 4th in term collaboration initiatives. The centrality of these countries in their various network subclusters may be due to resource advantages in term of funding/aids and vaccines provision to partner countries; personnel and equipment sharing. In most cases, vaccine technology and point-of-surveillance kits/resources are not available in their partner countries (Fig. 4c).
4. Conclusion

Following the observation as mentioned in various section, tables and figures of the study, it can be deduced that the pre-MDG/SDG has recorded an uncertain non-report of cholera outbreaks which are associated with various strains of Vibrio, with indicative prevalence reports traced to the V. parahaemolyticus and V. cholerae. However, the MDG/SDG which has shown high research based intervention, collaborative approach, control strategies and a public interest studies continues to show increased as well as undulating case report of affected people with yet high death rate and highest percentage mortality
which are associated with *V. parahaemolyticus* and *V. cholerae* as indicated in Fig. 5 and Table 8. Careful and astute approaches are suggestive in studies associated with cholera to enhance future case judgement and encourage appropriateness in research tested control and/or mitigation strategies in the MDG/SDG era. (see Table 7)

**Declaration of competing interest**

No conflicting interest was declared.

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