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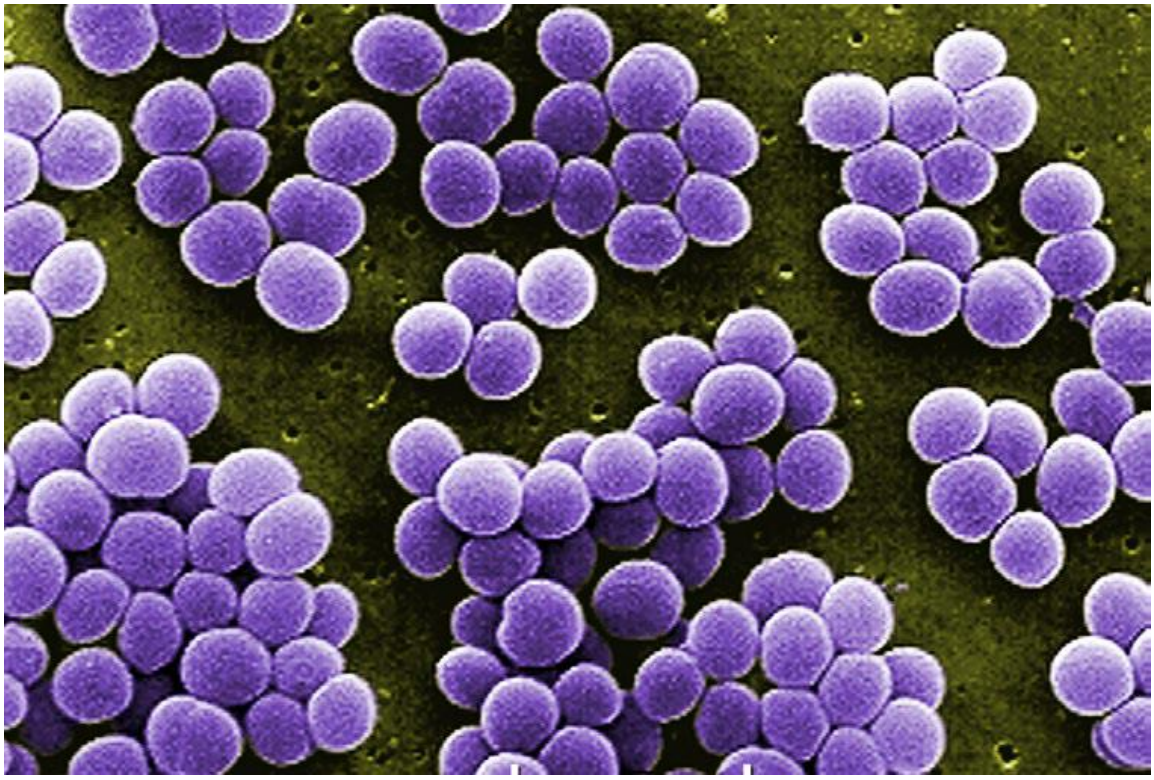

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Table of Contents

Executive Summary

Background

Over the years, many public health and animal health surveillance systems have been developed world-wide. These focus either on one condition or have a wider remit. The UK Five Year Antimicrobial Resistance Strategy 2013 to 2018 prioritised surveillance data as one of the key areas for action. A number of attributes of surveillance systems have been identified in the literature as influencing the ability of systems to provide information that can be used by human and animal health professionals to combat health conditions. This systematic review was conducted to determine whether surveillance and monitoring systems are effective for the prevention and control of AMR-related conditions in humans and animals.

Methods

Seven databases were searched for evaluations of human and animal health surveillance systems. Differences in context and study design as well as the examination of a number of attributes of systems rather than a single primary outcome, precluded the possibility of conducting statistical meta-analysis. A narrative review of attributes was conducted instead.

Results

Out of 49,001 titles included in the initial identification process, 42 studies met the inclusion criteria for the review (40 in human health and 2 in animal health). They were conducted in 11 countries (three in the UK) and evaluated surveillance systems of nine health conditions or microorganisms (24 were evaluations of Tuberculosis surveillance systems).

Most of the studies were exclusively quantitative (35/42), with the other seven employing mixed methods. The majority were retrospective analyses of routinely collected data (39/42). The quality of reporting was poor in most of the studies.

The evaluations examined 18 attributes of systems, regrouped into 11 that shared similar definitions. These were acceptability; completeness; concordance; flexibility; positive predictive value; representativeness; simplicity; specificity; stability; timeliness and usefulness.

The results indicate that there is little evidence of effectiveness of current health surveillance systems in terms of the provision of information that can be used by human and animal health professionals to combat AMR. Two characteristics of surveillance systems (*ease of use* and *awareness of the system*) were associated with both greater acceptability and completeness (defined as percentage of cases of condition reported). None of the other system characteristics were associated with benefits regarding more than one attribute.

Conclusions

There is a need to conduct rigorous evaluations of AMR-related surveillance systems, based on the appraisal of attributes identified in the literature as being associated with effective surveillance and monitoring systems.

Definitions and List of Abbreviations

Abbreviation	
AMR	Antimicrobial Resistance
bTB	Bovine Tuberculosis
CDC	US Centers for Disease Control and Prevention
ECDC	European Centre for Disease Control
EFSA	European Food Safety Authority
HMIS	Health Management Information System for monitoring TB (Afghanistan)
NTP	National TB Control Programme (Afghanistan)
PPV	Positive Predictive Value
TB	Tuberculosis
WHO	World Health Organisation

1. Background

1.1 Surveillance Systems

Surveillance has been defined as the *"systematic and continuous collection, analysis and interpretation of data, closely integrated with the timely and coherent dissemination of the results and assessment to those who have the right to know so that action can be taken"* [1]. The information provided by a surveillance system can have the following functions [2]:

- Guide urgent action for cases of public health importance;
- Measure the burden of a disease and monitor trends;
- Inform the planning and implementation of programmes to prevent and control diseases;
- Evaluate public policy;
- Detect changes in clinical practice and their effect;
- Help prioritise the allocation of limited resources;
- Describe the clinical course of disease;
- Provide a basis for epidemiological research.

Over the years, a large number of public health and animal health surveillance systems have been developed world-wide, either with a focus on one condition or with a generic remit (for example, looking at antimicrobial-resistant organisms). In the context of combating antimicrobial resistance (AMR), the World Health Organisation (WHO) views surveillance as being essential for providing information on the magnitude and trends in AMR and for monitoring the effects of interventions [3].

1.2 Evaluating Surveillance systems

Several approaches to evaluation of disease surveillance systems have been developed to assess different aspects. A recent systematic review describing these systems has been published (Calba et al. [4]). Most assess a range of attributes using a combination of qualitative and quantitative techniques [5]. The most widely recognised of these approaches are the guidelines developed by the US Centers for Disease Control and Prevention (CDC) [2]. These describe the usefulness of a system in terms of its contribution to the prevention and control of adverse health events, including an understanding of the implications of those events, based on consideration of nine attributes: Simplicity, Flexibility, Data Quality, Acceptability, Sensitivity, Positive Predictive Value (PPV), Representativeness, Timeliness and Stability. Below is a brief description of each attribute:

- Simplicity: the structure and ease of operation of the system means a system is as simple as possible while still meeting their objectives.
- Flexibility: can adapt to changing information needs or operating conditions with minimal additional time, personnel, or allocated funds.
- Data Quality: the completeness and validity of the data recorded in the public health surveillance system.
- Acceptability: the willingness of persons and organizations to participate in the surveillance system.
- Sensitivity: at two different levels: case reporting, where it refers to the proportion of cases of a condition detected by the system; and the ability to detect outbreaks, including the ability to monitor changes in the number of cases over time.
- PPV: the proportion of reported cases that have the health-related event under surveillance.

- Representativeness: the extent to which the system accurately describes the occurrence of a health-related event over time and its distribution in the population by place and person.
- Timeliness: the speed between steps, in particular the interval between the onset of the health-related event and its reporting to the public health agency responsible for initiating control and prevention actions.
- Stability: the reliability (ability to collect, manage and provide information without failure) and availability of the system (the ability to be operational when needed).

The CDC acknowledges that there is no perfect system and that focusing resources to improve one attribute might have an adverse effect on another; for example, as sensitivity increases, the PPV might decrease, and efforts to increase sensitivity and PPV could result in a more complex surveillance system with reduced acceptability and timeliness.

A recent overview article of AMR surveillance in England by Johnson [6], described the voluntary reporting of microbiological diagnoses by hospital laboratories to Public Health England as having wide geographical coverage and receiving a large amount of data that is available on a continuous basis. The author, however, also identified limitations in the system in the form of incomplete data collection as a result of the voluntary basis of reporting and variations in reporting methods.

It is also worth noting that Lewis [7] identified a set of only three essential attributes for an AMR surveillance system for human health: timeliness, reliability and representativeness. Timeliness was identified as important for AMR trends at local level and to assist clinicians in the rational choice of antibiotic. The author, however, acknowledged that prescribing decisions needed to be supported by evidence on what constitutes unacceptable levels of resistance. Reliability (referring to the consistency in the laboratory data production process) was seen as important to assess trends over time and for benchmarking of resistance rates. The geographic, demographic and socioeconomic representativeness of the populations served by the laboratories where samples are generated was also seen to be important in order to be able to produce generalizable results.

1.3 Rationale for Review

The UK Five Year Antimicrobial Resistance Strategy 2013 to 2018 advocated that "*better sharing of local, regional and national information and data on emerging [AMR] issues in human and animal health together with use of early warning systems is needed to trigger appropriate containment measures to limit the spread of resistant organisms*" [8]. The evidence supporting the use of early warning systems and, more widely, surveillance systems, to achieve the Strategy's overall goal of slowing the development and spread of AMR has not been reviewed systematically. It has been suggested that AMR surveillance systems often suffer from methodological limitations which may limit their role in combatting AMR [9].

This systematic review was undertaken to synthesise the results of evaluations of attributes of surveillance systems that influence their ability to provide information that can be used by human and animal health professionals to combat AMR.

1.4 Primary Research Question

Are surveillance and monitoring systems effective for the prevention and control of AMR-related conditions in humans and animals?

1.4.1 Secondary Research Question

Do health surveillance and monitoring systems relevant to AMR meet the CDC definition of the attributes of high quality surveillance systems [2]?

2. Methods

2.1 Protocol Registration

The study protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO), registration number: CRD42018085346.

2.2 Inclusion and Exclusion Criteria

Evaluations that followed a research design in the list identified below and had a focus on a surveillance system of organism(s) in the subsequent list, were included in the review.

Research designs of evaluation included:

- Prospective observational designs (controlled and uncontrolled before and after studies).
- Retrospective observational evaluations, including case-control studies, retrospective cohort studies and audits. Data sources include primary data collected for research and secondary data (for example, health insurance claim data).
- Interventions using an experimental design.
- Qualitative research studies.

Organisms considered by a system:

- Bacteria whose antibiotic susceptibility status was recorded by the surveillance system.
- Bacteria relevant to AMR. A list was collated from the key AMR threats that have been identified by the WHO [10], the CDC [11], European Centre for Disease Control (ECDC) [12], European Food Safety Authority (EFSA) [13] and the key drug-bug combinations identified by Public Health England in the UK AMR Strategy [8].

The following were excluded from the review:

- Evaluations of public surveillance systems that monitor non-bacterial microorganisms (for example, viruses or fungi).
- Evaluations of surveillance systems that monitor bacterial microorganisms that are not on any of the priority lists described in the inclusion criteria above.
- Screening systems that are limited to a single or group of hospitals, and where the information is not shared outside the hospital system.
- Studies published prior to 1988, when the first CDC guidelines for evaluating Public Health Surveillance systems were published.
- Articles published in languages other than English.

2.3 Search Strategy

The following databases were searched for relevant articles:

- OVID MEDLINE
- EMBASE
- Cochrane Central Register of Controlled Trials (CENTRAL)
- Global Health (OVID)
- Web of Science
- Open Grey
- Scopus

The search terms used can be found in Appendix 1. They were adapted for databases in accordance with the repository's interface and search options. All search strings were run in English and all the records were exported to Endnote reference management software v 18.0.2 and Excel 2016.

In addition to searching databases, we also performed reference searches of the identified papers to ensure relevant papers were not missed.

2.4 Data Extraction

The number of studies excluded at each stage was reported in the form of a PRISMA diagram [14]. The screening process took place at three stages: title screening; abstract screening; and full-text screening. Data from each of the included studies were extracted into an Excel Spreadsheet.

2.5 Quality Assessment

The use of retrospective analysis of routinely collected data employed by most studies included in the review precluded use of the Effective Public Health Practice Project (EPHPP) Quality Assessment Tool [15] or the STROBE Statement [16] for assessing the quality of studies. Instead, an overall assessment of the risk of bias was conducted. The Critical Appraisal Skills Programme (CASP) Toolkit was used for qualitative data [17].

2.6 Data Synthesis

Differences in context and study design and the examination of a number of attributes of systems rather than a single primary outcome, precluded the possibility of conducting statistical meta-analysis. A narrative review of attributes was conducted instead.

3. Results

3.1 Outcome of Study Identification Process

A total of 49,001 records was identified from the different repositories and the manual search of reference lists, which was reduced to 42 studies to be included in the review. Figure 1 provides the details of the records excluded at every stage.

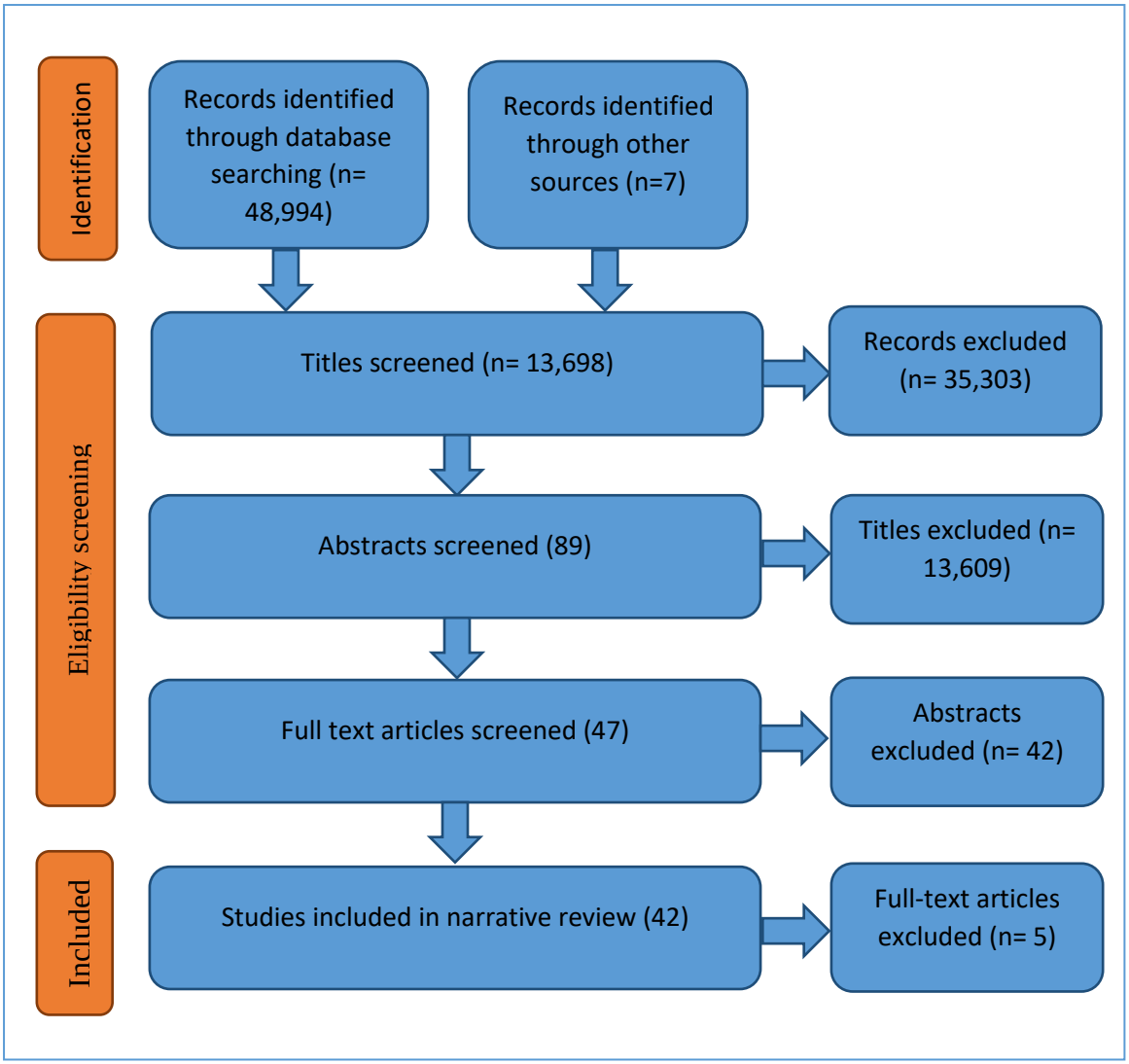

Figure 1: PRISMA diagram of studies included at each stage of the screening process

3.2 Characteristics of Included Evaluations

3.2.1 Setting

The evaluations included took place in 11 countries (Table 1), with the largest number in the US (nine studies), followed by Australia and South Africa (four evaluations each). Three studies took place in the UK. Most of the evaluations related to human health (40/42). The included articles were published between 1991 and 2017.

Table 1: Country where evaluation took place

Country of study	Number of studies
Afghanistan	1
Australia	4
Botswana	1
Brazil	3
France	2
Germany	1
Ghana	1
Ireland	1
Italy	1
Japan	1
Netherlands	1
Norway	1
Republic of Korea	1
Romania	1
Saudi Arabia	1
South Africa	4
Spain	2
Sweden	2
Taiwan	1
UK	**3**
USA	9
Total	**42**

3.2.2 Study Design

The majority of studies were exclusively quantitative (35/42), with the other seven employing mixed methods. None of the studies was purely qualitative. The majority were retrospective analyses of routinely collected data (39/42) (Table 2). Of these, six combined retrospective quantitative analysis with semi-structured interviews and four incorporated capture/recapture methods to measure completeness of data.

Table 2: Number of studies included in the review by study design

Study design	Number of studies
Retrospective analysis of routinely collected data	27
Retrospective analysis of routinely collected data combined with semi-structured interviews	6
Retrospective analysis of routinely collected data combined with capture-recapture statistical methods	4
Retrospective analysis of routinely collected data combined with a questionnaire survey	2
Prospective analysis of routinely collected data	2
Statistical simulation model	1
Total	**42**

Over half of the studies (26/42) included a comparison group derived from alternative data sources (laboratory reports, prescription data, medical records or health insurance claims data), or alternative notification technologies. These comparators had been treated by researchers in three different ways:

- Some used another surveillance system (such as the CDC Emerging Infections Programme) as a high quality reference standard against which to compare (for example, Nguyen et al. [18])
- The comparator (e.g. a different mode of notifying cases) was considered as a second "arm" of the evaluation. An example was comparing electronic reporting against other forms of reporting.
- Two systems were compared against each other (for example Saeed et al. [19]).

The sample size of the included studies, which in most instances was the number of patients or samples, ranged from 35 in an evaluation of a system for reporting active Tuberculosis (TB) among US military service members [20], to a maximum of 251,693 records in an evaluation of TB surveillance in Brazilian micro-regions [21].

3.2.3 Surveillance Systems' Attributes Evaluated

The 42 studies identified used 18 attributes in their assessment of health surveillance systems. However, on inspecting the description of these attributes and how they were applied in the studies, they could be grouped into 11, as some authors were using different terms to describe the same attributes. For example, the term "completeness" was sometimes used to describe the proportion of cases of a condition that are detected by the surveillance system under examination. The same definition was used to describe "sensitivity" in other studies. Furthermore, authors used the same term to describe different characteristics of systems. For example, "completeness" (defined above) was also used to describe the extent to which forms containing the details of each case identified were complete. A description of attributes as they were used in the studies included in this review can be found in Table 3.

The number of attributes examined in each evaluation ranged from 1-10. The attribute most commonly used (20/42) was "completeness" (the proportion of cases identified by the system). Appendix 2 provides the list of attributes used in each evaluation.

Table 3: Attributes identified and their definitions

Attribute name	Description of attribute as used by evaluators
Acceptability	Awareness of, and adherence to, the surveillance system protocol by staff.
Completeness (also described as sensitivity, coverage, validity)	Either: The proportion of cases reported by the system (established by looking at other systems or by estimating using the capture-recapture method). Also known as sensitivity or coverage. Or: Extent (or proportion) of the fields that are completed in the forms. In some studies, critical categories to be completed were identified. Also known as validity.
Concordance (also known as reliability or consistency)	The level of agreement between the different systems on the data collected for each case.
Flexibility	The degree to which a system can adapt to changing information needs or operating conditions with little additional time, personnel, or allocated funds (CDC Definition) [2].
Positive Predictive Value (also known as Predictive Value Positive) PPV	The proportion of reported cases that actually have the health-related event under surveillance (CDC Definition) [2].
Representativeness	Geographic or population coverage of system.
Simplicity	Features that make a system easy to use (including the method of notification).
Specificity	Correctly identifying patients who are free of the condition.
Stability	Ability to collect, manage, and provide data properly without failure and ability to be operational when needed [2].
Timeliness	Period between different time points in the notification process.
Usefulness	Ability of system to provide information that can be (or is) acted on. Also known as efficacy.

3.2.4 Health Conditions and Microorganisms Monitored by Systems

The majority of surveillance systems had been established to monitor the incidence of TB (26/42), plus one that monitored bovine TB (bTB). Table 4 provides details of the number of evaluations by health condition. Appendix 3 lists the attributes examined by health condition or microorganism.

Table 4: AMR related health conditions and Microorganisms Monitored in Surveillance Systems

Health Condition/ Microorganism	Number of included evaluations
TB (Pulmonary or extra-pulmonary)	24
Salmonella/ salmonellosis	8
Infections with penicillin-resistant pneumococci	2
MRSA	2
Neisseria gonorrhoeae/ Gonoccoal infections	2
Shiga-toxin producing or enter-haemorrhagic E-Coli	2
Shigellosis	2
TB in HIV patients	2
bTB	1
Campylobacter	1

3.3 Quality Assessment of Studies

An analysis of the potential for sampling bias in the 27 studies [17, 18, 22-47] that used retrospective analysis of routinely collected data revealed that the rationale for the choice of time period and geographic area was not provided in all studies. Furthermore, the studies did not all include a description of who collected and analysed the data and whether they had an affiliation with the programme (i.e. whether they were independent or not). These are potential sources of data collection and analysis bias. However, the four studies which included the use of the capture-–recapture statistical method to measure completeness of systems [20, 36, 48, 49] all acknowledged the potential source of bias that could result from the violation of one of the principles of the test that refers to the independence of the data sources.

The CASP checklist [17] of qualitative elements identified a number of problems in the seven studies that included such methods [19, 21, 22, 50-53]. These included the suitability of using a qualitative approach for answering predominately close-ended questions [19, 21, 53] and the absence in all studies of details of how data were collected or analysed. However, all studies included an introductory section that stated clearly the aims of the study.

3.4 Performance of Systems in Relation to their Attributes

The findings of the narrative synthesis are presented for each of the 11 attributes of a good surveillance system.

3.4.1 Acceptability

This attribute was examined in five evaluations. They found varying levels of acceptability, related to: awareness of the system; ease of use of the system; and the implications of providing data to the system. For example, the National TB Control Programme in Afghanistan was found to have poor acceptability as health workers lacked awareness about the procedures to follow. Delayed reporting (and sometimes failure to report) indicated refusals to co-operate with the protocol [19]. The Australian Gonococcal Surveillance Programme had high acceptability for the reference laboratories that were contributors, even though some of the stakeholders identified the breakdown in the feedback of surveillance data as an issue [54]. The acceptability of the salmonella surveillance system in London and South East England [55] was found to be related to the method used to follow up case reports, with telephone questionnaires being more successful than mailed ones.

In relation to animal health, butchers and cattle merchants identified financial disincentives as reasons for low acceptability of a bovine TB (bTB) reporting system [53]. The explanation given was that farmers were not compensated for the animals condemned on suspicion of bTB. An evaluation of a TB surveillance system in Brazil found that acceptability and timeliness were linked to each other when Brazil's micro-regions were dichotomised into two groups according to the relative performance of the system [21].

3.4.2 Completeness

As identified above, the term "completeness" was used to describe two distinct attributes: the proportion of cases of the condition that are picked up by the system (also referred to as sensitivity or coverage); and the extent to which the fields in the forms are completed. The findings in relation to these two attributes will be covered in turn.

Eighteen evaluations used the first interpretation of the term in their assessment of surveillance systems [18-20, 24-26, 28, 33, 34, 40, 41, 43, 46, 48, 49, 52, 56, 57]. The proportion of cases captured by the different surveillance systems compared with a variety of alternative sources of data, or estimated using the capture-recapture method, ranged from 45% of cases in a TB surveillance system in Saudi Arabia [34], to 99.9% for a salmonellosis surveillance system in Sweden [56].

Most studies concluded that the completeness of the surveillance systems could be improved. This included switching to electronic reporting and training of personnel [26]; raising awareness among healthcare practitioners about the importance of reporting the conditions under surveillance [46]; incorporating data from other data collection systems (from primary care, hospitals and pharmacies) [18, 20, 25, 28, 57] and making the notification process simpler [52].

The studies also identified characteristics that were associated with a higher or lower likelihood of cases being reported. An evaluation of the Swedish statutory surveillance system for communicable disease, which monitors salmonellosis and penicillin-resistant pneumococci, alongside other conditions, observed that it had higher sensitivity for recording diseases with a longer tradition of reporting (such as salmonellosis) [56]. An evaluation of TB notification in the Republic of Korea [40] noted that the type of medical institution (e.g. clinic or general hospital) and the nationality of the patient influenced the likelihood of the case being reported, with patients from general hospitals and those who were Korean nationals being more likely to be reported. The evaluation of a TB surveillance system in Italy [41] observed that under-notification was significantly higher in female patients and those with extra-pulmonary TB.

Fourteen studies [19, 21, 25, 27, 29, 30, 34, 41, 42, 44, 50-53] investigated the second interpretation of the term “completeness” (the extent to which fields are completed in forms). There was variation in how studies calculated the completeness of the fields in the case forms, with different approaches to classifying fields being used. For example, one study dichotomised fields into demographic and clinical variables [50] whilst another focused on a number of critical fields, for example, the site of the disease [27].

Completeness ranged from 34% to 90% but the extent to which this was considered acceptable varied depending on the nature of the condition under surveillance, with a general view expressed that action needed to be taken to improve rates. In the case of the TB surveillance system in Botswana [42], the authors observed that 60% of the records with missing data for pre-treatment sputum smears had in fact undergone a smear test, therefore, concluding that the TB programme was performing better than the surveillance system was indicating. A more concerning finding of the national TB surveillance system in Afghanistan was that the audit uncovered fields which were completed incorrectly, whereby facilities reported examining sputum smears when they did not have a microscope [19].

3.4.3 Concordance

Seven evaluations included this attribute [21, 22, 25, 32-34, 50]. These studies established the accuracy of data within surveillance systems by exploring the level of agreement of data collected either at different organisational levels (e.g. facility and province) [22], from different sources (microbiologists or clinicians) [32] or in different formats (paper sources and electronic formats) [25, 34]. In addition, data from surveillance systems were compared with mandatory notification systems [33]. Generally, the level of agreement between sources was found to be higher for patient

demographic data (k>0.80) than for clinical data [22, 25, 32, 50]. Podewils et al. [25] recommended unifying different systems (paper, electronic and laboratory) to reduce these discrepancies.

3.4.4 Flexibility

Two evaluations measured this attribute, one relating to gonococcal infections [54] and the other to bTB [53]. Samaan et al. observed that the reduced availability of isolates for testing (a result of the introduction of molecular-based methods to diagnose gonococcal infections) had challenged the flexibility of the Australian gonococcal surveillance programme. It was trying to adapt to this situation by communicating with the public and private laboratories and asking them to forward any isolates they had available. Another challenge to the Australian system's flexibility was the introduction of additional antimicrobials for the treatment of gonococcal infections. The system adapted through changes such as modifying its quality assurance process to include new resistance testing.

The bTB surveillance system evaluation [53] reported that the form used to report suspected cases could also be used to capture other diseases, which was taken as an indication of its flexibility.

3.4.5 Positive Predictive Value (PPV)

This attribute was examined in only four evaluations [19, 20, 46, 53]. There was wide variation, with the lowest value (11%) being reported for the Afghan National TB Control Programme (NTP) [19], whereas two systems (the bTB System in Ghana and the TB Notification System of the United States Military) scored 100% [20, 53].

3.4.6 Representativeness

Representativeness was included in only four evaluations [19, 47, 53, 54]. An evaluation of an MRSA surveillance system in Japan, that used health insurance claims [47], observed that the surveillance system was accurately representing the ages of patients. Saeed et al. [19] observed that the Health Management Information System for monitoring TB (HMIS) in Afghanistan only included public health facilities with no data from the private sector (which it is attempting to cover). Furthermore, the system favoured rural areas with little attention to urban settings and secondary hospitals. Conversely, the evaluation of the Australian gonococcal surveillance system [54] observed that the reliance on molecular methods to diagnose infections had reduced the number of isolates available for AMR testing, especially in rural areas where molecular methods were increasingly used due to their greater cost-effectiveness. In relation to animal health, Lopes et al. [53] observed that only three districts out of ten in the Greater Accra Region were reporting on bTB in their monthly reports and only one did this regularly. Additionally, not all cattle were slaughtered under veterinary supervision, hence the reported bTB levels might have been underestimated in official reports.

3.4.7 Simplicity

This was examined in four evaluations [19, 52-54]. The evaluation of the Campylobacter Infection Surveillance Programme in Victoria (Australia) found it to be "cumbersome" to use for case referral and investigation [52]. Similarly, the Australian Gonococcal Surveillance Programme was observed by Samaan et al. [54] to have reduced the simplicity of the system as a result of duplication of data entry for the isolates received from the initial diagnostic laboratories. However, the survey of stakeholders

undertaken as part of the same evaluation found that 88% of respondents felt that the system was sufficiently simple. Those who did not find it so cited the poorly defined terminology in reports as one of their concerns. Saeed et al. [19] also reported divergent findings in relation to the simplicity of two TB monitoring systems in Afghanistan (the HMIS and the NTP). The HMIS system was found to be simple as case definitions were followed and consistent forms were used. The NTP system, on the other hand, was found to be complex due to multiple complicated forms that need to be completed, the use of paper forms, a lack of integration with the HIMS system and difficulties in providing training for staff. In relation to animal health, Lopes et al. [53] reported that the bovine TB (bTB) system was viewed as complicated in structure as detection required special training. Furthermore, the lack of transportation needed to send samples to the only laboratory that could test for bTB in the region further complicated matters.

3.4.8 Specificity

The only evaluation to consider this attribute [35] was an evaluation of the National Mycobacterial Surveillance System that screened for TB among new refugees in New South Wales, Australia. The study reported that in nearly one third of the cases notified as having active TB (n=60), the individuals did not actually have active disease, which suggests low specificity and over-estimation of disease levels.

3.4.9 Stability

Stability was included as an attribute in two evaluations [19, 53]. One investigated two TB surveillance programmes in Afghanistan and found that the HMIS was able to collect, manage and provide data from its facilities and produced monthly reports [19]. The only problem reported that affected stability related to extraction of data from the system as a result of interruptions to the electricity supply. The authors, however, also identified computer viruses as a potential threat. The other TB surveillance system in that evaluation was the NTP which was given a lower rating for stability due to being paper-based, possibly resulting in reporting delays.

The second evaluation [53], which looked at a bTB surveillance system in Ghana, concluded that it had poor stability due to the manual storage of data or on personal computers, which meant that some reports could not be traced. Furthermore, staff on the programme were poorly resourced and there was irregular funding for the programme.

3.4.10 Timeliness

This attribute was included in 18 studies [19, 21, 23, 26, 27, 31, 36-40, 44, 45, 52-55, 58], which used different reference periods to measure timeliness. These included the interval between: the onset of symptoms and the notification to health authorities [23, 37]; specimen collection to case reporting [26, 36, 52]; onset of symptoms to completion of case investigation [38]; reporting within one week of starting treatment [27]; starting treatment to notification [40]; notification within one or two incubation periods [23]; and reporting delays regularly more than three months [19]. With the exception of one [54], all evaluations reported that timeliness of reporting could be improved and some recommended that future research should explore the bottlenecks in the reporting process [31, 36]. Suggestions made for improving the timeliness of reporting included transmitting laboratory reports electronically [58], and reducing the laboratory electronic reporting period [55].

3.4.11 Usefulness

Three evaluations included usefulness as an attribute [19, 53, 59]. Saeed et al. [19] investigated the possible use of the data generated by two surveillance systems in Afghanistan: the HMIS and the NTP. They reported that the HMIS data were useful for planning and monitoring but less so for detecting outbreaks. In contrast, proper analysis of the data from the NTP system could detect and allow a response to outbreaks.

Lopes et al. [53], looked at whether the data provided by the bTB surveillance system were being acted on to protect public health. They described the usefulness of the system as low, as only 32% of carcasses that were suspected to be bTB positive were partially or totally condemned. Similarly, only 59% of animals that were detected to be bTB infected in screening were culled. Another evaluation of animal health [59] observed that the system provided limited protection for human health as the probability of a carcass being sampled from a herd was small (mean probability 2% for the smallest 10% of herds and 25% for the largest 10%).

4. Discussion

4.1 Overview and Implication of Findings

This systematic review was undertaken to understand whether surveillance systems are effective for the prevention and control of AMR-related conditions in humans and animals. Only two studies (out of 42) used all of the CDC attributes in their evaluations [19, 53], with the majority focusing on only one or two attributes. The results indicate that the surveillance systems that have been evaluated have not generally achieved the attributes associated with effectiveness. Two characteristics, *ease of use* and *awareness of the system*, were associated with both greater acceptability and completeness (percentage of cases of condition reported). None of the other system characteristics were associated with benefits across more than one attribute.

There are three main reasons for caution when generalising the results of this review. Firstly, most evaluations (26/42) were of TB surveillance systems. This condition is at the forefront of the AMR challenge, as it is estimated that in 2017 there were 558,000 new cases of TB worldwide that were resistant to Rifampicin (the most effective first-line drug), and 82% had multidrug-resistant TB [61]. However, it is also a condition that is caused by a single pathogen, whereas the majority of infections (such as those affecting the upper and lower respiratory tracts and the urinary tracts) are caused by a range of pathogens, and hence empirical treatment decisions require both the knowledge of the likely organisms and their likely susceptibilities to antibiotics [6].

Secondly, most studies (37/42) were not evaluations of AMR surveillance systems *per se*, but rather of health conditions that are important in the AMR context as identified in the list of key AMR threats collated by the researchers. The degree to which information provided by these systems can contribute to the prevention and control of AMR-related conditions is unknown.

Thirdly, eight studies in the review were published between the 1990 and 1999, and a further 13 were published between 2000 and 2009. These older studies may be of little relevance to current systems.

There are specific factors that need to be considered when generalising these findings to the UK setting. Firstly, only three studies were conducted in the UK, with the remainder being conducted in systems with varying levels of resourcing. One of the three British studies looked at the timeliness of reporting of Salmonella infections and the acceptability of the follow-up process. The system, which used electronic reporting, in 2010 in London and South East England may not be relevant given that CoSurv software for recording laboratory isolates and case notifications that was examined in that study has since been replaced in England by the Second Generation Surveillance System (SGSS) Communicable Disease Module CDR [60]. The generalisability of a second study was also limited as the evaluation [24] was conducted between 1991-1993. The third study by Teo et al. [49], which investigated the Enhanced Tuberculosis Surveillance Scheme across England, Wales and Northern Ireland using a prospective rather than retrospective study design, was less prone to biases that may result from missing or erroneous entries. However, similar to the previous two, the age of the study (conducted between 2003 and 2005) limits its generalisability to the current surveillance system in the UK.

4.2 Strengths and Limitations of the Research

The main strength of this systematic review is that it used focused research questions with explicit inclusion and exclusion criteria. This enabled synthesis of the results of evaluations by attribute, in a manner that has not been reported previously. The review, however, suffers from three limitations:

1) Screening process: completing the review within a tight timeframe meant that the screening process was conducted by only one researcher instead of two acting independently. Relevant studies may have been missed, although a manual search of the reference list of the identified reviews minimised such a risk.
2) Language restrictions: the search was restricted to studies published in English so some relevant studies may have been missed.
3) Animal health: Despite contacting animal health experts, the small number of animal health surveillance systems identified raises the possibility that some relevant studies may have been missed.

4.3 Recommendations

Given that all attributes cannot be maximised simultaneously, policy-makers need to decide which are the priority features that they seek to include in health surveillance and monitoring systems. Ease of use and awareness of surveillance systems have been shown to be associated with high levels of acceptability and higher levels of completeness of data collection and could be targeted as priority areas for improvement of existing systems.

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Appendix 1 Search Terms Used in Databases

Generic search terms

Antimicrobial resistance OR Drug resistance OR Escherichia coli OR Bacteremia OR Sepsis OR Enterobacteriaceae OR Klebsiella pneumoniae OR Neisseria gonorrhoeae OR Acinetobacter OR Campylobacter OR beta-Lactamases OR Cephalosporin resistance OR Vancomycin resistance OR Enterococcus OR Pseudomonas OR Carbapenem resistance OR Salmonella OR Fluoroquinolone resistance OR Tuberculosis OR TB OR Mycobacterium OR Shigella OR Methicillin-resistant Staphylococcus aureus OR MRSA OR Streptococcus pneumonia OR Clarithromycin resistance OR Helicobacter pylori OR Haemophilus influenzae OR Communicable Diseases OR Infectious disease

AND

Surveillance OR Reporting OR Monitoring OR Notification OR Warning OR System OR Network

Web of Science search terms

"antimicrobial resistance" OR "drug resistance" OR "escherichia coli" OR Bacteremia OR Sepsis OR Enterobacteriaceae OR "klebsiella pneumoniae" OR "neisseria gonorrhoeae" OR Acinetobacter OR Campylobacter OR beta-Lactamases OR "cephalosporin resistance" OR "vancomycin resistance" OR Enterococcus OR Pseudomonas OR "carbapenem resistance" OR Salmonella OR "fluoroquinolone resistance" OR Tuberculosis OR TB OR Mycobacterium OR Shigella OR "methicillin-resistant Staphylococcus aureus" OR MRSA OR "Streptococcus pneumonia" OR "clarithromycin resistance" OR "helicobacter pylori" OR "haemophilus influenzae" OR "communicable diseases" OR "infectious disease"

AND

Surveillance OR Reporting OR Monitoring OR Notification OR Warning OR System OR Network

Open Grey search terms

("antimicrobial resistance" OR "drug resistance" OR "escherichia coli" OR Bacteremia OR Sepsis OR Enterobacteriaceae OR "klebsiella pneumoniae" OR "neisseria gonorrhoeae" OR Acinetobacter OR Campylobacter OR beta-Lactamases OR "cephalosporin resistance" OR "vancomycin resistance" OR Enterococcus OR Pseudomonas OR "carbapenem resistance" OR Salmonella OR "fluoroquinolone resistance" OR Tuberculosis OR TB OR Mycobacterium OR Shigella OR "methicillin-resistant Staphylococcus aureus" OR MRSA OR "Streptococcus pneumonia" OR "clarithromycin resistance" OR "helicobacter pylori" OR "haemophilus influenzae" OR "communicable diseases" OR "infectious disease") AND (Surveillance OR Reporting OR Monitoring OR Notification OR Warning OR System OR Network)

Scopus search terms

{antimicrobial resistance} OR {drug resistance} OR {escherichia coli} OR Bacteremia OR Sepsis OR Enterobacteriaceae OR {klebsiella pneumonia} OR {neisseria gonorrhoeae} OR Acinetobacter OR Campylobacter OR beta-Lactamases OR {cephalosporin resistance}

OR

{vancomycin resistance} OR Enterococcus OR Pseudomonas OR {carbapenem resistance} OR Salmonella OR {fluoroquinolone resistance} OR Tuberculosis OR TB OR Mycobacterium OR Shigella OR {methicillin-resistant Staphylococcus aureus} OR MRSA

OR

{Streptococcus pneumonia} OR {clarithromycin resistance} OR {helicobacter pylori} OR {haemophilus influenza} OR {communicable diseases} OR {infectious disease}

AND

Surveillance OR Reporting OR Monitoring OR Notification OR Warning OR System OR Network

Appendix 2: Attributes Used in Evaluations

Author	Acceptability	Completeness (proportion of cases)	Completeness (variables collected for each case)	Concordance	Flexibility	Positive Predictive Value (PPV)	Representativeness	Simplicity	Specificity	Stability	Timeliness	Usefulness
Heunis				✓								
Reijn											✓	
Devine		✓										
Gimenez-Duran		✓										
Auld			✓	✓								
Podewils		✓	✓	✓								
Trei		✓									✓	
Lo			✓								✓	
Nguyen		✓										
Cojocaru		✓										
San Gabriel		✓										
Lirio			✓									
Santos			✓									
Mlotshwa			✓									

Author	Acceptability	Completeness (proportion of cases)	Completeness (variables collected for each case)	Concordance	Flexibility	Positive Predictive Value (PPV)	Representativeness	Simplicity	Specificity	Stability	Timeliness	Usefulness
Takahashi											✓	
Grills	✓	✓	✓					✓			✓	
Khue				✓								
Guerrin-Tran		✓		✓								
da Silva	✓		✓	✓							✓	
Mancuso		✓				✓						
Teo		✓										
Saeed	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
Sandberg												✓
Alkhalawi		✓	✓	✓								
Jansson		✓										
Marks									✓			
Jansson											✓	
Severi	✓										✓	
Birkhead											✓	
Dominguez											✓	
Kirk											✓	

Author	Acceptability	Completeness (proportion of cases)	Completeness (variables collected for each case)	Concordance	Flexibility	Positive Predictive Value (PPV)	Representativeness	Simplicity	Specificity	Stability	Timeliness	Usefulness
Altmann											✓	
Kang		✓									✓	
Migliori		✓	✓									
Alpers			✓									
Trepka		✓										
Lopes	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
Nicolay			✓								✓	
Curtis											✓	
Driver		✓				✓						
Tanihara							✓					
Samaan	✓				✓		✓	✓			✓	

Appendix 3: Attributes Examined by Health Condition or Microorganism

Condition/ Microorganism	Acceptability	Completeness (proportion of cases)	Completeness (variables collected for each case)	Concordance	Flexibility	Positive Predictive Value (PPV)	Representativeness	Simplicity	Specificity	Stability	Timeliness	Usefulness
TB	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Salmonella/ salmonellosis	✓	✓	✓								✓	✓
Infections with penicillin-resistant pneumococci		✓									✓	
MRSA		✓					✓					
N. gonorrhoeae/ Gonoccoal infections	✓	✓			✓		✓	✓			✓	
Shiga-toxin producing or enter-haemorrhagic E-Coli											✓	
Shigellosis											✓	
bTB	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
Campylobacter	✓	✓	✓					✓			✓	