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Do we protect ourselves against West Nile virus? A systematic review on knowledge, attitudes, and practices and their determinants.

Marco Fonzo, Chiara Bertoncello*, Liliana Tudor, Liana Miccolis, Michele Serpentino, Daniele Petta, Irene Amoruso, Tatjana Baldovin, Andrea Trevisan

Hygiene and Public Health Unit, Department of Cardiac Thoracic Vascular Sciences and Public Health, University of Padova, Padova, Italy

**corresponding author; chiara.bertoncello@unipd.it; via Loredan 18, 35131 Padova, Italy*

Abstract

Background. West Nile virus (WNV) is a mosquito-borne flavivirus. In humans, 80% of infections are asymptomatic, while approximately 20% experience influenza-like symptoms. Fewer than 1% develop the neuroinvasive form which can lead to encephalitis, meningitis, acute flaccid paralysis, and even death. The global spread of the virus to areas where it was not previously present has become a growing concern. Since the 2000s, there have been numerous outbreaks affecting local and travelling populations worldwide. Given the lack of a vaccine, preventative measures are primarily focused on surveillance, vector control, and the use of personal protective behaviours (PPBs). The importance of PPBs is central to public health recommendations. However, translating these messages into coherent action by the public can prove challenging, as the uptake of such measures is inevitably influenced by socio-economic factors, awareness, knowledge, and risk perception.

Methods. A PRISMA-based systematic research was conducted on EMBASE, PubMed/MEDLINE, and Web of Science databases. PROSPERO registration number CRD42023459714. Quality of studies included in the final stage was evaluated using the *Critical Appraisal Checklist for Cross-Sectional Study* (CEBMa).

Results. 2,963 articles were screened, and 17 studies were included in the final round. Out of these, six were deemed of high quality, ten were of medium quality, and one was of low quality. In almost all studies considered, both awareness and knowledge of WNV transmission were above 90%, while concern about WNV ranged from 50% to 80%. Concern about the safety of repellents, either with or without DEET, ranged from 27% to 70%. The percentage of people actually using repellents ranged from 30% to 75%, with the lowest usage reported among individuals over 60 years old (29%) and pregnant women (33%), and the highest among students aged 9-11 (75%). Concern for West Nile Virus (WNV) was consistently linked to an increase in taking preventative measures, including the use of repellents, by two to four times across studies. The school-based intervention was effective in increasing the practice of removing standing water (AOR=4.6; 2.7-8.0) and wearing long clothing (AOR=2.4; 95%CI: 1.3-4.3), but did not have a significant impact on the use of repellents.

Conclusions. The present systematic review provides an overview of the knowledge, attitudes, and practices (KAP) of WNV and their determinants. While concern about West Nile Virus (WNV) and its effects can be a significant motivator, it is important to promote evidence-based personal protective behaviours (PPBs) to counter unwarranted fears. For example, the use of repellents among the most vulnerable age groups. Given the geographical expansion of WNV, it is necessary to target the entire population preventively, including those who are difficult to reach and

areas not yet endemic. The findings of this investigation could have significant implications for public health and support well-informed and effective communication strategies and interventions.

Keywords

West Nile; systematic review; knowledge; perception; personal protective behaviours; mosquito; repellent; vector-borne; climate change; global warming.

Introduction

West Nile virus (WNV) is a mosquito-borne flavivirus, related to the viruses causing dengue and yellow fever. It shares genetic and antigenic similarities with other members of the Japanese Encephalitis virus complex, including Usutu virus [1,2]. The virus normally circulates in mosquitoes and birds, particularly Passeriformes, but can also infect other vertebrates, including humans and equids, as dead-end hosts [3,4]. Dead-end hosts are defined as hosts which are susceptible to the infection, but that are unable to re-transmit the virus to mosquitoes [5].

In humans, approximately 80% of WNV infections are asymptomatic. Roughly 20% experience influenza-like symptoms, while fewer than 1% develop the neuroinvasive form of disease that can lead to encephalitis, meningitis, acute flaccid paralysis, and death [2]. The severity of symptoms and clinical course of the disease is generally determined by the patient's physical conditions and the specific WNV strain responsible for the infection [6]. Immunocompromised individuals and older adults are at an elevated risk for developing invasive WNV infection and encephalitis. In children, the likelihood of severe manifestation is lower, although they are approximately four times more likely to get infected with WNV [7–9].

Mosquitoes are the primary vectors of WNV, particularly species from the *Culex* genus. Although ticks have been found to carry WNV, their competence as vectors remains uncertain [6,10]. Occasional and supplementary modes of transmission include transfusion of infected donor blood and organs, breast milk, or transplacental infection [11]. However, given the significant proportion of asymptomatic individuals, these modes of transmission should also be duly considered. The actual extent of the disease might be significantly underestimated, as for other infectious diseases, whether vector-borne or not [12–16].

Globally, the virus has spread to regions where it was not previously present, with an increasing number of countries affected, which is cause for concern. From the 2000s, widespread outbreaks of WNV have been reported, affecting both local populations and international travellers [4,17].

The initial identification of WNV took place in 1937. A female patient presented with fever in Omogo, located in the West Nile District of the Northern Province, in Uganda. This was during a campaign aimed at tracking the circulation of the yellow fever virus. Consequently, the virus was named after the aforementioned location [6]. Over the latter half of the 20th century, several cases of WNV emerged in countries like Israel, Egypt, France, South Africa, Algeria, and Morocco. Notably, more substantial outbreaks were reported in Russia and Romania [2,18–20]. In 1999, the first case of WNV was identified in New York City, USA, marking the introduction of the disease to the new world [21]. In the 21st century, significant West Nile virus (WNV) outbreaks were recorded in Argentina, Canada, China, and across Europe, including more extensive outbreaks in Hungary, Greece, Italy, and Serbia [22–27].

In the environment, WNV circulation is sustained predominantly by migratory and resident wild birds [28]. During the year, in Northern America and Europe, the incidence of WNV disease reaches its highest point at the end of summer and in early autumn. There is a distinct pattern of transmission in both rural and urban ecosystems. In rural areas, the primary sources of transmission are wild birds and mosquitoes, whereas in urban environments the role of domestic birds as reservoirs and mosquitoes feeding on both humans and birds cannot be excluded [29].

Mosquito populations in temperate regions are predicted to rise as a result of global warming. The observed temperature increase has been suggested as the reason for the link between WNV transmission and an extended mosquito season in Europe [30]. In North America, the range of *Culex* spp. has expanded, with *C. pipiens* now present in Canada [31,32]. The case-crossover study conducted by Soverow and colleagues in the USA highlighted the impact of global warming on the diffusion of WNV. It was observed that a rise of 5°C in the mean maximum weekly temperature led to a 32-50% higher incidence of WNV infection in the population [33].

In addition, it is expected that changes in rainfall patterns, drought periods, and soil degradation will create more favourable conditions for the colonisation of new areas, ultimately leading to an increase in mosquito populations [31]. Not only is global warming sustaining this increase in mosquito populations, but it is also driving migratory birds to modify their routes towards more northern areas in the boreal hemisphere. They come into contact with local bird populations, ultimately leading to the endemic presence of WNV in areas where previous climate conditions had hindered its circulation, affecting both rural and urban areas [29,34]. Furthermore, recent research supports that the virus can overwinter in both infected mosquitoes and local birds in temperate climate regions, implying that the reintroduction of the virus by migrating birds may not be necessary to maintain the chain of infection, although this has yet to be clearly demonstrated [35–37].

To date, there is no specific treatment for West Nile disease or a vaccine available for human use. Therapeutic measures primarily consist of supportive care, including corticosteroid and intravenous immune globulin treatment [38,39]. At present, in the absence of a vaccine, the most effective prophylactic interventions are limited to controlling vector populations responsible for maintaining transmission and using personal protective behaviours (PPBs) to prevent mosquito bites [38,40]. It has been estimated that using PPBs reduces the risk of WNV infection by approximately 50%, making it the most effective method to prevent WNV infection [41]. However, the adoption of such actions and behaviours by individuals is a complex result of various factors, including socio-economic determinants, awareness, knowledge on the subject, and perception of risk. These factors cannot be ignored when addressing a public health issue of this magnitude. Thus, a systematic review was undertaken to identify, evaluate, and analyse the globally available evidence on the knowledge, attitudes, perceptions, and practices (KAP) of WNV and their possible determinants.

Methods

The study conduct and the obtained evidence synthesis adhere to the current Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (S1, Appendix). A review protocol was established in which the scientific question, definitions, search strings used to locate relevant articles in the databases under consideration, inclusion and exclusion criteria for screening articles, and instructions for extracting pertinent data from each article included were defined. The protocol was registered in PROSPERO (CRD42023459714), and it is available at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=459714. The protocol was not published in any peer-reviewed journal.

A systematic research was conducted on 4 May 2023 using EMBASE (via Ovid), PubMed/MEDLINE, and Web of Science. The objective of this review was to gather all primary studies on West Nile virus KAP among the general population and the potential modifying factors. The search was carried out to include original data and to ensure a comprehensive coverage. The research was focused on two principal concepts: WNV and KAP. Thus, the search string utilised, modulated after each database query syntax requirements, is as follows: #1 (west nile OR wnv) AND #2 (knowledge OR attitude OR practice OR perception OR awareness OR behavior OR behaviour OR education OR campaign OR health promotion OR communication OR strategy). No MeSH terms or similar tools were used to avoid excluding very recent papers not yet indexed. No geographical, time or language restrictions applied. All studies that assess the level of knowledge, attitudes, perceptions, and practices concerning WNV, as well as those researching potential predictors for these factors were included in our analysis. Studies that focus on specific subgroups based on profession (such as WNV knowledge among healthcare workers), qualitative studies (such as focus group research), and case reports were not included.

After extracting the data from the three databases under consideration, the records were imported and managed using the Zotero v6.0.26 software. Any duplicate records were automatically deleted using Zotero's functionality, while the rest were removed manually. Remaining records were then exported to Microsoft Excel and initial screening was independently carried out by two reviewers, with the help of a specially prepared sheet.

The extraction form comprised 21 primary questions aimed at gathering data on the characteristics of the sampled population, sample size, location, investigation date, investigation type, and whether the study was employed as an assessment tool before and/or after a public health intervention (e.g. media awareness campaign, dedicated school programme, etc.). Findings on awareness of WNV, knowledge of WNV transmission and higher risk groups, concern for WNV infection, repellent and insecticide safety, local city authority pesticide use approval, acceptance of a potential vaccination and perceived WNV infection severity and contraction risk were also collected. The extraction form underwent pre-testing by all team members to ensure clarity of questions and consistency throughout the entire process. Once pre-testing had concluded, data were independently extracted by the two reviewers.

If conflicts between the reviewers arose, a third reviewer was consulted to resolve the disagreement. All papers retrieved for the final stage underwent reference screening to identify further studies that were not initially identified in the main research. Reasons for exclusion were recorded.

The present systematic review focuses on five practices that are globally recognized and considered effective, including the removal of standing water around the house, the avoidance of mosquito-prone areas or times of the day, the use of repellents containing *N,N*-Diethyl-*meta*-toluamide (DEET) or other components, the wearing of long-sleeved clothing and long trousers, and the regular use and upkeep of window screens [42].

The two reviewers also independently evaluated the studies' quality in the final stage, using the critical appraisal tool by the Center for Evidence-Based Management (CEBMa) [43]. In case of discrepancies, a third reviewer served as an arbiter. This tool offers a structured approach to evaluate various aspects of each study, such as the suitability of study design, the sample selection's risk of bias, the assessment of statistical significance of results, the impact of confounding factors for potential bias, and the potential generalisation of findings. As the CEBMa tool is firmly established, rigorously scientific and widely used, external validity was not assessed. The tool comprises 12 simple questions with a response option of 'Yes/No/Can't tell'. More in detail, the questionnaire used was the *Critical Appraisal Checklist for Cross-Sectional Study (Survey)*. The original tool does not require an overall assessment of each study. However, to enhance readability, a summary evaluation was given by classifying it as "Low/Medium/High" quality, in alignment with preceding studies that followed the same tool [44–46]. A summarised account of the context and key discoveries from the gathered studies was ultimately carried out. To illustrate the geographical spread of all the studies selected in the final phase, a map was produced employing Datawrapper.de (Datawrapper GmbH) [47].

Results

After removing duplicates, 2,963 citations were screened based on their title and abstract for relevance to the review aims. Only 25 of these were assessed for eligibility by reading the full text. Following the complete selection process, 17 studies met the inclusion criteria as per protocol and were subsequently analysed in the present review. The PRISMA flowchart depicted in Figure 1 provides a detailed account of the information flow during the review process.

A descriptive overview of key features of studies included is presented in Table 1. The role of potential predictors for the measured outcomes of interest is reported in Table 2, noting findings form studies carrying out bivariate or multivariable analysis.

Systematic review descriptive statistics and critical appraisal of studies

All studies included in the final stage were conducted between 2000 and 2017, with only two studies from the second decade of the 2000s. As indicated in Figure 2, except for five (29%) studies carried out in Canada, all of the others were conducted in the United States. The number of participants recruited by each study ranged from 100 to 1,800. The primary investigated sample encompasses the general adult population. There are, however, a few exceptions, including research on parents of children under the age of 16 [48], pregnant women [49], students below the age of 18 [8,50], elderly participants [51] and international travellers [52]. Five studies were conducted after media campaigns aimed at preventing WNV infection [48,53–56]. One study conducted a pre-post analysis after a public health intervention at a school [8], while other studies did not report any relation to a specific population exposure to health promotion interventions.

All the outcomes of interest were assessed via questionnaires, which were either self-administered or administered by a researcher, most commonly through a phone interview or an on-site household interview. A written survey was used as a pre-post intervention assessment tool in only one instance [8]. Two studies, despite being published in different years (2005 and 2006), were merged into one, since they are based on the same survey and collected data [53,54].

The results of the critical assessment included studies can be found in the supplementary materials (S2, Appendix). Out of the 17 studies examined, six were considered to be of high quality, 10 were of medium quality, and one was of low quality. In general, most studies did not report considerations regarding the sample's calculated size or efforts to minimize selection bias. However, the study aims and designs were generally relevant, and the main findings were reported with statistical significance in the majority of cases.

Knowledge and awareness of WNV and WNV-related issues

Awareness of WNV was assessed in 12 (70%) studies, usually by means of the dichotomous question "Have you ever heard of WNV?" (Table 1). In most of cases, awareness was greater than 95%, with the exception of a 2002 study in Ottawa, Canada (77%) [57], a pre-post school-based health promotion intervention for students aged 9-11years (pre: 27%; post: 84%) [8], and a survey of an internet-recruited panel of US international travellers (85%) [52]. The only study to report stratified data on awareness showed that awareness was significantly higher ($p<0.05$) among males (83% vs 74%), rural areas (83% vs 69%) and those with higher education (84% vs 68%) [57].

Correct knowledge of WNV transmission was assessed in 8 (47%) studies. In most studies, participants were asked to tick the correct mode of transmission from several suggested in the questionnaire or by the researcher. Knowledge of transmission was greater than 93% in all studies considered, with the exception of a study with participants aged 60 years or older in 2012 (75%) [51] and a study from the New York State in 2006 (82%) [40].

Knowledge about which age groups are at higher risk of developing disease after WNV infection was measured in 5 studies (29%). The results of the selected articles varied widely, ranging from 25% to 96%. Of these, 3 studies reported a correct knowledge in 60-70% of participants, while it was 96% in a study from Connecticut in 2002 reported 96% correct knowledge [58], and a study from Maryland in 2012 reported 25% correct knowledge in participants aged 60 years and older [51]. The only study to report on potential predictors of correct knowledge of higher risk groups found that those with a university education were more likely to recognise them (AOR=3.5, 95%CI: 1.1-10.9), while no significant differences (p>0.05) were found for area of residence (urban/rural), gender or age [40].

Attitudes, concerns, perceptions

As shown in Table 1, 10 studies (59%) assessed concern for WNV. In 7 of these, the proportion of participants reporting some level of concern about WNV ranged from 50% to 80%. In one case the proportion was 22% [40], while in two other studies the proportion peaked at 88-89% [48,55]. One of these latter studies was conducted among parents of children under 16 years of age. Stratified results from a study conducted in Canada in 2002 showed that concern was higher among women and those with a high school education or less compared to those with a higher education [57].

The perception of the risk of infection with WNV and/or the severity of the potential illness was measured in 4 studies (23%). The risk of infection was perceived as relevant (i.e. medium or high on a summary scale of "low-medium-high") by 13% of participants in a study of international travellers [52], 45% in a study of adults [53,54], and 92% in a study of people aged 60 years or older [51]. The proportion of people concerned about the severity of illness caused by WNV infection was 96% in people aged 60 years and older [51], 72% in international travellers [52], and 41% in the general population in a 2006 study in New York State [40].

Concern about the safety of repellents (either with or without a specific question about the use of DEET) was assessed in 5 (29%) papers. The proportion of people expressing concern varied considerably, ranging from 27% to 70%. In particular, in a study of parents of children and pregnant women, this proportion was 51% and 63%, respectively [48,49].

Concerns about the safety of larvicides/pesticides were assessed in 4 studies and ranged from 26% to 59%. The study with the lowest concern was the one with children aged 5-17 years [50]. In 4 other studies, participants were asked whether they supported the use of larvicides/pesticides by the local government. The proportion was over 67% in all studies considered. In the general population study by Jones and colleagues, people aged 50+ were significantly more supportive of the use of pesticides for vector control than those under 50 (77% and 71%, respectively, p=0.02), as were participants from high-incidence areas compared with low-incidence areas (80% and 59%, respectively) [55]. The study by Mitchell and colleagues in older people also showed that knowledge of people with WNV infection and lower education were associated with less favourable use of pesticides (OR=0.1; 95%CI: 0.01-0.7 and OR=0.5; 95%CI: 0.3-0.9, respectively) [51].

Practices and their specific drivers

The proportion of people who regularly removed standing water around their property was reported in 11 (64.7%) studies (Table 1). It ranged from 54% to 89%, with the highest proportion reported in the study of parents of children under 16 years of age [48]. Jones reported that the proportion was significantly higher in people aged 50+ than in younger adults (72% vs 64%, p=0.002) [55], although multivariable analysis by Mitchell showed that people aged 60-69 were four times more likely to engage in this practice than older people (AOR=4.4; 95%CI: 2.0-9.6) [51]. Similarly, higher education and concern about WNV were associated with 2.5 and 2.9 times higher odds of removing standing water, respectively (Table 2) [51]. The school-based intervention described by LaBeaud and colleagues was also effective in more than quadrupling the use of this practice among students [8].

Avoidance behaviour was assessed in 11 studies (65%). The proportion ranged from 21% to 80%. The highest reported value was found in Kiehn's study in pregnant women [49], while the lowest values were found in the 2006

New York State study [40] and in the study of children aged 5-17 years [50] (21% and 37%, respectively). The regression analysis conducted by Gurjal in the general population showed that age, sex and income were not associated with avoidance behaviour, whereas concern about WNV was associated with a 2-fold increase (AOR=2.1; 95%CI: 1.3-3.5) [42]. Kiehn confirmed this finding in pregnant women (AOR: 3.0; 95%CI: 2.2-4.2) [49]. Perceiving the risk of WNV as probable and the illness as serious also increases the likelihood of engaging in avoidance behaviour by +60% [59].

The use of repellent was investigated in 13 studies (76%). The proportion ranged from approximately 30% to 75%, with the lowest findings in studies examining individuals over 60 (29%) [51] and pregnant women (33%) [49], and the highest in students aged 9-11 (75%) [8]. All studies investigating age as a predictor for the use of repellent all agree by showing that younger age is associated with its use. On average, people aged less than 50 accept and use repellent twice as much as older individuals [42,57,58]. Similarly, all studies indicate a correlation between concern for WNV and increased use of repellent. The use of repellent is more common among females, according to Elliot (AOR=1.3, 95%CI: 1.1-1.6) [56], although no significant association was found by Gujral [42]. Additionally, spending time outdoors in the evening (OR=2.3; 95%CI: 1.5-3.6) [58], and observing mosquitoes in the home (AOR=1.4; 95%CI: 1.1-1.8) (AOR=1.4; 95%CI: 1.1-1.8) [56] are also linked with a greater likelihood of repellent use. Concerns about the safety of repellent have been shown to reduce use by 50% (AOR=0.5; 95%CI: 0.4-0.7) [49]. A 4-month follow-up study of the school intervention described by LaBeaud found no significant impact on the use of repellents among students, either positively or negatively [8].

Studies examining the practice of wearing long-sleeved clothing were 13 (76%). The lowest frequencies were reported in two studies on children conducted by LaBeaud (8% and 25%) [8,50], one on adults (19%) [50], and one on international travellers (28%) [52]. Conversely, the highest values were seen in studies on parents of children (60%) [48], older adults (56%) [51], and pregnant women (54%) [49]. The findings of Kiehn and Gurjal affirm the validity of concern towards WNV as a predictor of engaging in protective clothing, with AOR of 1.4 (95%CI: 1.1-1.8) and 2.6 (95%CI: 1.2-5.3), respectively [42,49]. Furthermore, females with concerns about the safety of repellents are more likely to don long clothing (AOR=1.4; 95%CI: 1.1-1.9) [49]. In contrast, age, gender, education, and income have no association with protective clothing in the general population [42]. Among international travellers, wearing protective clothing was not identified as being driven by awareness of the virus or perceived risk of infection or severe disease [52]. LaBeaud's school intervention demonstrated effectiveness in increasing the use of protective clothing among children (AOR=2.4; 95%CI: 1.3-4.3) [8].

The investigation of the utilization and upkeep of window screens was the subject of six (35%) studies. The percentage of individuals who regularly use window screens varied greatly, with rates ranging from 33% in a 2003 study from Kansas [53,54], to 100% in a 2006 study from New York State [40]. None of the studies examined, performed either a bivariate or multivariable analysis to ascertain factors associated with the use of window screens.

Predictors of engaging in preventive measures in general

Several studies included in the current systematic review reported logistic regression models aimed at identifying factors associated with taking one or more general preventive actions, without specifying a particular action. A summary of findings in this regard can be found at the bottom of Table 2. Four studies investigated age as a predictor for taking action. The results of the studies were mixed. Three studies found that individuals over the age of 65 (or 55) were more likely to take preventive measures with a three-fold increase when compared to younger adults [40,58,60], However, Wilson and colleagues reported the opposite for those aged 50+ versus younger individuals, with an adjusted odds ratio of 0.4 (95%CI: 0.2-0.7) [57]. Notably, the female gender was associated with taking preventive measures, as reported in all studies with an approximately two-fold increase when compared to males. Concern for West Nile Virus (WNV) was strongly linked to taking at least one preventative measure, increasing the likelihood by two to four times, as well as a perceived high risk of infection (OR=2.6, $p<0.05$). Information sources such as newspapers (OR=1.8, 95%CI: 1.1-2.9), the internet (OR=3.1, 95%CI: 1.4-6.9) and word of mouth (OR=2.2, 95%CI: 1.4-3.5) were found to be associated with people taking preventative measures [53,54].

Discussion

In the absence of a vaccine, the use of PPBs is of paramount importance, along with surveillance and community-based vector control measures. The importance and effectiveness of PPBs in reducing the risk of mosquito bites are central to the recommendations of public health professionals. However, it is often difficult to translate this evidence into feasible, acceptable and concerted action by the population, as ultimately the adoption of effective behaviours results from the complex interplay of factors such as socio-economic determinants, awareness, knowledge of the issue and risk perception itself. Indeed, according to the theoretical framework known as the "health belief model", people will take action against the possibility of contracting a disease if they believe they are susceptible, the disease is known to have potentially serious consequences, the course of action is beneficial, or the benefits of taking action outweigh the costs [61]. In light of this, understanding the factors that may influence the adoption of PPBs is crucial to plan effective WNV prevention and control programmes [59]. This systematic review aims to provide a synthesis of the evidence from studies that conducted KAP surveys on WNV infection. To our knowledge, this is the first systematic review to collect information on KAP in the general population in relation to WNV.

Disentangling the multifaceted relationship between knowledge, perceptions, attitudes, concerns, beliefs and, finally, taking concrete actions is definitely not an easy task. As well known in literature, perceptions can occupy an intermediate position between knowledge and the decision to take action [62]. Nevertheless, knowledge remains worth targeting in any health promotion intervention. In fact, even in our review, studies show that concern is higher among the less educated [57], but at the same time, the only study that examined predictors of good knowledge through a logistic regression model shows that a high degree of education is associated with better knowledge (AOR=3.5; 95%CI: 1.1-10.9), and also results the only statistically significant one among those included in the model, such as urban or rural area of residence, gender or age [40].

However, the role of educational attainment in the context of vector-borne, and specifically mosquito-borne, diseases is not clear. Recently, a study of women in the Philippines found similar results regarding knowledge of the Zika virus, with women with higher education showing greater knowledge of the virus [63], as did another study conducted of pregnant women in the USA [64]. However, other studies have found no association between educational attainment and knowledge of the Zika virus in similar populations [65], or even the opposite, as in the case of Stefopoulou, who reported poorer knowledge of mosquito ecology among people with higher educational attainment [66]. According to an argument put forward by the authors of the latter study, this result could be justified by the fact that people with less education may have higher motivation, which is supported by the results of an earlier study [67].

Adequate knowledge of the virus and its potential impact on human health among the general population could not only translate into concrete help in reducing the spread of infection through the immediate adoption of PPBs, but it can also be assumed that the level of acceptance could be higher should a vaccine become available. Partial support for this thesis seems to be provided by the results of a cross-sectional study conducted in Indonesia on the Zika virus, in which knowledge of the virus was a valid predictor of acceptance of a vaccine in terms of willingness to pay in both univariate and multivariate logistic regression analyses (OR=2.98; 95%CI: 1.91-4.66; AOR=2.37; 95%CI: 1.44-3.88) [68]. Even in the case of a potential vaccine that was not yet available, such as COVID-19 in the pre-vaccine era, people with higher levels of education were less reluctant to be vaccinated once the vaccine was available [69].

To complete the picture, it is interesting to note that concern about WNV appears to be a predictor of all prevention behaviours examined in this review. In fact, it is associated with a 50% to approximately 4 times greater likelihood of actually performing such PPBs. These findings are consistent with those of KAP surveys on other mosquito-borne diseases and on mosquitoes as vectors in general, which report correlations between attitudes and practices [63,70].

However, it must be emphasised - and this certainly is a limitation of the present systematic review - that although not all studies reported the spatio-temporal allocation of the survey in relation to a possible WNV outbreak and subsequent media campaigns, the role of these two factors cannot be neglected. As an example, and remaining within the scope of the studies included in this review, international travellers recruited throughout the USA, at least some of whom may not be specifically familiar with WNV because they do not come from endemic areas, showed a low perceived risk of infection, but 72% of them perceived WNV disease as severe [52]. Recent studies have clearly shown that people from countries where arboviruses are generally endemic have a higher level of awareness than people living in non-endemic countries, but differences within countries must also be taken into account, for example due to the presence of different ethnic groups that may have had different exposures to mosquitoes in the past [60,71]. The perception of mosquitoes, usually as the perceived activity of mosquitoes in the immediate environment or the frequency of mosquito bites, is also a strong cue to action, as reported by Tuitien (AOR=4.5; $p<0.05$) [40]. Other studies considering the presence of mosquitoes in general (both WNV-vectors and non-significant WNV-vectors species) from different geographical areas of the world are consistent with this finding [70,72]. A survey conducted in the US in 2012 among the general population revealed that willingness to pay for interventions aimed at controlling disease-carrying mosquitoes was lower than for measures aimed at nuisance control in general. However, at higher risk levels of infection, the willingness to pay for WNV-tailored interventions increased and overlapped with nuisance control. Public health interventions aimed at increasing awareness of WNV therefore appear to be of primary importance in sustaining PPB.

When looking at age as a predictor of general preventive measures, the results are not clear. Looking at specific measures, Jones showed that the proportion of people who regularly remove standing water is significantly higher in people over 50 than in younger people (72% vs. 64%, $p=0.002$) [55], but Mitchell pointed out that when only people over 60 are considered, the youngest (60-69 years) are more likely to remove standing water than those over 70 [51]. As explained by Tuiten, the reasons for not removing water may be due to a physical difficulty, and this may be even more important in older age groups [40].

More surprisingly, however, older age is strongly associated with about 50% less use of insect repellents for self-protection compared to all other age groups, and this finding is consistent across all four studies that analysed this association [42,51,57,58]. While Mitchell's study of older people shows that behaviours to avoid exposure to mosquitoes were practised by about half of them, it also shows that repellents were used by only 29%, despite very high levels of concern about the risk of infection (92%) and perceived severity of illness (96%). In addition, among the same older people, knowledge of the age groups at higher risk was dramatically and paradoxically low (25%), certainly the lowest of all the sampled populations described in the studies reviewed [51]. This subgroup requires targeted public health messages as they may face an elevated risk of WNV sequelae. However, they appear hesitant to use insect repellents, despite expressing significant concern about WNV. Studies indicating the relationship between WNV concern and repellent use reveals that concern may lead to an 80% to 370% increase in use [42,51,56,58,73], the reasons may lie elsewhere and further research would be highly desirable.

One hypothesis could be that there is concern regarding the safety of repellents, regardless of whether they contain DEET as an active ingredient. Studies conducted on the general population showed that a significant percentage of participants - 27% to 70% - had this fear. In Kiehn's study of pregnant women, fear for the safety of repellents had a significant impact on their usage, with multivariate analysis showing a drastic reduction (AOR=0.5; 95%CI: 0.4-0.7). Arthropod-borne flaviviruses such as Zika, Dengue, Japanese encephalitis, Yellow fever and West Nile viruses are of high concern in pregnancy and the neonatal period. The risk of congenital malformations, more severe disease course in pregnancy and postnatal period can be quite marked, although there are significant differences among these viruses [74]. A matched case-control study by Pridjian on 50 women and their newborns demonstrated that the risk for adverse pregnancy and newborn outcomes following WNV disease during pregnancy is low overall, although more research is needed to determine the existence of a potentially small hazard [75]. In any case, the results of an RCT investigating insect repellents for malaria prevention imply that the safety profile of DEET is favourable and the risk of DEET accumulating in the foetus is low. Therefore, DEET can be considered safe for use during the second and third trimesters of pregnancy [76]. The Centers for Disease Control and Prevention strongly recommend using DEET-containing repellents as personal protection against mosquito bites to prevent Zika virus infection [77].

Indirect evidence regarding fears about the safety of repellents containing DEET derives from a health promotion intervention that took place in 2007 in Ohio, USA, involving children aged 9-11. The intervention comprised a 30-minute scripted slide presentation at school, followed by a 10-minute interactive project, with both pre- and post-intervention assessments along with a 4-month follow-up. Comparison was made with a different group of children who had completed a short course on an entirely unrelated subject. The intervention was effective in increasing students' awareness significantly, from 27% to 84%, and in promoting the use of PPBs, such as removing standing water and wearing trousers and long sleeves (AOR=4.6; 95%CI: 2.7-8.0 and AOR=2.4; 95%CI: 1.3-4. 3, respectively). These effects were observed on the students and their families, although the latter results were not reported here. However, the same intervention failed to yield significant results in altering the use of insect repellents among both the students and their families (AOR=1.1; 95%CI:0.6-1.9). Notably, prior to the intervention, approximately 70% of respondents already reported using repellents, indicating a high proportion of users [8].

In light of such considerations, effective public education is vital to any successful strategy. However, it is not enough for public health professionals to simply communicate their message - they must also carefully evaluate its uptake to ensure that people take on board the message, adapting their approach as necessary in line with determinants that may influence uptake, including education [56,78,79]. Since the spread of West Nile Virus infection involves both urban and rural areas, it is crucial for public health practitioners to reach individuals in remote locations. In this regard, utilizing effective interventions to facilitate access to treatment and health promotion methods would be preferred [80].

The main limitation of the current review is the incomplete representation of global populations. Despite no restrictions on publication years or language, the geographical coverage is incomplete. Surveys of this type are largely connected to the phenomenon's growth in North America, which is evidenced by the origin of selected articles and when the studies were undertaken. Thus, comparisons between various regions of the planet, with varying levels of exposure to the virus and vector, diverse cultures and economic possibilities, were not feasible. Research utilising the KAP methodology to prevent dengue fever, demonstrated localised discrepancies in knowledge, attitudes, and practices, underscoring their significance in developing communication and intervention strategies tailored to the local context [81,82]. Furthermore, while the review solely examined quantitative studies (focus group studies or qualitative studies in general were excluded beforehand), conducting a meta-analysis proved unfeasible since the operational definitions employed in the various studies were not consistently aligned. Publication bias was not evaluated, due to the limited number of articles retrieved.

Conclusions

The present systematic review offers an overview of general population knowledge, attitudes, and practices (KAP) regarding West Nile virus (WNV) and its potential consequences. We consider that the findings from this investigation could have vital implications for public health and back the development of completely informed and efficacious communication strategies and interventions. Such messages and interventions should be customized for the intended audience, taking into account important socio-economic determinants, as well as awareness among groups at higher risk. Although concern about WNV and its effects is a significant cue to action, the promotion of evidence-based personal protective behaviours (PPBs) should also counter unwarranted fears. For instance, the usage of repellents, especially among age groups that are most vulnerable to the consequences of infection, should be incentivized. Considering the geographical expansion of WNV infection, it is also necessary to target the entire population preventively, even those who are most difficult to reach. This should not only include residents in areas where the virus is already endemic, but also neighbouring areas at risk for WNV disease emergence.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

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Table 1. Main characteristics of the studies included in the systematic review. For readability, no decimal place is reported for each value. Stratified data were reported where available from the original papers. DEET: *N,N*-diethyl-*meta*-toluamide; WNV: West Nile Virus; BRFSS: Behavioral Risk Factor Surveillance System.

Reference	Sampled population (n)	Location	Date	Data collection method	Pre-post intervention assessment	Knowledge	Attitudes	Practices				
								Remove standing water	Avoidance behaviour	Use of repellents	Protective clothing	Window screens
Aquino 2004 [59]	General population ≥18 (309)	Canada, British Columbia	2003, July-August	Phone interview	No	▪ Transmission 99% ▪ At-risk groups 58%	▪ Concern for DEET safety 27% ▪ Concern for DEET environmental toxicity 35%	68%	58%	56% (DEET)	-	-
Averett 2005 and Fox 2006* [53,54]	General population ≥18 (534)	USA, Kansas	2003, August-October	Phone interview	Post media campaign	▪ WNV awareness 97% ▪ Transmission 94%	▪ Concern for DEET safety 35% ▪ Perceived risk of contractin	54%	59%	27% (18% DEET)	37%	33%

						▪ At-risk groups 70%	g WNV: 45%					
Elliot 2008 [56]	General population ≥18 (1650)	Canada, Ontario, Oakville	2003, March-April	Phone interview	Post public health department campaign	▪ WNV awareness 99% ▪ Transmission 99%	▪ Concern for WNV 78% ▪ Concern for pesticide safety 59%	-	-	35%	50%	-
Gujral 2007 [42]	General population ≥18 (957)	USA, Colorado, Loveland and Fort Collins	2004, May-June	Phone interview (BRFSS)	No	-	-	72%	41%	59% (DEET)	25%	
Jones 2005 [55]	General population ≥18 (1200)	USA, Tennessee	2003, February-March	Phone interview	Post media campaign	▪ WNV awareness 94% ▪ Transmission 93%	▪ Concern for WNV 89% ▪ In favour of the use of pesticides by city authorities: - 71-77% (aged <50 vs 50+ p=0,02); - 80-59% (high vs low incidence areas)	64% (aged <50) 72% (aged 50+) (p=0.002)	-	-	-	-
Kiehn 2008 [49]	Pregnant women (1035)	Canada, Toronto	2006, August	Self-administered questionnaire in the clinic	No	▪ WNV awareness 97% ▪ Transmission 93%	▪ Concern for WNV 64% ▪ Concern for repellent safety 63%	61%	80%	33%	54%	68%
Kraftcheck 2003 [48]	Parents of children <16 (352)	Canada, Ontario, Hamilton area	2003, July	Self-administered questionnaire in the clinic	Post media campaign	WNV awareness 99%	▪ Concern for WNV 88% ▪ Concern for DEET safety 51% ▪ In favour of the use of pesticides by city	89%	47%	64% (DEET)	60%	76%

							authorities 67%					
LaBeaud 2007 [50]	General population ≥18 (1007)	USA, Colorado, Cuyahoga County	2002, December	On-site household interview	No	WNV awareness 99%	▪ Concern for WNV 62% ▪ Concern for pesticide safety 44%	-	44%	-	19%	-
LaBeaud 2007 [50]	Children aged 5-17 (168)	USA, Colorado, Cuyahoga County	2002, December	On-site household interview	No	WNV awareness 98%	▪ Concern for WNV 49% ▪ Concern for pesticide safety 26%	-	37%	-	8%	-
LaBeaud 2009 [8]	Students aged 9-11 (181)	USA, Ohio, Cuyahoga County	2007, May-June	Written survey	Pre-post at school activity**	WNV awareness: pre 27%, post 84%	-	55% (pre)		70% (pre)	25% (pre)	
McCarthy 2001 [73]	General population ≥18 (730)	USA, Connecticut	2000, October	On-site household interview	No	WNV awareness 99%	▪ Concern for WNV 58% ▪ Concern for pesticide safety 48%	55%	55%	44%	43%	63%
Mitchell 2018 [51]	Aged ≥60 (211)	USA, Maryland	2012, October - December	Phone interview	No	▪ Transmission 75% ▪ At-risk groups 25%	▪ Perceived severity of WNV infection 96% ▪ Perceived risk of contracting WNV 92% ▪ In favour of vaccine 70%; ▪ In favour of the use of pesticides by city authorities 83%***	63%	51%	29%	56%	-
MMWR, CDC 2003 [58]	General population ≥18 (1791)	USA, Connecticut	2002, August-November	Phone interview (BRFSS)	No	At-risk groups 96%	Concern for WNV 56%	-	60%	57%	51%	-

Omodior 2018 [52]	International travellers ≥18 (1043)	USA	2017, June	Internet panel survey	No	WNV awareness 85%	▪ Perceived severity of WNV infection 72% ▪ Perceived risk of contracting WNV 13%	-	-	37%	28%	-
Trumbo 2015 [60]	General population ≥18 (384)	USA, Colorado, Greeley	2008, October - 2009, January	Self-administered mail survey	No	-	-	-	-	-	-	
Tuiten 2009 [40]	General population ≥18 (97)	USA, New York, Ithaca	2006, August-September	On-site household interview	No	▪ WNV awareness 100% ▪ Transmission 82%**** ▪ At-risk groups 59%****	▪ Concern for WNV 22% ▪ Concern for repellent safety (w/ or w/o DEET) 70% ▪ Perceived severity of WNV infection 41%	54%	21%	42% (of which 72% DEET)	34%	100%
Wilson 2005 [57]	General population ≥18 (491)	Canada, Ottawa	2002, July	Phone interview	No	▪ WNV awareness 77% (F: 74%, M: 83%, p<0,05; rural 83%, urban 69%; university 84%, high school 68%) ▪ Transmission 93%	▪ Concern for WNV 64% (higher in females and high school or lower) ▪ In favour of the use of pesticides by city authorities 80%	72% (higher in university vs high school)	-	73% (of which 77% DEET)	-	78%

* the data presented in the two documents originate from the same survey;
** 30-minute scripted slide presentation at school and 10-minute interactive art project; follow-up 4 months later;
*** knowledge of people with WNV infection OR=0.1 (0.01-0.7); lower education OR=0.5 (0.3-0.9);
**** predictors of higher knowledge: urban vs suburban area of residence not significant (NS); female vs male NS, aged <55 vs older NS, university education vs high school or less AOR=3.5 (1.1-10.9).

Table 2. Association between outcomes of interest and their predictors as investigated in included studies. For readability, only one decimal place is reported for each value. Odds-ratios and adjusted odds-ratios are followed by the relative 95% confidence interval in brackets. ORs and AORs are reported when bivariate or multivariate analysis was performed in the reference article, respectively. OR: odds-ratio; AOR: adjusted odds-ratio; B: unstandardized beta; NS: not significant (p>0.05); DEET: *N,N*-diethyl-*meta*-toluamide; WNV: West Nile Virus; BRFSS: Behavioral Risk Factor Surveillance System.

Outcome	**Predictors**	**Synthetic indicator***	**Strength of association**
Removal of standing water	Younger age	↑↑↑	AOR=4.4 (2.0-9.6); 60-69 vs older [51]
	Higher education	↑↑	AOR=2.5 (1.1-5.0); graduate vs less [51]
	Concern for WNV	↑↑	AOR=2.9 (1.3-6.5) [51]
	Intervention	↑↑↑	AOR=4.6 (2.7-8.0) [8]
Avoidance behaviour	Age	↔	NS [42]
	Female gender	↔	NS [42]
	Income	↔	NS [42]
	Concern for WNV	↑↑	AOR=2.1 (1.3-3.5) [42] AOR=3.0 (2.2-4.2) [49]
	Perceived risk of contracting WNV and severity	↑	OR=1.6 (1.2-2.1) [59]
Use of repellents	Younger age	↑↑	AOR=2.0 (1.2-2.3); aged <51 vs older [57] AOR=1.6 (1.2-2.2); aged <45 vs older [42] OR=2.0 (1.4-3.3); aged <65 vs older [58] OR=2.1 (1.2-3.8); aged 60-69 vs older [51]
	Female gender	↔ ↑	NS [42] AOR=1.3 (1.1-1.6) [56]
	WNV awareness		NS [52]
	Concern for WNV	↑↑	AOR=4.7 (2.9-7.5) [42] OR=2.0 (1.1-3.7) [58] AOR=1.8 (1.4-2.7) [56] OR=2.5 (1.3-4.7) [51] AOR=1.9 (1.3-2.6) [73]
	Perceived risk of contracting WNV and severity	↔	NS [52]
	Concern for repellent safety	↓	AOR=0.5 (0.4-0.7) [49]
	Concern for pesticide safety	↑	AOR=1.7 (1.1-2.6) [73]
	Spending evenings outdoor	↑↑	OR=2.3 (1.5-3.6) [58]
	Indoor exposure**	↑	AOR=1.4 (1.1-1.8) [56]
	Intervention	↔	NS [50]
Protective clothing	Younger age	↔	NS [42]
	Female gender	↔	NS [42]
	Higher education	↔	NS [42]
	Income	↔	NS [42]
	WNV awareness	↔	NS [52]
	Concern for WNV	↑	AOR=1.4 (1.1-1.8) [49] AOR=2.6 (1.2-5.3) [42]
	Perceived risk of contracting WNV and severity	↔	NS [52]
	Concern for repellent safety	↑	AOR=1.4 (1.1-1.9) [49]
	Intervention	↑↑	AOR=2.4 (1.3-4.3) [8]
	Older age	↑ ↓	OR=2.6 (1.7-3.9); aged 65+ vs younger [58] AOR=0.4 (0.2-0.7); aged 50+ vs younger [57]

			B=0.03 (p=0.01) [60] AOR~3; aged 55+ vs younger [40]
	Female gender	↑	OR=1.9 (1.4-2.6) [58] AOR=1.8 (1.5-2.2) [56] B=-1.21 (p=001); 1 = M, 0 = F [60] AOR=2.0 (1.2-2.9) [73]
	Rural area of residence	↔	NS [49]
	Higher education	↔	NS [49]
	Lower income	↑	OR=1.6 (1.1-2.2); medium (25,000-75,000$) vs high (>75,000$) [58]
Taking preventive actions (at least one, not specified)	Concern for WNV	↑↑	OR=2.5 (1.9-3.2) [49] OR=2.2 (1.2-3.9) [58] AOR=1.6 (1.2-2.1) [56] AOR=3.8 (2.2-6.5) [73]
	Perceived risk of contracting WNV and severity	↑↑	B=0.28 (p=0.01) [60] OR=2.6 (p<0.05) [40]
	Perceived mosquito activity around the house**	↑↑↑	AOR=4.5 (p<0.05) [40]
	Finding dead bird on the property	↑	AOR=1.8 (1.1-2.8) [73]
	Source of information		Newspaper OR=1.8 (1.1-2.9) [53,54] Internet OR=3.1 (1.4-6.9) [53,54] Word of mouth OR=2.2 (1.4-3.5) [53,54] Other sources: NS [53,54]

* ↓ (0<OR≤1); ↑ (1<OR≤2); ↑↑ (2<OR≤4); ↑↑↑ (OR>4); ↔ not statistically significant (NS)
**mosquitoes seen at least once a week

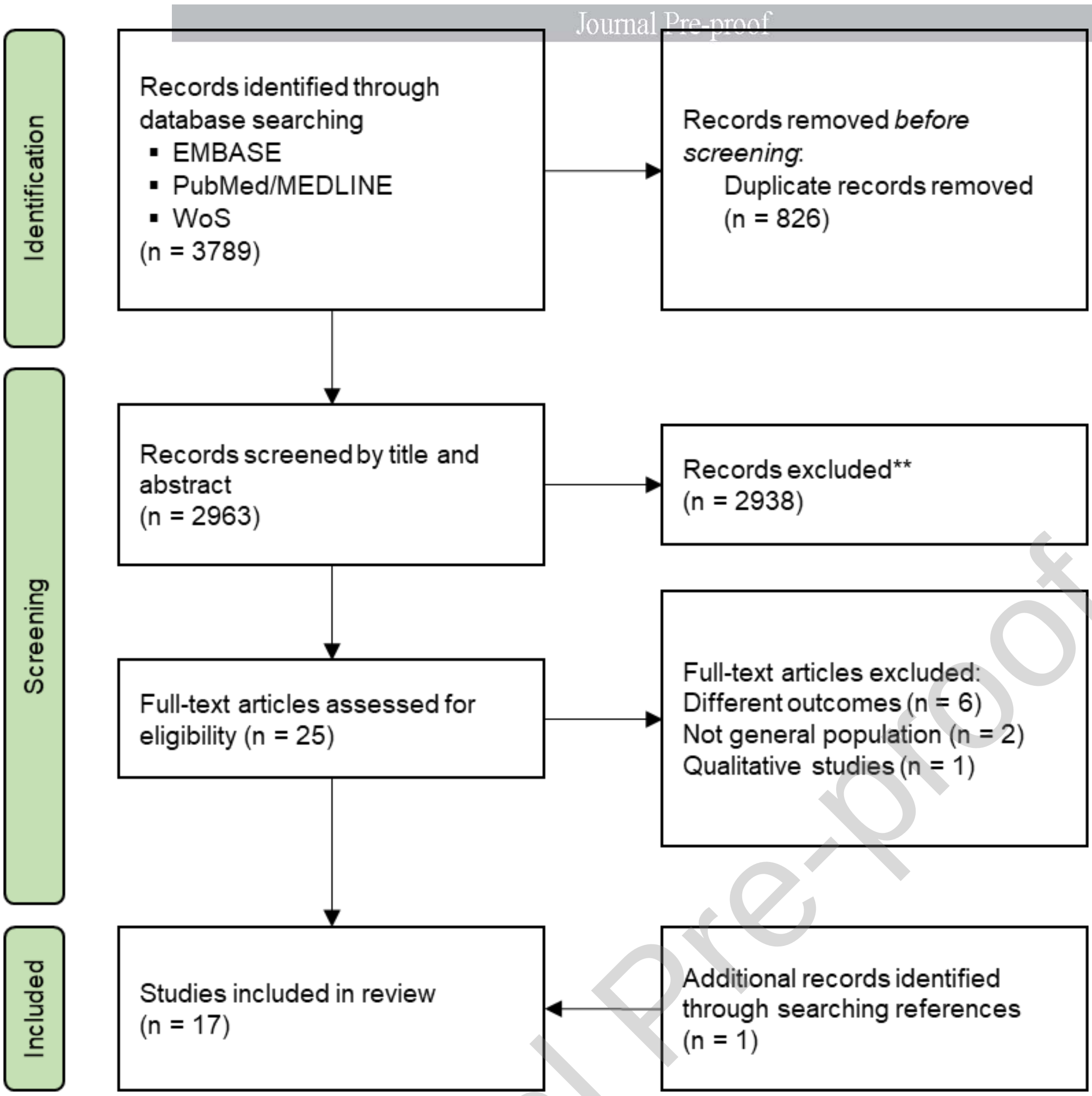

Figure 1. PRISMA flowchart of the review process.

Figure 2. Geographical distribution of studies included. The size of the blue circles is proportional to the sample sizes, as illustrated in the legend situated at the top left-hand corner.

Conflicts of Interest

The authors declare no conflict of interest.