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"SARS-CoV-2 is transmitted by particulate air pollution": Misinterpretations of statistical data, skewed citation practices, and misuse of specific terminology spreading the misconception☆

Alexander Ishmatov [a,b,c,*]

[a] Research Institute of Experimental and Clinical Medicine, Timakova St., Bild. 2., Novosibirsk, 630117, Russian Federation
[b] Kazan Federal University, Kremlyovskaya St. 18, Kazan, 420008, Russian Federation
[c] Togliatti State University, Belorusskaya St. 14, Togliatti, 445020, Russian Federation

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ABSTRACT

In epidemiology, there are still outdated myths associated with the spread of respiratory infections. Recently, we have witnessed the origination of a new misconception, to the effect that SARS-CoV-2 is transmitted in the open air by way of particulate air pollution (atmospheric particulate matter (PM)). There is no evidence to support the idea behind this misconception. Nevertheless, more and more people are involved in animated debate and the number of studies concerning atmospheric PM as a carrier of SARS-CoV-2 is growing rapidly.

In this work, the origin of the misconception was investigated, and the published papers which have contributed to the spread of this myth were analyzed.

The results show that the following factors lie behind the origin and spread of the misconception:

a) The specific terminology is not always clearly defined or consistently used by scientists.

In particular, the terms 'particulate matter', 'atmospheric aerosol particles', 'air pollutants', and 'atmospheric aerosols' need to be clarified, and besides they are often equated to 'infectious aerosols', 'virus-bearing aerosols', 'bio-aerosols', 'virus-laden particles', 'respiratory aerosol/droplets', and 'droplet nuclei'.

b) Authors misinterpret statistical data and information from other sources.

Interpretation of the correlation between PM levels and the increasing incidence and severity of COVID-19 infection, is often changed from "PM may reflect the indirect action of certain atmospheric conditions that maintain infectious nuclei suspended for prolonged periods, parameters that also act on atmospheric pollutants" to "PM could cause an increase in infectious droplets/aerosols containing SARS-CoV-2." This is a dramatic change to the meaning. Moreover, it is often not taken into account that PM may reflect activities in areas with high population density and this population density at the same time contributes to the spread COVID-19.

c) Skewed citation practices.

Many authors cite a hypothetical conclusion from an original study, then other authors cite the papers of these authors as primary sources. This practice leads to the effect that there are many witnesses to a 'phenomenon' that did not ever occur.

Thus, the terminology used in interdisciplinary communications should be more nuanced and defined precisely. Authors should be more careful when citing unconfirmed data (and hypotheses) as well as in interpreting statistical data so as to avoid confusion and spreading false information. This is especially important now in the era of the COVID-19 pandemic.

☆ Key message: Because of misinterpretations of statistical data, skewed citation practices, and misuse of specific terminology, the new misconception is spreading in the scientific community. These practices should be stopped.

* Research Institute of Experimental and Clinical Medicine, Timakova St., Bild. 2., Novosibirsk, 630117, Russian Federation.
E-mail addresses: ishmatoff@centercem.ru, ishmatoff@rambler.ru.

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1. Introduction

"Most of the terms used in the air pollution literature come from a wide range of disciplines – particularly chemistry (analytical, inorganic, and physical), meteorology, physics, and numerous branches of engineering and technology. Added to these are new terms that have been coined solely for use in air pollution work. All to frequently, terms that may appear to be commonly known are in fact not known with their correct meanings: such terms are consequently used incorrectly and interdisciplinary communication is hindered." (WORLD HEALTH ORGANIZATION REGIONAL OFICE FOR EUROPE, 1980)

A major challenge in the multidisciplinary field of airborne disease transmission is that the specific terminology is not always clearly defined or used consistently; thus, there is a risk of misunderstanding. The confusion has emanated from traditional terminology introduced during the last century (Tang et al., 2021a,b,c). In particular, the fundamental terms 'aerosol', 'infectious aerosol', 'droplet', 'droplet nuclei', 'particles', and 'particulate matter (PM)' are used inconsistently by different scientific communities and with different meanings and implications. We must differentiate the specific terminology to avoid confusion in the designation of infectious aerosols and atmospheric aerosol particles. Doing so is important for a transdisciplinary understanding of the modes of transmission of respiratory infections, especially in the era of the COVID-19 pandemic (Tellier et al., 2019; Milton, 2020; Bontempi, 2020a,b; Bontempi et al., 2020; Tang et al., 2021a; Pohlker et al., 2021; Anand et al., 2021a).

It is well known that both short- and long-term exposure to air pollution (atmospheric PM) contributes to the suppression of the protective mechanisms of the respiratory system. As a result, air pollution is an important aggravating factor through multiple mechanisms for susceptibility to SARS-CoV-2 infection, as well as COVID-19 severity and lethality (see related reviews in (Anand et al., 2021a,b; Bourdrel et al., 2021; Borro et al., 2020, Barakat et al., 2020; Bourdrel et al., 2021; Conticini et al., 2020; Ishmatov, 2020a,b; Toczylowski et al., 2021; Wang et al., 2020a; Wu et al., 2020)). Thus, PM affects the health status of subjects, exposing them to a high risk of infection by SARS-CoV-2. Furthermore, increasing numbers of people, including scientists, are becoming involved in an animated debate about how SARS-CoV-2 is transmitted in the open air via particle pollution (atmospheric PM). The number of studies concerning particle pollution (or atmospheric PM (PM10 or PM2.5)) as a carrier of SARS-CoV-2 is growing rapidly (Setti et al., 2020a-e; Coccia, 2020a,b; Anand et al., 2021a; Al Huraimel et al., 2021; Barakat et al., 2020; Belosi et al., 2021; Bontempi, 2020a,b; Bontempi et al., 2020; Borak, 2020; Comunian et al., 2020; Domingo and Rovira, 2020; Kayalar et al., 2021; Milton, 2020; Sanità di Toppi et al., 2020; Tang et al., 2020; The Guardian, 2020; Wang et al., 2020a; Chirumbolo, 2021; Kumar et al., 2021; Maleki et al., 2021; Martelletti and Martelletti, 2020; Mehmood et al., 2021; Mukherjee et al., 2021; Nor et al., 2021; Pivato et al., 2021; Shao et al., 2021; Tung et al., 2021).

Bontempi (2020a, 2020b) mentioned that a common problem in the studies on COVID-19 transmission is lack of suitable terminology and confusion arising from the perception that the diffusion of airborne viruses can be promoted by outdoor sources (such as PM). Bontempi (2020b) refutes this hypothesis, citing that no clear correlation exists between PM levels and the transmission of SARS-CoV-2. There had been a long discussion on this matter within the Italian Aerosol Society (IAS) and it has been written a note signed by more than 70 researchers (Società Italiana di Aerosol, 2020).

Similarly, Chirumbolo (2021) pointed out:

1. "The evidence that PM10 can bear SARS-CoV2 RNAs 1 has been erroneously translated by nonscientific and popular information as the ability of infectious SARS-CoV2 particles to colonize PM10 and to widespread wherever people lives."
2. "The animated debate about the possibility that infecting SARS-CoV2 are widespread in open-air via particulate matter (PM), should need a thorough reappraisal."

Recently, Anand et al. (2021a) and Maleki et al. (2021) analyzed the available scientific literature and concluded that there is no scientific evidence of transmission of COVID-19 through particulate matter pollution (PM10 or PM2.5). Furthermore, Anand et al. (2021a) found that the existing literature on this issue is mainly based on a statistical approach and characterized by a high level of uncertainty that does not support definitive scientifically valid conclusions.

The goal of this work is to analyze the main nodes in the citation network and the sources of origin of the new myth that air pollutants (PM) play a role in the transmission of COVID-19. Studies and reviews published before June 2021 were identified and analyzed using PubMed, Google/Google Scholar, ScienceDirect, Crossref, and Web of Science. The eligible studies included those claiming or citing the statements to the effect that 'SARS-CoV-2 creates clusters (coagulates) with outdoor PM in air', 'SARS-CoV-2 can be present on PM', 'COVID-19/SARS-CoV-2 spreads by particulate air pollution (or PM)', 'PM can bear SARS-CoV-2', and 'air pollutants (or PM) represent a carrier for SARS-CoV-2'.

But first of all, to understand and clarify the possibility of airborne transmission of COVID-19 and the role of air pollution in this process, we need to outline and differentiate the basic terms and vocabulary. It is also important to find and analyze the primary sources that served as the basis (first evidence) and led to the spreading of misconception.

2. Terms and vocabulary

Table 1 below summarizes the basic terms and vocabulary. Fig. 1 shows the idealized volume (mass) and number concentration distributions of atmospheric particles typical of a polluted urban area. It is possible to distinguish three modes in the particle size distribution (Whitby, 1978): a nucleation mode; an accumulation mode; and a coarse mode (it should be noted that this classification into three modes is too simplistic). The mass of the atmospheric particles is present mostly in the accumulation and coarse modes and the number concentration is dominated by ultrafine particles, as these small particles dominate particle numbers but are a minuscule fraction of PM10 mass. The nucleation mode corresponds to ultrafine particles that have been formed by chemical reactions in the air from gaseous molecules and have later grown via the condensation of other gaseous molecules and coagulation with other nucleated particles. They rapidly combine/coagulate with each other and larger accumulation-mode particles. The accumulation mode results from the emission of fine particles and from dynamic processes, such as condensation and coagulation, and are often found in combustion emissions. The coarse mode consists mostly of particles emitted via mechanical processes (abrasion, wind erosion, etc.). Coagulation in practice has no effect on these particles, due to their low number concentration (Whitby, 1978; Watson, 2002; Seigneur, 2019). The issue of coagulation of coarse particles (PM10) is important and is also discussed below, since it directly affects the topic of this article.

3. "First evidence"

Position papers published by the Italian Society of Environmental Medicine (SIMA) on March 16, 2020 (Setti et al., 2020c,d), and an editorial paper by Setti et al. (April 25, 2020b) claimed that the rapid spread of COVID-19 observed in selected regions of Northern Italy was supposedly related to PM10 pollution, with airborne particles serving as

Table 1
Basic terms.

Terms	Meaning
Particulate Matter (PM)	PM is a well-known proxy indicator for understanding pollution levels in air, and is commonly used by specialists when measuring ambient air quality (US EPA, 2021; Navarro et al., 2021). As indicated by the United States Environmental Protection Agency (US EPA, 2021): "PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air." PM contains various substances including organics, metals, elemental and organic carbon, sulfates, and nitrates (Watson, 2002; Seigneur, 2019; Maleki et al., 2021). Ambient PM is categorized into various sizes: inhalable ultrafine particles with a diameter ≤0.1 μm (PM0.1); inhalable submicron particles with a diameter ≤1 μm (PM1), which is the sum of PM1 and PM0.1; inhalable fine particles with a diameter ≤2.5 μm (PM2.5), which is the sum of particles with a diameter ≤2.5 μm; and inhalable coarse particles with a diameter ≤10 μm (PM10), which is the sum of all particles with a diameter ≤10 μm (see related review in Maleki et al., 2021; Navarro et al., 2021). Exposure scientists and industrial hygienists use the same size classification for exposure to aerosol particles (see related review in Milton, 2021; Navarro et al., 2021). Fig. 1 represents the size distribution of atmospheric particles typical of a polluted urban area (reprinted from (Seigneur, 2019)).
Air Pollution	Air pollution in the Cambridge Dictionary is defined as: "harmful substances in the air, often consisting of waste from vehicles or industry.". Maleki et al. (2021), in a systematic review of the association between atmospheric PM pollution and the prevalence of SARS-CoV-2, defined air pollution as "a mixture of natural or anthropogenic compounds in indoor or ambient air including solid particles (such as particulate matter (PM), bioaerosols), liquid (droplets) and gases (carbon monoxide (CO), nitrogen (NOx) and sulfur (SOx)."
Aerosol	An aerosol is defined in the Merriam-Webster dictionary (Merriam-Webster.com, 2021) as "a suspension of fine solid or liquid particles in gas." In the context of air pollution, an aerosol commonly refers to the PM in the air" (Merriam-Webster.com, 2021; Seinfeld and Pandis, 1998).
Bioaerosol	A bioaerosol is an airborne collection of biological material (bacterial cells and cellular fragments, fungal spores and fungal hyphae, viruses, pollen grains and products of microbial metabolism). It is assumed that the particle size of particulate material in bioaerosols is generally 0.3–100 μm in diameter; larger particles tend to settle rapidly and are not readily transported in the air (Stetzenbach, 2009).
Infectious Aerosol	Fennelly (2020) defines infectious aerosols as "particles with potentially pathogenic viruses, bacteria, and fungi suspended in the air, which are subject to the same physical laws as other airborne particulate matter." The term 'aerosol' (aerosol particles) can have different meanings for specialists from different fields. Clearly, the terms 'bioaerosols' and 'infectious aerosols' have a definite meaning for medical staff and epidemiologists; however, these terms cannot be directly associated with air pollution or atmospheric aerosol particles or PM, especially if the terms are used for analysis of the epidemiological process or the transmission of infections.
Droplet Nuclei and Virus-laden Particles/Droplets/Aerosols	Viruses and bacteria are not usually air dispersed as free particles, but are attached to soil, dust or organic aggregates, determined by the medium from which the viruses or bacteria were aerosolized (seawater, soil, bird feces, etc. (Reche et al., 2018)). The viruses involved in respiratory infections (including COVID-19) are also generally not transmitted on their own, but are embedded within much larger mucosalivary particles or droplets generated during respiratory activities (Cox et al., 2020; Póhlker et al., 2021). Initial respiratory droplets contain water and varying amounts of saliva and mucus, comprising inorganic and organic ions and glycoproteins (Nicas, 2005; Gralton, 2011; Thomas, 2013). It is well known that the respiratory droplets generated by a cough, sneeze, speech, or breath (e.g., d < 20 μm) can be airborne and remain airborne for a long time (Vuorinen et al., 2020: "… 20 μm droplets … can linger in still air for 20 min −1 h"). Airflow may carry these aerosols for long periods, although the duration depends on the context, which is true even without taking account of droplet drying, and is particularly true when drying is considered (drying strongly influences the airborne duration). It is known that droplets with a radius of less than 20 μm evaporate rapidly to 20–50% of their initial size and stay sedimented as so-called droplet nuclei for a long time. Droplet nuclei are dry particles that may include viruses and other pathogens and tend to remain airborne, and thus can be distributed over a greater area than initial droplets (Wells, 1934; Nicas et al., 2005; Ishmatov et al., 2013; Netz, 2020; Lieber et al., 2021). *It is important to note that there are a few myths concerning the airborne transmission of SARS-CoV-2. Recently, Tang et al. (2021a) dismantled six popular myths, the most popular being the delusion that all virus-laden particles larger than 5 μm cannot stay in the air for a long time and fall within 1–2 m of the source. This is an obvious outdated misconception and relates to the outdated and inaccurate use of the terms 'airborne', 'aerosols', 'droplets', and 'droplet nuclei' (Atkinson et al., 2009; World Health Organization, 2014). As was rightly noted by Tang et al. (2021c): "… the authors continually cite in support of their definition of these terms an 18-year-old WHO document on the 2003 SARS-CoV-1 outbreaks, rather than more recent articles that redefine these terms in a way that is more consistent with actual mechanisms of transmission …" Moreover, many people, including scientists, still mistakenly believe in the myth that "the virus is only 100 nm in size so filters and masks will not work," although, as explained, this is a delusion and reflects a lack of understanding of the principles of transmission of respiratory viruses.

a carrier of the pathogens ("the virus can create clusters with the particles and be carried and detected on PM10"). It is important to note that in the same period (March 20, 2020) the Italian Aerosol Society (IAS) assessed the statement by SIMA as premature suggesting caution in the interpretation of correlation as causation in respect of interaction of virus-laden aerosols with pre-existing atmospheric particles (PM). The covariance between poor air circulation, secondary aerosol production, and the accumulation of PM near the ground and virus spread cannot be assumed to be causal. In the case of complex systems, such as the one we are dealing with, interpreting simple correlations does not necessarily

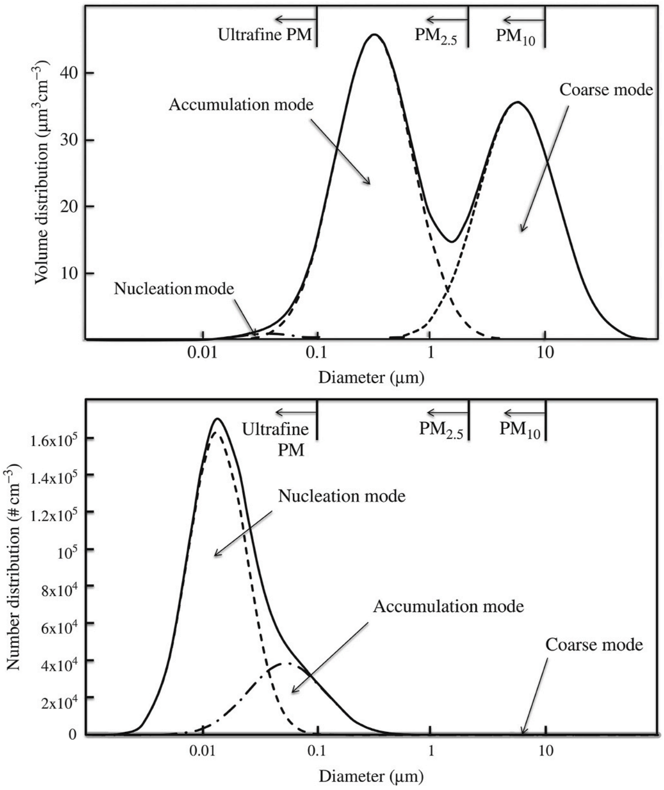

Fig. 1. Schematic representation of the size distribution of the volume concentration (top) and number concentration (bottom) of atmospheric particles typical of a polluted urban area. Source of the data: Whitby (1978). Reprinted from: Seigneur, C. (2019). Atmospheric Particles. In Air Pollution: Concepts, Theory, and Applications (pp. 190–238). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108674614.009 (Seigneur, 2019). Licence Date: 25/08/2021. PLSclear Ref No: 54346 (Cambridge University Press).

indicate causality (Società Italiana di Aerosol, 2020). The same opinion was expressed by Contini and Costabile (Apr. 10, 2020). Nevertheless, *Environmental Research* and SIMA established a thematic commission on COVID-19 and outdoor/indoor air quality, and announced a special issue dedicated to this problem. One of the main goals of the Commission's research concerns the preliminary evidence of PM as a "carrier" for the viral droplet nuclei (all data and references to the Commission have been deleted and are not available in the Web). As a result, the debate widened, and a cascade of works emerged to address the question of virus transmission by PM (Barakat et al., 2020; Borak, 2020; Bontempi, 2020a,b; Bontempi et al., 2020; Comunian et al., 2020; Domingo and Rovira, 2020; Milton, 2020; Sanità di Toppi et al., 2020; Tang et al., 2020; The Guardian, 2020; Coccia, 2020a,b; Wang et al., 2020a; Anand et al., 2021a; Al Huraimel et al., 2021; Belosi et al., 2021; Chirumbolo, 2021; Kayalar et al., 2021; Kumar et al., 2021; Maleki et al., 2021; Martelletti and Martelletti, 2020; Mehmood et al., 2021; Mukherjee et al., 2021; Nor et al., 2021; Pivato et al., 2021; Shao et al., 2021; Tung et al., 2021).

As was pointed out by different authors (Barakat et al., 2020; Bontempi, 2020b; Anand et al., 2021a; Chirumbolo, 2021; Maleki et al., 2021), all the early works on this matter were based on a correlation between air pollutants and COVID-19 cases (the 'statistical approach') while stopping short of establishing pollutants as a carrier of SARS-CoV-2. However, *Environmental Research* published an original study by Setti et al. (May 26, 2020a); as Anand et al. (2021a) pointed out in their review, this is the only study that used the RNA analysis approach (not the 'statistical approach').

Setti et al. (2020a) collected 34 p.m.10 samples in the Bergamo area (the epicenter of the Italian COVID-19 epidemic) using two air samplers over a continuous three-week period, from February 21 to March 13, 2020. They found that 20/34 (59%) PM samples were RNA positive for one gene, and 4/34 (11.8%) were positive for two genes, however, concentrations of virus-laden particles were not evaluated. As explained by Setti et al. (2020a), this study shows that sampling and analysis of outdoor/airborne PM10 can be useful in detecting airborne RNA traces of SARS-CoV-2, and thus identifying the presence of a potential viral hazard. Furthermore, Setti et al. (2020a) explicitly stated that claims that SARS-CoV-2 can create clusters (coagulate) with outdoor PM (PM10) in air, and that viable SARS-CoV-2 can spread by particulate air pollution, are hypotheses. Nonetheless, many researchers have cited this study as 'first evidence' that virus-bearing aerosols produced from human atomization likely undergo transformation in air, including coagulation with ambient preexisting PM (PM10), and that air pollutants (PM10) spread COVID-19 (see discussion below).

It is important to note that the authors of the original study (Setti et al., 2020a) made ambiguous statements in the media (including Prof. Setti's speech at TEDxMantova on November 13, 2020. https://www.youtube.com/watch?v=cc9vKOm_VVg&t=4s (accessed 18.08.20)) and in their later works, thereby perhaps provoking a wave of citations. In a popular article on The Guardian website (which has since been cited and replicated by other media worldwide) (The Guardian, 2020): "The pollution particle is like a micro-airplane and the passengers are the droplets," or, "Setti said tiny droplets between 0.1 and 1 µm may travel further when coalesced with pollution particles up to 10 µm than on their own. This is because the combined particle is larger and less dense than the droplet and can remain buoyed by the air for longer." Significantly, on The Guardian website, this statement was subject to doubt and criticism by other researchers.

It is obvious that virus-laden droplet nuclei (e.g., d $<$ 10–20 µm) can be airborne, and can be collected in PM10 samples. However, this fact does not show that virus-laden particles create clusters (coagulate) with outdoor PM (PM10 or PM2.5) in the air, as rightly noted by Prof. Contini (Head of the Lecce Section of the Institute of Atmospheric Science and Climate of the National Research Council (ISAC-CNR), Italy) in a discussion on this matter: (see related comment by Prof. Contini on 23rd Apr 2020 at the link: https://www.researchgate.net/post/Any_association_between_air_quality_and_virus_spread?isAnswerFieldFocused=true#view=5ea1bd46c620916f1b3acc9c): "Small droplets are released during respiration and speech and these could evaporate (partly or totally leaving more or less dried residue) and they are sufficiently small to be suspended in atmosphere and transported/dispersed like the other particles. So the question is why they should be "carried" by other particles in air? They will also be transported by themselves like any other particle." The same point of view can be found in (Robotto et al., 2021): "Exhaled droplets forming bioaerosol could be considered like particulate matter with an aerodynamic diameter lower than 10 or 5 µm (PM10 or PM5), in some cases even smaller than 1 µm (PM1), so bioaerosol could be considered as a gaseous pollutant while being transported and dispersed in atmosphere since no settling occurs."

The original study by Setti et al. (2020a) did not consider the possibility that virus-laden particles of different sizes ($<$10 µm) could be collected from the air or that these particles are not always equivalent to PM (air pollutants) with viruses attached. Thus, the data presented by Setti et al. (2020a) do not provide either direct or indirect evidence of the creation of clusters of SARS-CoV-2 with outdoor PM (PM10 and PM2.5) in the air. Here, based on statements by Prof. Setti in the media (The Guardian, 2020), it can be assumed that the authors (Setti et al., 2020a) became victims of their own assumption (false beliefs) that only 'tiny droplets' between 0.1 and 1 µm (meaning respiratory droplets with viruses attached) can be found in air. However, it is well known that respiratory droplets with sizes above 1 µm can also be found in the air (see related review in (Vuorinen et al., 2020)).

To demonstrate that virus-laden particles coagulate (create clusters) with outdoor PM (PM10 or PM2.5) and show virus-laden particles clustering with outdoor PM, a microscopic examination of the collected samples is required. However, microscopic examination of samples is a time-consuming and difficult task, and special measures are required when collecting samples (to exclude particle interaction post-collection). It is important to note that floor/ground-deposited virus-laden particles of different sizes can interact with dust (and other substances or PM on the ground) and then be resuspended in the air (like other dust particles), as suggested by Liu et al. (2020). In addition, fecal aerosol transmission (for example, aerosolization of wastewater) (Kang et al., 2020) may have been behind the presence of the markers for SARS-CoV-2 (viral fragments of coronavirus) in the air samples collected in the studies by Setti et al. (2020a), Santarpia et al. (2020), and Hu et al. (2020). Moreover, Kang et al. (2020), based on circumstantial evidence, concluded that fecal aerosol transmission may have caused the community outbreak of COVID-19 in a high-rise apartment building in Guangzhou, China. Again, these arguments do not mean that respiratory droplets/nuclei (virus-bearing aerosols produced from human atomization) interact/coagulate with PM10 (or PM2.5) in air. It is this interaction/coagulation that allows SARS-CoV-2 to survive in airflows for hours or days and be dispersed over larger distances.

In a further study, this time based on a statistical approach, Setti et al. (2020e) expanded their hypotheses and stated that:

> "It could be possible to look at the airborne route of transmission, and specifically to PM, as a 'highway' for viral diffusion, in which the droplet nuclei emitted by the exhalations are stabilised in the air through the coalescence of aerosol with the PM at high concentrations in stable conditions."

and

> "Nevertheless, coalescence phenomena require optimal conditions of temperature and humidity to stabilise the aerosols in the air, namely around 0°C–5°C and 90%–100% relative humidity."

Thus, the authors indicated the necessary conditions (without citing any sources) for the phenomenon which, in their opinion, underlie their hypothesis. However, the original study by Setti et al. (2020a) noted that "during the sampling period, average temperature and average relative humidity have been respectively recorded as follows: 8.5 °C and 61% for the period February 21st–27th; 6.8 °C and 69% for the period February 28th–March 5th; and 6.8 °C and 67% for the period March 6th–11th." Thus, the authors (Setti et al., 2020a-f) claim that they likely found confirmation that "the droplet nuclei emitted by the exhalations are stabilized in the air through the coalescence of aerosol with the PM," but the authors themselves indicate (Setti et al., 2020a) that the conditions during the sampling period were not favorable for stabilization of droplet nuclei in the air through the coalescence of aerosol with the PM (the humidity was below 90%).

Recently, Belosi et al. (2021) investigated theoretically the probability of interaction of a virus-laden aerosol with pre-existing particles of different sizes (through inertial impact, interception, and Brownian diffusion), with a specific focus on the cities of Milan and Bergamo (Italy). They found that the probability of coagulation of virus-laden aerosol with pre-existing PM was negligible for micron and submicron particles (>100 nm). For reference, it is well known that coagulation for large particles (d > 1 μm) in urban air is negligible because of their relatively small Brownian diffusivities. The coagulation rates are greater for ultrafine particles (d < 0.1 μm), and these particles coagulate preferentially with fine particles of diameters ranging from around 0.05 to 0.5 μm (Seigneur, 2019). Thus, if we consider the smallest possible sizes of respiratory droplet nuclei with the virus attached (d > 0.1–0.2 μm) (Liu et al., 2020), then the question of coagulation (and cluster formation) of virus-laden particles/droplets in air with coarse pollutant particles with a size greater than 1 μm (or PM10, as was suggested by Setti et al. (2020a-e)), becomes more confusing.

However, it is important to note that virus-laden particles could act as sinks for ultrafine PM (around 0.01 μm in diameter) (Belosi et al., 2021) or other substances and gases in urban air. Accordingly, this interaction may mitigate or intensify virus inactivation and this aspect is still to be researched. However, this interaction will not significantly change the dynamics behavior of virus-laden particles or their permanence time in air. It is notable that the virulence and stability of SARS-CoV-2 under different environmental conditions remains unclear. The association of climatic factors (such as temperature, humidity, precipitation, wind speed, and solar radiation) with SARS-CoV-2 survival, prevalence and spread, is very complicated and currently a matter of debate (Kumar et al., 2021; Oliveiros et al., 2020; Ahmadia et al., 2020; Coccia, 2020a; Yao et al., 2020; Biasin et al., 2021; Ratnesar-Shumate et al., 2020; Seyer and Sanlidag, 2020; Santarpia et al., 2020).

Recently, Anand et al. (2021a) concluded that there is no scientific evidence of the possible spread of COVID-19 infection through atmospheric particulate matter (PM10 or PM2.5). Moreover, Belosi et al. (2021) and Rowe et al. (2021) showed that theoretically, the probability of airborne transmission due to respiratory aerosol (infectious aerosols or droplets nuclei or virus-laden particles) is very low in outdoor conditions (even in crowded areas, the risk outdoors is much less than indoors). In addition, the results of the analysis by Bontempi (2020b) and Bontempi et al. (2020) demonstrate that it is not possible for air pollution to accelerate virus diffusion, and that a pandemic's diffusion patterns are typically caused by a multiplicity of environmental, economic, and social factors. In recent studies following the contagious dynamics over time, Bontempi et al. (2021) and Bontempi and Coccia (2021) use statistical analysis to show that international trade data can be considered one of the main indicators of diffusion of COVID-19 spread in Italy, France, and Spain.

It is important to note that Chirizzi et al. (2021) collected air samples during the pandemic, in May 2020, in northern (Veneto) and southern (Apulia) regions of Italy. Air samples tested negative for the presence of SARS-CoV-2 at both sites; viral particle concentrations were very small (<0.8 copies m^{-3} in PM10 and < 0.4 copies m^{-3})in all in all size ranges, from nanoparticles up to coarse particles. They concluded that outdoor air in residential and urban areas is generally safe for the public and not infectious (with the possible exception of very crowded sites). These low concentrations actually suggest that interactions with other atmospheric particles are very unlikely. Air samples collected by Pivato et al. (2021) during the peak of COVID-19 in Padua (Northern Italy), and air samples collected by Linillos-Pradillo et al. (2021) in Madrid (Spain) during May 2020, did not indicate the presence of SARS-CoV-2 RNA in the PM, thus confirming the low probability of virus airborne transmission through PM. However, in a recent study, Kayalar et al. (May 2021), inspired by the study of Setti et al. (2020a), collected 203 ambient PM samples from 13 sites across Turkey between May 13th and June 14th, 2020, and found that dual RdRP and N1 gene positivity were detected in 20 (9.8%) samples. Based on these results Kayalar et al. (2021) concluded: "We demonstrated that SARS-CoV-2 RNA can be present on ambient PM suggesting that the virus may be transported via PM pollution … It is likely that the liquid-like organic layer and surface of particles can provide a medium for the interaction between virus-containing particles and PM, and that the virus may also be transferred from a respiratory droplet to PM." The methodological part of this work is similar to the study by Setti et al. (2020a); thus, the authors had no grounds for reaching such premature conclusions.

In sum, the studies by Setti et al. (2020a-e), like all other available studies, are characterized by a high level of uncertainty preventing any definitive scientifically valid conclusions. Although the presence of markers of SARS-CoV-2 (viral fragments of coronavirus) in environmental samples (Setti et al., 2020a; Kayalar et al., 2021) is possibly an important finding, the claim that SARS-CoV-2 can create clusters with outdoor PM10 in the air, and SARS-CoV-2 spreads via particulate air pollution, is currently only a hypothesis that lacks direct or indirect supporting evidence. An interaction between respiratory droplets and air pollutants in real urban air, considering the temporal and probabilistic aspects of these events, may ultimately have no impact on the actual spread of viable SARS-CoV-2.

For clarity, Table 2 below summarizes the main points in the evidence that SARS-CoV-2 can create clusters with PM or the virus spreads via PM.

4. Citation network

The study by Setti et al. (2020a) and other available studies do not provide a sufficient basis for the conclusion that SARS-CoV-2 creates clusters with outdoor PM in air. Equally, there is no evidence that pollution particles are similar to "micro-airplanes" with the respiratory droplets being the "passengers" or that air pollutants (PM) play a role in the transmission of COVID-19. Nevertheless, due to the confusion in the specific terminology and unfounded speculation, we can observe a wave of citations of such statements/claims in the literature as fact (or the "first evidence"). Examples are as follows:

1) Setti et al. (2020d) in a position paper by the Italian Society of Environmental Medicine (March 27, 2020): "… it is possible to conclude that particulate matter fractions PM2.5 and PM10 represent an effective carrier for viruses transport and diffusion and proliferation of virus diseases as well."
2) Qu et al. (Mar. 23, 2020): "Adsorption of the COVID-19 virus on airborne dust and PM could also contribute to long-range transport of the virus. Therefore, investigations on adsorption, survival, and behavior of the COVID-19 virus with the surface of PM are needed to help to understand the role of air PM pollution in COVID-19 transmission."
3) Setti et al. (Apr. 17.2020f): "The hypothesis is that aerosol droplets emitted by infected persons during sneezing, coughing, or simply talking are stabilized in the air through the coalescence with PM at high concentrations and under conditions of atmospheric stability", and "When conditions of atmospheric stability and high PM concentrations occur, viruses may create clusters with the particles and, by reducing their diffusion coefficient, enhance both their residence time and abundance into the atmosphere."
4) Sharma et al. (May 20, 2020): "In the air, the SARS-CoV-2 virus may be present as droplets, or as dust, or particulate matter (PM)."
5) Setti et al. (May 26, 2020a): "This is the first evidence that SARS-CoV-2 RNA can be present on outdoor particulate matter, thus suggesting that, in conditions of atmospheric stability and high concentrations of PM, SARS-CoV-2 could create clusters with outdoor PM and – by reducing their diffusion coefficient – enhance the persistence of the virus in the atmosphere."

It is curious that in a recent paper (Barbieri et al., 2021), the same group of Italian researchers (eight out of 14 researchers took part both in the original study by Setti et al. (2020a) and in the study by Barbieri et al. (2021)) do not make conclusions and statements that "SARS-CoV-2 can create clusters with outdoor PM10 in the air" or that "SARS-CoV-2 spreads via particulate air pollution." For example, Setti et al. (2020a) used these words: "SARS-CoV-2 RNA found on particulate matter" and "the presence of SARS-CoV-2 RNA on particulate matter." However, in the recent study by Barbieri et al. (2021): "… Setti et al. (2020a) found SARS-CoV-2 RNA in PM10 daily filters (24h at 2.3 m3/h)" and "SARS-CoV-2 RNA detection on indoor air samples" or "detection of SARS-CoV-2 RNA in environmental air samples." It is obvious that such interpretations put everything in its place and leave no room for speculation. The text in the original study (Setti et al., 2020a) should therefore be corrected (given the content of Barbieri et al., 2021) to avoid further problems with citations and data interpretation.

6) Setti et al. (2020b): "… seems to confirm (at least in the case of atmospheric stability and high PM concentrations, as usually occurs in

Table 2
Main points in the evidence that SARS-CoV-2 can create clusters with PM or spreads via PM.

	Date	Reference	Personal point of view	Meaning
1	March 16, 2020	(Setti et al., 2020c,d)	First hypothesized that the rapid spread of COVID-19 related to PM10 pollution because SARS-CoV-2 can create clusters with the atmospheric particles and be carried and detected on PM10.	***Supports the hypothesis.*** Position papers/ hypothesis. Cannot be considered as direct or indirect evidence.
2	March 20, 2020	Società Italiana di Aerosol (2020).	Assessed the statement by SIMA as premature, suggesting caution in the interpretation of correlation as causation.	***Denies the hypothesis.*** A note signed by more than 70 researchers. Cannot be considered as direct or indirect evidence, but indicates the premature nature of the hypothesis.
3	April 10, 2020	Contini and Costabile (2020).	Assessed the statement by SIMA as premature, suggesting caution in the interpretation of correlation as causation.	***Denies the hypothesis.*** Cannot be considered as direct or indirect evidence, but indicates the premature nature of the hypothesis.
4	April 25, 2020	Setti et al. (2020b)	The authors of the hypothesis noted the importance of the hypothesis and the need for further research.	***Supports the hypothesis.*** Editorial paper/ hypothesis. Cannot be considered as direct or indirect evidence.
5	May–June 2020	(Bontempi, 2020a,b; Bontempi et al., 2020);	The results show that it is not possible to conclude that the COVID-19 diffusion mechanism also occurs through the air, using PM10 as a carrier.	***Denies the hypothesis.*** Statistical studies. Cannot be considered as direct evidence, but indicates the premature nature of the hypothesis and provides indirect evidence.
6	May 26, 2020	Setti et al. (2020a)	"This is the first evidence that SARS-CoV-2 RNA can be present on outdoor particulate matter, thus suggesting that, in conditions of atmospheric stability and high concentrations of PM, SARS-CoV-2 could create clusters with outdoor PM and – by reducing their diffusion coefficient – enhance the	***Supports the hypothesis.*** Setti et al. (2020a) found SARS-CoV-2 RNA in PM10 daily filters; concentrations of virus-laden particles were not evaluated. The findings in this work cannot be considered as direct or even indirect evidence (see the discussion above).

(*continued on next page*)

Table 2 (*continued*)

	Date	Reference	Personal point of view	Meaning
			persistence of the virus in the atmosphere."	
7	Sept., 2020	Setti et al. (2020e)	Based on a statistical approach, Setti et al. (2020e) expanded their hypotheses.	***Supports the hypothesis.*** Statistical study. Cannot be considered as direct or indirect evidence.
8	Dec. 8, 2020	Belosi et al. (2021)	Found that the probability of coagulation of virus-laden aerosol with pre-existing PM was negligible for micron and submicron particles (>100 nm).	***Denies the hypothesis.*** Theoretical work. Cannot be considered as direct evidence, but indicates the premature nature of the hypothesis and provides indirect evidence.
9	Nov. 12, 2020; Feb. 17, 2021; Apr. 16, 2021	(Chirizzi et al., 2021; Linillos-Pradillo et al., 2021; Pivato et al., 2021)	Did not indicate the presence of SARS-CoV-2 RNA in the PM samples	Cannot be considered as direct evidence, but indicates the premature nature of the hypothesis and provide indirect evidence.
10	April 16, 2021	Rowe et al. (2021)	Showed quantitatively that in most cases, the outdoor risk is orders of magnitude less than the indoor risk.	Theoretical work. Cannot be considered as direct evidence, but indicates the premature nature of the hypothesis and provides indirect evidence.
11	May 25, 2021	Kayalar et al. (2021)	"We demonstrated that SARS-CoV-2 RNA can be present on ambient PM suggesting that the virus may be transported via PM pollution."	***Supports the hypothesis.*** The methodological part of this work is similar to the study by Setti et al. (2020a). The findings of this work cannot be considered as direct or even indirect evidence (see the discussion above).

Northern Italy) that the virus [meaning SARS-CoV-2] can create clusters with the particles and be carried and detected on PM10."

7) Borak (2020), citing Setti et al. (2020a): "Further complexity is added by observations that COVID infections may also be spread by particulate air pollution."
8) Wang et al. (2020a), citing Setti et al. (2020a, e): "The high concentration of dust and airflow conditions in Northern Italy could promote SARS-CoV-2 viral transmission by forming viral clusters with PMs (48, 49)."

Moreover, Wang et al. (2020a) then concluded: "Airborne PM can also increase the transmission distance of SARS-CoV-2. If the cited studies are correct, this pollution may facilitate a second wave of infection by transmitting the virus from one country to another."

9) Wang et al. (2020b), citing Setti et al. (2020a,e): "A recent study reported that SARS-CoV-2 RNA can be present on outdoor PM, and suggested that, in conditions of atmospheric stability and high concentrations of PM, SARS-CoV-2 could create clusters with outdoor PM and – by reducing their diffusion coefficient – enhance the persistence of the virus in the atmosphere [22]. Setti et al. have emphasized the airborne route as a possible factor for interpreting the anomalous COVID-19 outbreaks in northern Italy, which is characterized by high PM concentrations [23]. Therefore, COVID-19 transmission is likely affected by airborne PM." or "Similar findings are reported in Bergamo of Northern Italy, where SARS-CoV-2 RNA was found on air particulate matter [22]."

In the same paper, Wang et al. (2020b), citing Setti et al. (2020f) "Concerning particles' role in the viral diffusion process, there is a hypothesis that aerosol droplets emitted by infected persons during sneezing, coughing or simply talking are stabilized in the air through the coalescence with PM at high concentrations and under conditions of atmospheric stability [46]. Therefore, higher levels of airborne particulate matter may increase the transmission of COVID-19."

10) Copat et al. (2020), citing Setti et al. (2020a): "… first preliminary evidence that SARS-CoV-2 RNA can be absorbed on outdoor particulate matter giving a suggestion that, …SARS-CoV-2 could create clusters with outdoor PM and enhance the persistence of the virus in the atmosphere …. "
11) He and Han (2021), citing Setti et al. (2020a): "Recently, Setti et al. (2020a) found that SARS-CoV-2 present on particulate matter showed increased persistence by forming clusters."
12) Tang et al. (2020), citing Setti et al. (2020a): "SARS-CoV-2 could create clusters with outdoor PM and, by reducing their diffusion coefficient, enhance the persistence of the virus in the atmosphere."
13) Al Huraimel et al. (2020), citing Setti et al. (2020a): "Under high PM concentration and atmospheric stability, viruses may create clusters with the PM reducing their diffusion coefficient and enhancing abundance into the atmosphere (Setti et al., 2020a). Setti et al. (2020a) present the first evidence of SARS-CoV-2 RNA presence on outdoor PM through analysis of 34 p.m.10 samples of outdoor/airborne PM10 from an industrial site of Bergamo Province."
14) Carraturo et al. (2020), citing Setti et al. (2020a,c): "The researchers therefore hypothesized a potential boosting effect of SARS-CoV-2 transmission, thanks to the vehiculation through the PM10 (Setti et al., 2020c). The hypothesis was confirmed by a research conducted by the same working group in Northern Italy, reporting the presence of SARS-CoV-2 viral RNA (using RT-PCR, detecting E, N, and RdRP genes) in over 30% of the 34 p.m.10 specimens of airborne PM10 sampled in the industrial area around the city of Bergamo (Italy) (Setti et al., 2020a)."
15) Comunian et al. (2020), citing Setti et al. (2020c): "… the position paper proposed by the Italian Society of Environmental Medicine (SIMA) considers PM as an important carrier that has contributed to the spread of COVID-19 [28]."

And then, Baron (2021), citing the statistical study by Comunian et al. (2020): "Another study by Comunian et al. confirmed the elevated levels of both PM2.5 and PM10 coincided with infection rates in Italy and reaffirmed the hypothesis that besides the adverse effects of particulate matter on pulmonary antimicrobial defences, PM could also act as a vector for COVID-19 [12]."

16) Coccia (April 2020a), based on statistical analysis: "… in polluting cities with low wind speed, the accelerated diffusion of viral infectivity is also due to a mechanism of air pollution-to-human transmission that may be stronger than human-to-human transmission", and "Overall, then, in the presence of polluting industrialization of cities and mechanisms of diffusion

of viral infectivity also based on air pollution -to-human transmission (airborne viral infectivity diseases), this study must conclude that …".

An analysis of the data reveals that Coccia (April 2020a) had no direct or indirect evidence to support such claims. As statisticians consistently emphasize: "Correlation does not imply causation."

Subsequently, Arslan et al. (2020), citing Coccia (2020a): "It was suggested that air transmission dynamics of COVID-19 are not mere "human-to-human transmission" but could also be "pollution-to-human transmission" which is associated with the airborne viral infectivity."

Then Arslan et al. (2020), without citing any sources: "Although SARS-CoV-2 is not an airborne virus, the adsorption on dust or particulate matter (PM) could allow its transport to long distances especially if these particles carry moisture. This phenomenon has also been coined as virus-laden-aerosols transmission."

Domingo and Rovira (2020), citing unpublished and unavailable data of Coccia (probably from the preprint available on medRxiv.com (Coccia, 2020b)): "In this same line, Coccia (2020b) has recently examined the mechanisms of transmission dynamics of COVID-19 in the environment for … The results revealed that accelerated transmission dynamics of COVID-19 in specific environments was due to two mechanisms given by: air pollution-to-human transmission, and human-to-human transmission in a context of a high density of population."

Then, Setti et al. (2020e), citing Qu et al. (2020), Domingo and Rovira (2020), and Sharma et al. (2020): 'This article presents the data that led to the publication of the position paper and triggered high interest in the research community working on the hypothesis of a possibility of further transmission via airborne dust, (24–26) …. "

Recently, Kumar et al. (2021), citing Coccia (2020a): "In highly polluted areas, the accelerated transmission dynamics of SARS-CoV-2 is major because of air pollution to human transmission (airborne viral infectivity) rather than human-to-human transmission (Coccia, 2020a)."

17) Dettori et al. (2020), citing Setti et al. (2020a) and statistical study by Peng et al. (2020): "Actually, a previously-proven phenomenon regarding the spread of other viruses (i.e., measles) (Peng et al., 2020) attests that the levels of atmospheric pollution and, above all, of particulates, could act as a vehicle for the spread of the virus throughout the territory. Nonetheless, Setti et al. recently demonstrated the presence of the SARS-CoV-2 RNA on particulate matter (Setti et al., 2020a)."

It is important to note that Peng et al. (2020) used descriptive statistics and correlation analysis to show that daily measles cases are associated with both air pollution and meteorological factors in Lanzhou, China. Obviously, this statistical study cannot be used as evidence that "particulates could act as a vehicle for the spread of the virus" as indicated by Dettori et al. (2020). Again, Setti et al. (2020a) found fragments of SARS-CoV-2 RNA in PM10 daily filters; this is not evidence of the interaction of SARS-CoV-2 with PM (or air pollution).

18) Zhang et al. (June 2020a), citing Setti et al. (2020a) [21], Guo et al. (2014) [27], Zhang et al. (2020b) [28], Peng et al. (2016) [29], Pyankov et al. (2018) [9], and van Doremalen et al. (2020) [12]: "In addition, nascent virus-bearing aerosols produced from human atomization likely undergo transformation in air, including coagulation with ambient preexisting PM and/or growth on a time scale of a few hours in typical urban air (27–29) [*Zhang et al. (2020a) proposed this assumption/speculation and cited three studies on the transformation of nanosized particles in the air*]. Such transformation, as recently documented in coarse PM in Italy (21) [*the first assumption/speculation on transformation of nanosized particles in the air has become a proven fact for transformation of coarse PM due to citing Setti et al. (2020a)*], may mitigate virus inactivation (9, 12), by providing a medium to preserve its biological properties and elongating its lifetimes [*a logical chain based on an unproven assumption/speculation with citation of studies on virus survival led to a new assumption/speculation*]."

19) Prather et al. (2020), without citing any sources: "Viruses [meaning SARS-CoV-2] can attach to other particles such as dust and pollution, which can modify the aerodynamic characteristics and increase dispersion."

Xu et al. (2020): "… viral agents attached on the PM …" and "the air pollutant concentration, such as PM2.5 and PM10 concentrations, may affect the aerosol transmission of SARS-CoV-2. Fine particles with viruses attached can …"

Prather et al. (2020) and Xu et al. (2020) made these statements without citing the original studies of Setti et al. (2020a-e). Perhaps they were inspired by the article in The Guardian (2020).

20) Zoran et al. (2020) based on statistical data: "It seems that under specific climate conditions (Bashir et al., 2020), air pollution acts as a carrier of the COVID-19 virus, facilitating its transmission and spreading, allowing its survival in active form with different residence times."

Then, Chen et al. (2021), citing Zoran et al. (2020) and Setti et al. (2020a): "… proposed that outdoor atmospheric particulates may be possible routes of SARS-CoV-2 diffusion (Zoran et al., 2020). As the first evidence showing SARS-CoV-2 harboring on airborne particles, Setti et al. (2020a) found clusters of SARS-CoV-2 RNAs on atmospheric particulate matter in Bergamo, …."

In the same paper Chen et al. (2021), citing Qu et al. (2020), Prather et al. (2020), and Setti et al. (2020a, f): "In an early viewpoint, Qu et al. (2020) hypothesized that SARS-CoV-2 can adsorb onto air dusts or particulates and facilitate its long-distance transmission. A similar opinion was proposed by Prather et al. (2020) that viruses can attach to airborne dust or other air pollutants which can facilitate their dissemination via increased dispersion and modified aerodynamic characteristics. Setti et al. (2020f) further proposed that SARS-CoV-2 may create clusters with atmospheric particles and subsequently enhance the dispersion and accumulation of the virus in air. Direct evidence on the presence of SARS-CoV-2 on airborne particles was reported by Setti et al. (2020a) … Based on these findings, the authors suggested that SARS-CoV-2 could form clusters with PM10 present in the outdoor atmosphere."

21) Sanità di Toppi et al. (2020), citing the study by Setti et al. (2020a): "The hypothesis that the novel coronavirus might exploit the "highways" made up of atmospheric particulates is a challenging point that, in our opinion, deserves further, immediate, and in-depth experimental investigations."

The above conclusion of Sanità di Toppi et al. (2020) was then mentioned by Domingo and Rovira (2020) without citation of the original studies of Setti et al. (2020a-e): "… Sanità di Toppi et al. (2020) have hypothesized that SARS-CoV-2 might be using a species of "highways", which would be made up of atmospheric particulates, increasing its indirect transmission."

Recently, Kumar et al. (2021), citing Sanità di Toppi et al. (2020) without citation of the original papers of Setti et al. (2020a-e): "Similarly, the possibility of SARS-CoV-2 for the exploitation of "highways" made up of atmospheric particulates has been hypothesized in another article (Sanità di Toppi et al., 2020)."

22) Martelletti and Martelletti (Apr 15, 2020), citing Setti et al. (2020c): "… the atmospheric particulate matter exercises a carrier (or boost) action along with the virus. The PM10 (particulate

matter) is composed of solid and liquid particles which allow to float in the airflow longer and to be widespread over larger distances. Atmospheric PM has a sub-layer that facilitates the virus survival in airflows for hours or days." Martelletti and Martelletti (2020) put forward an assumption/hypothesis and used a hypothesis (a 'private opinion' of Setti et al. (2020c)) as possible evidence for this.

The conclusion of Martelletti and Martelletti (2020) was mentioned by Domingo and Rovira (2020) without citation of the original studies of Setti et al. (2020a-e): "These authors [means Martelletti and Martelletti] have suggested that the SARS-CoV-2 could find suitable transporters in air pollutant particles."

Then, Trancossi et al. (2021), citing Domingo and Rovira (2020) [100], Bontempi, E. (2020b) [99], and Setti et al. (2020e) [101]: "Otherwise, it has been demonstrated that, in the presence of stable weather conditions and high concentrations of particulate matter (PM), the virus could create clusters with PM [99,100]. Further experimental evidence has been produced by Setti et al. [101]."

As shown above, the main idea that "the SARS-CoV-2 could create clusters with PM" belongs to Setti et al. (2020a-e). Domingo and Rovira (2020) simply supported this idea and cited Martelletti and Martelletti (2020) without citing the original studies by Setti et al. (2020a-e). Moreover, Trancossi et al. (2021) cited Bontempi (2020b), but Bontempi (2020b) did not support this idea and directly stated that "the results show that it is not possible to conclude that COVID-19 diffusion mechanism also occurs through the air, by using PM10 as a carrier."

Tung et al. (2021), citing Martelletti and Martelletti (2020) without citation of the original papers of Setti et al. (2020a-e): "Viruses may be adsorbed through coagulation onto PM and remain airborne for hours or days (Martelletti and Martelletti, 2020), thereby increasing inhaled concentrations of virus via PM in the lungs."

Moreover, Tung et al. (2021) based on unproven facts (without direct or indirect supporting evidence) concluded: "In brief, PM2.5 may provide a good platform to "shade" and "carry" the SARS-CoV-2 during atmospheric transport. Thus, PM containing SARS-CoV-2 could be a direct transmission model in a highly polluted area."

Then, Shao et al. (2021), citing Tung et al. (2021) without citation of the original papers of Setti et al. (2020a-e) or Martelletti and Martelletti (2020): "It is assumed that PM could be the transmission model of SARS-CoV-2 infection and could be the "carrier" of SARS-CoV-2, which enters the human body directly (Tung et al., 2021)."

Kumar et al. (2021), citing Martelletti and Martelletti (2020) without citation of the original papers of Setti et al. (2020a-e): "It was further explained that the particulate matter in the atmosphere serves as a carrier or transporter for virus particles [means SARS-CoV-2] enabling them to float in the airflows for a larger period of time, promoting its diffusion to longer distances. In airflows, the virus particles could survive for hours to days (Martelletti and Martelletti, 2020)."

Cao et al. (2021), citing Martelletti and Martelletti (2020) without citation of the original papers of Setti et al. (2020a-e): "Ambient aerosols play a carrier or enhancement role for SARS-CoV-2 (Martelletti and Martelletti, 2020)."

Furthermore, Cao et al. (2021) concluded: "The described evidence above shows that SARS-CoV-2 can combine with ambient aerosols and enter the human body, but there is little experimental evidence about the combination of the SARS-CoV-2 and aerosols. Whether virus aerosol detected around patients are human-exhaled aerosol or ambient aerosol is worth further experimental verification."

Pegoraro et al. (2021), citing Setti et al. (2020a,c) [47,26] and Martelletti L, Martelletti P [5]: "One of the ideas underneath the potential relationship between airborne PM and Covid-19 diffusion is that the atmospheric PM might exercise a carrier action along with the virus [5, 26]. Setti and colleagues recently demonstrated the presence of the SARS-CoV-2 RNA on PM [47]."

Poyraz et al. (2021), citing Martelletti and Martelletti (2020) and statistical study by Conticini et al. (2020): "Recent reports of the statistical data on pandemic displayed that Lombardi and Emilia Romagna in northern Italy had higher incidence of COVID-19 mortalities compared to other zones of Italy (Conticini et al., 2020). Consequently, the viruses are adsorbed onto dPMs and remain in the air for a long time (Martelletti and Martelletti, 2020). Thereby the accumulation of virus concentration increases via inhaled PM in the respiratory tract. … In brief, contamination of dPM 2.5 provides a suitable medium to "keep" and "carry" the SARS-CoV-2 during the transportation via respiratory air (Fig. 1B)."

Recently, Maleki et al. (2021), citing Martelletti and Martelletti (2020) without citation of the original papers of Setti et al. (2020a-e): "Additionally, Martelletti and Martelletti (2020) reported that areas in northern Italy with high PM10 and PM2.5 concentrations had the most COVID-19 affected individuals. Therefore, they expressed that the COVID-19 may find appropriate transport vectors among airborne particles." It is important to note that the paper by Maleki et al. (2021) is an example of the incorrect use of specific terminology — this work is discussed in detail below.

23) Maleki et al. (2021) in the systematic review on the association between atmospheric particulate matter pollution and prevalence of SARS-CoV-2, citing Setti et al. (2020e): "SARS-CoV-2 may use a type of "highway" composed of atmospheric particles that increases its indirect transport (Setti et al., 2020e)."

Then Maleki et al. (2021), citing Setti et al. (2020a,e): "Setti et al. (2020a,e) confirmed the presence of the virus RNA on suspended particles (PM) at the peak of the Italian epidemic, thereby suggesting that it could coagulate with the ambient PM10, reduce it diffusivity and thus, increase the longevity of SARS-CoV-2 in the atmosphere."

Also of interest is the use of the term 'PM' by Maleki et al. (2021): "There is evidence demonstrating that the virus can survive in PM for up to 3 h (Santarpia et al., 2020; van Doremalen et al., 2020)." It is important to note that the sources cited by Maleki et al. (2021) did not mention or use the term 'PM' (or particulate matter, or atmospheric particles) or make any reference to air pollution. In particular, Santarpia et al. (2020) used the term 'virus-laden particles' and van Doremalen et al. (2020) used the term 'aerosol'. It is clear that Maleki et al. (2021) incorrectly cited conclusions from sources and manipulated the terminology, thereby potentially misleading the reader.

Moreover, the same problem can be found from the next line from the paper by Maleki et al. (2021) where they cited the statistical study by Fronza et al. (2020): "Therefore, they hypothesized that an enhanced concentration of PM2.5 could cause an increase in infectious droplets/aerosols containing SARS-CoV-2 less than 2.5 μm in diameter (Fronza et al., 2020)." This claim involves manipulation too, because the original text (Fronzaet al., 2020) has a different meaning: "We thus hypothesized that airborne transmission of SARS-CoV-2 can be influenced by, but is not limited to, indirect action of certain atmospheric conditions that maintain infectious nuclei suspended for prolonged periods of time; parameters that also act on atmospheric pollutants. We thus hypothesized that the increase in concentration of PM2.5 may reflect the rise of infective droplets with a diameter inferior to 5 μm."

Here, Maleki et al. (2021) dramatically change the main conclusion (hypothetical assumption) of Fronza et al. (2020) by replacing "PM2.5 may reflect (in Fronza et al., 2020) with "PM2.5 could cause" (in Maleki et al., 2021).

24) Mukherjee et al. (2021), in a review article, equate respiratory droplets (virus-laden droplets and infectious aerosols) with air pollutants (and PM) and include respiratory droplets in a "list of pollutants responsible for airborne transmission of SAR-CoV-2."

Moreover, Mukherjee et al. (2021), citing Bar-On et al. (2020): "Since the size of the coronavirus is small in diameter (having an average size of 0.1 μm), it can easily adhere to the fine dust particles (PM2.5) leading to chronic as well as acute respiratory disorder or syndrome [55].”

It is noteworthy that Bar-On et al. (2020) did not mention that SARS-CoV-2 or other viruses (virions) can easily adhere to fine dust particles (or PM) or that such events can lead to chronic as well as acute respiratory disorders or syndromes.

Thus, confusion in terminology and incorrect citation policies in the study by Mukherjee et al. (2021) could be misleading to potential readers.

25) Mehmood et al. (2021), citing Setti et al. (2020a, e): “Recently, it is found that SARS-CoV-2 RNA can exist on outdoor particulate matter, and noticed that, in environments of atmospheric stability and high concentrations of particulate matter, SARS-CoV-2 could develop clusters with outdoor particulate matter and thus by reducing their diffusion coefficient increase the endurance of the virus in the atmosphere (Setti et al., 2020a). In another study (Setti et al., 2020e), has confirmed the airborne transfer factor likely to be the interpreting anomalous COVID-19 pandemic in northern Italy, that is distinguished by high particulate matter load especially PM2.5 concentrations. Consequently, such results suggest that COVID-19 transmission is possible influenced by airborne PM2.5.”
26) Tretiakow et al. (2021), citing Setti et al. (2020a): “The observations of Setti et al. on the possibility of creating clusters of SARS-CoV-2 virus with particulate matter (dust) in the external environment are fascinating [45].”
27) Linillos-Pradillo et al. (2021), citing Setti et al. (2020a,e): “The presence of SARS-CoV-2 RNA in 34 p.m.10 samples in the ambient air of an industrial site in the province of Bergamo, which in March 2020 was the epicentre of the Italian epidemic, seems to confirm (at least in the case of atmospheric stability and high PM concentrations) that the virus can create clusters with the particles and be transported and detected in PM10 samples (Setti et al., 2020a, 2020e).”
28) Marques et al. (2021), citing Setti et al. (2020a): “The preliminary detection of SARS-CoV-2 in particulate matter (PM) strengthened the associative hypothesis between PM and COVID-19, suggesting that inhalation of PM might be a potential pathway of transmission (Setti et al., 2020)”; and “Anyhow, the potential role of PM10 as a carrier of SARS-CoV-2 must be confirmed at lab scale, with the detection of the coronavirus in PM10. In relation to this, Setti et al. (2020a) recently detected SARS-CoV-2 in PM10 sampled in Bergamo (Italy) during the lockdown, confirming PM10 and COVID-19 might have not only an associative, but also a casuistry relationship.”

Moreover, Marquès et al. (2021), citing Bontempi (2020b): “… our findings are in agreement with Bontempi et al. (2020), who already hypothesized that PM10 might be a carrier of COVID-19.”

Here Marquès et al. (2021) cited Bontempi (2020b), but on the contrary Bontempi (2020b) do not support this idea and directly state in the paper: “The results show that it is not possible to conclude that COVID-19 diffusion mechanism also occurs through the air, by using PM10 as a carrier.”

29) Lorenzo et al. (2021), citing Setti et al. (2020a): “Higher concentrations of PM10 have been shown to prolong the spread of the virus in the atmosphere, as evidenced by a recent study conducted in Italy that provided evidence showing that the COVID-19 virus can be detected on outdoor particulate matter (Setti et al., 2020a).”
30) Amoatey et al. (2020), citing Setti et al. (2020d) and the preprint (short position paper) by Gaddi and Capello (2020): “The study found a strong positive correlation ($R2 = 0.97$) between a number of infected people with the virus and exceedance of PM10 levels (50 μg/m3) across seven provinces based on lag 14 days (Setti et al., 2020d). According to Gaddi and Capello (2020), the virus infection could mimic the spread of other air pollution-related diseases, and thus, SARS-CoV-2 virus droplets of 0.3–2.5 μm and 2.5–10 μm could be carried by PM2.5 and PM10, respectively. Therefore, indoor environments of Middle Eastern countries, where PM2.5 and PM10 are mainly produced by incense burning (Amoatey et al., 2020; Elsayed et al., 2016; Vallès et al., 2019), have the potential to spread the virus despite lockdown strategies adopted by these countries.”

Then, Zhu et al. (2021), citing Amoatey et al. (2020): “In this context, Amoatey et al. (2020) have revealed that indoor burning could enable the possible transmission of SARS-CoV-2 virus droplets through PM.”

31) Senatore et al. (2021), citing Setti et al. (2020a): “Setti et al. (2020) found a high correlation ($R2 = 0.98$) between the number of new coronavirus infections in the north of Italy and the concentration of particulate matter ≤10 μm in diameter (PM10) in the air. This relationship would seem to indicate that fine dust particles can act as a carrier for the SARS-Cov-2 virus, boosting its spread and viability.”

Then, Zhu et al. (2021), citing Senatore et al. (2021) and (Robotto et al., 2021):“Several studies have suggested that SARS-CoV-2 can transmit through various indoor and outdoor aerosols, particularly by PM (Robotto et al., 2021; Senatore et al., 2021)”. It is important to note, in the review paper by Robotto et al. (2021) no mention that SARS-CoV-2 can be transmitted through PM was made.

32) Recently, Nor et al. (2021), citing Liu et al. (2020) and Guo et al. (2020): “Transmission of SARS-CoV-2 in a range of particulate matter (PM) from submicrometer and/or supermicrometer have been reported (1,10). This suggests that the virus can be transported via solid aerosols.”

It is important to note that Liu et al. (2020) and Guo et al. (2020) never mentioned or used the term ‘particulate matter’ (or PM, or air pollution) in their papers. Here, Nor et al. (2021) associated the term ‘PM’ with SARS-CoV-2. Thus, they incorrectly used the terminology and, as a result, come to incorrect conclusions.

Then, Nor et al. (2021), citing Chan et al. (2020) and Ong et al. (2020): “Recent findings based on air particle measurements have suggested that SARS-CoV-2 can be carried by PM2.5 in the air when healthcare workers remove their personal protective equipment (PPE) (2,5).” Here Chan et al. (2020) and Ong et al. (2020) never mentioned or used the term ‘particulate matter’ (or PM, or air pollution) in their papers.

Then, Nor et al. (2021), without citing any sources: “PM2.5 is known to have a significantly longer lifetime in the air where it can be suspended at an extended period compared to respiratory liquid droplets.”

Recently, Zhu et al. (2021), citing Nor et al. (2021), Anand et al. (2021a), Tung et al. (2021), and Setti et al. (2020a): “PM could act as direct carrier and has prominent role in transmission of SARS-CoV-2 virus (Anand et al., 2021b; Tung et al., 2021). For instance, Setti et al. (2020c) have found the SARS-CoV-2 RNA on PM of Bergamo in Northern Italy. Further, PM2.5 produced from healthcare facilities could influence the presence of SARS-CoV-2 RNA in indoor environments (Nor et al., 2021).”

Here, Zhu et al. (2021) cited Anand et al. (2021a). However, on the contrary, Anand et al. (2021a) did not support this idea and directly state this in their paper. In the abstract in the same paper, Zhu et al. (2021) concluded: “In recent days, PM exposure could be related as a carrier for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus transmission and Coronavirus disease 2019 (COVID-19) infection."

33) Ho et al. (2021), citing Setti et al. (2020a): "Second, the SARS-COV-2 virus may spread through the air by attaching to PM2.5/PM10 particles as demonstrated in previous study (35), thereby spreading COVID-19 disease to other people."
34) Varotsos et al. (2021), citing Setti et al. (2020d): "In addition, the rapid spread of COVID-19 infection in selected areas of northern Italy is believed to be related to PM10 pollution due to airborne particles that may serve as carriers of pathogens (Setti et al., 2020d)."
35) Kayalar et al. (2021), citing Setti et al. (2020a): "The only study confirming the presence of virus in atmospheric PM has reported qualitative results (negative or positive) (Setti et al., 2020b), . …"

In the same paper Kayalar et al. (May 2021): "Correspondingly, COVID-19 may have a contagion route via airborne transmission on atmospheric PM (Bontempi, 2020b; Coccia, 2020a; Zhang et al., 2020c)."

In the same paper, Kayalar et al. (May 2021): "Correspondingly, COVID-19 may have a contagion route via airborne transmission on atmospheric PM (Bontempi, 2020b; Coccia, 2020a; Zhang et al., 2020c)". It is curious that Bontempi (2020b) did not support this idea and directly clarified this matter in the paper. The study by Coccia (2020a) also cannot be used as a cited source in this vein (see discussion above). Zhang et al. (2020c), in a statistical study, analyzed the effects of atmospheric conditions on daily new confirmed cases of COVID-19 in Chinese prefecture cities from January 24 to February 29, 2020, using the Kendall and Spearman rank correlation tests and multivariate estimation models. Zhang et al. (2020c) did not directly state that "transmission of SARS-CoV-2 via/on atmospheric PM". However, they cited two studies (Andrée, 2020; Zhu et al., 2020) in this vein: "Air pollution may exert a significant impact on the transmission of and infection by COVID-19. This is partly because COVID-19 is a respiratory disease, and a denser concentration of ambient fine particulate matter could carry the coronavirus in the air for longer, and across larger distances (Andrée, 2020; Zhu et al., 2020)". Further analysis of this citation chain shows that Andrée (2020) and Zhu et al. (2020) did not make statements that PM (or air pollutants) carry the SARS-CoV-2 in their papers either. Andrée (2020 preprint) performed regression analysis to investigate the relationship between COVID-19 incidence and exposure to particulate matter in 355 municipalities in the Netherlands. And Zhu et al. (2020) aimed to explore the statistical relationship between daily COVID-19 confirmed cases and meteorological variables, and concentration of air pollution in 120 Chines cities obtained from January 23rd, 2020 to February 29th, 2020.

The paper by Kayalar et al. (2021) deserves a separate analysis and is not considered here due to the word limits.

36) Travaglio et al. (2021), citing Setti et al. (2020a): "Furthermore, airborne particulate matter (PM) was recently shown to increase the viability of SARS-CoV-2, suggesting that direct microbial pathogenic transmission occurs through the air and the opportunity for infection is increased in highly polluted areas (Setti et al., 2020a)." It is important to note that the study by Setti et al. (2020a) has nothing with this statement.
37) Dunker et al. (2021), citing Setti et al. (2020a): " …, while in regions with higher PM load, transmission via PM could be an additional pathway (Setti et al., 2020b)."
38) van der Valk and In 't Veen (2021), citing Setti et al. (2020a): "PMs could act as a carrier through the aerosol, conveying viruses and further increasing the spread and survival of the associated virus. By this mechanism, PM could play an important role in the spread of SARS-CoV-2. Setti et al. revealed that SARS-CoV-2 was present in PM samples obtained in the Bergamo area, the epicentre of the Italian COVID-19 epidemic (24)."
39) Ingram et al. (2021), citing Setti et al. (2020a) [48] and Martelletti and Martelletti (2020) [49]: "Particulate matter may be involved in the direct transmission of COVID-19. Setti et al. showed that PM is a carrier of SARS-CoV-2 in northern Italy, indicated by the presence of viral RNA [48]; Martelletti and Martellitti [49] argue that the virus may be absorbed onto PM, thus surviving longer and becoming more aggressive in the immune system; …."
40) Ram et al. (2021), citing Setti et al. (2020a) and other sources: "The typical RT [residence time] of PM is about a week, therefore, any association of the SARS-CoV-2 with ambient aerosols via adsorption on surfaces, especially PM2.5, would allow the droplet nuclei to stay in the atmosphere as long as a week … (Setti et al., 2020b; Stadnytskyi et al., 2020; van Doremalen et al., 2020)."

In the same paper Ram et al. (2021), without citing any sources: "High concentrations of indoor PM are mostly of submicron sizes … and thus, smaller droplets may get attached to a pre-existing particulate matter."

Ram et al. (2021), citing Belosi et al. (2021) and Nor et al. (2021): "It is important to note that SARS-CoV-2 can be transmitted not only by coming in direct contact with the infected droplets, but also by inhaling droplet nuclei and/or by virus attached to a susceptible host particle. The host particle can be preexisting PM in the air (Belosi et al., 2021; Nor et al., 2021)."

The paper by Nor et al. (2021) is the node of the citation network — it was discussed in detail above. Further, Belosi et al. (2021) did not support the idea of "SARS-CoV-2 attached to PM" and directly made this point in the paper. It is obvious that Ram et al. (2021) were incorrect to use the citation in the text.

Moreover, Ram et al. (2021) incorrectly cited Belosi et al. (2021): "However, smaller/nanodroplets are likely to be lingering in the atmosphere for a longer time … or get attached to a pre-existing atmospheric aerosol (Belosi et al., 2021).“; and "As suggested by many recent studies, a possible transmission of COVID-19 via ambient aerosols exists (Belosi et al., 2021)."

Ram et al. (2021) also incorrectly cited Liu et al. (2020): "This study also reports that in the hospital indoor environment the viral RNA was mostly associated with atmospheric aerosols$\leq$2.5 μm (Liu et al., 2020). This is a very important finding because SARS-CoV-2 not only get associated with atmospheric aerosols, but also remain suspended in an indoor environment for several hours increasing their probability of getting recirculated without proper ventilation."

It is important to note that Liu et al. (2020) never used the term 'atmospheric aerosols' (or PM, or air pollution) in their paper. Here, Ram et al. (2021) incorrectly used the terminology, and thanks to this came to the wrong conclusions.

The visualization and cluster analysis of the citation network, depicting the studies reviewed above, is shown in Fig. 2.

For the analysis, 65 studies were selected:

54 were involved in spreading the misconception (Al Huraimel et al., 2020; Amoatey et al., 2020; Arslan et al., 2020; Baron, 2021; Borak, 2020; Cao et al., 2021; Carraturo et al., 2020; Chen et al., 2021; Coccia, 2020a,b; Comunian et al., 2020; Copat et al., 2020; Dettori et al., 2020; Domingo and Rovira, 2020; Dunker et al., 2021; Gaddi and Capello, 2020; He and Han, 2021; Ho et al., 2021; Ingram et al., 2021; Kayalar et al., 2021; Kumar et al., 2021; Linillos-Pradillo et al., 2021; Lorenzo et al., 2021; Maleki et al., 2021; Marquès et al., 2021; Martelletti and Martelletti, 2020; Mehmood et al., 2021; Mukherjee et al., 2021; Nor et al., 2021; Pegoraro et al., 2021; Poyraz et al., 2021; Prather et al., 2020; Qu et al., 2020; Ram et al., 2021; Sanità di Toppi et al., 2020; Shao et al., 2021; Sharma et al., 2020; Senatore et al., 2021; Setti et al., 2020a-f; Tang et al., 2020; Trancossi et al., 2021; Tretiakow et al., 2021; Tung et al., 2021; van der Valk and In 't Veen, 2021; Varotsos et al., 2021; Wang et al., 2020a,b; Xu et al., 2020; Zhang et al., 2020a,c; Zhu

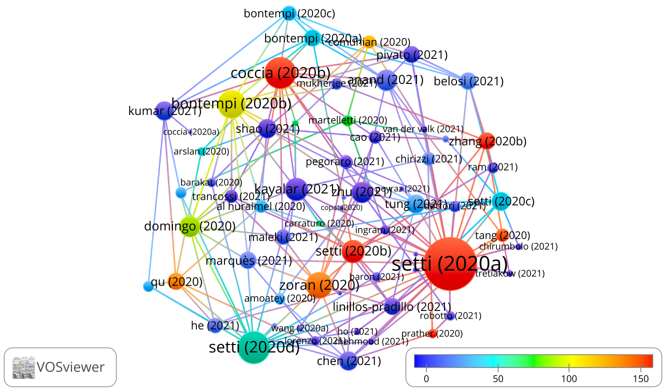

Fig. 2. VOSviewer visualization of the citation network, depicting the studies which formed the basis for the origin of the myth that SARS-CoV-2 creates clusters with outdoor PM and/or air pollutants spread the COVID-19. The sizes/weights of the labels/studies are determined by the citation links between the studies in the citation network. The colors of the labels are determined by the total number of citations received by the studies. VOSviewer software was used for analysis (www.vosviewer.com; van Eck and Waltman, 2014). An interactive version of the graph is available online at: https://app.vosviewer.com/?json=https%3A%2F%2Fdrive.google.com%2Fuc%3Fid%3D1Tmf05WrcKnrT7EGnICJjHO2VUGUmVV8C. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

et al., 2021; Zoran et al., 2020);

11 opposed the misconception and directly stated that there is no scientific evidence of the possible spread of COVID-19 infection through atmospheric particulate matter (PM10 or PM2.5) (Anand et al., 2021b; Barakat et al., 2020; Belosi et al., 2021; Bontempi et al., 2020; Bontempi et al., 2020 a,b; Chirumbolo, 2021; Chirizzi et al., 2021; Pivato et al., 2021; Robotto et al., 2021; Rowe et al., 2021).

Fig. 2 shows that articles supporting the misconception have the greatest weight in the citation network. Moreover, the main nodes of the citation network are most often cited by other researchers, indicating that these works have a high level of interest in the scientific community. It is important to note that the reason for citation frequency may also be that these works were published earlier than other works and this played a role; over time, the citation pattern should change. It is also worth noting that the studies opposing the misconception (Anand et al., 2021b; Barakat et al., 2020; Belosi et al., 2021; Bontempi et al., 2020; Bontempi et al., 2020 a,b; Chirumbolo, 2021; Chirizzi et al., 2021; Pivato et al., 2021; Robotto et al., 2021; Rowe et al., 2021) do not have as much weight and are less cited, with the exception of studies by Bontempi et al. (2020) and Bontempi (2020a,b). However, as shown above, even the study by Bontempi (2020b) (*this study opposed the misconception) was incorrectly cited by some researchers as evidence confirming the hypothesis that SARS-CoV-2 creates clusters with outdoor PM and/or air pollutants spread the COVID-19.

Thus, the analysis of the published papers shows:

a) Specific terminology is not always clearly defined or consistently used by the authors.
b) Authors misinterpret statistical data and information from other sources.
c) Authors frequently cite hypothetical conclusions/claims from reviews inappropriately and use secondary sources instead of the original articles and conclusions confirmed by scientific experiments.

It is important to note that skewed citation practices are not new for the scientific community. In a study published in 2013, Teixeira et al. (2013) surveyed ecology journals and found that authors frequently misinterpret original information. In addition, 22% of the citations were inaccurate and another 15% unfairly gave credit to the review authors for other scientists' ideas. Unfortunately, today, due to misinterpretation of statistical data, skewed citation practices, and misuse of specific terminology, the new misconception is spreading widely in the community.

5. Conclusion

Today, there is controversy about the transmission route of COVID-19. The issue of the spread of COVID-19 is an important multidisciplinary challenge, with many scientists from related fields working on it. Unfortunately, premature and unsubstantiated claims that SARS-CoV-2 coagulates (creates clusters) with outdoor particulate matter (PM10) in the air, and that SARS-CoV-2 can be transported by air pollutants, have been widely circulated and cited by many researchers as fact, as a result of the misinterpretation of statistical data and misuse of specific terminology. The current work shows that these mistakes have resulted in the creation of a new epidemiological myth and the "effect of the existence of many witnesses to a phenomenon that never occurred."

The causal role of air pollutants in COVID-19 transmission remains speculative, given ecologic biases and uncontrolled confounding. Furthermore, the definition of essential concepts related to the relationship between air pollution and coronavirus is highly ambiguous, including the concepts "air pollution as a factor for health risk," and "SARS-CoV-2 spreads by particulate air pollution," and the constituents of 'virus-laden particles', 'droplet nuclei', 'virus-bearing aerosols produced from human atomization', and 'particulate matter (air pollutants) with viruses attached' remain controversial.

Even though many researchers are skeptical about this misconception, every day more and more scientific papers participate in the dissemination of the myth. Researchers need to edit manuscripts more thoroughly and make sure that primary sources are cited correctly to differentiate scientifically proven facts and pre-scientific claims or unconfirmed hypotheses. Special attention should be given to the interpretation of statistical data because "the links provided by positive regression coefficients are statistical links, not causal ones."

> "Now, it is time to move on to more precise and nuanced terminology to facilitate the communication and transdisciplinary collaboration necessary to limit the damage from COVID-19 and get everyone safely back to school and work, together, again." (Milton, 2021).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The opinions and points of view expressed in this work are solely those of the authors and do not necessarily reflect the official positions or policies of affiliated institutions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.112116.

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Ethics approval and consent to participate.
Not applicable.

Consent for publication

Not applicable.

Availability of data and material

All data and materials are included in this article.

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