University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Ambient Air Quality and Health Impact of Exposure to Outdoor Air Pollution in the Moroccan Population: A Systematic Review

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Article Info

Article type:
Review Paper

Article history:
Received: 12 Sep 2022
Revised: 12 Nov 2022
Accepted: 18 Jan 2023

Keywords:
Atmospheric Pollutants
Risk Assessment
Exposure
Air Quality Monitoring
Environmental Pollution

ABSTRACT

Evidence of the health impact of air pollution in Morocco is scarce. We aimed to test our hypothesis that exposure to air pollutants has a significant impact on the health of Moroccans. For this systematic review, we searched PubMed, ScienceDirect, LILACS, and ProQuest databases, Google Scholar, and forward and backward citations for studies published between the database inception and August 16, 2022. All studies and reports that measure air quality in Morocco and its health impact were included, without language restrictions. This study is registered on PROSPERO under number CRD42020163948. Studies were selected based on inclusion and exclusion criteria rather than their methods. The data was extracted, coded, and prepared for future examination. After that, descriptive and thematic analyses were carried out. Of 1230 records identified, 31 were eligible, all of which had annual air pollutant concentrations in excess of WHO Air Quality Guidelines. The health impact was demonstrated in five studies. The most studied pathologies were asthma, respiratory and cardiac infections in children under 12 years and adults. In addition to heavy metals, the most investigated pollutants were PM_{10}, O_3, SO_2, and NO_x. The significant association between exposure to air pollutants and health in the Moroccan population has been demonstrated, even if it is not causal. Future research should quantify the health impact of pollution in other Moroccan cities.

Cite this article: Bouchriti, Y., Ait Haddou, M., Kabbachi, B., Achbani, A., Cherrat, Z., Rida, J., Sine, H., Gougueni, H., Amiha, J., & Ezaidi S. (2023). Ambient Air Quality and Health Impact of Exposure to Outdoor Air Pollution in the Moroccan Population: A Systematic Review. *Pollution*, 9 (2), 660-677.
http://doi.org/10.22059/POLL.2022.348613.1626

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DOI: http://doi.org/10.22059/POLL.2022.348613.1626

INTRODUCTION

The air we breathe today is more heavily and more diversely polluted. While there are natural sources of pollution, the major concern is pollution from human activities. Globally, automotive and industrial emissions, as well as emissions from biogenic sources and biomass combustion, have been implicated for their impact on air quality (Martin et al., 2013; Butt et

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al., 2016; Klimont et al., 2017; Wallace et al., 2018). Air pollution is currently recognized as a serious public health and environmental health concern that warrants more scientific attention (Brunekreef & Holgate, 2002; Landrigan, 2017; Sun & Zhu, 2019; Agbo et al., 2021). In 2021, The World Health Organization (WHO) estimates that 4.2 million deaths are caused each year by exposure to ambient air pollution, since 2016, air pollution has become the world's fourth greatest cause of mortality. As a result, the recent mapping of systematic reviews and meta-analyses on the health impacts of air pollution has revealed a significant rise in the production of knowledge on air pollution and human health (Dominski et al., 2021).

Furthermore, many other pollutants can produce ambient air pollution, although the most investigated are PM, O_3, CO, SO_2, and NO_2 (Brook et al., 2004). What is more, the most often used particle matter descriptors are $PM_{2.5}$ and PM_{10}. However, epidemiological studies discriminate between the short-term and long-term effects of air pollution exposure. Multicenter studies based on time series analysis are used to investigate short-term impacts (Gryparis et al., 2004; Ballester, 2006; Larrieu et al., 2007). These studies all concur that there is an association between O_3 and both total and cardiorespiratory mortality. (Gryparis et al., 2004; Saez et al., 2002; Bell, 2004; Biggeri et al., 2005; Ito et al., 2005), and O_3 and hospitalizations for respiratory diseases (Stafoggia et al., 2009). Cohort studies reveal an association between $PM_{2.5}$ exposure and overall mortality, cardiovascular mortality, and lung cancer mortality over the long term (Pope III, 2002; Pope et al., 2004; Beelen et al., 2008).

WHO data show that almost all of the world's population (99%) breathes air that exceeds WHO guidelines and contains high levels of pollutants, with low- and middle-income countries being the most exposed. Morocco is giving more and more consideration to the problems of air pollution due to accelerated industrial activities or intense road traffic. The cost of air pollution in this nation has been estimated to be 1.03% of GDP (Croitoru & Sarraf, 2017). According to WHO guidelines, Morocco's air quality is moderately dangerous. Furthermore, Moroccan cities are exposed to high particle air pollution as a result of automotive traffic and industry, as well as considerable terrigenous inputs related to the aridity of the climate and proximity to the desert. However, because monitoring networks are still in their early stages, data on these cities is limited. Cities in the South are now exposed to pollution from industrial sources and urban traffic of polluting automobiles as a result of late industrialization (Nejjari et al., 2003). Nonetheless, according to the most recent WHO statistics from 2016, the annual average $PM_{2.5}$ concentration is 28.38 $\mu g/m^3$ [23.6-35.6], exceeding the recommended 10 $\mu g/m^3$ threshold. However, International Association for Medical Assistance to Travelers reports high levels of air pollution in Meknes and Kenitra. In this regard, the Moroccan government has implemented initiatives to monitor air quality, enhance the legal arsenal, and decrease air pollution. The national air quality monitoring network now consists of 29 fixed stations. The purpose of this study was to provide a comprehensive assessment of the human health risk associated with air pollution in Morocco by synthesizing prior research in the country and identifying knowledge and research gaps to support future projects.

MATERIAL AND METHODS

This systematic review was carried out in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) document's methodological requirements (Page et al., 2021). The protocol was previously registered and published (PROSPERO: CRD42020163948/ https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020163948).

Morocco is a country in western North Africa, with Rabat as its capital and Casablanca as its major city and economic capital. Among the most important cities are Mohammedia, Kenitra, Sale, Fez, Marrakech and Agadir. Morocco borders the Mediterranean Sea to the north and the Atlantic Ocean to the west, with the Strait of Gibraltar in the middle. It is bounded to the east

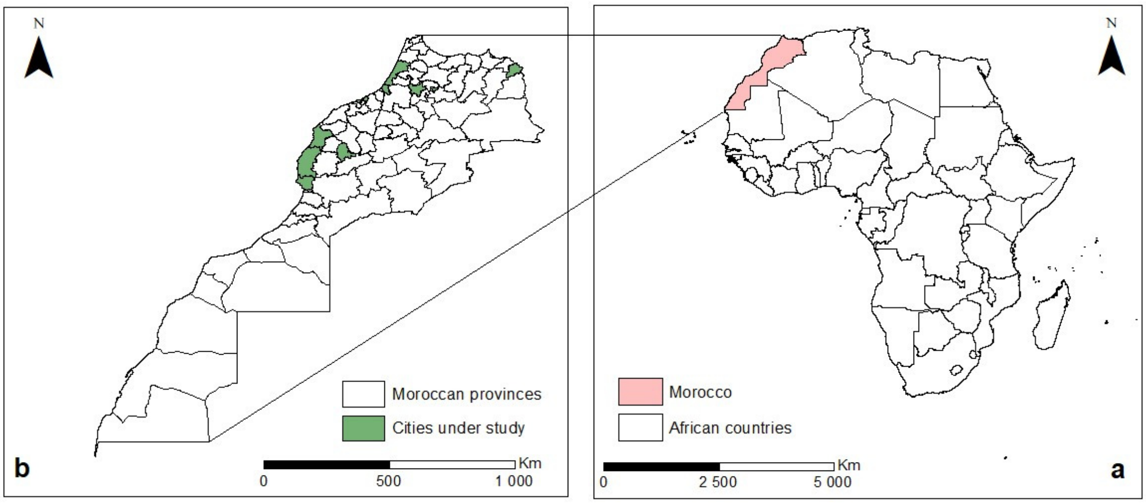

Fig. 1. Location map of study area: **a** Morocco in Africa and **b** Cities included in systematic review

by Algeria and to the south by Mauritania. Geographically, it is distinguished by mountainous or desert areas, and it is one of the few countries with coastlines on both the Mediterranean Sea and the Atlantic Ocean. Morocco's climate varies by area; in the north, it is Mediterranean, in the west, it is oceanic, and in the south, it is desert. The coastal areas have a moderate climate (Figure 1 a).

This study is an organized investigation of publications related to air quality in Morocco and its impact on human health. It was conducted in July 2020. All articles, books, and reports between 1998 and 2022 were retrieved (last query on August 16, 2022). The search databases were PubMed, ScienceDirect, LILACS, and ProQuest. Other data sources were organization study reports by hand search and publications on Google Scholar for grey literature searching by keyword search. There were no limitations on study methods. We imported references from several databases into distinct libraries, then combined the libraries to form a single library. Duplicate records were removed from the library, and just one record was kept. The papers selected for this research underwent descriptive and thematic analysis.

The keywords used in **PubMed** were: ("air pollution*" OR "atmospheric pollutants" OR "climate change and health" OR "air quality" OR "road traffic" OR "pollutant emissions" OR "air quality monitoring" OR "nitrogen dioxide" OR "nitric oxide" OR "sulfur dioxide" OR "ozone" OR "particulate matter" OR "particulate" OR "carbon monoxide") AND ("study" OR "panel study" OR "investigation" OR "time series" OR "timeseries" OR "time-series" OR "case crossover" OR "case control" OR "cohort" OR "cross sectional") AND ("mortality" OR "morbidity" OR "death" OR "admission" OR "hospital admission" OR "emergency services" OR "Primary Health Care Center*" OR "accident & emergency" OR "health effect" OR "health impact*" OR "health complications" OR "short-term effect" OR "long-term effect" OR "ALRI" OR "COPD" OR "LC" OR "IHD" OR "AVC" OR "acute lower respiratory infection" OR "chronic obstructive pulmonary disease" OR "ischemic heart disease" OR "cerebrovascular disease" OR "stroke" OR "asthma") AND ("Morocco*") AND ("1998/01/01"[PDAT] : "2021/12/31"[PDAT]). For **ScienceDirect**: "air pollution" AND "health" AND "Morocco". For **LILACS**: (air pollution) AND (health) AND (Morocco) AND (year_cluster:[1998 TO 2022]). For **ProQuest**: air pollution+Morocco. For **Google Scholar**: "* air pollution *"+"* Morocco *"+"* health effect*" + "* health impact*".

The literature search using the combination of keywords and manual search found 1104 documents in databases and 126 documents in grey literature (Figure 2, identification part of the flow chart). By examining the abstract, two researchers (MA and RA) assessed the eligibility of all citations. When citations could not be excluded based on the title or abstract, or when discrepancies were discovered, the complete text of the article was retrieved and evaluated. After reviewing all titles and abstracts, the same two research authors found full papers with potentially eligible citations. The eligibility and inclusion of these papers in the research were then confirmed by one author (YB). There were no restrictions on the language of publishing. Data was retrieved systematically from papers that matched the inclusion criteria using a specifically designed data extraction form. The following were column headers in the summary tables: Authors, publication year, city, study type, setting, air pollutants examined, methods, and main findings (Table 1). There was no quality evaluation of the included papers.

The search was restricted to items published after 1998. This review includes articles that satisfied the inclusion criteria, which were summarized in summary tables and discussed in the text. Similarly, articles about air pollution research. Review articles, research articles, book chapters, conference abstracts, case reports, correspondence, discussion, mini-reviews, and short communications were among the works featured. This review excludes studies on indoor air pollution, editorials, encyclopedias, news, practice guidelines, and articles published before 1998.

A total of 1230 documents were identified in this search; 10 studies were duplicated; 130 documents were included after abstract review; and 70 studies were considered evaluated as eligible. Finally, 31 studies were selected and examined (Figure 2).

The 31 studies included in this review concerned the cities of Casablanca, Mohammedia, and Kenitra (5 studies each, 16.13%), Mohammedia and Casablanca (5 studies each, 15.63%), Agadir (4 studies, 12.90%), Oujda and Meknes (2 studies each, 6.45%), Salé, Safi, and Marrakech (1 study each, 3.23%) (Figure 1. b). There were studies that concerned a group of cities, such as the study conducted by Abrouki et al. (2021) on the cities of Casablanca, Mohammadia, Agadir, Marrakech, Salé and Fez; the study conducted by Sekmoudi et al. (2021) on the cities of Casablanca, Marrakech, Fez and Essaouira; the study by El Rhzaoui et al. (2015a) on the cities of Mohammedia and Kenitra; the study by Khomsi et al. (2020) on the cities of Casablanca and

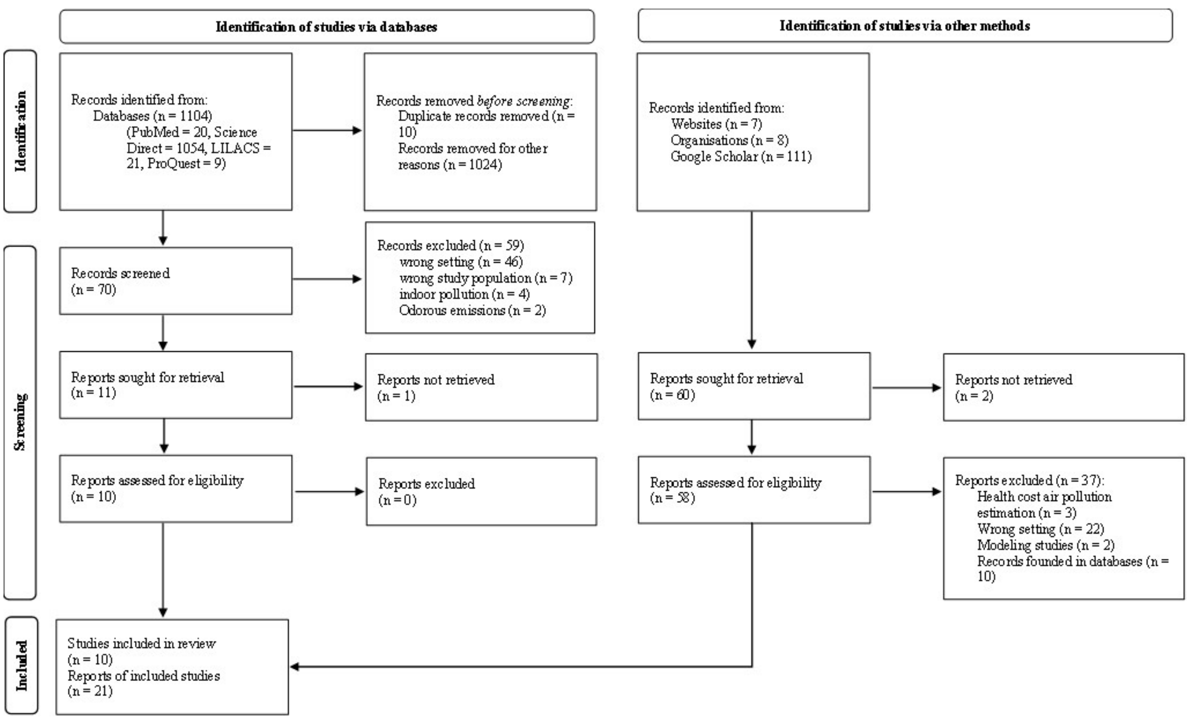

Fig. 2. The PRISMA diagram for Databases and Grey Literature

Marrakech; and finally the State of Morocco's Environment Report in 2020 on several Moroccan cities.

These studies focused on characterization of air pollution (72.97%), health impact assessment (13.51%), and modeling (13.51%). Gaseous pollutants including O_3, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ were the most investigated, as were heavy metals as Hg, Cd, Ti, Co, Sb, As, Pb, Sn, Se, Te, Cr, Cu, Mn, Ni, V, and Zn. There were three publications (Houssaini et al., 2007; Abrouki et al., 2021; Nejjari et al., 2021) and two reports (in 2000 and 2003) from the Ministries of Land Management, Water and Environment and Health that investigated the impact of air pollution on human health. Asthma, respiratory infections, and heart infections were studied in children under five years old and in children under twelve years old.

RESULTS AND DISCUSSION

Through a systematic review, this study sought to establish Moroccan air quality and its potential effects on Moroccan health. Few Moroccan research have looked into the association between air pollution and health. Data on the yearly and daily concentrations of the major pollutants were collected fragmentary, mostly through sensors or from periodic measurements by permanent stations. These fixed stations frequently have technical or functional difficulties. Also note the small number of measuring stations throughout the country. This means that the results obtained cannot generally reflect the air quality in Morocco. Thus, these results should be interpreted with caution. The current study looked through all accessible publications in an attempt to compile a complete list of studies on air quality and the impact of air pollution on health. This study simply identified the investigated air pollution parameters indicated in the collected publications and documents, which may or may not be significantly associated to the diseases caused by these pollutants. Assuming that these parameters have a statistically significant association with morbidity and mortality it is necessary to identify their causal association. As a result, further research is needed to determine the associations between these air pollution parameters and human health. Furthermore, it is important to emphasize that the research included in this analysis did not calculate risk measures in order to identify a significant association.

Since 1998, the current study has been able to extract a list of studies that meet the inclusion criteria on the characterization of air pollutants and their health impacts in Morocco (Table 1)

A network of fixed stations monitoring ambient air quality in many countries. Such a network does not exist in Morocco, where just 29 stations are deployed in 15. As a result of the small number of stations in Moroccan cities, it is difficult to precisely describe the general population's exposure, which illustrates the critical association between ambient air pollution levels and induced human health impacts (Snyder et al., 2013; Holstius et al., 2014; Kerckhoffs et al., 2015). Furthermore, the General Directorate of Meteorology monitors the pollutants measured at these stations against two major thresholds: public information, which requires the permanent air quality monitoring and surveillance committee to take all available public information measures, and alert, which authorizes local authorities to take all necessary emergency measures to limit the effects of high pollutant concentrations (Table 2).

These stations give a broad picture of pollution levels in cities and regions, but they do not detect local impacts, such as air pollutants produced recently by local sources (Knibbs et al., 2014; Kerckhoffs et al., 2015), knowing that the majority of Morocco's energy and electricity sources are largely carbon intensive (84.5%) and that their combustion is an anthropogenic source of mercury, SO_2 and $PM_{2.5}$ emissions according to (Ministry of Energy, Mines and Environment, Department of Environment in 2020. This is why it was necessary to adopt an alternative to physical measurements of air pollutants, such as the use of modeling tools. These tools enable us to understand the phenomena and extend current measurements to areas devoid

Table 1. Studies on air pollutants and their health impacts in Morocco

Authors and publication year	Study area	Type of study	Context	Air pollutants investigated	Methods	Main results
Sekmoudi et al. 2021 (Sekmoudi et al., 2021)	Casablanca, Marrakech, Fez, and Essaouira	Modeling	Possible use of the CAMSRA[a] global analysis in the Moroccan context	PM_{10}	PM_{10} concentrations from global and regional CAMSRA data were examined in relation to daily average PM10 concentrations collected by six Moroccan fixed air quality stations in 2016	Data from the CAMSRA global analysis could be used to estimate climatology, study trends, evaluate models, compare other reanalysis, or serve as boundary conditions for regional models for past periods
Nejjari et al. 2021 (Nejjari et al., 2021)	Casablanca	Air pollutant characterization and health impact assessment	Associations between ambient air pollutants and morbidity and emergency department visits in children and adults	NO_2, SO_2, O_3 et PM_{10}	Conditional Poisson model for 2011-2013	Non-negligible impact on morbidity of outdoor air pollution by NO_2, SO_2, O_3 and PM_{10}
Abrouki et al., 2021 (Abrouki et al., 2021)	Casablanca, Mohammadia, Agadir, Marrakech, Salé, and Fez	Air pollutant characterization and health impact assessment	Impact of ambient air pollution exposure on asthma in children less than one year old	SO_2 et NO_2	Principal components analysis	Asthma incidence was positively correlated with SO_2 and NO_2 concentrations
Ajdour et al., 2020 (Ajdour et al., 2020)	Agadir	Modeling	Ambient air quality modeling	PM, O_3, SO_2, NO_2 et CO	Air quality modeling based on CHIMERE [c] /WRF [d]	Preliminary mapping of the spatial distribution of PM, O_3, SO_2, NO_2, and CO
Otmani et al. 2020 (Otmani et al., 2020)	Salé	Air pollutant characterization	Assessment of PM_{10}, NO_2 and SO_2 level variations during confinement periods	PM_{10}, SO_2, and NO_2	Continuous measurement of PM_{10}, SO_2 and NO_2 before and during the Covid-19 confinement period	Results showed that the difference between the concentrations recorded before and during the containment period was 75%, 49% and 96% respectively for PM_{10}, SO_2 and NO_2
Khomsi et al. 2020 (Khomsi et al., 2020b)	Casablanca and Marrakech	Air pollutant characterization	Assessment of PM_{10} concentrations and study of their relationship with large-scale atmospheric circulation	PM_{10}	Correlations with atmospheric indices (NAO, MO, ENSO) and extreme PM_{10} events	Particulate pollution can be partly induced by the flows that invade the study areas

[a]: Copernicus Atmosphere Monitoring Service Reanalysis
[b]: Air Quality Health Index
[c]: Multi-scale Eulerian chemical transport model
[d]: Meteorological database CHEMIRE option

Continued Table 1. Studies on air pollutants and their health impacts in Morocco

Authors and publication year	Study area	Type of study	Context	Air pollutants investigated	Methods	Main results
El Morabet et al. 2019 (El Morabet et al., 2019)	Mohammadia	Air pollutant characterization	Identification of air pollutant sources and presentation of the different toxicological impacts	NO_2, SO_2, O_3 et PM_{10}	Meteorological and clinical data analysis using mathematical models and geographic information systems	AQHI [b] is unfavorable for 30% of the observed period and in some cases exceeds 8 AQHI
Elhaddaj et al., 2019 (Elhaddaj et al., 2019)	Agadir	Modeling	Dispersion modeling of road traffic emissions	NO_x	SIRANE dispersion modeling	NO_x concentrations are high only near roads. Ozone concentration near roads is about half of the background concentration. SIRANE model efficiency for application to traffic pollution in high traffic urban areas.
Arfala et al., 2018 (Arfala et al., 2018)	Oujda	Air pollutant characterization	Assessment of heavy metals released into the air from cement kilns that burn waste	Hg, Cd, Ti, Co, Sb, As, Pb, Sn, Se, Te, Cr, Cu, Mn, Ni, V, and Zn	Long-term assessment of heavy metals conducted from January 2010 to December 2015 for cement kiln emissions	Presence of various trace metals of Hg, Cd, Ti, Co, Sb, As, Pb, Sn, Se, Te, Cr, Cu, Mn, Ni, V, and Zn in cement kiln air emissions
Inchaouh et al. 2018 (Inchaouh et al., 2018)	Casablanca	Air pollutant characterization	Assessment of pollution from road traffic	NO_2, PM_{10}, CO, and C_6H_6	Overview and comparison of changes to national air quality guidelines	Spatial variability of traffic pollutants
El Morabet et al., 2017 (El Morabet et al., 2017)	Kenitra	Air pollutant characterization	Ambient air quality	O_3 and PM	Analysis of 4652 records from Al Idrissi regional hospital, and 423,890 records from 21 health centers from 2014	Classification in 3 levels of pollution (low: 24%, moderate: 35% and high: 41%)
Tahri et al., 2017 (Tahri et al., 2017)	Kenitra	Air pollutant characterization	Seasonal and spatial variation of $PM_{2.5-10}$ and $PM_{2.5}$ and their chemical compositions over a one-year period	$PM_{2.5-10}$ and $PM_{2.5}$	Chemical composition of PM by total X-ray fluorescence and atomic absorption spectroscopy and spatial distribution by HYSPLIT model	The highest $PM_{2.5-10}$ concentrations were observed in summer and the lowest in winter

[c]: Hybrid Single-Particle Lagrangian Integrated Trajectory model

Continued Table 1. Studies on air pollutants and their health impacts in Morocco

Authors and publication year	Study area	Type of study	Context	Air pollutants investigated	Methods	Main results
Inchaouh et al., 2017 (Inchaouh, 2017)	Marrakech	Air pollutant characterization	Spatial and temporal variation of NO_x, SO_2, O_3 and PM_{10} (2009-2012)	NO_x, SO_2, O_3, and PM_{10}	Pollutant measurements at 3 fixed stations	SO_2 concentrations are low compared to the permitted emission limit values. Exceedance of thresholds for PM_{10} and O_3
Kouddane et al., 2016 (Kouddane et al., 2016)	Mohammadia	Air pollutant characterization	Assessment of heavy metal concentrations	Pb, Cd, and Zn	Study of Pb, Cd and Zn concentrations in the blood of pigeons (Columba livia)	Industrial activities and road traffic are the most important sources of pollution
Gourgue et al., 2015 (Gourgue et al., 2015)	Agadir	Modeling	Pollutant dispersion from stacks and road traffic (NO_x)	NO_x	Industrial site	Interaction between meteorological and geographical conditions and the degree of dispersion
Boularab et al., 2015 (Boularab et al., 2015)	Meknes	Air pollutant characterization	Quantification of dust in g/m2/month, at 14 sampling points (11/05/2009 - 10/06/2009)	PM	Spatial distribution of pollutants using IDW [f] and Kriging [g] methods	High levels of dust in different degrees
El Rhzaoui et al., 2015a (El Rhzaoui et al., 2015a)	Kenitra and Mohammadia	Air pollutant characterization	Five heavy metal concentrations in the lichen Evernia prunastri (11 locations)	Fe, Pb, Zn, Cu, and Cr	Principal components analysis between heavy metal accumulation and atmospheric purity index	High total metal concentration in Sidi Yahya, Mohammedia and Bouznika. Concentrations of most heavy metals in thalli differed significantly between sites
El Rhzaoui et al., 2015b (El Rhzaoui et al., 2015b)	Forest sites in northeastern Morocco (Kenitra, Sidi Boughaba, Mkhinza, Green Belt near the city of Temara, Skhirat, Bouznika, and Mohammedia)	Air pollutant characterization	Concentration of five heavy metals in the lichen Xanthoria parietina	Fe, Cr, Zn, Pb, and Cu	Inductively coupled plasma - atomic emission spectrometry (ICP-AES) measurement Scanning electron microscopy (SEM) of particulate matter on lichen.	Total concentration of metals Kenitra and the Green Belt near the city of Temara. High level of Cu, Cr, Zn, and Pb in samples taken near roads.

[f]: Inverse distance weighting
[g]: Geostatistical technics

Continued Table 1. Studies on air pollutants and their health impacts in Morocco

Authors and publication year	Study area	Type of study	Context	Air pollutants investigated	Methods	Main results
Zaoui et al., 2014 (Zaoui et al., 2014)	Oujda	Air pollutant characterization	Ozone monitoring	O_3	Automatic ozone analysis using UV absorption technology (2 measurement campaigns)	In hot season, 60.07% of the recorded values are lower than the Moroccan guideline and in cold season 92% of the recorded values are lower than the Moroccan guideline
Tahri et al., 2013 (Tahri et al., 2013)	Kenitra	Air pollutant characterization	Study of $PM_{<2.5}$ and $PM_{2.5-10}$	$PM_{<2.5}$ and $PM_{2.5-10}$	Gent Stacked sampling on nucleopore polycarbonate filters and analysis by total reflection X-ray fluorescence (TXRF) and atomic absorption spectroscopy (AAS)	Higher PM concentrations observed in summer. Soil, road dust and traffic emissions were common sources for coarse and fine particles
(Ait Bouh et al., 2013) (Ait Bouh et al., 2013)	Meknes	Modeling	Air quality modeling	PM_{10}, Ca, Cl, Cr, Cu, Fe, K, Mn, Ni, Pb, S, Sr, Ti, Al, and Zn	PM_{10} sampling by stacked filters (SFU) Gent (Between March 2007 and April 2008). Concentrations of Ca, Cl, Cr, Cu, Fe, K, Mn, Ni, Pb, S, Sr, Ti and Zn determined by XFTR [h]. Al was determined by Atomic Absorption Spectrometry.	Measured concentrations are higher than the European and WHO GAQG. Seasonal variation is less important.
Zghaid et al., 2009 (Zghaid et al., 2009)	Kenitra	Air pollutant characterization	Particulate and metallic pollution study	SO_2, Pb, Ni, $PM_{2,5-10}$ and PM_{10}	Sampling and measurement (Partisol, dichotomous, and Gent)	PM_{10} concentrations high in summer. Terrigenous inputs and resuspension. SO_2, Pb and Ni concentrations well above guidelines.
Houssaini et al., 2007 (Houssaini et al., 2007)	Mohammadia	Air pollutant characterization and health impact assessment	Assessment of the health impact of air pollution on the development and exacerbation of asthma (Multivariate analysis, Student's t-test and OR IC95%)	PM and SO_2	Continuous measurement of SO_2 and PM concentrations for 4 years	Air pollution is a determinant for increasing the risk of asthma in children.

[h]: X-ray Fluorescence with Total Reflex ion

Continued Table 1. Studies on air pollutants and their health impacts in Morocco

Authors and publication year	Study area	Type of study	Context	Air pollutants investigated	Methods	Main results
Bounakhla et al., 2006 (Bounakhla and Azami, 2006)	Safi	Air pollutant characterization	Evaluation of the level of air pollution and determination of its effect on public health (2 sites near phosphoric acid production areas, with very high population density and significant road traffic)	S, Cl, Ca, Fe, Cu, and Pb	High Volume Sampler and analyzing the samples using Atomic Absorption Spectroscopy (AAS) Dichotomous Sampler to collect inhalable particles and the X-ray Fluorescence (XRF)	S, Cl, Ca, Fe, Cu and Pb using XRF and Cd by AAS are superior to the WHO GAQG
(Ourzazi, 2003) (Ourzazi et al., 2003)	Marrakech	Air pollutant characterization	Measurement of major air pollutants at six fixed stations	SO_2, NO, NO_2, CO, and O_3	Measurement of SO2 using pararosaniline MCT [i], and NO2 using Griess-Saltzman MCT	Mean values of the concentrations are higher than the WHO GAQG
Mohammadia AirPol study, Ministry of Land Management, Water and Environment and Ministry of Health, 2003	Mohammadia (Only one measurement station)	Air pollutant characterization and health impact assessment	Short-term correlation between air pollutants and asthma attacks and respiratory symptoms in asthmatic children. (19/11/2001 - 07/04/2002)	SO_2 and NO	Longitudinal panel study. Linear regression method (Liang and Zeger) - SO2: P5 = 1µg/m³, P50 = 11.9 µg/m³, P95 = 70.5 µg/m³ - NO: P5 = 2 µg/m³, P50 = 6 µg/m³, P95 = 18.5 µg/m³	Increased asthma and respiratory disease symptoms from P5 to P50 and P5 to P95
Casablanca Airpol study, Ministry of Land Management, Water and Environment and Ministry of Health, 2000	Casablanca (Only one measurement station)	Air pollutant characterization and health impact assessment	Health impact of PM (black carbon) on health events	$PM_{2.5}$	$PM_{2.5}$ measurement. P_5 = 9 µg/m³, P_{50} = 22 µg/m³, P_{95} = 87 µg/m³)	Increase of some health events from P5 to P50 and from P5 to P95
Khatami et al., 1998 (Khatami et al., 1998)	Casablanca	Air pollutant characterization	Air Emissions Inventory for Major Pollutants	SO_2, NO_x, NMCOV [j], and CO	Localization of all emission sources and determination of spatial distributions of emissions using GIS	The most important sources of pollutants are biogenic and anthropogenic

[i]: Tetra Chloro Mercurate
[j]: No-methane volatile organic compounds

of instrumentation. OSPM (Kakosimos et al., 2010), AERMOD (Kumar et al., 2006), CALINE4 (Zhang and Batterman, 2010), ADMS-Urban (Righi et al., 2009), and SIRANE (Soulhac et al., 2011) are some of the most extensively used models. The models can handle air dynamics, or the movement of pollutants away from their origins, as well as chemical and photochemical reactions.

According to the SIRANE model, NO_x concentrations are high only around highways. Because the ozone concentration near roadways is around half that of the background concentration, this model is useful for addressing traffic pollution in densely populated metropolitan areas (Elhaddaj et al., 2019). Furthermore, similar modeling approaches may still be utilized to profitably estimate emissions and their overall impact at the city scale, including the identification of pollution hotspots. Thus, both biogenic and anthropogenic sources of pollution are significant, and, opposed to the global situation in Europe, NO_x production is not dominated by road traffic (Khatami et al., 1998). The analysis of emissions from industrial stacks and road traffic, on the other hand, revealed that the degree of NO_x dispersion is the consequence of the combination of climatic and topographical factors (Gourgue et al., 2015). Data from the CAMSRA global analysis might also be used to compute climatology, examine trends, evaluate models, compare other reanalyzes, or act as boundary conditions for regional models for previous eras (Sekmoudi et al., 2021). Similarly, the CHIMERE/WRF model was used to create a preliminary map of the geographical distribution of PM, O_3, SO_2, NO_2, and CO concentrations. CHIMERE's results range from an overestimation of wind speed and O_3 and CO concentrations to an underestimating of temperature and NO_2, SO_2 and PM_{10} concentrations. For ozone, the modeled and measured data show nearly identical trends, although with a bias (Ajdour et al., 2020).

Furthermore, the current trend in eco-epidemiological studies is towards the use of indicator species as reliable and cost-effective ecological indicators to assess changes in the environment (Asif et al., 2018).

Table 2 shows Moroccan law's air quality guidelines and public disclosure thresholds for air quality monitoring, as well as the WHO and EU limit values. Since the last version of WHO Air Quality Guidelines (WHO AQG) in 2005, there has been a dramatic rise in the quantity of evidence demonstrating air pollution impacts several elements of health. As a consequence of a systematic review of the accumulated data, the WHO lowered almost all of the baseline thresholds on September 22, 2021, noting that exceeding these new air quality thresholds is associated with significant health risks, whereas meeting these baseline levels could save millions of lives. The Moroccan law has not yet been amended in accordance with the most recent WHO AQG. Thus, data of air pollutant concentrations were compared using the 2005 version of the WHO AQG.

Pollutant sources mostly include car traffic, especially extremely old public transport, diffuse or focal sources of industrial pollution, and land-based inputs. The arid environment enables particle concentrations to be high. Indeed, PM trends reveal that concentrations are higher in the summer compared to other seasons. Thus, coarse and fine particles were commonly emitted by soil, road dust, and traffic emissions (Tahri et al., 2013). Furthermore, the concentrations of PM and heavy metals in Kenitra were much higher than in other African cities (Tahri et al., 2017). Bouchriti et al (2022) researched indoor dust in Agadir, Morocco, in a promising and first-of-its-kind study. They discovered that the household dust particles originated from a distant source, were large, and their diameters varied from 0.2 to 363 µm, with a mean value of 22.8 ± 0.6 µm (Bouchriti et al., 2022). Also, particle pollution can be caused in part by seasonal flows that enter the studied regions (the Saharan depression and the Azores anticyclone) (Khomsi et al., 2020b). Although surpassing the 2005 WHO AQG (10 $\mu g/m^3$), annual $PM_{2.5}$ values in Morocco remain the lowest among EMRO countries (Figure 3).

According to the findings of this analysis, the concentrations of the major air pollutants in Moroccan cities appear to be higher than the WHO AQG. High concentrations of PM_{10} have been

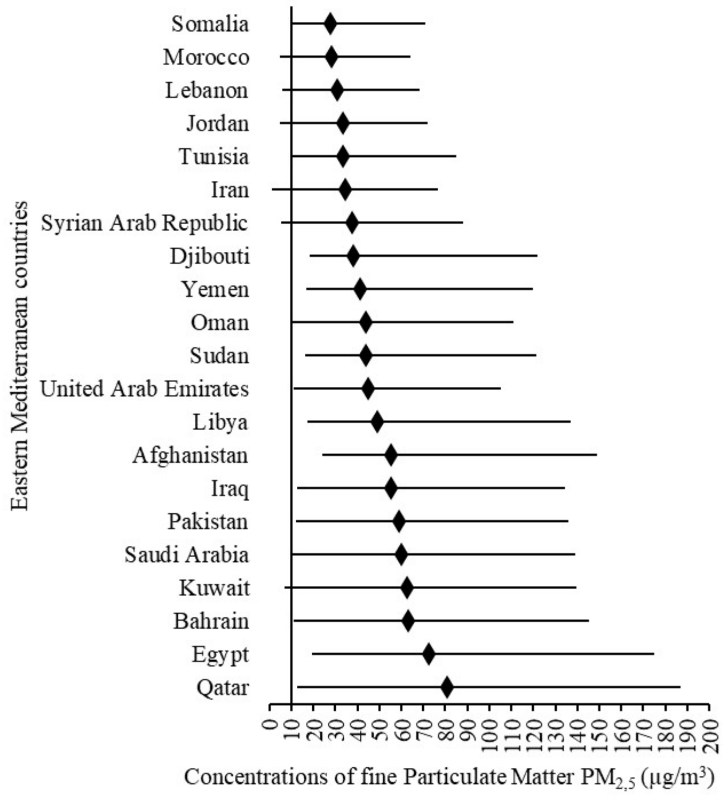

Fig. 3. Concentrations of fine particulate matter ($PM_{2.5}$) in Eastern Mediterranean countries (Data source: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/concentrations-of-fine-particulate-matter-(pm2-5))

reported in Kenitra (Zghaid et al., 2009), Marrakech, Casablanca (Inchaouh et al., 2018), Oujda (Zaoui et al., 2014), and Meknes (Ait Bouh et al., 2013; Boularab et al., 2015). Furthermore, the concentrations of SO_2, NO, NO_2, CO, and O_3 in Marrakech were above the guidelines (Ourzazi et al., 2003). High levels of heavy metal concentrations have been recorded mostly in cities with extensive industrial activity, such as Mohammadia (Kouddane et al., 2016) and Safi (Bounakhla & Azami, 2006). As opposed to Oujda, these metals were in trace quantities (Arfala et al., 2018). Finally, as many studies across the world have revealed, Morocco's air quality improved significantly during the confinement period imposed during the pandemic COVID-19 from 20 March to 20 August 2020 (Khomsi et al., 2020; Otmani et al., 2020).

There has been very few eco-epidemiological research conducted. These are the study reports of the city of Casablanca in 2000, the city of Mohammedia in 2003, and the result of the air pollution research in the city of Safi in 2005. The Ministry of Health and the Ministry of Land Management, Water, and the Environment collaborated on these reports. For the first time, these investigations demonstrated an association between air pollution and health impacts in terms of morbidity and premature mortality.

The main findings of the Casablanca study revealed a positive correlation between air pollution and respiratory diseases, with an increase in certain health indicators such as medical consultations for low respiratory infections and increases in children under the age of five, bronchitis, and conjunctivitis. Research in the city of Safi identified an association between bronchial symptoms and particles. According to the findings of the Mohammedia research, air pollution has a significant impact on the health of asthmatic children. Asthma occurrence was positively correlated with SO_2 and NO_2 concentrations (Abrouki et al., 2021). According to Croitoru and Sarraf (2017), there were between 2,200 and 6,000 premature deaths in Morocco in

Table 2. Air quality guidelines in Morocco and EU AGQ and WHO AGQ

Pollutants	Health protection limit value [a]	Ecosystem protection limit value [b]	Information thresholds [c]	Alert thresholds [d]	WHO AGQ 2005	WHO AGQ 2021	EU AGQ 2015
SO_2 (μg/m^3)	125 percentiles 99.2 of daily averages	20 (annual average)	350 (hourly average)	550 (average measured over 3 consecutive hours)	20 (annual average)	40 (annual average)	50 (annual average)
NO_2 (μg/m^3)	200 percentile 98 of hourly averages 50 (annual average)	30 (annual average)	200 (hourly average)	400 (hourly average)	40 (annual average) -	10 (annual average) 25 (daily average)	40 (annual average)
PM_{10} (μg/m^3)	50 percentile 90.4 of daily averages	-	150 (daily average)	200 (daily average)	20 (annual average) 50 (daily average)	15 (annual average) 45 (daily average)	40 (annual average) 50 (daily average, not to exceed 35 days per year)
$PM_{2,5}$ (μg/m^3)	-	-	-	-	10 (annual average) 25 (daily average)	5 (annual average) 15 (daily average)	25 (annual average)
O_3 (μg/m^3)	110 (average over an 8-hour period)	65 daily averages not to be exceeded for more than 3 consecutive days	250 (260 (average measured in one hour)	260 (average measured in one hour)	- 100 (daily maximum over 8 hours) [e]	60 (Peak season) [f] 100 (daily maximum over 8 hours)	120 (daily maximum over 8 hours)

[a]: Decree No. 2-09-286 of December 8, 2009 setting air quality guidelines and air monitoring requirements.
[b]: Decree No. 3750-14 of October 29, 2014, establishing information thresholds, alert thresholds, and modalities for the application of emergency measures relating to air quality monitoring.
[c]: The public information threshold directs the Standing Committee on Air Quality Monitoring and Surveillance to take all available measures to inform the public.
[d]: The alert threshold entitles the Governor or Wali to take all necessary emergency measures to limit the extent of the peak on the population.
[e]: 99th percentile (i.e., 3-4 exceedance days per year).
[f]: Daily maximum concentration average: 8-hour average of O_3 for the six consecutive months with the highest six-month average O_3 concentration

2014 as a result of air pollution, 50% of which occurred in Casablanca; this corresponds to 0.79% of Moroccan GDP in 2014. They also stated that ischemic heart disease and stroke account for 70% of the health effects of pollution in Morocco (Croitoru & Sarraf, 2017). Also, Khomsi et al. (2020) attribute an average of 13,000 deaths per year in Morocco to air pollution, which represents 7% of all deaths, making it the eighth leading cause of death in the country (Khomsi et al., 2020a). While Farrow et al. (2020) showed that between 3,300 and 7,300 of the premature deaths in Morocco were associated with air pollution generated by fossil fuels. These deaths have a cost equivalent to 0.6 to 1.4% of Moroccan GDP (Farrow et al., 2020).

However, according to Marais et al. (2017), there will be 48,000 avoidable deaths in Africa by 2030, with the mortality rate of electricity producers being three times that of transport. Similarly, Marais et al. (2019) predict 1,000 to 9,999 deaths from air pollution due to fossil fuel consumption for electricity and transport in Morocco in 2030 in a more general prediction of air quality and health effects across Africa (Marais et al., 2019). This study also found that SO_2 and NO_x emissions, which are precursors of fine particulate matter ($PM_{2.5}$), will nearly double in Africa between 2012 and 2030. In this regard, children under 5 years old may have an increased risk of asthma of up to 12% per 10 μg/m^3 increase in NO_2, PM_{10}, SO_2, and O_3 (Nejjari et al., 2021). An increase of 10 μg/m^3 of air pollutants in children ages of five and adults can cause a rise of up to 3% and 4% in respiratory consultations and acute respiratory infections, respectively.

Furthermore, Houssaini et al. (2007) showed that respiratory diseases, highly polluted areas, and infectious diseases are high risk factors for asthma. The prevalence of asthma varies significantly by area (Houssaini et al., 2007; Bouchriti et al., 2021; Rida et al., 2021). Also, air pollution is a determining factor but not the only one to increase the risk of asthma in children; other factors such as respiratory diseases, infectious diseases, genetics, and passive smoking represent a high-risk threat. Research in Agadir city found that the most prevalent clinical symptoms experienced by the community were nervous, respiratory, ocular, and rhino-laryngological. Age, the number of hours spent in the house, the floor occupied, allergies, and medical consultations all have an impact in these symptoms (Bouchriti et al., 2021). Similarly, El Morabet et al. (2019) showed that exposure to high concentrations of PM_{10}, SO_2 and O_3 has an effect on the cardiovascular, respiratory and neurological systems (El Morabet et al., 2019).

CONCLUSION

Studies conducted in recent years have demonstrated the health effects of air pollution. These studies have shown the causal nature of the association between exposure to fine particles (PM_{10} and $PM_{2.5}$), O_3, and short and long-term health impacts. However, the impact of air pollution on public health is greater than at the individual level. Hence, the usefulness of air pollution health impact assessments, which allow one to objectively quantify this impact within a population. This study was conducted to identify the state of knowledge of air quality in Morocco and the health impact of exposure to air pollutants on Moroccans through a systematic review. It seems that the main air pollutants studied were PM_{10}, O_3, SO_2 and NO_x, in addition to the dominant pathologies such as asthma, respiratory and cardiac infections in children and in the adult population. The studies included in this review confirm that the annual levels of these pollutants exceed the WHO AQG. It should be emphasized that the quality of the papers included in this review has not been assessed, therefore the level of uncertainty of the articles studied must be debated.

Also, the association of exacerbation of symptoms of certain pathologies with exposure to high concentrations of these pollutants has been demonstrated. Although these associations have not been shown to be causal, it is therefore necessary to complement these studies with other quantitative and qualitative studies covering other Moroccan cities.

If the current level of air pollution in Morocco is more or less moderate, there is no question of not worrying about it. Moreover, air pollution has an important cost both on the national economy and, more particularly, on the health of Moroccans. As a developing country, Morocco suffers the consequences of global warming as well as other similar countries. This phenomenon is caused by other polluting countries. Certainly, our country has strengthened its legal and institutional arsenal against air pollution, but there is still much to do, practically the development of public policies for the reduction of greenhouse gas emissions. The few national research on the issue makes it difficult to assess the impact of air pollution on Moroccan health.

As a consequence of the study's findings, the following recommendations can best quantify the impact of air pollution at the national level:

- Extending the country's air quality monitoring network, particularly in cities with high industrial activity.
- Using low-cost air pollution sensors rather than expensive stationary measuring stations.
- Management of air pollution measurement stations by Moroccan university research laboratories rather than municipal administrations.
- Improving health data quality through a consistent reporting system for all hospitals and primary care centers.
- Establishing a spatial air quality monitoring network to create a nationwide geographic information system.
- Advancement of research on air pollution bioindicators.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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