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Air pollution due to road transportation in Morocco: evolution and impacts

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***Abstract*—Morocco is experiencing a strong demographic and socioeconomic growth which negatively affect the environment and the population health. Air pollution is the biggest environmental health problem over urban areas. Transport is the major source which contribute with almost 15% of the total emissions (carbon monoxide (CO), nitrogen oxides (NOx) and particles forms). Several factors linked to the vehicles fleet, road infrastructures, fuels, and inadequate reduction measures, are all responsible for the high pollution levels. The alarming rates in some Moroccan cities indicates that there is an urgent need to fight against this phenomenon. This study is a review of air pollution due to road transportation; we first evaluate the effects of air pollution on the human health using data from a large cohort drawn from different study areas including those from Morocco to assess the relationship between road traffic air pollution and health problems; we then present the daily cycle of nitrogen oxide, the main marker of road traffic air pollution.**

Keywords: Air pollution, road transportation, Exposure indicators, Morocco

I. INTRODUCTION

Air pollution is a major environmental risk for health all over the world. Many studies of the World Health Organization (WHO) reveals catastrophic estimates for the mortality generated by this scourge which is directly attributable to human activities. Road transportation has been identified as one of the largest contributors to this pollution. Motor vehicles constitute a diffuse source of air pollution and permanently produce a mixture of toxic gases so-called air pollutants, which create serious risks and lasting harms to the human health and the environment .the greatest health impacts are mainly found in urban areas, where air pollution levels are at their highest. Morocco is a developing country that has experienced over the last decades an important socio-economic development which caused several environmental damages especially on the air quality. In 2003 the cost of air degradation was evaluated at about 3,6 billion Dirham (about 1.03% of the gross domestic product (GDP)). Aware of the magnitude of this situation, Morocco has been committed in a serious approach to fight against the air pollution. Several projects and regulatory measures have emerged, such as the decree on traffic and rolling policy adopted in January 1998 which sets the standards for gasoline vehicles at 4,5% and the opacity of black smoke emitted by diesel at 70%. Nowadays, the national guidelines are trying to regulate the causes by multiplying the prevention, warning and communication measures. In effect, automobile pollution is difficult to identify, it calls a finer and more complex metrology because it gives rise to secondary pollutants that are less stable than industrial pollution indicators. In our study we will try to give a comprehensive overview of the situation in Morocco and establish the link between the road transport emissions and their impact on the air quality and the public health.

II. ROAD TRANSPORT IN MOROCCO

Transport sector is an essential element in the development of the Moroccan economy. The main economic indicators related to transport sector (all modes confused) assured that the sector contributes with 6% to the GDP; it participates with 15% to the revenues of the state budget; absorbs 35% of the national energy consumption and 50% of petroleum products and employs about 10% of the urban workforce. However, the transport sector by its high consumption of energy and its strong growth, is considered as one of the most polluting sectors of the urban atmosphere and is responsible for almost 15% of the total greenhouse gas emissions in Morocco. The Moroccan fleet is experiencing a great growth with an annual rate which is exceeding 4% (Tab.1); in 2014 the country reported about 3.4 million light motor vehicles. Two thirds of the circulating vehicles fleet are older than 10 years, only one in five has an average age of between 5 and 10 years, Models of 1970s and 1980s are still outstanding especially in rural areas. More than one vehicle in two (57%) still run on diesel. For utilities, diesel is still strong with 82% and gasoline dominates the tourist park with 53%.

TABLE I. REGISTERED MOTOR VEHICLES IN MOROCCO

Year	No. of vehicles	Annual Growth Rate
2004	1950802	**4,05%**
2005	2036329	**4,38%**
2006	2146621	**5,42%**
2007	2284060	**6,40%**
2008	2436204	**6,66%**
2009	2624858	**7,74%**
2010	2791004	**6,33%**
2011	2954073	**5,84%**
2012	3118364	**5,56%**
2013	3286421	**5,39%**
2014	3437948	**4,61%**

Source: Road Transport in Numbers - Ministry of equipment, Transportation and Logistics

The total motor vehicles population in morocco has increased from about 1.95 million in 2004 to approximately 3.43 million in 2014, of which two wheelers and goods vehicles saw a growth compared to the Passenger vehicles that have seen a decline. The numbers and percentage of various types of vehicles registered from 2004 to 2014 in morocco are given in table 2. The growth of registered vehicles under various categories over the years up to 2014 is shown in figure1.

TABLE.2. REGISTERED VEHICLES UNDER VARIOUS CATEGORIES

Year	2 Wheels		Passenger vehicles		Goods vehicles	
	No. of vehicles	*% of total*	*No. of vehicles*	*% of total*	*No. of vehicles*	*% of total*
2004	22304	1,14%	1420775	72,83%	507723	26,03%
2005	23227	1,14%	1477330	72,55%	535772	26,31%
2006	24130	1,12%	1551527	72,28%	570964	26,60%
2007	25377	1,11%	1642348	71,90%	616335	26,98%
2008	26821	1,10%	1741224	71,47%	668159	27,43%
2009	28784	1,10%	1864805	71,04%	731269	27,86%
2010	31353	1,12%	1976172	70,81%	783479	28,07%
2011	33765	1,14%	2083710	70,54%	836598	28,32%
2012	36177	1,16%	2192448	70,31%	889739	28,53%
2013	38792	1,18%	2314826	70,44%	932803	28,38%
2014	41101	1,20%	2423609	70,50%	973238	28,31%

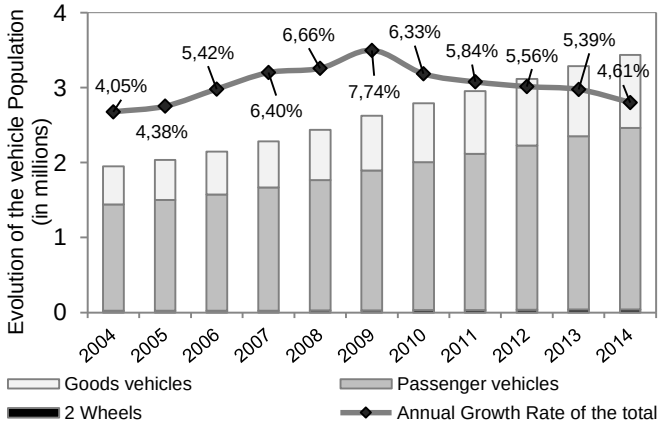


Fig.1. *Composition of vehicle Population (% of total)*

The road is the main mode of mobility of people (90%) and freight transport (75%). The Moroccan road network is considered among the best road networks in Africa, road infrastructure projects and local facilities occupies a prominent place within the various open or scheduled sites both in urban and rural areas. The road network distribution is represented in the following table (Tab.3).

TABLE.3.DISTRIBUTION OF ROAD NETWORK BY ROAD CLASS (KM)

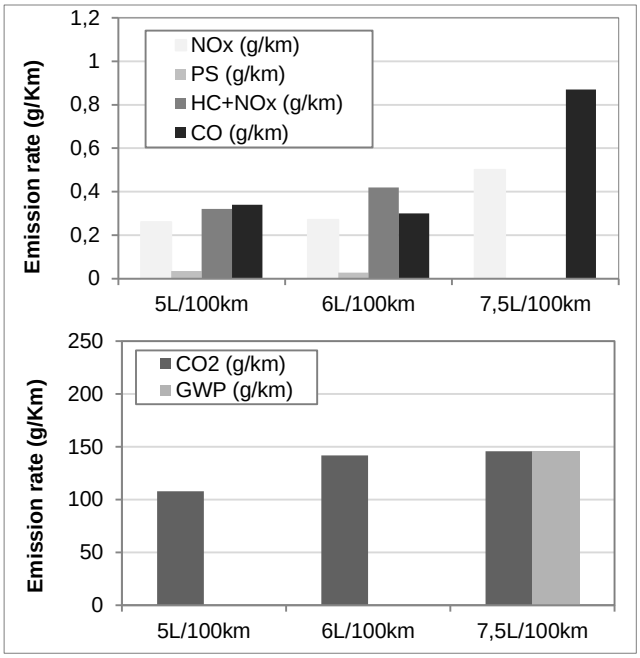
Road classes	Length (Km)
Highways	1511
Unpaved	14721
Coated	41102 → **National**: 9813 **Regional**: 9221 **Provincial**: 22068

III. VEHICULAR EMISSIONS AND AIR POLLUTION

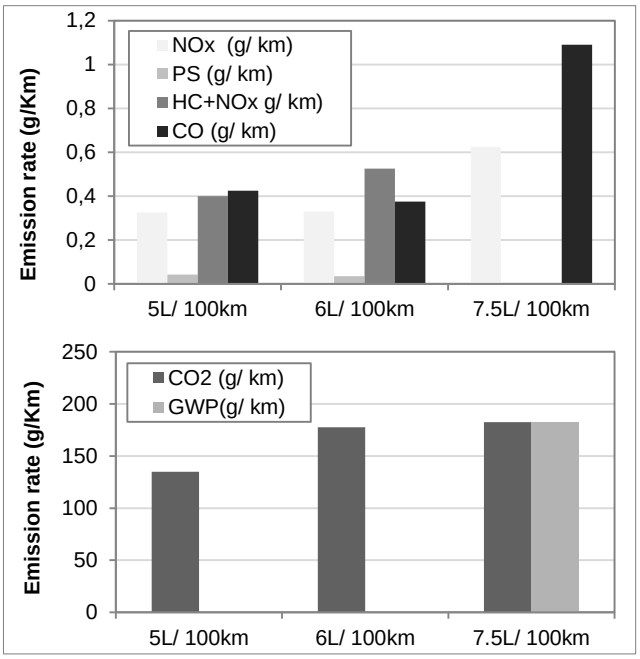
All motor vehicles release air pollutants through the exhaust fumes. Main sources of emission are the Crankcase Emission (or running loss emissions) which is unburnt or partially burned fuel components, the Evaporative Emissions which are directly lost in the atmosphere because of the volatile nature of petrol, and the Exhaust Emission such as carbon monoxide (CO); nitrogen oxides (NOx); volatile organic compounds (VOCs) including hydrocarbons; sulfur dioxide (SO_2); polycyclic aromatic hydrocarbons (PAHs); Particulate matters and metals dust. The couple NOx / Micro particles is the main marker of vehicular pollution; NO_2 results from the oxidation of nitrogen monoxide (NO) released by the exhaust with the ozone of the air. The particles may have metallic origin (friction and wear of engine parts) but also from the abrasion of tires, brake pads and road surfaces. The CO, related to the incomplete combustion, is also considered as automobile pollution indicator. Statistical studies confirms that NO is a very good indicator of automobile traffic because it takes into account the diesel vehicle fleet, while the CO is more sensitive to traffic congestion [1]. Air quality varies across space and time, and depend upon climatic conditions. Time scales that characterize the pollutant dispersion phenomena are multiple, the life time of a pollutant depends essentially on the speed of chemical reactions in the atmosphere [2]. At the local scale, pollution levels can be occasionally very high and varies rapidly with weather and infrastructures configuration.

New cars have more and better emissions control. As such, when the emissions control systems are working correctly cars release less of CO and NOx. In order to prove this, we established the average rates of pollutants rates from new vehicles by using the data bases released by car manufacturers of different brands based on the average fuel consumption per 100 km (Fig.2.a, b). As for used vehicles the emissions are at least 25% higher (Fig 3).

(a).



(b).



GWP: Global Warming Potential = CO2 + 40.NOx + 3CO

Fig.2. *Average emission rates in (a).New Vehicles and (b).Used Vehicles*

Diesel or gasoline, both emit pollutants such as carbon monoxide, nitrogen monoxide, etc., but in different proportions. Diesel vehicles have lower CO_2 emissions than their gasoline counterparts [3]. That places the diesel in an advantageous position towards the greenhouse effect; however, its intrinsic characteristics results in the release of fine particles particularly harmful to health even in the presence of a particulate filter [4]. Diesel and gasoline vehicles have larger differences in their emissions of other atmospheric pollutants, diesel engines emit greater levels of NOx and potentially harmful particles of carbon soot than gasoline. As for evaporation losses, it is one of the vulnerabilities of the gasoline engines, despite the installation of vapors recovery devices (canisters), losses are inevitable as well in refueling at gas stations (on the order of 1 g / liter of liquid fuel introduced) than in Parking and courses, mainly in summer periods (more than 1 g / hour) [5]. In diesel engines, volatilization losses are less important because the diesel is heavier in mass composition.

IV. Air pollution health impacts - Epidemiological evidences

As defined by the WHO; Epidemiological studies have the purpose of showing the distant effects of air pollution (long-term) or intermediate effects (weeks, months), or even the immediate effects (short-term) exposure of individuals to certain pollution rates [6]. During the last twenty years, these studies have emphasized the relation of causal links between exposure to air pollution and the incidence of disease. The results argue that short-term exposure to air pollution can have harmful effects that mainly affect respiratory and cardiovascular functions [7] - [12]. Children and the elderly are more sensitive to pollution [13]. In Morocco, a very limited number of eco-epidemiological studies was realized, this concerns the Casablanca Airpol, Mohammedia Airpol, and the study on air pollution in Safi area. These studies established for the first time a link between air pollution and health effects (morbidity and premature mortality). The main results of Casablanca Airpol revealed a direct correlation between air pollution and respiratory diseases among the population of Casablanca; with an increased incidence of certain health indicators as follows: 38% of medical consultations for lower respiratory infections in Children under 5 years; 9% for bronchitis; 43% for conjunctivitis; 15% for upper respiratory infections in Children under 5 years. The Safi study showed the existence of a significant correlation between bronchial syndromes and particulate matter. As for Mohammedia Airpol, the study confirms the health impact of air pollution on the population especially for children with asthma. However, the information available remains restricted to have a real appreciation of Morocco's situation in relation to the phenomenon of air pollution [14]. The diversity of epidemiological methods used by various teams in different places and the overall consistency of the observations shows that the short- or long-term effects of exposure to indoor and outdoor pollutants, although weak remain detectable [15].

V. Traffic-related air pollution and health

Air pollution from nearby traffic is due to a combination of the so-called background pollution and the local impact of road traffic. particularly in urban areas, populations suffers from the harmful effects of air pollution, many studies conducted at certain urban areas asserts that the local atmospheric pollution related to a dense urban fabric are more subject of the nuisance felt and denounced by the citizens [16]. This

pollution can affect the air of multiple microenvironments such as sidewalks, vehicle passenger compartment, houses, classrooms, offices... [17]; however the road users are the most exposed to this pollution. In Morocco, no recent studies have been conducted to assess the relationship between the traffic-related air pollution and health problems. Despite this lack, we tried to review previous works carried out in different countries. The results of these studies (table 4) confirm the existence of a very close relationship between road traffic pollution exposure and the incidence of disease. Exposure to air pollution is an integrated effect of the concentration of a pollutant in the air, the length of time individual is in contact with it; their activity level and their sensitivity to the particular pollutant. These factors combine to form a received dose of pollutant, the effect it has on the individual, such as impaired health, is known as response. At a time when the assessment of background pollution has a set of scientific and technical tools for surveillance and prevision, the nearby traffic-related pollution is more difficult to characterize [28] ,This issue remains difficult to treat at the era of sustainable development,. Despite the age of the straits and nuisances of the phenomenon on urban areas, the offset is important between the recurrence of the phenomenon in certain areas and treatment modalities and answers that partially satisfies the residents [16] .In order to overcome this gap, a large number of studies including those of the World Health Organization, highlighted the need to establish an air pollution exposure indicator based on the application of exposure-risk relationships from epidemiological studies, local data of exposure to air pollution (permanent measures data of regulated pollutants) and local data on health (mortality, hospital morbidity due to respiratory or cardiovascular causes) . This will allow estimating the potential impact of the reduction pollutants concentrations scenarios across the studied agglomeration.

TABLE. 4. SYNTHESIS OF THE TRAFFIC-RELATED EXPOSURE STUDIES

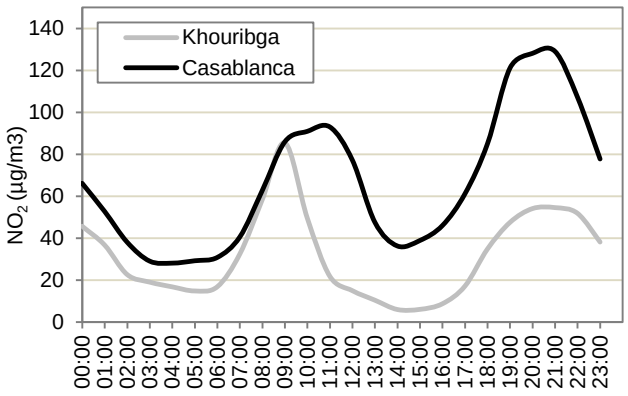
Reference	Location	Context	Methods	Results
Mary B. Rice and al; 2015 [18]	Northeastern USA	Effect of long-term exposure to traffic emissions and $PM_{2.5}$ in lung function decline	·FEV1 and FVC measures ·Land-use model ·Mixed-effects models ·Linear regression models	Positive associations between Proximity to a major roadway and long-term exposure to $PM_{2.5}$ and lung function decline
Johanna .L, and al, 2014 [19]	Boston USA	Effect of long-term exposure to black carbon on levels and rates of decline in lung function in the elderly	·FVC and FEV1 measures ·Spatiotemporal regression model ·Linear mixed models	Long-term exposure to traffic particles accelerate the lung function decline in the elderly
Vette, Alan, and al ,2013 [20]	Detroit, Michigan USA	Traffic related air pollutants and respiratory outcomes in asthmatic children	·Integrated measurement ·Modeling approach	Evidence of roadway impacts and variability between participants
Gruzieva, Olena, and al. 2013 [21]	Stockholm Sweden	Development of asthma and related symptoms longitudinally over the first 12 years of life in relation to air pollution from road traffic	·Individual long-term exposure ·Source-specific exposure ·Emission inventories ·Dispersion models	Modest positive associations between air pollution exposure from traffic during infancy and asthma in children during the first 12 years of life
Zhang, Kai, and al 2013 [22]	Michigan, USA	Risks of traffic for on- and near-road populations	·Simulation modeling ·NO2 scenarios	Health risks from congestion are potentially significant; additional traffic can significantly increase risks
Gehring, Ulrike, and al 2010 [23]	Netherlands	Traffic-related air pollution and the development of asthma and allergies during the first 8 years of life	·Individual exposures to NO2 and PM2.5 ·logistic regression analysis	Exposure to traffic-related air pollution may cause asthma in children monitored from birth to 8 years of age
Morgenstern, Verena, and al. 2008 [24]	Munich Germany	Individual-based exposure to traffic-related air pollutants and allergic disease outcomes in a prospective birth cohort study during the first 6 years of life	·Geographic information systems ·Pollutants measurements ·Regression models	Strong evidence for the adverse effects of traffic-related air pollutants on atopic diseases as well as on allergic sensitization
Kim.J, and al. 2004 [25]	San Francisco California USA	Respiratory symptoms and exposures to traffic-related air pollutants among children near busy roads	·Epidemiologic approach ·Logistic regression model	Positive associations between traffic-related pollution and the respiratory symptoms in children
Hoek, Gerard, and al. 2002 [26]	Netherlands	Traffic-related air pollution and mortality in participants of the Netherlands Cohort study on Diet and Cancer (NLCS)	·Black smoke and NO2 measurements ·geographic information system geocoding	Long-term exposure to traffic-related air pollution may shorten life expectancy
Künzli, Nino, and al,2000 [27]	Europe	Impact of outdoor (total) and traffic-related air pollution on public health in Austria, France, and Switzerland	·Epidemiology-based exposure-response functions	Air pollution caused 6% of total mortality About half of all mortality caused by air pollution was attributed to motorized traffic

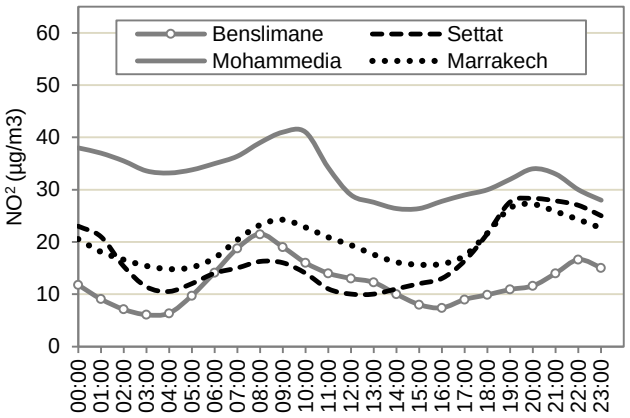
VI. SPECIFIC SITUATION OF AIR POLLUTION IN MOROCCO

In Morocco, the main sources of air emissions are transport, industrial units and energy installations (thermal power stations and petroleum refineries). According to statistics of the Secretariat of State at the Ministry of Energy, Mines, Water and Environment, road traffic emissions would account for 50 to 60% of total emissions. In some large cities which knows an important urban concentration such as Casablanca, Rabat, Tangier, Marrakech and Meknes, the concentration rate of some pollutants such as NOx and PM exceeds the national regulatory standards and those tolerated by the WHO, with pollution episodes (or peaks) that usually occurring during the winter, spring and summer months, while weather conditions are favorable to the accumulation of pollutants and limits their dispersion. The encountered difficulty in Moroccan cities lies in the fact that road traffic is becoming more important because of the ever-increasing cars fleet and the increasing use of diesel-powered engines in addition to limited road spaces.

We here propose to study the evolution of the daily cycle of NOx, the main marker of automobile pollution. This typical cycle represents a day type obtained on average for every hour of the day; It allows highlighting variations in emissions from human activities throughout the day and the major physicochemical phenomena induced by the solar cycle; It also helps to highlight the evolution of the dispersive conditions in the atmosphere during the day (stability of the lower layers during the night). In order to study the influence of road traffic on the air quality, we established the daily profile of nitrogen dioxide, for some Moroccan cities, from the measurement data recorded on the Moroccan air quality monitoring network database. The daily evolution shows correlated maxima during morning and evening rush hours due to the home-work commuting trips. These peaks which are more or less marked; are directly related to automobile traffic and local dispersion conditions. During periods of low traffic, pollutant levels are equivalent to the general atmosphere. The highest levels in Casablanca and Khouribga reflect the importance of road traffic density in those cities.

Fig.3. Mean daily cycle of NO_2 in different cities of Morocco





VII. CONCLUSION

In Morocco, the fight against air pollution is today placed in the heart of the strategies of sustainable development and the protection of the environment, by reinforcing the policies of action through massive investments in prevention and management. Despite the progress made with the renewal of buses and taxi's parks, installation of tramway networks in some major cities, even today, the urban population is daily exposed to traffic pollution. It is likely that the reduction in unit emissions of vehicles by the use of catalytic converters and that the reduction and improvement of the fluidity of traffic in urban areas will lead in the long term to a reduction in average levels, particularly in primary pollutants. However, the reduction of air pollution in urban areas can only be achieved through the organization of the information on the air quality state and the improvement of road safety in towns, while opting for clean transport patterns.

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