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ASSESSMENT OF THE PRESENT LEVEL OF THE MAIN COMPOUNDS OF POLLUTANT EMISSIONS FROM INLAND WATERWAY TRANSPORT SYSTEM IN THE DANUBE REGION WETLANDS-GREEN DANUBE

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Abstract

In order to quantify the NO, NO_2 and NO_X, SO_2, CO and PM emissions from ship traffic on the Danube, seasonal measurements (autumn, spring and summer) were performed during the period 2017-2018, using high precision mobile equipment. It is the first-time air quality monitoring actions and activities of this type have been carried out on inland waterway traffic in Romania. The selected indicators were analysed according to ISO standards in force, using chemiluminescence-based methods and non-dispersive infrared spectroscopy. The results were supplemented by measurements of ambient temperature, humidity and with observations on the number of ships transiting the fixed point, their category and the time interval. The statistical analysis is based on the daily average measurements for the monitoring points located upstream of the Danube Delta Biosphere Reserve; for Sulina monitoring area in the Danube Delta, hourly average values were used in correlation with the environmental factors. The results showed significant increases in emissions in the diurnal range, and the statistical analysis of the data showed good correlations between the power developed by ship engines and nitric gases. It has also been observed that the emission peaks can be attributed to the maximum power developed by the ships' engines. Ambient temperature and air humidity showed values typical of the monitored period, and the wind direction was favourable during the three monitoring campaigns.

Key words: carbon monoxide (CO), Danube navigation, nitrogen dioxides (NO_2), pollutant emissions, particulate matter (PM10 and PM2.5), sulphur dioxide (SO_2)

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1. Introduction

At both European and global level, the reduction of pollutant emissions is one of the priorities with a high degree of importance (Dunea et al., 2017; Rusanescu et al., 2018). In addition to industry and urban agglomerations, the transport sector is presented in many studies as a major emission factor (Beloev et

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al., 2017; Du et al., 2018; Rosu et al., 2016;). Compared to land transport, shipping is considered as a relatively clean form of transport if we take into account the tonnage/distance ratio (Cullinane and Bergqvist, 2014; Rosu et al, 2016; Viana et al., 2007). However, about 15% of NO_X emissions have an anthropogenic source, out of which about 8% can be attributed to waterborne transport (Eyring et al., 2005; Viana et al., 2014). Also, the increased use of resources and the scale of trade in the last decades have impacted on inland waterway traffic and consequently the increase of inland waterway transport capacities has been achieved without much attention to the negative impact on the neighboring areas of the waterways, often being wetlands or protected reserves.

Danube River is clearly not used to its full potential for navigation purposes. Cargo volumes transported on the Danube are only between 10% and 20% of those carried on the Rhine River (Nicolae et al., 2017). Increasing ship traffic will aggravate local ecological problems on the Danube River and its surroundings, but its potential could be better exploited by enhanced multimodality, improved infrastructure, and modernization of the fleet in order to reduce the negative impact of emissions.

Over the last decades there has been a lack of investment and little innovation in the river fleet of Danubian countries such as Romania, Bulgaria, Serbia, Hungary, Slovakia and Croatia whereas the state of waterway infrastructure raises safety issues, impacting the transport efficiency (possible payload) and fuel consumption.

Another important aspect in the field of shipping is that the vast majority of engines used for propulsion is represented by diesel engines that often use lower quality diesel as compared to road vehicles (Viana et al., 2014). Due to low fuel quality, even the most modern ship engines produce high levels of emissions (Cullinane and Bergqvist, 2014).

If for sea traffic levels quantification of emissions is based on fuel consumption (Corbett and Farell, 2002, Nicolae et al., 2017) and on measurements using satellite imagery, in the case of Danube ship traffic, there have been no measurements made in situ, so far. In this context, the present study aims at quantifying the main components of pollutant emissions, namely, the nitrogen dioxides (NO_2), carbon monoxide (CO) and particulate matter (PM) coming from ships on inland waters in order to limit their impact on the quality of the environment.

The EU has committed itself to pursue the goal of shifting transport to less energy-intensive, cleaner and safer modes of transport. Danube River can play a prominent role in reaching these targets. The Danube region includes one of the air pollution “hot spots” in Europe.

This paper describes the atmospheric pollution along the Danube River in context with the impact of Inland Water Transport by performing the measurements of pollutant emission levels in four critical environmental areas. GREEN DANUBE project responded to identified challenges through direct contribution to more effective and integrated approaches to limit impacts of Inland Waterway Transport on the Danube ecosystem by performing the measurements of pollutant emissions level in critical environmental areas along the Danube and analysing pollutant emissions impact on air quality.

2. Materials and method

The monitoring of pollutant emissions was carried out between 2017 and 2018 in three seasonal campaigns (autumn, spring and summer). At the same time, measurements have been made on temperature, wind rose, humidity and observations on the number of ships that have crossed the fixed point, their category and the time interval. The duration of a set of measurements was 24 hours, under optimal conditions (weather and hydrological level) for navigation.

The importance of conducting this study started from the need to know the present level of the main compounds of pollutant emissions, namely, nitrogen oxides (NO), carbon monoxide (CO), sulphur dioxide (SO_2) and particulate matter (PM10 and PM2.5) resulting from ship traffic on four Danube selected areas that are part of the UNESCO list and part of Natura 2000 (2016).

An area plan has been drawn for measurements (Fig. 1), with the representation of the Danube region areas and the points where the measurements were made. The following 4 (four) critical environmental areas along the Danube River were selected as the most relevant ones for the performance of air pollutant emission measurements.

Danube Delta: Sulina Channel MM 0-MM 34 (RO) - It is a uniquely dynamic relatively wild ecosystem with a rich diversity of wetland habitats but at the same time, it is the main access route for seagoing ships.

Iron Gates I km 930-km 947(RO-RS) - This area of the Danube is the route for maritime transport in Romania, Bulgaria, Serbia, Hungary, Austria and Germany and is characterized by the presence of the Iron Gates 1 hydroelectric power plant, the largest dam on the Danube and one of the largest hydropower plants in Europe, located on the Iron Gate, between Romania and Serbia. Gemenc (Baja) km 1475-km 1480 (HU) – It is a unique forest area between Szekszárd and Baja, Hungary, located in the vicinity of the navigable Danube sector for the transport of goods, passengers and leisure. It is a Ramsar site, a wetland of international importance, the only remaining tidal area of the Danube in Hungary.

Confluence of the Danube River and Inn River (Engelhartszell) km 2200 - km 2224. (DE-AT) - Along Engelhartszell-Confluence of the Danube and Inn section, there is one of the starting points for cruises. There are only a few small settlements and the Donauleiten Park in this area.

Prior to the measurements, the following items were taken into consideration: components to be measured, methods to ensure representative samples, applicable standard techniques, ways to ensure accuracy or uncertainty requirements and conditions of the air pollution source. A set of main air pollutant emissions CO, SO_2, NO_2, PM10 and PM2.5, according to ISO 17025 standard was collected and the equipment (Fig. 2) used for the measurements was in full compliance with the reference method mentioned in Annex VI of the EC Directive (2008) and certified according to the following European Standards: EN 14211 (2012), EN 14212(2012), EN 14626 (2012), EN 12341 (2014).

The device can generate three types of values: instantaneous, short-term and long-term. 24 hour - continuous determinations of the concentrations were performed in all the measuring points. The device was placed on the wind direction, at the maximum possible distance away from industrial areas and urban agglomerations.

The data collected also included observations on the number and types of vessels passing by the fixed point and on the time interval. The observation of the ships was also made visually using the Marine Traffic application at the same time the equipment was measuring the concentrations of the pollutants in the investigated ambient air.

3. Results and discussion

3.1. General analysis of results

Concerning the first mechanism, the European Directives currently regulating concentrations of main pollutants in ambient air are outlined to avoid, reduce and even put a stop to harmful effects of these pollutants on human health and the environment. Air Quality Standards under Directive 2008/50/EU (EC, 2008), can apply over different periods due to the fact that health impact linked to certain pollutants can arise over different exposure; these are summarised in Table 1)

Table 1. Limit value and period under *Directive 2008/50/EU* - Air pollutant

Air Pollutant	*Concentration (Standard introduced by Directive)*	*Averaging period*	*Permitted Exceedances each year*	*Maximum value measured*
Fine particles (PM_{10})	50 µg/ m^3 40 µg/ m^3	24 hours 1 year	35 n/a	not exceeded
Fine particles ($PM_{2.5}$)	25 µg/ m^3	1 year	n/a	not exceeded
Sulphur dioxide (SO_2)	350 µg/ m^3 125 µg/ m^3	1 hour 24 hours	24 3	not exceeded
Nitrogen dioxide (NO_2)	200 µg/ m^3 40 µg/ m^3	1 hour 1 year	18 n/a	not exceeded
Carbon monoxide (CO)	10 mg/m^3 (1ppm = 1.15mg/m^3)	Maximum daily 8-hour mean	n/a	not exceeded

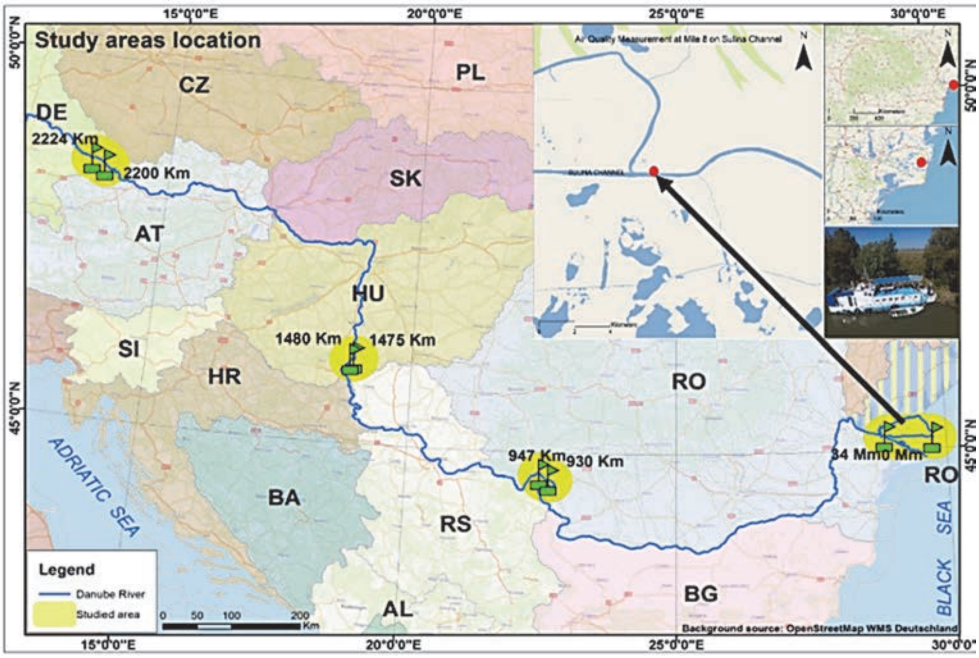
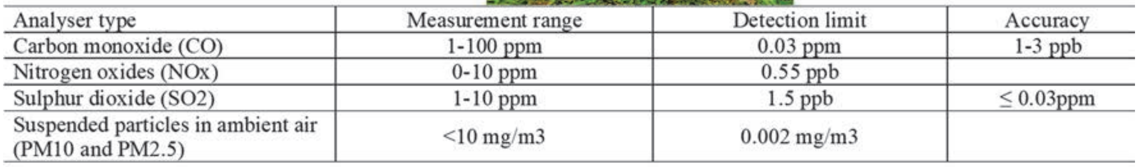


Fig. 1. Map of the monitoring points



Analyser type	Measurement range	Detection limit	Accuracy
Carbon monoxide (CO)	1-100 ppm	0.03 ppm	1-3 ppb
Nitrogen oxides (NOx)	0-10 ppm	0.55 ppb	
Sulphur dioxide (SO2)	1-10 ppm	1.5 ppb	≤ 0.03ppm
Suspended particles in ambient air (PM10 and PM2.5)	<10 mg/m3	0.002 mg/m3	

Fig. 2. Measurement equipment and measuring capabilities

It is important to distinguish contamination representing the presence of elevated concentrations of a particular air pollutant from pollution which means the evidence that these concentrations have adverse effects on different ecosystems. In this respect, the evidence that elevated concentrations have significant ecological impacts is more limited (Richard et al., 2016). The intensity of vessel traffic has been measured by the number of vessels passing within a time unit, in this case 24 hours (Fig. 3).

The naval traffic in Sulina Channel and Iron Gates selected areas is uniformly distributed over the three sampling seasons, with the highest number of ships recorded in July, and consisting of speed boats, almost 80% (Fig. 3). This confirms the importance of the area for tourism activities in summer and naval transportation as a significant activity for these two areas. During the three periods in which the measurements were made, the largest number of both passenger ships and powered barges were recorded at Engelhartzell and Gemenc.

These types of crafts use only diesel as fuel. The direction of navigation (upstream/downstream) could be a factor influencing gas emissions as a greater power is needed to navigate upstream, especially with heavy loaded transports.

During the three monitoring campaigns there were completely different ambient and traffic conditions, the graphical analysis of total PM concentrations did not reveal links between vessel traffic intensity and hourly dynamics of this indicator. We estimate that for this parameter, the high humidity conditions of the Danube are of decisive influence.

In the first set of measurements (October 2017) a smaller number of motor boats were observed, most of them being large vessels or barges, especially in Iron Gates. In April and July 2018, the variation and the values are similar, with values ranging from 15 to 20 µg/m3 (fig. 4). Because in the afore mentioned months the number of ships and the power generated by their engines have different dynamic, not being so well synchronized, we can conclude that the source emitting those PMs is not represented by naval traffic, especially in the monitoring points located in Engelhartszell and Gemenc, where the access for road traffic was in the vicinity of the Danube. In case of the Danube River, we compared two measured indicators for the studied areas. Fig. 4 shows the air pollutant concentration and trends in PM2.5, PM10 for all selected critical environmental areas.

An increase in NO_2 emissions (Fig. 4) comparable to the increase in particulate matter less than 2.5 microns/ PM2.5 was observed in Gemenc, possible sources of particulate matter (fraction PM10) being the influence of road traffic and industrials areas, besides emissions from vessels transiting the river at the time of the measurements or the direction/intensity of the wind and atmospheric humidity. In the case of PM2.5, the significant variations over monitored period could not be attributed to the traffic of the ships that crossed the monitoring point. (reviewer_2). The maximum values for this parameter were up to 28.75 µg/m3 and are comparable to those reported by Kurtenbach et. al, (2016) in a study conducted in Germany on the Rhine River (km 843), near "Wunderland Kalkar". PM10, showed the same pattern of variation as PM2.5.

Nitrogen dioxide (NO_2) is a gas with a sharply strong smell that, together with fine airborne particulate matter (PM), gives smoggy air its reddish-brown haze appearance (WHO Report, 2003).

The monitoring area of the Sulina channel is discussed in point 3.2. Detailed analysis of results - Case study: Sulina channel. Regarding CO emissions (Fig 5) the average values recorded showed variations of up to 0.48 ppm between the monitored areas. In terms of seasonality, the largest variations were identified in the Sulina channel monitoring area. However, the average values did not exceed 0.65 ppm. Considering the maximum permitted levels for this parameter (Table 1), we can see that there are no reasons for concern regarding this type of pollutant.

Analyzing the obtained concentrations, it can be observed that the average measured SO_2 values were below 2 ppb (Fig. 6). These values are most likely due to the legislative restrictions at European levels (ECA) which imposed the use of low sulphur content fuels by ships. (Kotchenruther, 2015). (reviewer_2) The highest average value was 1.68 ppb obtained in October at the Iron Gates I. It is possible that these significantly higher values are caused by the relief of the area (mountain gorge), which caused the exhaust gases to be concentrated in the monitored area.

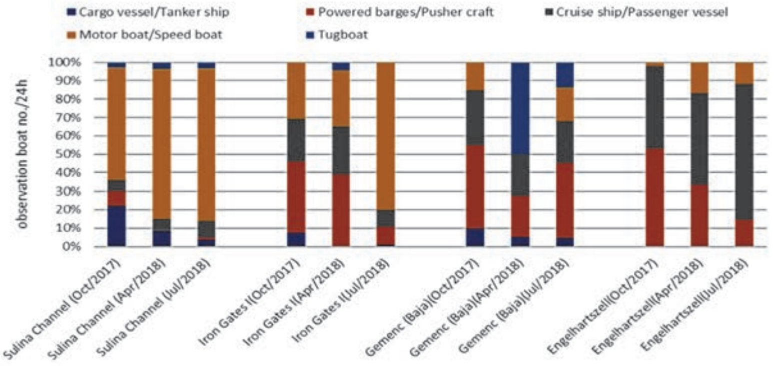


Fig. 3. Number and category of vessels crossing the monitoring points in 24 hours

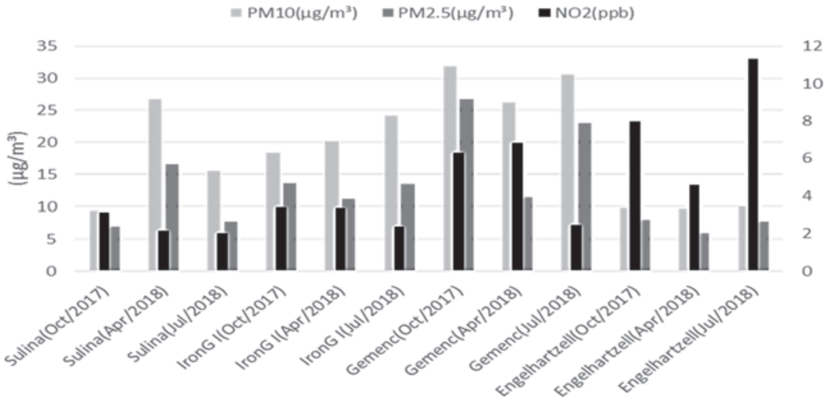


Fig. 4. The average concentrations (24h) of PM2.5, PM10 and NO_2 measured in all fixed points

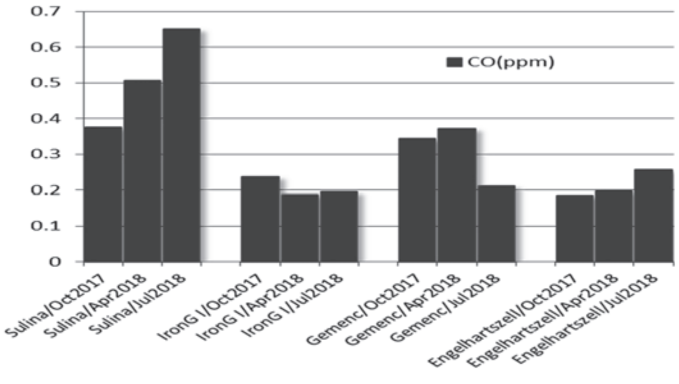


Fig. 5. The average concentrations (24h) of carbon monoxide (CO) in air quality measurement

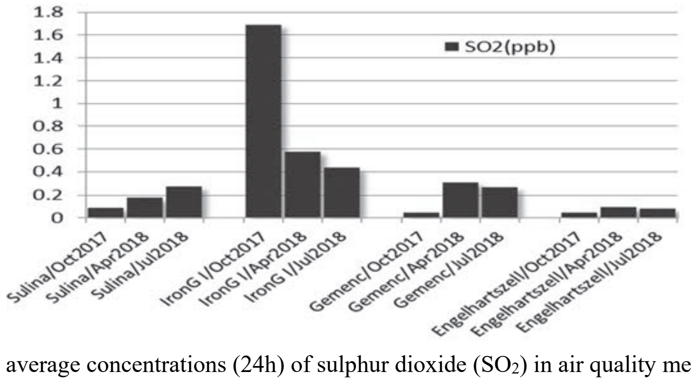


Fig. 6. The average concentrations (24h) of sulphur dioxide (SO_2) in air quality measurement

3.2. Detailed analysis of results - Case study: Sulina channel

Sulina channel in the Danube Delta Biosphere Reserve was selected for the detailed analysis of the results. The location of this monitoring area (N45°10'25.2"/E029º29'11.8") makes the influence of large urban and industrial agglomerations to be at a minimum level compared to the other upstream areas.

Starting from the ship traffic situation, respectively the power developed by the engines of the ships crossing the fixed point, reported in KW, depending on the type of fuel (Fig 7a), the hourly dynamics of monitored pollutants was develop. Fig. 7 Ship traffic and dynamics of pollutants monitored in meteorological conditions - temporal variation, October 2017

Taking into account the day / night interval, a relative stability was noticed at night, namely in the interval 20:00 – 06:00 for nitric gas (NO, NO_2, NO_X) (Fig. 7b), when their values did not exceed the threshold of 2 ppb, while in the case of carbon monoxide (CO) (Fig. 7d), the values were below 2 ppm. A significant increase was noted during the day when 2 emission peaks with different duration of presence were observed. In the case of the first emission peak, which was measured between 08:00-09:00 respectively 13:00-14:00 for both nitric gases and carbon monoxide (Fig. 7b-d), the correspondence with the two power peaks developed by diesel engines in the range 09:00- 10:00 →14:00-15:00 is obvious (Fig. 7a). Also, in the case of these gases, a good correlation with the power developed by the engines of the vessels (Fig. 8a-d) is observed, which shows that the values of the pollutant concentrations are directly proportional to the power developed by the engine ships. The 1 hour gap between the peak of gases and power developed by diesel engines can be attributed to the predominant wind direction, namely S-SE (Fig. 7c), which favoured the faster movement of pollutants towards the monitoring point. The second peak, measured between 16:00-17:00 respectively 18:00-19:00, cannot be correlated with ships that have crossed the monitoring point and is most likely the result of wind-borne emissions from other neighbouring areas. Possible sources in this case are maritime and fluvial-naval vessels waiting to enter the Sulina Marine Line at a distance of 8 MN (14.8 km) from the monitoring point, as well as the ships in Sulina port, which, during the standstill, have the generating sets in operation. Also, the possibility that the measured emissions came from much more distant sources was not ruled out.

In the case of total PMs (Fig. 7f), significant variations over the diurnal/ nocturnal range cannot be attributed to the traffic of ships that crossed the monitoring point. The maximum values for this parameter were up to 28.75 $\mu g/m^3$ and are comparable to those reported by Kurtenbach et al. (2016) in a study conducted in Germany on the Rhine River (km 843) near "Wunderland Kalkar". There is no correlation between the hourly dynamics of the total PMs and the power developed by the engines of the ships that crossed the monitoring point (Fig. 8e), which shows that this parameter was not influenced by the ship traffic. Atmospheric humidity and ambient temperature during the monitored period (Fig. 7c) showed usual values for October, namely maximum of 93.6% and 22.010C, during the 24 hours of monitoring there were no anomalies of these parameters.

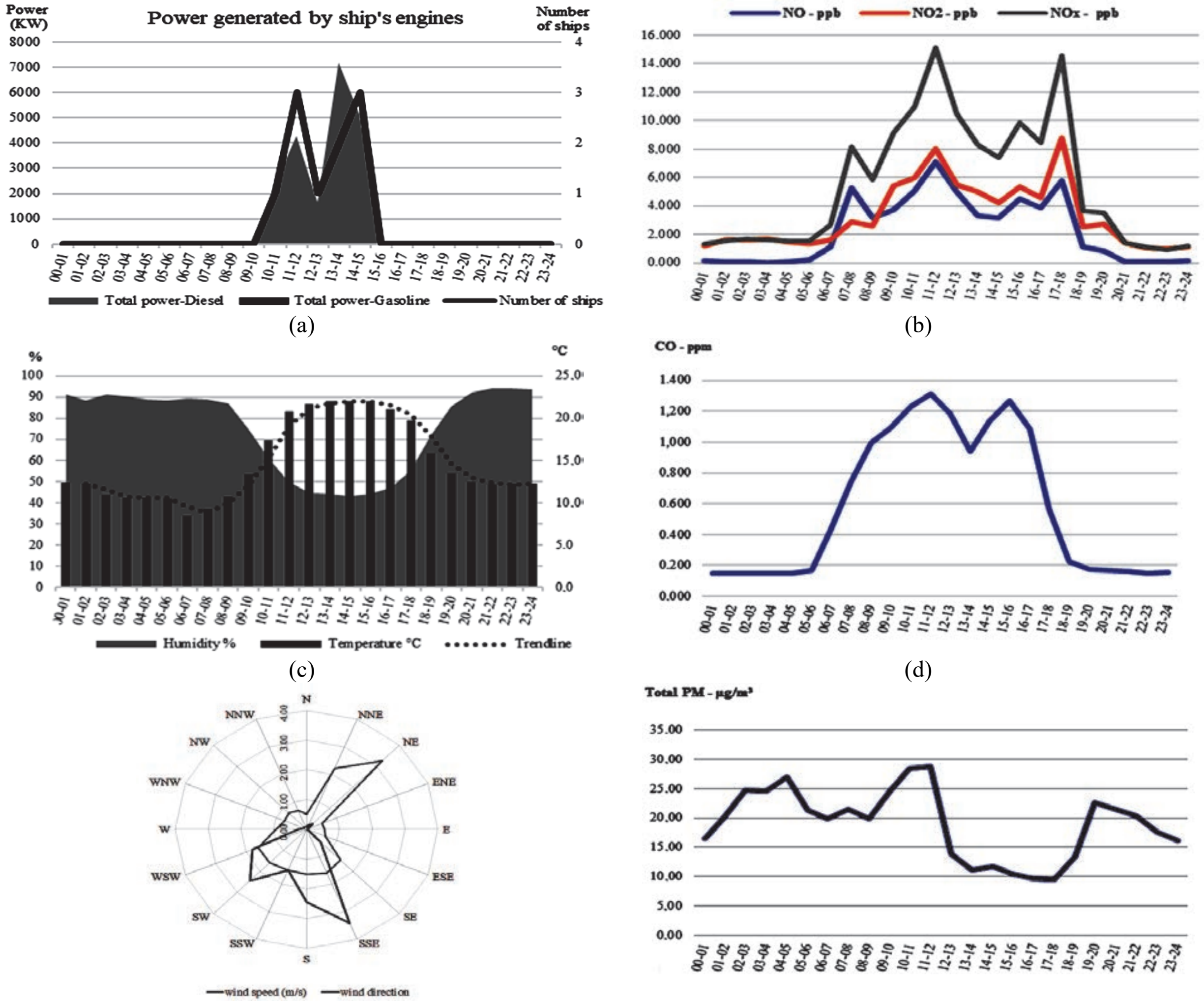
If during the October 2017 measurements, ships crossing the monitoring point were all equipped with diesel engines (engines that use diesel fuel or equivalent), during the April 2018 campaign, a second type of engine was met, respectively petrol engines (Fig. 9a). Another aspect that differentiated the set of measurements in April was the ambient temperature, with values inferior to the previous campaign, reaching maximum 19.40C and air humidity variations between 55.8 % and 92.5% (Fig. 9c).

Although there were significant differences in atmospheric conditions and in the number of ships crossing the monitoring point, in the case of nitric gases (NO, NO_2, NOx) (Fig 9b), there was the same number of emission peaks between 11:00-12:00 → 13:00 – 14:00 and 13:00-14:00 →15:00-16:00 that can be attributed to the two peaks of power developed by diesel engines in the same timeframe (Fig 9a).

This finding is supported by the good correlation of nitric gases (NO, NO_2, NO_X) with the power developed by diesel engines (Fig 10). In the case of power developed by petrol engines, there were no differences in the hourly dynamics of the above-mentioned pollutants. It is worth mentioning that ships crossing the monitoring point and having petrol engines do not have the capacity to develop a maximum power of more than 223.7 KW, compared to diesel engine cases with ships having the capacity to develop power of up to 4800 KW.

However, the statistical analysis revealed a correlation, statistically significant ($\alpha = 0.50$) in the case of petrol engines, too (Fig 10). Also, for the spring period, it was noted that the maximum values recorded for nitric gases/ nitrogen oxides (NO, NO_2, NOx) were up to 58% lower compared to the autumn campaign measurement set.

This difference was most likely caused by the higher ambient temperature in October, which led to an acceleration of oxidation process of atmospheric NO_2, first of NO and then of NO_2, to which it was added a difference of about 2000KW in the maximum power developed by ships crossing the monitoring point in October compared to April. A similar situation is presented in the studies conducted by Sadanaga et al. (2008) and Geddes et al., (2009). In the case of carbon monoxide (CO), variations within the range of 0.146-0.203 ppm in the diurnal / nocturnal range are observed. In the hourly interval 13:00-14:00 respectively 15:00-16:00 there is an emission peak with values up to 0.435 ppm (Fig. 9d), which can be attributed to the power peak developed by diesel engines in the same timeframe.

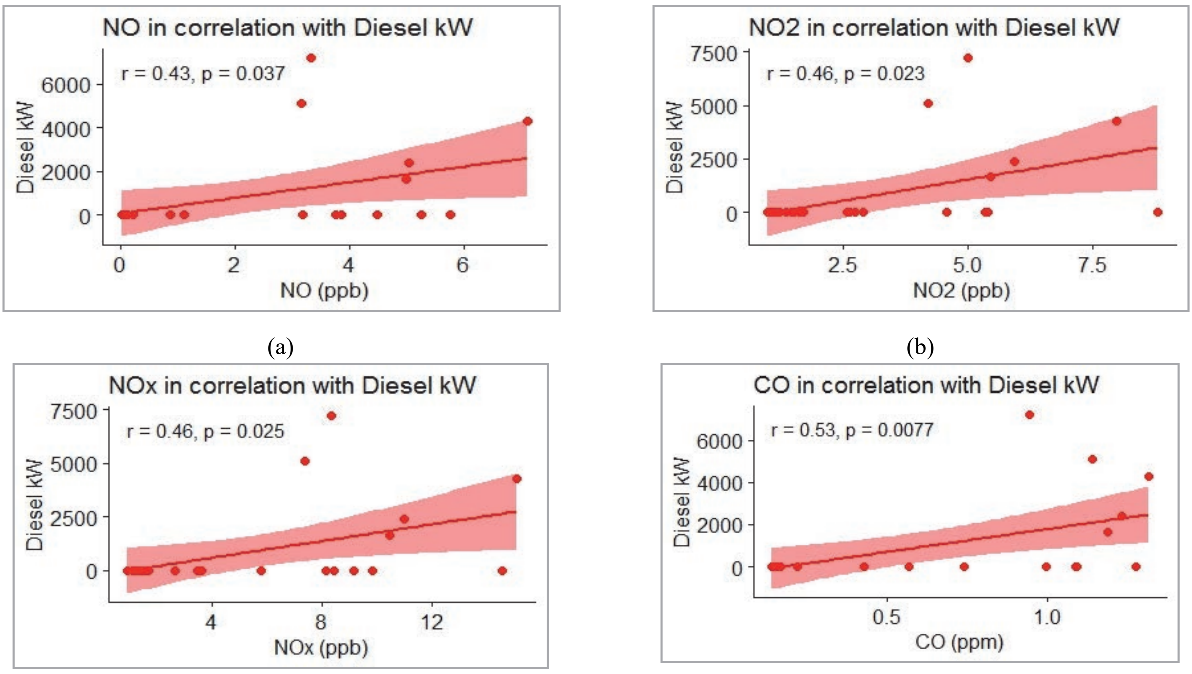


(a) (b)

(c) (d)

(e) (f)

Fig. 7 Ship traffic and dynamics of pollutants monitored in meteorological conditions - temporal variation, October 2017 (a) power generated by ship's engines; (b) concentration of NO, NO_2, NO_X; (c) temperature and humidity dynamics in 24 hours; (d) CO concentration in 24 hours; (e) wind rose an direction in 24 hours; (f) Total PM concentration in 24 hours



(a) (b)

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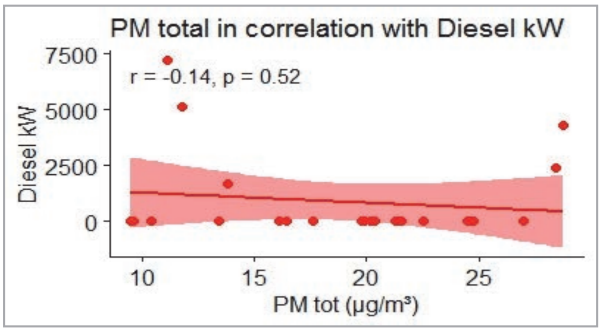
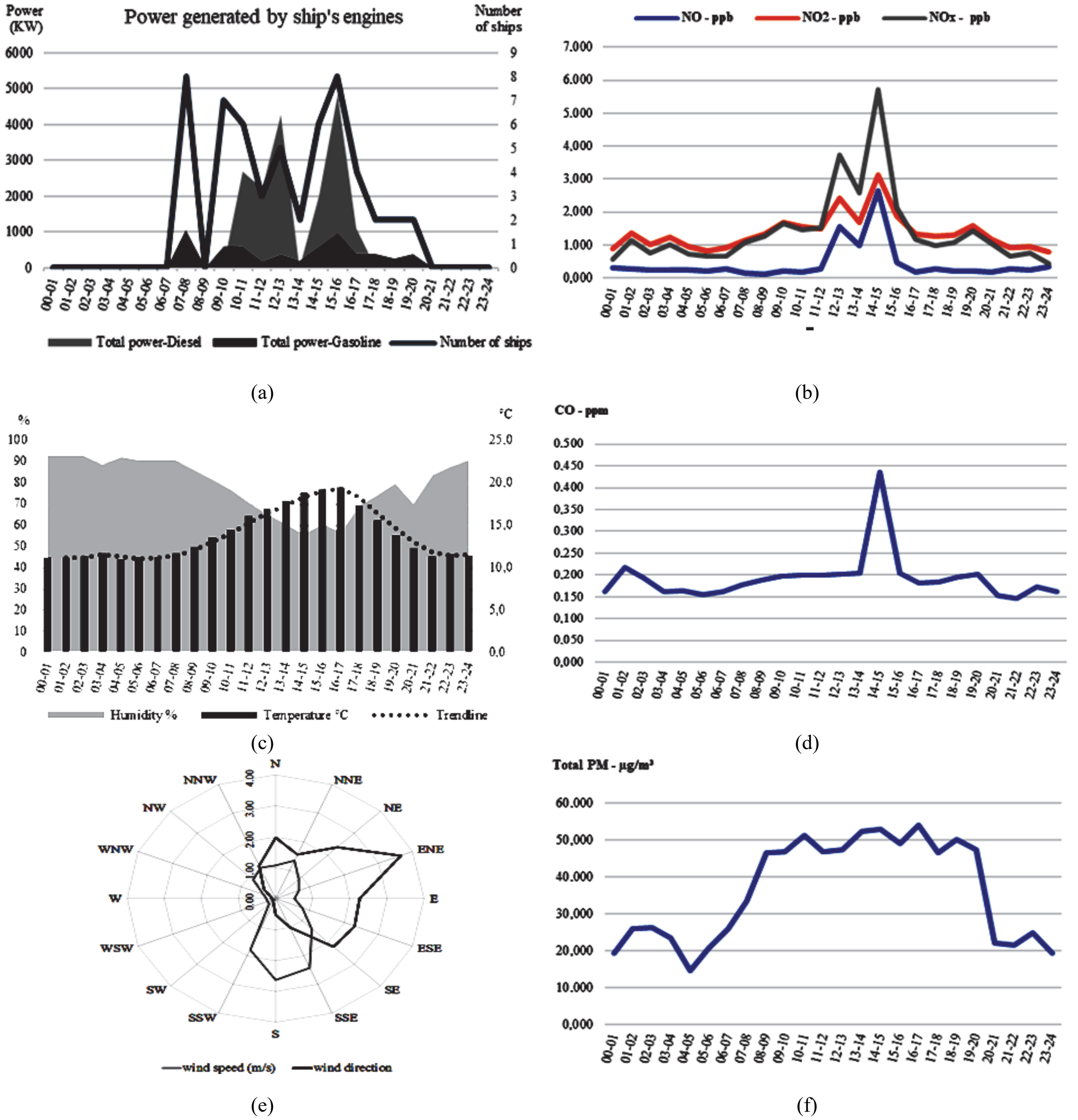


(e)

Fig. 8. The correlation between developed power (KW) and gas concentration (a) NO (b) NO_2; (c) NO_X; (d) CO; (e) PM; - October 2017



(a) (b)

(c) (d)

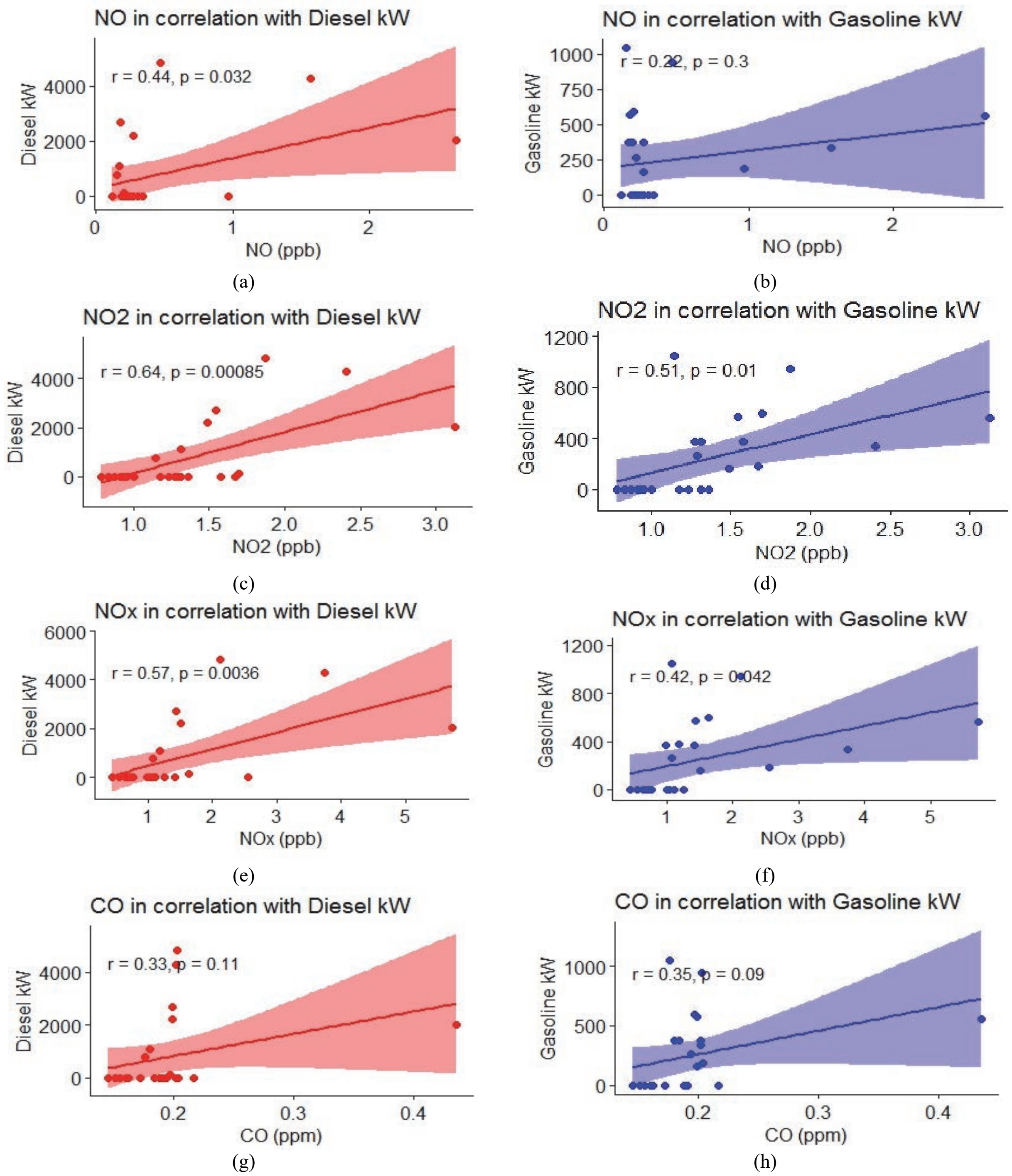
(e) (f)

Fig. 9. Ship traffic and pollutant dynamics monitored in meteorological conditions of April 2018: (a) power generated by ship's engines; (b) concentration of NO, NO_2, NO_X; (c) temperature and humidity dynamics in 24 hours; (d) CO concentration in 24 hours; (e) wind rose and direction in 24 hours; (f) Total PM concentration in 24 hours

For the first peak of power developed between 11:00-12:00 →13:00 – 14:00, in the hourly dynamics of carbon monoxide (CO), there is a slight increase in concentrations compared to the time interval 0500-0600, when the monitoring point was not transited by any of the two types of ships. Compared with nitric gases NO_2 and NOx, there is no significant correlation between carbon monoxide (CO) and the power developed by the two types of engine (Fig. 10).

The total PMs monitored in the spring campaign (Fig. 10) showed the same variation pattern on the diurnal / nocturnal interval compared to the previous campaign and the maximum values showed differences of up to 21.0 µg/m³ higher than values in autumn.

Despite the fact that starting from the graphical representation of PM concentrations, none of the emission peaks can be attributed to ship traffic, the correlation between this indicator and the power developed by the two types of motorization reveals a strong link supported by the values of those two correlation coefficients (Fig. 10).

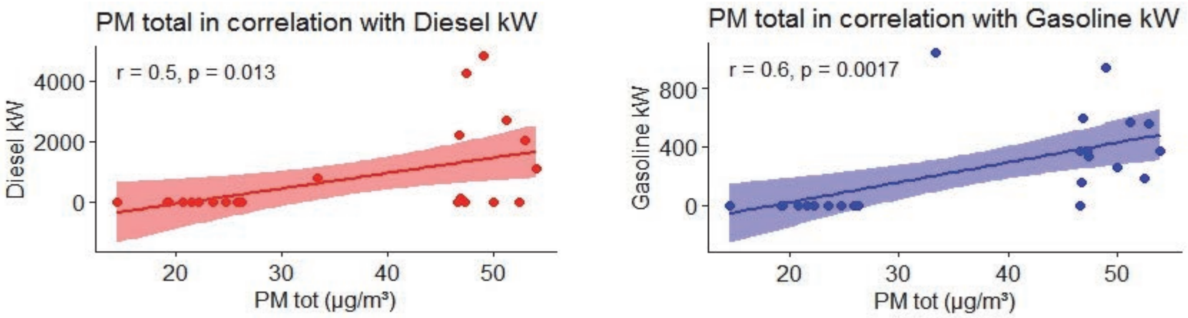


(a) (b)

(c) (d)

(e) (f)

(g) (h)



(i) (j)

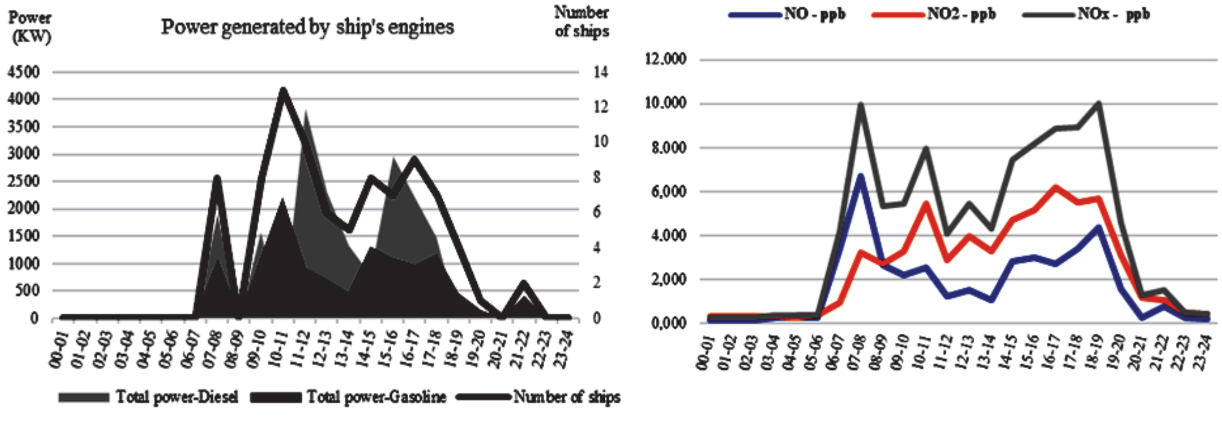
Fig. 10. Correlation between developed power (KW) and concentrations of (a) NO in diesel; (b) NO in gasoline; (c) NO_2 in diesel (d) NO_2 in gasoline; (e) NO_x in diesel (f) NO_x in gasoline; (g) CO in diesel (h) CO in gasoline; (i) PM in diesel (j) PM in gasoline in the set of measurements April 2018

The set of measurements in the summer period (July 2018) was carried out under conditions of ship traffic with a significantly higher intensity of petrol engines. The maximum power developed by petrol engines was up to 2199 KW, and in the case of diesel engines, 3828.42 KW (Fig. 11a). At the same time, during this campaign, the maximum ambient temperature was also identified, with values up to 27,8^{0}C. Atmospheric humidity has been similar to the previous two campaigns, but during the daytime interval the percentages were significantly lower (Fig. 11c)

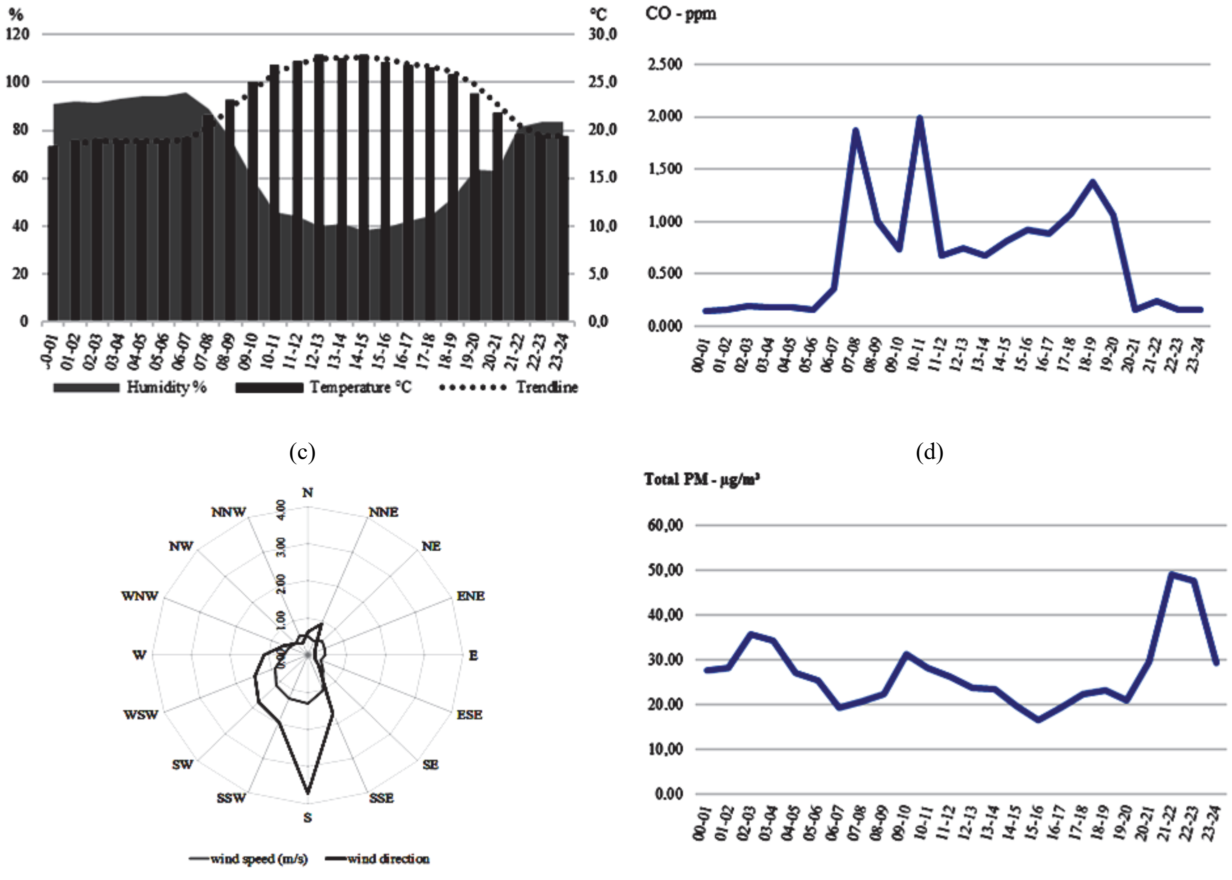
Compared to the two previous campaigns, when the diesel engines were predominant and emission peaks were predominantly identified over the same time slot with the power peaks developed by this type of engine, in the summer campaign set of measurements, a more special case was identified - in the 09:00-10:00 → 10:00-11:00 time slot there was a power peak developed by the diesel engines amounting to 1580.13KW, and another power peak significantly higher, developed by gasoline engines amounting to 2199KW, which contributed simultaneously but with a different impact to the emission peak of the same time frame identified in the graphical analysis of nitric gases (NO, NO_2, NOx) (Fig. 11c).

Taking into account the spring campaign measurement set, when the emission peaks could not clearly be attributed to the power developed by the petrol engines, it is assumed that underlying the emissions peak between 0900-1000 → 1000-1100 are diesel engines, to which a much lower share of petrol engines is added, although the greater share of the developed power is the one of petrol engines. It is to be mentioned that our hypothesis is supported by the study of Degraeuwea et al. (2016). Moreover, in the study by Weiss et al. (2012) on diesel engines, this type of engine has been found to have higher NO_X emissions in traffic than during laboratory tests.

Although we cannot definitely assign each emission peak in the graphical representation of carbon monoxide (CO) (Fig. 11d), in the case of the July measurement set, the first two peaks of emissions identified in the 06:00-07:00 → 09:00-10:00 and 09:00-10;00 → 11:00-12:00 time slots correspond to the same time slot of the first two peaks of power developed by the engines of the ships that have passed by the monitoring point. Also, a significant increase in carbon monoxide (CO) concentrations over the day has been observed, coinciding with the timeframe of shipping and is supported by a good correlation of the values obtained for this indicator and the power developed by ship traffic (Figs. 12g -h).



(a) (b)



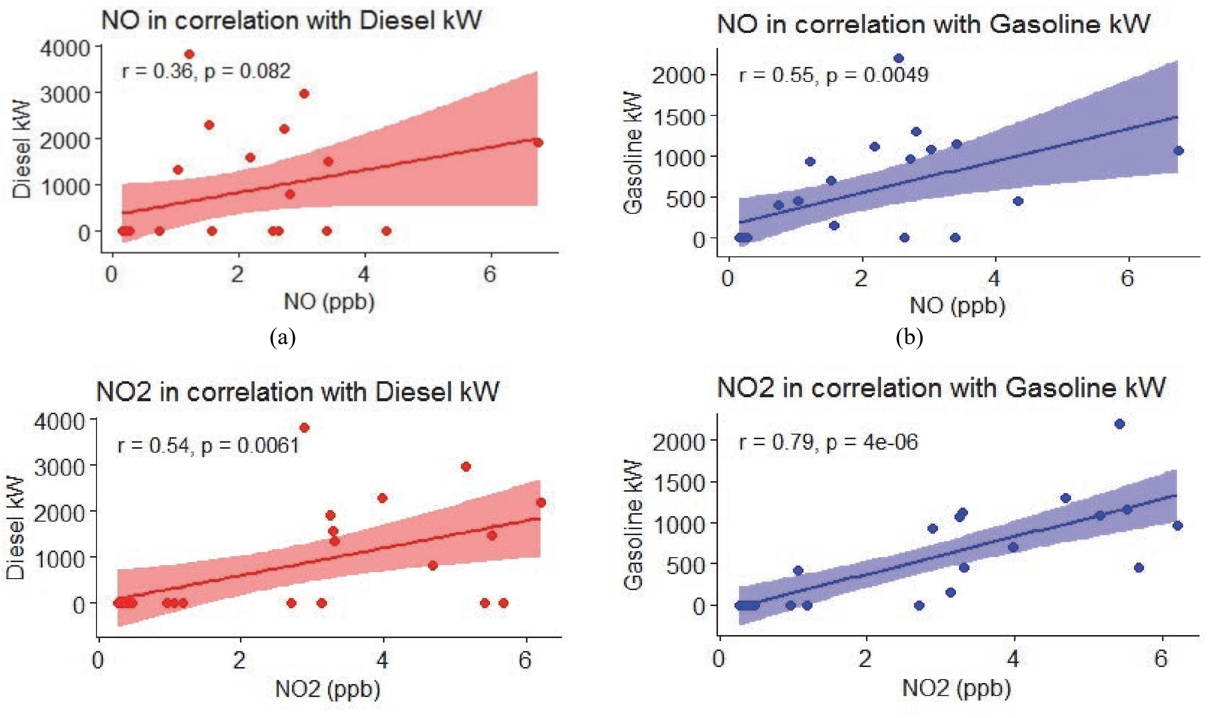
(c)

(d)

(e)

(f)

Fig. 11 Situation of ship traffic and pollutant dynamics monitored in summer weather conditions (July 2018): (a) power generated by ship's engines; (b) concentration of NO, NO_2, NO_X; (c) temperature and humidity dynamics in 24 hours; (d) CO concentration in 24 hours; (e) wind rose and direction in 24 hours; (f) Total PM concentration in 24 hours

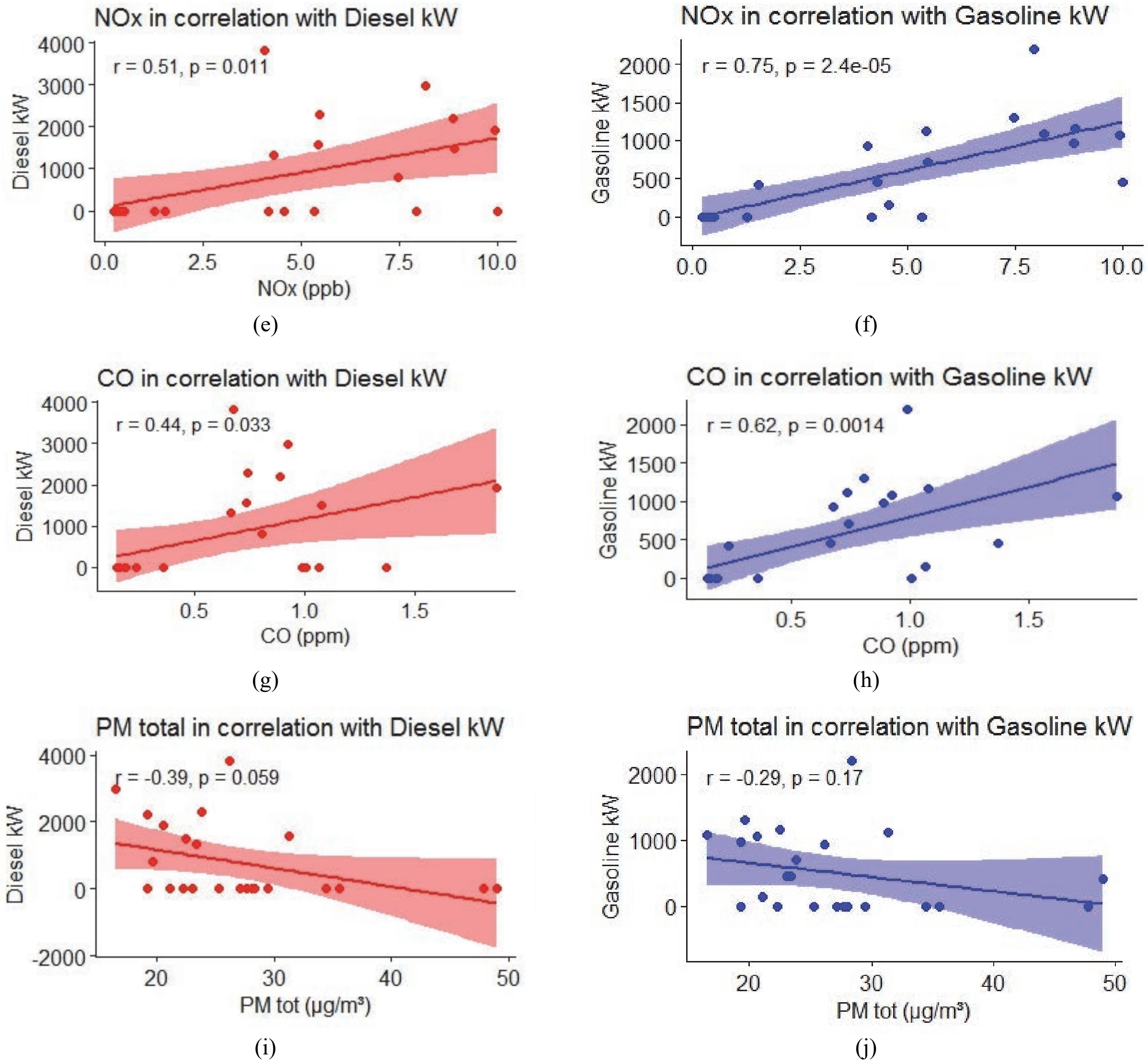


(a)

(b)

(c)

(d)



(e) (f)

(g) (h)

(i) (j)

Fig. 12. Correlation between developed power (KW) and concentrations of (a) NO in diesel; (b) NO in gasoline; (c) NO_2 in diesel (d) NO_2 in gasoline; (e) NO_x in diesel (f) NO_x in gasoline; (g) CO in diesel (h) CO in gasoline; (i) PM in diesel (j) PM in gasoline in the set of measurements - July 2018

4. Conclusions

Considering the concentrations of the pollutants which have been obtained through measurements with the number of ships crossing the monitoring points, it was noticed that the pollutants concentrations are not correlated with the number of ships, but to the total horsepower developed by the diesel engines. As far as the emission peaks of the nitric gases are concerned, the majority of them can be attributed to the amount of horsepower developed by the engines.

An increase of inland naval traffic will evidently cause an increase of pollutant emissions, but the effects on biota as already suggested is hard to be predicted because of the large inter- and intra-specific variability in the sensitivity of organisms to air pollution and the lack of relevant studies.

From detailed analysis of results, obtained from measurements on the Sulina channel, significant differences between the night and day interval were observed and values showed substantial increases during the shipping traffic. As far as the emission peaks of nitric gases are concerned, these could be attributed in their majority to the peaks of power developed by diesel engines. Exceptions to this pattern were the total PMs.

Although during the three monitoring campaigns there were completely different ambient and traffic conditions, the graphical analysis of total PM concentrations did not reveal links between vessel traffic intensity and hourly dynamics of this indicator. We estimate that for this parameter, the high humidity conditions of the Danube Delta are of decisive influence.

Based on the measurements made, it was found that the nitric gases concentration values are directly proportional to the power developed by the diesel engines. Moreover, this type of engine is the main polluter for the atmospheric air in the adjacent areas of the Sulina channel.

After seasonal investigations, it was concluded that an increase in ambient temperature favours the acceleration of oxidation processes of atmospheric N2 into NOx, thus having a decisive influence on nitric gases concentrations in the atmosphere.

Having a network of monitoring sites along the Danube would represent a good option to gather more consistent and significant data to model the air pollution resulted from navigation activities and investigate the effects on biological communities.

Based on the pioneering approach demonstrated in the present study assessing the contribution of inland waterway transport to air pollution in Danube areas, further investigations on methodological aspects and monitoring procedures are recommended, in particular for the evaluation of the exposure to pollutants.

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