Extended air pollution index (API) as tool of sustainable indicator in the air quality assessment: El-Nino events with climate change driven

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ABSTRACT

The main purpose of this research is to detect the air quality changes with a shorter period of timescale over space that can improve and optimize the risk characterization and conjunctive air quality assessment. Air quality assessment could be based on a very large number of various indicators, including the physical parameter, chemical and biological namely sulphur dioxide (SO2), carbon monoxide (CO), particulate matter (PM), humidity, air pressure and temperature. Nevertheless, often it is not easy to interpret the results of the air quality status when numerous quality elements are analyzed since each parameter indicates different types of quality classes. Moreover, providing appropriate information on air quality to policymakers, including the public, can be challenging. Hence, with this research there is a need to interpret the results in a more simple way and realistic enough by producing one single number for better and more subjective classification on the air quality rather than using the concentrations-based. Therefore, the Air Pollution Index (API) application in this research will overcome this problem by providing a single score that characterizes the air quality and contamination in a more absolute way. In line with that also, the study could help to improve the existing methodology for air quality assessment in a more simplified way and better evaluation of the air quality status, thus can become an alternative way for analysis of changes in air quality, especially in the absence or limitations of the historical or baseline data for comparison, in response for a better and more sustainable indicator in air quality assessment and management. The research shows that the API values across the Regions were recorded largely higher when El-Nino events occurred during the southwest monsoon season with more than 50% frequency of unhealthy days to hazardous status were detected from the API assessment. HYSPLIT model also shows that the air mass has mostly passed through the biomass burning areas from the neighboring country. Hence, the extension application of API was established in this research with the purpose of strengthening the air quality management in Malaysia, and to maximize the usage of the API and at the same time to filling up the gap of the uncertainty on the overall air quality in Malaysia, especially in terms of combine effects of the air pollutants parameters.

1. Introduction

Surface air quality deterioration has become a serious and major concern worldwide due to the increased of pollution and climate change [1]. Poor air quality has been linked to public health concerns, thus threatening the economic development, therefore many countries have implemented a number of tools to assist in the air quality protection measures and monitoring regimens [2]. To better understand the air quality conditions, however it is always crucial, thus critical to assess the air quality especially the major contributors to its spatial and temporal variations from the pollutants. Adding to that, limitation with lacking of historical data for comparison for some nations, as well as lack of a universal standard for air quality assessment is even more salient in giving bad implications onto the air quality monitoring and assessment. Air quality analysis is an investigation to gather all the information quantitatively on-air components physical compositions, biological and chemical properties through representative sampling [3]. One approach that can describe the air sample quality is the concentrations loading of everything sampled and contained [4]. Such a list would be as long as the number of air composites or variables analysed can be anything from the 20 common to hundreds, including heavy metals, organic compounds that exist in the surface...
atmosphere [5]. Moreover, such a list will make little sense and meaning to anyone except well-trained air quality experts. In view of the time-series analyses of the temporal and spatial variation in the meteorological-hydrology-chemistry process of the atmosphere, regular monitoring programs are required and usually conducted often to obtain a vast number of data-sets to estimate the quality of the atmosphere. This frequently complicates the datasets from the physical-chemical values that have no definitive answers and usually do not easily provide meaningful information, particularly to laymen. It is also often difficult to convey and provide the relevant information on the air quality to the policy makers and to the public who do not know and have the technical knowledge about the components of the atmospheric condition and health [6].

The quantification of the air quality changes often faces difficulties, especially dealing with a wide range of air quality indicators. Parameters that represent different aspects of quality, that we do not know which one to choose from that can be reliable in providing us the exact and most accurate results that could tell us the entire or as overall condition of the air quality. For example, with SO2 and CO concentrations that one is high and one is low and in the end it is difficult to conclude what is the absolute condition of the air quality. In addition, from the economic side of it, costing is always seen as very expensive to conduct air quality monitoring. Especially to build the air quality base stations at any monitoring sites which is not cost-effective, and the values of the data/findings using physical, chemical and biological parameters are not easily understandable [7]. Some of the variables need to be sampled to the field and analysed in the laboratory, and also involves lots of monitoring frequencies and a number of samples that can be very costly.

It has also been realized that each of the air quality parameters has been analysed individually and this does not represent the actual condition of the air components inside the real and actual atmosphere bodies and not supposed to be separated and it has to be combined with the whole parameters inside the atmosphere [1, 3]. The air quality assessment should not be conducted individually by each component and separated by individual the air quality variables to describe the quality. However, it has to integrate and combine interactions of the parameters with the physical, chemical and biological reactions as one or as a whole and overall air quality because that is the actual condition inside the actual atmosphere bodies and compositions [6, 8]. So, therefore, to overcome these problems, the Air Pollution Index (API) has been applied in this research to extract the important information from the complicated and combined datasets especially involving large data set from the long term analysis of the air quality assessment [7]; that turns it into one single number and one single qualitative status that would be more subjective and represent the overall air quality condition [9, 10].

Several national and international organizations have formulated air quality indices, and each of the index system vary depending on the authority of each country. Currently, there are several national and international index systems used by different countries such as Air Pollution Index (API), Pollutant Standard Index (PSI), Air Quality Index (AQI) and including Air Quality Health Index (AQHI). All of the indices might not be similar as each index has a different approach and different intensive related to the economy, lifestyles and more of the country. These indices have been applied to evaluate air quality in a particular area and at a particular region varying by number and types of air quality variables with the respective standards [9]. Initially, two main types of AQI currently exists which are: - 1) relative indices and 2) absolute indices. Relative indices lead to an improvement of the legislation threshold or standard with the actual concentrations using a binary approach that indicates whether the criteria are achieved and then averaged together to form their AQI. On the other hand, absolute indices are wholly based on measurements of air quality and consist independently of the air variable concentrations that sum up whole together as one single value and do not involve the thresholds or any standards.

Creating the AQI involves three main steps [10]-: 1) obtain measurements on individual air quality indicators; 2) transform measurements into ‘sub index’ values to represent the coefficient influence or weightage of each contributor of each air quality parameter onto the overall or the whole air quality; 3) aggregate the individual values into an overall AQI value. The Air Quality Index (AQI) formula in principle is built on the significant variables and established by the following three stages, which involve: i) Variable Determination performed by qualified experts, professionals, authorities, agencies that are identified as important for the regulatory judgment; ii) Assessment on the attribute value factor (numerical slope) for each of the variable weightage for the Sub-Index; to translate the non-scale values to the sub-indices values from the variables with its various units such as ppm, saturation percentage, counts, volume; and iii) establishing mathematical expression from the sub-indices formation and usually performed by using arithmetic and geometric averages.

The Air Pollution Index (API) is an index system that classifies ambient air quality towards health effects [11]. Instead of utilizing the actual concentration of air contaminants, the API is built in a readily understandable ranges of values to report air quality. The API is used by assembling the main five pollutants namely nitrogen dioxide (NO2), sulphur dioxide (SO2), particulate matter (PM2.5 and PM10), ozone (O3) and carbon monoxide (CO), only included fine particulate matter (PM2.5) in 2014, and only taking the highest sub-index value as the API value on a particular time. The API value will then be categorised according to the five classes which are good, moderate, unhealthy, very unhealthy and hazardous as the API classes and the respective air quality status. Each class will indicate a different levels of air quality with different health exposure risks. The API evaluation tool as well, it also can show the pollutants that are mainly impairing the air quality [12]. In Malaysia, the Air Pollutant Index (API), which is based on the Pollutant Standard Index (PSI) developed by the United States Environmental Protection Agency (US-EPA), was only established in 1996 and is now used as one of the air quality management tools to strengthen the country’s air quality management [13]. It is used to inform both decision makers and the general public on the status of ambient air quality, which ranges from excellent to harmful [14].

However, it was seldom or none at all been used as the main and important tool in air quality management [15]. In addition, with the absence of data set and the problem of accessibility to this kind of database for some countries, makes it even more difficult to do the long-term analyses that normally will involve lots of databases and extensive work that is complex in technicality and interpretations for the air quality monitoring. These kinds of obstacles and limitations create a research gap in air quality that often will stop other researchers from continuing the long-term analysis due to the incomplete dataset for the analysis, which they forget this type of limited data set can be very important to extract the information from it, especially to deal with the uncertainty on the overall air quality in Malaysia. By this research, instead of using a very large of database for the long-term analysis, the absolute average of the mean from any existing data could be used by applying the API calculations that will give the same results as the traditional method. Hence, this research was performed to maximize the usage of API especially in filling up the gap in the efforts to simplify the methodology to be more practical and functional, in order to overcome data limitations and deem to minimize air pollution, thus maximizing the efficiency of the air quality management tool by applying the analysis more onto short-term changes using that exact period of time and more targeted/specific event for greater accuracy of quality assessment.

2. Materials and methods

2.1. Study area

The country of Malaysia is the subject of the research. It was chosen because it is precisely in the middle of the haze occurrences, where recurring events may be observed. In the meantime, the country region is subjected to lengthy drought every year during the monsoon season,
which may worsen air quality. Meanwhile, most of Malaysia’s borders were located on the shores [16]. As a result, the study region is more vulnerable to long-distance transportation of contaminants from other continents. This was important to see if transboundary pollution contributed to the atmospheric composition of the investigated area during the monsoon season [17]. Aside from that, overcrowded and urbanized Malaysia, thus with many man-made structures, massive road congestion, and numerous industrial projects, causing the surface air temperature fluctuates dramatically during the day, potentially affecting recirculation and the concentration of urban air pollutants [18]. Among all the 13 states and three federal territories in this country, the air quality status for each may vary depending on the meteorological factors such as wind power and pattern, humidity, rainfall intensity at a particular time. Thus, the data from every air monitoring station in each state were analyzed for the air quality status for a particular conditions. But for a better comparison, the air quality was compared by region. The monitoring stations are divided into six regions which involve (1) Klang Valley; (2) Northern Region; (3) Southern Region; (4) East Coast Region; (5) Sarawak; and (6) Sabah.

2.2. Air quality data collection

The ambient Malaysia’s air quality secondary data were used from 2010 to 2016 that were collected from the Department of Environment (DOE). Currently, DOE uses 65 air quality monitoring stations to get the hourly concentration of major pollutants such as particulate matter (PM2.5 and PM10), ozone (O₃), nitrogen dioxide (NO₂), sulphur dioxide (SO₂) and carbon monoxide (CO). These air quality monitoring stations were built to continuously collect, measure and monitor the stated ambient air quality data. Every air quality monitoring station consists of a set of equipment where each of the main pollutants was measured by using different methods. For the monitoring of particulate matter, the β-ray attenuation mass monitor (BAM-1020) was used and it was controlled by an advanced microprocessor system that makes it fully automatic. Next, the concentration of SO₂, NO₂, CO and O₃ were measured using Teledyne API Model 100/100E, Teledyne API Model 200/200E, Teledyne API Model 300/300E and Teledyne API Model 400/400E respectively [9]. All of these were using the Beer Lambert's non-dispersive, infrared absorption technique except for NO₂ where it was using the chemiluminescence detection technique. The installation, operation and management of the equipment were conducted by Alam Sekitar Malaysia Sdn. Bhd. (ASMA). ASMA is a private company that has been awarded a 20-year concession to provide air quality monitoring for the DOE. However, this research only covered the air quality from 2010 to 2016 as the only year's period datasets provided by the DOE, and at the same time, extreme events such as haze reoccurred. Thus, from there only the data from 52 monitoring stations were used since the other 13 monitoring stations are only available starting in the mid-April 2017 [19], and the PM₂.₅ was also excluded because its concentration was only taken into API calculation in Malaysia since 16th August 2018 [20].

2.3. El-Niño events

The El-Niño events were used in the study to determine if extreme weather correlates with Air Pollution Index (API) value. The historical El-Niño episodes were obtained from Climate Prediction Center (CPC), National Oceanic and Atmospheric Administration (NOAA). For 7 years between 2010 and 2016, the data of El-Niño was accessed through the website of CPC, NOAA which is https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml. CPC, NOAA provides past and current El-Niño Southern Oscillation (ENSO) conditions using indexes such as Oceanic Niño Index (ONI). ONI is described as the 3-month running mean of ERSSST v5 SST anomalies in the Niño 3.4 region (5°N - 5°S, 120°W - 170°W) which is centered on 30-year base periods that are updated every 5 years [18, 19]. When the ONI is >0.5 °C or higher, El-Niño conditions are considered to be present while when the ONI is -0.5 °C or lower, La-Niña conditions occur and these values should be met for a minimum of 5 consecutive overlapping seasons to consider the occurrence of stated conditions [21].

2.4. Air pollution index (API) calculations and trend analyses

The API calculation involved the calculation of average concentration levels of the five major air pollutants involving five major pollutants namely as carbon monoxide (CO), ground-level ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂) and particulate matter (PM₁₀,₂₅) with the averaging time for each pollutant was according to the Recommended Malaysian Air Quality Guideline (RMAQG) where PM₁₀ and SO₂ hourly value was averaged over a 24-hour running period, CO was averaged over eight-hours period, O₃ and NO₂ were read hourly [22]. Next, the specific sub-index value for each of the five air pollutants was determined using either the standard sub-index formula or the conversion table. After that, the highest sub-index value among all of the five sub-indexes was selected as the API value for the specified time period of a particular area. Lastly, the calculated API values were categorized into different air quality statuses based on the ranges for each class of API. The API was classified as either Good (0-50), Moderate (51-100), Air Quality Advisory (101-200), Very Unhealthy (201-300), Hazardous (301-500) or Emergency (>500). Meanwhile, for the trend analyses of air pollution index in Malaysia; Mann-Kendall trend test was used to assess the changes in pollutant concentration over time [23] whether the trend is positive, negative or none exist; and coefficient variation test to show the dispersion or variation of the datasets variables [24].

2.5. Air pollution assessment using API and hybrid single-particle Lagrangian integrated trajectory (HYSPLIT)

The pollution hotspots in Malaysia were identified using the frequency of exceedance for which values exceeded the threshold of 50 (API >50). Furthermore, the pollutant that acts as the main contributor to the higher API value was also identified. The potential associated sources of the main pollutant that bring about the high API were then determined. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model and satellite map with fire records were applied to observe the transport pathways and the potential emission sources of the pollutant from neighbour countries. HYSPLIT is the internet-based model provided by the National Oceanographic and Atmospheric Administration (NOAA), which can produce the simulation of air parcel trajectory to predict the transport and dispersion of pollutants in the atmosphere [25]. Using this model, the backward trajectories for the selected monitoring stations were developed for 120 h to determine the long-range transport of pollutants (see Figure 1).

3. Results and discussions

3.1. Air pollution index (API) and trend analyses

Overall, the findings show that 32 monitoring stations have significant varied increasing trend mainly from Malaysia’s Northern Peninsular Region with a total average of coefficient variation, cv of 37±5%, p-value of 0.02±0.01, Kendall’s value of 0.17±0.12 and Sarawak Region with value cv of 47±13%, p-value of 0.03±0.01, Kendall’s value of 0.09±0.07. Meanwhile 12 monitoring stations with significant decreasing trends from Malaysia’s Southern Peninsular Region (cv 37±4%, p-value of 0.00±0.00, Kendall’s 0.02±0.01), East Coast Peninsular Region (cv 36±6%, p-value of 0.00±0.00, Kendall’s -0.29±0.00) and Sabah Region (cv 32±2%, p-value of 0.01±0.00, Kendall’s -0.05±0.13); and another remaining 8 stations with the non-significant trend found mainly from Klang Valley Region (cv 37±4%, p-value of 0.17±0.03, Kendall’s -0.04±0.01). The Mann-Kendall Trend Test (MK) and Coefficient Variation (CV) for each monitoring station in the studied Regions are shown in Table 1 with diurnal variations of API in each station and the
trend slope analysis. For diurnal variations analysis of Air Pollution Index (API), Klang Valley have reached either Very Unhealthy (API:201–300) and Hazardous (API:300–500), especially in Klang, recorded hazardous the highest mean of API at 450, followed by Banting very healthy with 264, both occurred in 25th June 2013 and 14th March 2014. In Northern Peninsular, the highest daily mean is in Seri Manjung with 270 followed by Seberang Jaya with 240, which took place on the 25th June 2013 and 22nd October 2015 respectively, which is under Very Unhealthy status (API:201–300) (see Table 2).

For Southern Peninsular, Bukit Rambai recorded at the highest daily mean of API with 397, followed by Melaka at 351, which both occurred on the 23rd June 2013 with Hazardous category (API:301–500). For the East Coast region showed Kemaman marked the highest daily mean with 215 fell under Very Unhealthy status (API:201–300) and the second-largest daily mean was recorded in Balok Baru with 174 under the Unhealthy category (API:101–200) both occurred on the 15th September 2015. In the meantime, for both Borneo Regions, for Sarawak stations recorded the highest daily mean of API in Permijaya (Miri) at 387 under Hazardous category (API:301–500) that took place on the 21st February 2015. In addition, all these highest means of API were recorded during the southwest monsoon season, bringing a very dry season with less precipitation that greatly influenced the air mass trajectory and wind direction to the Regions. The concurrent occurrence of both El-Nino and southwest monsoon caused the climatic conditions to be extremely dry. It caused the large hotspots of biomass burning during the season [13,18] as shown in Figures 6 and 7. Meanwhile, the negative slopes of significant trends from the analysis indicate the improvement of API air quality for these monitoring stations both in the Peninsular and Borneo regions. This shows that the Northeastern monsoon season has influenced the heavy rainfall and lower temperature of climatic conditions that lowered the air pollutants concentration in the atmosphere [12].

From the coefficient variation, CV analyses, the API for Klang Valley Region is identified to be varied at the range of 31%–44% which indicates that the API values in this region are largely scattered around the mean, and the Klang stations recorded has the highest API at this region. It also shows that all of the stations in the Klang Valley Region have significant trends except for Klang, Petaling Jaya and Shah Alam where these three stations showed no significant trends. Kuala Selangor and Cheras have decreasing trends while Putrajaya, Batu Muda and Banting have increasing trends. In addition, it shows that overall, the air quality in Putrajaya, Batu Muda, and Banting is getting worse. There are no changes in Klang, Petaling Jaya, and Shah Alam while in Kuala Selangor and Cheras, the air quality is getting better from 2010 to 2016.

Meanwhile, for the Northern Peninsular Region, the highest daily maximum mean of API was recorded in Seri Manjung with 270 and Seberang Jaya with 240, respectively. Both of these maximum daily means are in Very Unhealthy status (API:201–300), while Langkawi has shown the lowest overall API mean value with 35. Based from Table 1 also indicates that the API values in the region of Northern Peninsular are seen to have spatially varied between 29% to 44%. In addition, a

### Table 1. Calculation equation of Malaysia API sub-index for each pollutant based on Pollution Standard Index (PSI) (Source: Malaysian Department of Environment DOE).

| Pollutant   | API calculation equation |
|-------------|--------------------------|
| CO (Based on eight-hour average concentration) | conc. < 9 ppm API = conc. X 11.11111 |
|            | 9 < conc. < 15 API = 100 + {(conc. - 9) x 16.66667} |
|            | 15 < conc. < 30 API = 200 + {(conc. - 15) x 6.66667} |
|            | > conc. 30 ppm API = 300 + {(conc. - 30) x 10} |
| O₃ (Based on one-hour average concentration)  | conc. < 0.2 ppm API = conc. X 1000 |
|            | 0.2 < conc. < 0.4 API = 200 + {(conc. - 0.2) x 500} |
|            | > conc. 0.4 ppm API = 300 + {(conc. - 0.4) x 1000} |
| NO₂ (Based on one-hour average concentration) | conc. < 0.17 ppm API = conc. X 588.23529 |
|            | 0.17 < conc. < 0.6 API = 100 + {(conc. - 0.17) x 232.56} |
|            | > conc. 0.6 ppm API = 200 + {(conc. - 0.6) x 166.667} |
| SO₂ (Based on 24-hour average concentration) | conc. < 0.04 ppm API = conc. X 2500 |
|            | 0.04 < conc. < 0.3 API = 100 + {(conc. - 0.04) x 384.61} |
|            | > conc. 0.3 ppm API = 200 + {(conc. - 0.3) x 333.33} |
|            | > conc. 0.6 ppm API = 300 + {(conc. - 0.6) x 500} |
| PM₁₀ (Based on 24-hour average concentration) | conc. < 50 pg/m³ API = conc. |
|            | 50 < conc. < 150 API = 50 + {(conc. - 50) x 0.5} |
|            | 150 < conc. < 350 API = 100 + {(conc. - 150) x 0.5} |
|            | 350 < conc. < 420 API = 200 + {(conc. - 350) x 1.25} |
|            | > conc. 420 API = 400 + {(conc. - 420) x 1.25} |

| Concentration | Maximum Index |
|---------------|---------------|
| Air pollutant  | Individual pollutants |
| Index (SO₂)   | Index (NO₂)    |
| Index (CO)    | Index (PM₁₀)   |
| Index (O₃)    | Select Max. Index |
| API           | Air Pollution Index |
Table 2. Mann-Kendall Trend Test (MK) and Coefficient Variation (CV-%) analysis for the Air Pollution Index (API) for the year 2010–2016 in each monitoring stations at the six studied Regions which involves. (a) Klang Valley; (b) Northern Region; (c) Southern Region; (d) East Coast; (e) Sarawak; and (f) Sabah.

| Station | Min | Max | μ | σ | CV (%) | p-value (α = 0.05) | Kendall Slope | Significant Trend |
|---------|-----|-----|---|---|--------|---------------------|---------------|------------------|
| (a) Klang Valley Region | | | | | | | | |
| Klang | 0 | 450 | 56 | 20 | 37 | 0.12 | 0.02 | 0.00 | No |
| Petaling Jaya | 11 | 196 | 46 | 16 | 35 | 0.24 | 0.02 | 0.00 | No |
| Shah Alam | 0 | 248 | 47 | 18 | 39 | 0.99 | 0.00 | 0.00 | No |
| Kuala Selangor | 0 | 215 | 40 | 18 | 44 | -0.00 | -0.08 | -0.00 | Negative |
| Putrajaya | 2 | 196 | 43 | 17 | 39 | -0.00 | 0.20 | 0.01 | Positive |
| Cheras | 3 | 164 | 48 | 15 | 31 | 0.00 | -0.04 | -0.00 | Negative |
| Batu Muda | 10 | 196 | 44 | 18 | 40 | 0.00 | 0.05 | 0.00 | Positive |
| Banting | 0 | 264 | 51 | 17 | 34 | -0.00 | 0.17 | 0.00 | Positive |
| (b) Northern Peninsular Malaysia Region | | | | | | | | |
| Perai | 9 | 183 | 40 | 14 | 34 | 0.00 | -0.05 | -0.00 | Negative |
| Ipoh | 2 | 164 | 43 | 13 | 30 | -0.00 | 0.17 | 0.00 | Positive |
| Seberang Jaya | 8 | 240 | 48 | 14 | 29 | -0.00 | 0.12 | 0.00 | Positive |
| Sungai Petani | 9 | 227 | 47 | 16 | 34 | -0.00 | 0.38 | 0.01 | Positive |
| Taiping | 5 | 149 | 40 | 16 | 41 | -0.00 | 0.16 | 0.01 | Positive |
| Langkawi | 1 | 223 | 35 | 14 | 40 | -0.00 | 0.27 | 0.01 | Positive |
| Kangar | 2 | 221 | 38 | 15 | 40 | -0.00 | 0.08 | 0.00 | Positive |
| Minden | 7 | 196 | 40 | 15 | 37 | -0.00 | 0.34 | 0.01 | Positive |
| Alor Setar | 1 | 221 | 38 | 15 | 43 | -0.00 | 0.27 | 0.01 | Positive |
| Seri Manjung | 0 | 270 | 39 | 18 | 44 | 0.24 | 0.02 | 0.00 | No |
| Tanjung Malim | 0 | 166 | 35 | 15 | 43 | 0.00 | 0.05 | 0.00 | Positive |
| Pegoh | 2 | 173 | 45 | 14 | 31 | -0.00 | 0.12 | 0.00 | Positive |
| (c) Southern Peninsular Region | | | | | | | | |
| Pasir Gudang | 12 | 265 | 47 | 15 | 33 | -0.00 | 0.09 | 0.00 | Positive |
| Bukit Rambai | 12 | 397 | 53 | 17 | 32 | -0.00 | -0.06 | -0.00 | Negative |
| Nilai | 0 | 215 | 43 | 16 | 36 | 0.70 | 0.01 | 0.00 | No |
| Larkin | 3 | 187 | 42 | 14 | 34 | -0.00 | 0.15 | 0.00 | Positive |
| Melaka | 0 | 351 | 43 | 18 | 33 | -0.00 | 0.12 | 0.00 | Positive |
| Muar | 6 | 330 | 43 | 17 | 40 | -0.00 | -0.12 | -0.00 | Negative |
| Seremban | 6 | 179 | 43 | 16 | 37 | 0.00 | 0.04 | 0.00 | Positive |
| Port Dickson | 0 | 267 | 46 | 15 | 33 | -0.00 | -0.06 | -0.00 | Negative |
| Kota Tinggi | 7 | 264 | 43 | 14 | 32 | 0.84 | 0.00 | 0.00 | No |
| (d) East Coast Peninsular Region | | | | | | | | |
| Kemaman | 3 | 215 | 45 | 15 | 33 | -0.00 | 0.24 | 0.01 | Positive |
| Jerantut | 1 | 161 | 32 | 15 | 47 | -0.00 | 0.06 | 0.00 | Positive |
| Kuantan | 3 | 148 | 37 | 12 | 34 | -0.00 | 0.10 | 0.00 | Positive |
| Balok Baru | 0 | 174 | 45 | 16 | 35 | -0.00 | -0.25 | -0.01 | Negative |
| Kota Bharu | 0 | 120 | 41 | 14 | 34 | -0.00 | 0.14 | 0.00 | Positive |
| Fasa | 0 | 149 | 34 | 15 | 44 | -0.00 | 0.15 | 0.00 | Positive |
| Kuala Terengganu | 2 | 114 | 42 | 13 | 30 | -0.00 | -0.17 | -0.00 | Negative |
| Tanah Merah | 1 | 119 | 45 | 15 | 33 | -0.00 | -0.29 | -0.01 | Negative |
| (e) Sarawak Region | | | | | | | | |
| Kuching | 2 | 187 | 34 | 16 | 46 | -0.00 | 0.18 | 0.00 | Positive |
| Sibu | 5 | 209 | 35 | 14 | 39 | 0.01 | 0.04 | 0.00 | Positive |
| Bintulu | 2 | 99 | 38 | 15 | 38 | 0.00 | 0.04 | 0.00 | Positive |
| Miri | 1 | 131 | 30 | 13 | 45 | -0.00 | 0.25 | 0.01 | Positive |
| Sarawak | 0 | 139 | 37 | 13 | 35 | -0.00 | 0.05 | 0.00 | Positive |
| Limbang | 0 | 82 | 26 | 10 | 40 | -0.00 | 0.10 | 0.00 | Positive |
| Kota Samarahan | 0 | 170 | 32 | 17 | 52 | 0.31 | -0.01 | 0.00 | No |
| Sri Aman | 0 | 182 | 32 | 17 | 52 | -0.00 | 0.07 | 0.00 | Positive |
| Kapit | 0 | 121 | 29 | 13 | 44 | 0.02 | 0.03 | 0.00 | Positive |
| Permyjaya | 0 | 387 | 27 | 22 | 83 | -0.00 | 0.09 | 0.00 | Positive |
| (f) Sabah Region | | | | | | | | |
| Kota Kinabalu | 2 | 84 | 33 | 11 | 33 | -0.00 | 0.15 | 0.00 | Positive |
| Tawau | 1 | 153 | 31 | 10 | 32 | -0.00 | -0.14 | -0.00 | Negative |
| Keningau | 0 | 95 | 29 | 11 | 36 | 0.47 | -0.01 | 0.00 | No |
| Sandakan | 0 | 75 | 29 | 9 | 30 | 0.02 | -0.03 | -0.00 | Negative |
| Labuan | 1 | 94 | 32 | 11 | 34 | -0.00 | -0.20 | -0.00 | Negative |
significant positive trend can be seen in the majority of the stations in this region except for Perai, which has a significant negative trend, and Seri Manjung which has no significant trend throughout the period of study. Hence, it can be concluded that the air quality in most of the monitoring stations in Northern Peninsular is getting worse especially Sungai Petani since it has the highest increasing slope recorded in this region and also in Malaysia.

For Southern Peninsular Region, the highest daily maximum mean of API is recorded in Bukit Rambai with 397, followed by Melaka with 351. These maximum daily means are categorized in the Hazardous class (API: 301–500) for the region’s air quality. For the total overall mean, Bukit Rambai has shown the highest value of API with 53, while the smallest value is recorded in Larkin with 42. The daily API values in this region have spatially varied around 32%–43%. The trends shown in this region are diverse, where there are four monitoring stations (Pasir Gudang, Larkin, Melaka & Seremban) with increasing significant trends. Meanwhile, three stations (Bukit Rambai, Muar & Port Dickson) with decreasing significant trends and two stations (Nilai & Kota Tinggi) with no significant trends. Larkin showed the highest slope, which indicates that this area has experienced the worst degradation of air quality among the monitoring stations in the Southern Peninsular Region.

In the East Coast Region, it is shown that Kemaman has the highest daily maximum mean of API with 215, which fell into Very Unhealthy status (API: 201–300). The second-largest daily maximum mean was recorded in Balok Baru with 174, which fell into Unhealthy (API: 101–200). Moreover, these two stations have also recorded the highest overall API means both with 45, respectively. In contrast, Jerantut is recorded with the lowest overall API mean at 32. The diurnal API in this region can be seen at the range 30%–47% level of variation. All of the monitoring stations show significant trends were Balok Baru, Kuala Terengganu and Tanah Merah with negative slopes. Meanwhile, the remaining stations have positive slopes, indicating that the air quality has worsened, especially Kemaman as it has the highest slope in this region.

For Sarawak Region, the highest daily maximum mean of API is recorded in Permijaya with 387, which is in the Hazardous status (API: 301–500). For the overall mean of API, Bintulu has the highest mean with 38, whereas Limbang has the lowest mean with 26. The coefficient variation of monitoring stations in this region is spatially varied in between 35% to 83%. With the highest CV, Permijaya has shown the highest dispersion level relative to the mean. Significant positive trends can be observed in all monitoring stations for trend analyses, except for Kota Samarahan station. This shows that in Sarawak, the air quality was not getting better. Instead, it was getting unhealthier with Miri experiencing the worst air quality deterioration with the highest slope in the Sarawak region.

In Sabah Region, the highest daily maximum mean of API is recorded in Tawau with 153 which has fallen into the Unhealthy status (API: 101–200). In spite of this, Kota Kinabalu is the one that has the highest overall mean of API with 33, while Keningau has the lowest mean with 29. Daily API has shown considerable spatial variation in this region with coefficient variation in the range of 30%–36%. With the exception of Keningau monitoring station, all of the stations in Sabah Region have a significant trend where Kota Kinabalu showed an increasing trend while the others showed decreasing trends. Therefore, in this region, Kota Kinabalu is the only station with air quality that becomes unhealthful throughout the year 2010–2016.

3.2. Air pollution index (API) assessment on human health exposure risk

Frequency of exceedance (%) was used to further assess the Air Pollution Index (API) in order to assess the impacts exposed to the human by the air quality, which is calculated by the percentage of exceeding the Good level of pollution (API: 0–50) in each monitoring stations were identified. By comparing the frequency of exceedance between all the studied monitoring Regions, Klang Valley was identified to have the highest mean for overall frequency of exceedance. This is probably because it is in a mainstream economic region in Malaysia with the massive physical development of the infrastructure, industrialisation and urbanisation, which have significantly deteriorated the air quality [26]. Klang Valley has been recognized as the well-most-developed area in Malaysia where the capital city of the country is also known to be a part of this region. All of the maximum percentages for every year in this region have exceeded 50% of the API good level of air pollution, which is more than half a year people in Klang Valley have been exposed to the poor air, especially in 2015. Additionally, in 2015, around 64% of the population in this region was analytically exposed to unhealthy air quality conditions.

As the Southern Peninsular is the second most industrialized and urbanized region, the region has the second-highest mean for overall frequency of exceedance. All of the frequencies can be seen to be more than 10%. Bukit Rambai has shown a distinct pattern of having a consistently high percentage of exceedance in the earlier years (2011–2013), causing it to be recorded as the hotspot area in Malaysia for these three consecutive years. This monitoring station is located in an industrial area in the southern part of Malaysia. Thus, the pollutants released from the manufacturing facilities in the furniture and wood industry could worsen the air quality and, hence, could reduce human health through short-term or long-term effects [27]. Additionally, Melaka is observed to have the highest increase in exceedance for this region from 2010 to 2016. This may be because of the high particular events (HPE) in 2013 and 2014 and the super El-Nino occurrence from 2015 to 2016. HPE caused a higher temperature and an evident fluctuation in concentrations of pollutants [28]. Hence, this increased the number of unhealthy days in an urban area of Melaka.

In the Northern region, the highest frequency of exceedance for each year is increased throughout the study period. In the earlier year, most of the monitoring stations in this region have low percentages exceeding the Good category of API. However, these monitoring stations are noticeably increased in terms of having moderate to polluted air in 2015 and 2016, and the region no longer had a frequency below 10%. This indicates that the air quality in this region was degraded throughout the years, which caused the increase of human exposure risk toward poor air. Sungai Petani was seen to have a distinctly high exceedance during 2014–2016 and hence, it is identified to be the hotspot area for this region. The highest percentage was in 2016 with 84.7%. However, Sungai Petani is known as a semi-urban area in Kedah. Thus, the high number of days exceeding the Good category may cause by air pollutant distribution affected by meteorological factors, geographic location, and the season for the emission period [22]. Among these three factors, meteorological conditions have largely been involved in the high number of unhealthy days. This is probably due to the dry weather caused by the annual occurrence of Southwest Monsoon and the coincidence with super El-Nino [29].

In this region, the highest frequency of exceedance was recorded in Balok Baru with 72.9%, making this area the hotspot area in this region and Malaysia, particularly in 2010. It is one of the industrial areas in Pahang. Thus, the pollution may have originated from industrial activities. According to [30], the development of new residential areas and the transformation of Kuantan port (located 8 km from Balok Baru) into a mega port for shipping hub have caused the drastic emission of pollutants. However, this station can be seen to have lower exceedances afterward. In addition, Kota Bharu has shown an evident rise of exceedance in 2015. This may be due to the transportation of pollutants from biomass burning in Indochina (Vietnam, Cambodia and Laos) to the area, and in Sumatra during the occurrence of super El-Nino in September–December. Kota Bharu has also experienced a massive flood from December 2014 to January 2015 due to extreme weather caused by climate change [31].

For Sarawak and Sabah Region, there can be seen having a relatively low frequency of exceedance that may be due to its lower population density that could cause lower human activities contributing to the air pollution. In addition, it is also a less-industrialized region when...
compared to the other regions in Peninsular Malaysia. In Sarawak, all monitoring stations have undergone fluctuations in terms of exceedance, with a distinct increase in 2015. Among all stations, Bintulu was seen to have a relatively high frequency of exceedance throughout the years. According to [32], this station is located near to the industrial area dominated by petrochemical industries. While in Sabah, smaller fluctuations were observed compared to Sarawak. Plus, the evident rise of exceedance frequency could be seen in 2015, similar to every other region.

In the Sabah region, Kota Kinabalu has shown the highest increase in exceedance from 2010 to 2016. It has also shown a tremendous increase of exceedance in 2015 and thenceforth, continue to escalate, which causing it to reach the highest frequency for this region in 2016. This may probably be because it is the most urbanized city in Sabah. Considering it is a more developed area than the other monitoring stations in this region, it has received a greater impact of haze episodes. Plus, the expansion of city areas and a high number of motor vehicles are also the main factors of high exceedance in this station. According to [33] motor vehicle exhaust emissions and gases released from industrial activities are the main sources of air pollution in this station. Further details of the frequency exceedance (%) of API more than 50 for each monitoring station in the six studied Regions are shown in Figure 2.

### 3.3. Main pollutant contributing to air pollution index (API), El-Niño events – climate change associated and transboundary pollution potential sources: backward trajectory and fire hotspots analysis

Based on the Air Pollution Index (API) calculations, the main pollutant that mainly contributes to the API reading is particulate matter (PM10). This is because its sub-index often has the highest value compared to the sub-index of other pollutants. Figure 3 shown the daily sub-indexes for each main pollutants which are carbon monoxide (CO), ground-level ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2) and particulate matter (PM10) in the six monitoring Regions.

Particulate matter (PM10) is a suspended solid or liquid particle existing in the air, including aerosols, dust, soot, ashes, smoke, spores and more. One factor which may explain why PM10 has frequently contributed to the API reading is because it is mostly observed near the surface and its mechanism formation is different from gases [23]. The particulate matter could be originated from both natural and anthropogenic sources as either a primary or secondary pollutant. Particulate matter may have been emitted into the atmosphere primarily from volcanic eruptions, construction sites, vehicles, fires and more. The particulate matter could also have appeared in secondarily formed where have previously undergone further attachment to the environmentally persistent free radicals and biologically active chemicals such as metals (toxic) and organic compounds (PAHs) [34]. Thus, the variation of forms and sources of particulate may have contributed to its higher concentration and therefore, having a higher sub-index. In addition, according to [35], particulate matter with a smaller size has a longer residence time that could remain in the atmosphere for several days or weeks and be subjected to movement through the atmospheric circulation. The particulate could also be transported to even more distant locations and even with no anthropogenic emission found in the area [23, 34]. Therefore, from this point of view, the air mass backward trajectory (HYSPLIT) was performed and produced using the primary pollutant PM10 in this case, as shown in the image result in Figure 5, which shows higher potential function from the neighbouring countries nearby. Both estimation equations of PSCF (Potential Source Contribution Function) and CWT (Concentration Weighted Trajectory) were applied for the backward trajectory analyses HYSPLIT as shown in both the equations below:-

\[
PSCF = \frac{m_{ij}}{n_{ij}}
\]

\[
CWT = \ln(C_{ij}) = \frac{1}{\sum_{k=1}^{N} \ln(c_k \tau_{ijk})}
\]

where:
- \(m_{ij}\) = number of times pollutants source was high
- \(n_{ij}\) = number of times the trajectories passed through the cell (i, j)
- \(c_k\) = pollutants measured upon arrival of trajectory k and \(\tau_{ijk}\) = residence time of trajectory k in grid cell (i, j)
- \(i\) and \(j\) = indices of grid
- \(k\) = index of trajectory
- \(N\) = total number of trajectories used in the analysis
- \(C\) = air parcels passing over cell (i, j) causing high pollution at the receptor site

As stated in the previous chapter, all of the monitoring stations across Malaysia have shown a rise in the API values and frequencies of exceedance in 2015. This may be due to the occurrence of super El-Niño on that year. In Figure 4 shows the daily values of API throughout the period of study along with the index for El-Niño known as Oceanic Niño Index (ONI). Based on Figure 4, the El-Niño incident can be seen in (a) which has reached a very strong level from August 2015 to March 2016. In the meantime, almost all of the monitoring stations have recorded (b) the higher API readings to the extent all of these stations reached maximum API that are more than 100 (Unhealthy) and some stations even reached more than 200 (Very Unhealthy). Thus, it can be concluded that there was an association between Air Pollution Index (API) and El-Niño incident. When there was the occurrence of El-Niño events, especially the very strong ones, the Air Pollution Index (API) values could be seen higher, which was caused by the higher sub-index of PM10. This could be supported by the study conducted by [36] which has stated that during the El-Niño event, specifically on September to October 2015, almost 10 million Malaysian was on average exposed to PM10 concentrations higher than 100 \(\mu\)g m\(^{-3}\) (double the daily WHO limit) by taking into account that this pollutant has predominantly contributed to API. However, from the Equation Model produced by the simulation as shown in Figure 4 its recorded at R\(^2\) at 0.2598 which is at 26% correlation of the El-Niño event could be explained by the recorded API in the regions.

According to [23, 35, 36] the Ocean Niño Index (ONI) is a primary indicator responsible for monitoring the El-Niño-Southern Oscillation (ENSO) based on the anomaly of the sea surface temperature (SST), relative humidity, cloud cover, including the aerosol concentrations which derive from satellite wider data coverage from the Climate Prediction Centre (CPC) of National Oceanic and Atmospheric Administration (NOAA), that indicated the occurrence of El-Niño and La-Nina. In this study, the ONI index has been associated and correlated with the API datasets as it has more and wider spec of data coverage that can be related or link them with the other Regions (including the neighbouring countries) that causing the API to be higher during El-Niño and droughts events, and not looking into specific/particular time of meteorology. It also has been cited from previous researchers [22, 26, 35] stated that ONI influenced and relied on meteorological factors that determined the atmospheric properties, and in this study we improved and added value by using API as the sum up and combined interactions of all the pollutants towards and relate them with the index of ONI, thus that will represent the meteorological conditions during events of El-Niño and droughts occurred during that period of time, in order to simplify the previous methodology, as the main purpose of this research.

For singular effects from the meteorological variables onto the API values during the El-Niño and drought events is shown in Table 3, which shows a higher correlation recorded when each meteorological variable analysed separately with the API values during the extreme weather events. Table 3 presents the Spearman rank correlation coefficients between the API and meteorological factors. Generally, the influence of wind, humidity and air temperature has highly significant correlation effects (with R > 0.70) with air pollution under the API performance.
Both humidity and air temperature have a positive effect with the API, while wind speed has a negative effect on polluting the air quality. Heating and transport from outside the Region with the accumulation and formation effects of air pollutants from wind direction are the major contributors to a higher API [36]. However, higher wind speed has a reverse influence on the lower API. Higher wind speed could highly affect the scattering, ventilate and disperse the air pollutants away and cause lower concentrations of the pollutants [25]. For humidity, it could significantly affect the formation of secondary aerosol such as sulphate and nitrate caused by man-made emissions or the products from photo-chemical reactions [22]. The higher accumulating factor of particulate matter is often associated with higher humidity due to the moisture of the
mass, leading to dry deposition of the particles to the atmosphere [34]. High temperature in the tropical climate usually increases the quantity of biomass burning and evaporation process that will cause dry weather and a more stable atmospheric stratification makes pollutants harder to dilute diffusion thus accumulated [23].

To further investigate, the number of selected stations was reduced to only one station per region in this study for greater comparison accuracy. The selection for each region is based on the station with the highest API and highest frequency of exceedance that are selected to represent each of the six main regions, and also the factor that its located as the main cities in each of the regions that have given the significant positive trends of air pollution in their cities. The selected best station which involved Banting, Sungai Petani, Melaka, Kemaman, Miri and Kota Kinabalu. Using the HYSPLIT model and satellite images, the potential associated sources of high pollutants in these monitoring sites were identified as the trans-boundary transport and some local sources. This is shown in Figure 5, which displays the outcomes of the HYSPLIT model from the backward air

Figure 3. Sub-indexes of Air Pollution Index (API) for six monitoring regions which involves Klang Valley Region; Northern Peninsular Region; Southern Peninsular Region; East Coast Peninsular; Sarawak; and Sabah.

![Figure 3](image)

Figure 4. Diurnal variations of Air Pollution Index (API) with trend line and correlation ($R^2 = 26\%$) with Oceanic Niño Index (ONI) analysis for the period of 2010–2016.

![Figure 4](image)

Table 3. Correlation coefficients of the major meteorological variables onto API during the year 2015's El-Nino.

| Variable     | Air Pressure | Rainfall | Wind Speed | Humidity | Temperature | API |
|--------------|--------------|----------|------------|----------|-------------|-----|
| Air Pressure | 1.00         |          |            |          |             |     |
| Rainfall     | -0.77*       | 1.00     |            |          |             |     |
| Wind Speed   | -0.10        | 0.02     | 1.00       |          |             |     |
| Humidity     | -0.18        | 0.16     | -0.62*     | 1.00     |             |     |
| Temperature  | 0.10         | 0.18     | -0.41      | -0.46    | 1.00        |     |
| API          | 0.39*        | -0.48    | -0.71*     | 0.74*    | 0.81**      | 1.00|

(Data obtained from: Malaysian Meteorological Department, 2020).

* Correlation is significant at $P < 0.05$ (two-tailed).

** Correlation is significant at $P < 0.01$ (two-tailed).
Figure 5. Backward air mass trajectory analyses for six monitoring regions (a) Klang Valley; (b) Northern Region; (c) Southern Region; (d) East Coast; (e) Sarawak; and (f) Sabah.
Events such as drought in Malaysia and Indonesia. Moreover, all and atmospheric circulation are disrupted, triggering extreme climate this period. During El-Niño and even for La-Nina.

According to these figures, the pollutants may have originated from the huge biomass burning of peat swamps in neighbouring country which is Indonesia. The pollution in the Peninsular Malaysia monitoring stations (Banting, Sungai Petani, Melaka and Kota Bharu) have contributed from Sumatra while the pollution in Malaysian Borneo (Miri and Kota Kinabalu) has been emitted from Kalimantan. At the same time, both of these areas also have shown a large-scale of biomass burning were detected. In addition to the trans-climatic conditions were extremely dry and caused the large hotspots of precipitation during the southwest monsoon. Hence, with the boundary pollution, the anthropogenic sources also intensified the air pollution. Local emissions from urban and industrial areas with high population density and the number of motor vehicles, factories and machinery were added up the pollutants in the atmosphere. The fire records can be seen in both West and East Malaysia as shown in Figures 6 and 7. Therefore, the open burning in these areas was also the associated high PM10 in Malaysia.

4. Conclusions and future research recommendation

In conclusion, more than half of the monitoring stations in Malaysia have significant positive trends. This indicates that the Air Pollution Index (API) in Malaysia overall is increased, and the air quality has gotten worse during the year 2010–2016. Next, the frequency of exceedance that surpassed the API Good level (API >50) was recorded the highest in Klang Valley and Southern Region mainly due to high urbanization and industrialization. However, Sarawak and Sabah Regions showed the lowest exceedance. Meanwhile, the contributing pollutant during that period was found to be from particulate matter (PM10). With the coincident of the extreme drought from El-Niño and the dry season because of the southwest monsoon, the larger scale of biomass burning could be spotted in Indonesia, particularly in Sumatra and Kalimantan. Besides, the backward trajectories have also shown that the pathways of air mass came from this neighbouring country which further supports that this forest fire is one of the major sources of high API values. To conclude, the extended API in this study applies a simpler way to analyse the air quality yet efficient by not depending on the time series to analyse the temporal trends that are usually for long-term analysis of change. In this research, we utilize less amount of air quality data by getting the absolute mean average, which is actually the same thing that will be used at the end of the long-term analysis, as the components of variation (trend, seasonality and the remainder). It also fits to be applied for extreme events (extreme data) when it reoccurs at the specific period of time and the specific period of that event. In a different context, a recommendation for future research could be followed from our findings here, including to further test the application that we have developed to use it for all the existing air pollution indexes for comparative analyses in order to improve its robustness and to maximize the usage of the API application in air quality assessment, particularly when dealing with the climate change events such as El-Niño and even for La-Nina.

Declarations

Author contribution statement

Payus, C.M.: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Nur Syazni M. S.: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Sentian, J.: Contributed reagents, materials, analysis tools or data.

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Additional information

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