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Front Pages

Athens Journal of Sciences

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The current issue is the second of the eighth volume of the *Athens Journal of Sciences (AJS),* published by Natural & Formal Sciences Division of ATINER.

Gregory T. Papanikos, President, ATINER.

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Monitoring Particulate Matter Air Pollution in Urban Centers: New Insights from Douala, Cameroon

By Aguh Akeh Nug[*], Cheo Emmanuel Suh[±], Johan Boman[‡] & Godwin Sendze Yinda[+]

Air quality progressively deteriorates as urbanization, motorization and economic activities increase. Aerosol particles smaller than 2.5μm ($PM_{2.5}$), a widespread form of pollution is an emergent threat to human health, the environment, quality of life, and the world's climate. The composition of these particles is an important aspect of interest not only related to possible health and environmental effects of the elemental content but the elemental determination which also adds valuable information for source apportionment. This study investigates and evaluates the level of $PM_{2.5}$ in Douala, Cameroon. Particles were collected using a cyclone that separates the $PM_{2.5}$ from the air stream and impacts them on polycarbonate filters which were changed every 24-hour sampling period. Samples were analyzed for particulate mass concentration, black carbon (BC) and trace elements. Trace element analysis was done by EDXRF (energy dispersive x-ray fluorescence spectroscopy). Cl, K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Br, Sr, and Pb were identified and quantified for samples. Local meteorology was used to study variations in $PM_{2.5}$ mass concentrations. Possible sources for the pollutants were also investigated. The mean particle mass concentration was 252 ± 130μg/m^3 while BC attained a maximum of 6.993μg/m^3. The influence of leaded gasoline was inferred while combustion and road traffic were identified as the major anthropogenic sources. Trends in meteorological parameters were influenced by thunderstorms. Sea spray was identified as another major contributor to aerosol PM. This study highlights high pollution levels in Douala.

Keywords: *$PM_{2.5}$, air quality, aerosol, mass concentration, source identification*

Introduction

With the recent upsurge in globalization and industrialization coupled with increasing pressures of global climate change, deforestation and shifts in land use pattern, air pollution is emerging as one of the major factors influencing human health, agriculture and natural ecosystems (Agrawal et al. 2003, Kuan et al. 2017, Sánchez de la Campa et al. 2018). Air quality is of particular concern due to the degradation of human health attributed to it. Air borne particles that play pivotal roles in human health and atmospheric processes such as fog and cloud formation, visibility, solar radiation and precipitation, acidification of clouds, rain and fog, and climate change as a whole are of particular interest (Goldoni et al. 2006,

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Dawson et al. 2007, Kawata et al. 2007, Donaldson et al. 2009, Kelly and Fussell 2011, Tiwari et al. 2012, Amodio et al. 2013).

The health burden due to particulate matter (PM) air pollution (PM_{10} and $PM_{2.5}$) is one of the biggest environmental health concerns globally (Kuan et al. 2017, Loxham and Nieuwenhuijsen 2019). According to Loxham and Nieuwenhuijsen (2019) and Ariundelger et al. (2020), exposure to ambient airborne PM is a major risk factor for mortality and morbidity, associated with asthma, lung cancer, heart disease, myocardial infarction, and stroke, and more recently type 2 diabetes, dementia and loss of cognitive function especially in urban centers where urbanization, motorization, and rapid economic growth rapidly deteriorate the quality of the air (Boman et al. 2009a, Bell et al. 2009, Kuan et al. 2017, Cao et al. 2018). The size of particles affects their ability to penetrate the human respiratory system causing adverse health effects (Schwarze et al. 2006, Seinfield and Pandis 2006, Kaonga and Ebenso 2011). Exposure to fine particles especially $PM_{2.5}$ which are aerosol particles with aerodynamic diameter $\leq 2.5\mu m$ can cause short and long term effects such as decreased lung function, alterations in tissue and lung structure, increased respiratory symptoms, alterations in the respiratory tract and even premature death (Tsai et al. 2003, Katsouyanni et al. 2009, Kuan et al. 2017). Increased toxicity and PM carcinogenicity have been strongly associated with the elemental composition of PM and the presence of polycyclic aromatic hydrocarbons (PAHs) in the finer particles. New evidence shows that long-term exposure to air pollution not only affects outcomes such as premature deaths but also contributes to the development and progression of subclinical and clinical disease such as serious cardiopulmonary defects, as well as some unexpected responses in the liver and brain (WHO 2007).

More attention is required for "Heavy metals", usually referred to as metallic chemical elements having a relatively high density and toxic or poisonous at low concentrations (Hg, Cd, As, Cr, Ni and Pb). In addition, trace metals are proven to be useful tracers and are extensively used to identify sources of emissions to be targeted by the emission reduction policies (Gotschi et al. 2005, Querol et al. 2006, 2007, Viana et al. 2007, Jeong et al. 2008).

According to WHO (2005), Forster (2007) and Tai et al. (2012), climatic conditions have direct effects on the concentration, dispersion and life time of aerosol particles in the atmosphere. The dynamics of the atmosphere and the meteorological conditions play a vital role in governing the fate of air pollutants. Lecoeur et al. (2012) states that concentrations of PM are strongly dependent on meteorological conditions of which temperature, wind speed, humidity, rain rate and mixing height are the variables that impact PM concentrations the most. In this study, the relationship between ambient PM concentration and meteorological variables, such as temperature, rainfall, wind speed and direction and relative humidity is statistically analyzed.

In Cameroon, Douala is of particular interest for air pollution studies because of its dense population coupled with intense industrial and commercial activities (Kemajou et al. 2007). However, there has been limited air pollution research in this city.

With focus on $PM_{2.5}$, spatial analysis and temporal variations of air pollution in areas of different development typology in Douala, the economic capital of Cameroon was studied. Detailed measurements of air pollution ($PM_{2.5}$) were carried out at street sites in 2 industrial zones (1 semi industrial interspersed with residential and commercial neighborhoods, and 1 absolute industrial zone) and a residential neighborhood all of which were centrally located and paved neighborhoods.

Literature Review

Ambient PM is a complex mixture of solid and liquid particles suspended in air (Seinfeld and Pandis 2006, Adams et al. 2015). The size, chemical composition, and other physical and biological properties of particles vary with location and time. This variability in pollutant levels derives from differences in pollutant sources, and the characteristic weather parameters of the area (Pinto Miranda Garcia et al. 2018). The sources may be natural, such as forest fires volcanoes, dust storms, forest and grassland fires, living vegetation and sea spray (Omidvarborna et al. 2015, Adams et al. 2015, Loxham and Nieuwenhuijsen 2019), or the result of human activities, such as the burning of fossil fuels in vehicles (Omidvarborna et al. 2015), stubble burning, manufacturing and power plants (Adams et al. 2015), wet cooling towers in cooling systems and various industrial processes, also generate significant amounts of particulates. Coal combustion in developing countries is the primary method for heating homes and supplying energy thus a significant source of PM (Omidvarborna et al. 2015). Salt spray over the oceans is the overwhelmingly most common form of particulate in the atmosphere. As stated by Webb and Pierre (2018) and Wang et al. (2018), anthropogenic aerosols currently account for between 10% and 60% of the total mass of global aerosols in the atmosphere.

According to Seinfeld and Pandis (2006), Brook et al. (2010), Heal et al. (2012), Adams et al. (2015) and Manisalidis et al. (2020), air pollutants may either be emitted directly into the atmosphere (primary pollutants) or formed within the atmosphere itself through chemical reactions and physical processes (secondary pollutants). Heal et al. (2012), further classifies them as inhalable, thoracic and respirable dust fractions depending on the depth of penetration of the particle into the respiratory system. The inhalable dust fraction with a size threshold of about 50μm can be captured by inhalation in the nasal cavity (easily filtered by cilia or mucus). The dust fraction reaching all the way to the lungs (lower respiratory tract) is the thoracic dust fraction. These are particles ≤ 10 but > 2.5μm (Boman et al. 2010, Fortoul et al. 2012, Manisalidis et al. 2020), and the fine dust that can penetrate even further into the bronchioles and alveoli (gas exchange region) is known as the respirable dust fraction. These particles are not ejected by breathing out, coughing, or expulsion by mucus, and approximate a particle size threshold of about 3.5–4μm. In effect, they are < 2.5μm (WHO 2003, Boman et al. 2010, Fortoul et al. 2012, Heal et al. 2012), and are capable of reaching the gas exchange surfaces of the alveoli (Heal et al. 2012).

It should be noted that ambient PM levels in any particular location are also affected by local ambient mixtures of gaseous pollutants, meteorology, geography, and seasonal patterns (Adams et al. 2015, Pinto Miranda Garcia et al. 2018).

Meteorological Implications of Particulate Matter

According to Tai et al. (2012), Lecoeur et al. (2012) and Li et al. (2017), the fate of air pollutants is influenced by the movements and characteristics of the air mass into which they are emitted. The measurements of wind speed and direction, temperature, humidity, rainfall and solar radiation are important parameters used in the study of air quality and can assist in furthering understanding of the chemical reactions that occur in the atmosphere (Lecoeur et al. 2012, Wei et al. 2012, Pinto Miranda Garcia et al. 2018).

As stated by Tai et al. (2010) and Li et al. (2017), $PM_{2.5}$ concentrations depend on meteorological conditions, suggesting that climate change could have significant effects on $PM_{2.5}$ air quality and vice versa. PM is comprised of many different species, and meteorology can have complex effects on total PM concentrations due to its impacts on individual species (Dawson et al. 2007, Zhou et al. 2020). Aerosol SO_4^{2-} concentrations depend on the temperature-dependent oxidation of SO_2 in both the gas and aqueous phases, and sunlight intensity (Seinfeld and Pandis 2006, Dawson et al. 2007, Zhou et al. 2020). On the other hand, concentrations of semi-volatile NO_3^- and organic aerosols are temperature and relative humidity dependent; they can also vary with the amount of oxidants present, which is linked to photolysis rates and, therefore, cloud cover (Dawson et al. 2007). Tai et al. (2010), Dawson et al. (2007) and Tsigaridis and Kanakidou (2007) report that SO_4^{2-} concentrations are expected to increase with increasing temperature due to faster SO_2 oxidation, but semi-volatile components such as NO_3^- and organics are expected to decrease as they shift from the particle phase to the gas phase at higher temperature.

Higher relative humidity (RH) promotes the formation of ammonium nitrate, but an increase in precipitation causes a decrease in all $PM_{2.5}$ components through scavenging and since all species have wet deposition as a sink, precipitation is expected to have a significant effect on aerosol concentrations (Dawson et al. 2007). During a study by Dawson et al. (2007), it was observed that the changes in $PM_{2.5}$ resulted even in areas with little or no base-case precipitation indicating that changes in precipitation in upwind areas affected $PM_{2.5}$ concentrations in downwind areas. Seinfeld and Pandis (2006) conclude that changes in absolute humidity have the largest effects on concentrations of ammonium nitrate aerosol with concentrations increasing with increased absolute humidity and that increases in humidity shift the equilibrium of the ammonia-nitric acid system toward the aerosol phase, resulting in higher concentrations of ammonium nitrate aerosol.

Finally, mixing and dilution influence PM concentrations, so wind speed and mixing height are expected to have an impact as well. According to Tai et al. (2010), if the air is calm and pollutants cannot disperse then the concentration of these pollutants will build up. Conversely, if a strong, turbulent wind is blowing any pollution generated will be rapidly dispersed into the atmosphere resulting in

lower pollutant concentrations in the air. Wind speed changes affect all species that comprise $PM_{2.5}$, with increases in wind speed generally leading to decreases in $PM_{2.5}$ concentrations, and decreases in wind speed generally leading to increases in $PM_{2.5}$ (Dawson et al. 2007, Ya-Gao et al. 2019). According to Brook et al. (2010), increases in wind speed leads to changes in advection and transport resulting in decreases in $PM_{2.5}$ concentrations.

Objectives

This study seeks to investigate and evaluate the level of PM in the industrial town of Douala in Cameroon. The objectives of the study were to analyse and quantify $PM_{2.5}$ in terms of mass and mass concentration and the elemental composition of the PM found in Douala. The study also focused on determining the influence of meteorological parameters on $PM_{2.5}$ concentration in Douala, embarked on apportioning sources to the different PM components that would be identified, and analyzing the variation of fine particles with meteorological parameters, and determine the sources of the $PM_{2.5}$ in the area.

Methodology

Sample Collection

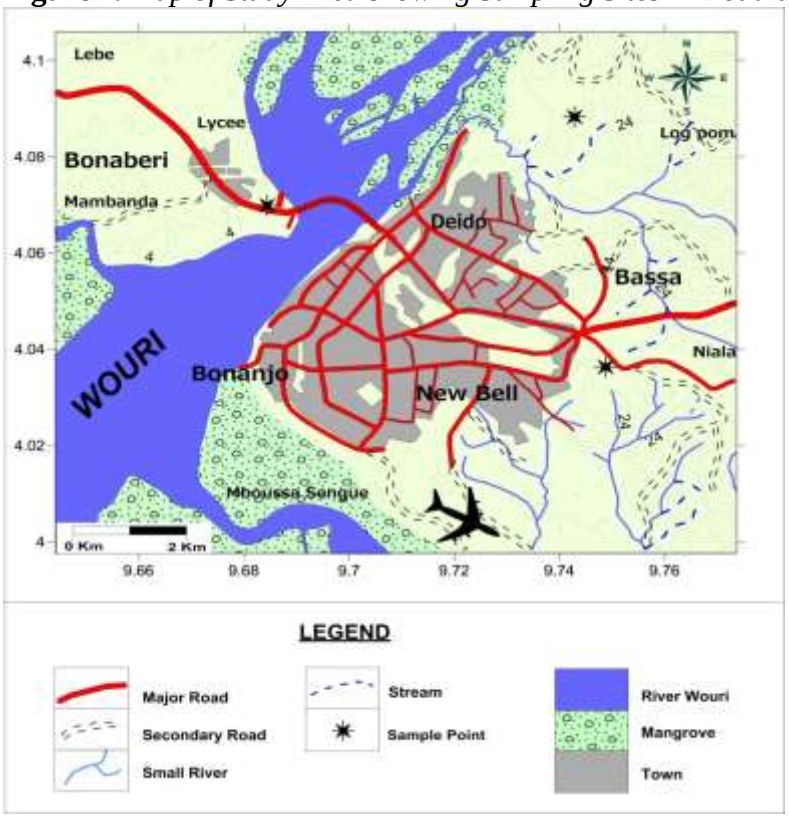
Sampling was done using an electrically powered cyclonic sampler (Casella Group Ltd) capable of collecting PM in $PM_{2.5–10}$ size fractions. The cyclone separates the $PM_{2.5}$ particles from the air stream and impacts them on polycarbonate filters. Operating at a constant volumetric flow rate of 3L/min, $PM_{2.5}$ particles were collected for a period of 1 month. The flow through the cyclone was kept constant by a critical orifice (accuracy of ± 15%) to maintain a particle cut off diameter of 2.5µm. Sample collection was done at a daily temporal resolution and temporal coverage from 30/10/2012–29/11/2012. The set up was mounted at each location for 9 sampling days after which it was mounted at the next location. Filters were changed after every 24h sampling period. Since the same setup was used during the whole campaign the different samples can be compared with each other without being influenced by possible differences in sampling flow (Boman et al. 2010)

Purposefully, samples were collected at 3 sites in the industrial town of Douala (Figure 1); Site 1, the Bonaberi industrial zone (longitude 09^{o}74" East and latitude 04^{o}09" North), Site 2, the Bassa industrial zone (longitude 09^{o}68" East and latitude 04^{o}07" North) and Site 3, the Bonamoussadi residential zone (longitude 09^{o}75" East and latitude 04^{o}04" North). At site 1, the sampler was placed at a height of 8.5m above ground with the intake nozzle placed 1.5m above the platform on which the sampler was placed. The nozzle was placed such that airflow was unobstructed (at all sites) about 200m away from the industrial area and 50m away from the road. The Bassa site saw similar sampling conditions. The sampler was placed facing the industrial zone but away from the road 100m away.

It was placed 8.0m above ground and 80m away from the railway. At site 3 the sampler was placed on the flat roof 5m above ground with the nozzle position 2m above the roof and 100m away from the roadside. The sampler was placed such that air flow was unobstructed. Effective sampling time was ± 24hours.

Particle collection was done on 25mm diameter Teflon filters with a pore size of 0.4µm. The polycarbonate filters were initially preconditioned at 45% relative humidity and 20°C (equilibrium conditions intended to minimize the liquid water associated with soluble compounds and to minimize the loss of volatile species as stated by Chow and Watson (1998). These conditions ensure that particle growth due to accumulation is minimized) before they were weighed and placed in Petri dishes. After sampling, the filters were again placed and stored in the same dishes. An OHAUS Adventurer Pro electronic analytical microbalance with a sensitivity of 0.0001 mg was used for gravimetric determination of the sampled particle mass. The set up was mounted at each location for 9 sampling days. Since the same setup was used during the whole campaign the different samples can be compared with each other without being influenced by possible differences in sampling flow.

Figure 1. *Map of Study Area showing Sampling Sites in Douala*



Source: Fieldwork 2012.

The climate of this region is uniform and is described as a particular equatorial type marked by a lengthy rainy season (at least nine months), abundant rainfall (about 4000 mm per annum), high and stable average annual temperatures (26.7°C) (Siegfried et al. 2009). The mean of the minimum temperature calculated in Douala for 30 years is 22.6°C in July and the mean of the maximum temperature

is 32.3°C in February. The relative air humidity remains high throughout the year with a mean value of 82.6%; the lowest value being around 60% in February and the highest is 100% in the rainy season (Din et al. 2008). Rainfall is bimodal, peaking at July and August with minimal rainfall in January and February and varies from 78.0–1215.0 mm/month and an average rainfall of 2900 mm/year (Djuikom et al. 2011, Fonge et al. 2011).

Sample Analysis

The samples were analyzed for PM mass concentration, elemental composition and black carbon. A principal component analysis (PCA) was conducted to apportion PM sources.

Gravimetric analysis was performed to determine the mass concentration of the sample aerosol.

The total volume of air sampled was determined from the volumetric flow rate of 3L/min. The concentration of $PM_{2.5}$ in the ambient air is computed as total mass of collected particles divided by the volume of air sampled in actual conditions. The concentrations are expressed in micrograms per actual cubic meter ($\mu g/m^3$). The equation governing the gravimetric analysis is given below:

$$C_{PM} = \frac{M}{V}$$

Where,

C_{PM} = PM Mass Concentration
M = Net mass of the particulate matter collected on the sample filter
V = The volume of air sampled

Samples obtained were analyzed for elemental composition by Energy Dispersive X-Ray Fluorescence (EDXRF) spectrometry (Van Grieken and Markowicz 1993). The spectrometer based on a three-axial geometry consisted of a Siemens Mo-anode X-ray tube with a Mo secondary target that facilitated a good signal to background ratio giving low detection limits (Table 2), and a Kevex Si (Li) detector. According to Boman et al. (2009a) and Gatari et al. (2006), the spectrometer was operated at 50kV and 25mA and the samples were analyzed for 1000s. To ensure and verify the validity of the results obtained, a certified reference material (#2783, Air Particulate on filter media, NIST, USA) was used. For spectrometer calibration, thin film standards with specified uncertainty of 5% in the elemental concentration were used (Micromatter Inc., Seattle, WA, USA). By repeatedly analysing two aerosol filter samples the mean analytical precision of the spectrometer was determined to be 5% (Moln´ar et al. 2006). Sample elemental spectra were obtained and evaluated by a quantitative x-ray analysis system (QXAS) software provided by the International Atomic Energy Agency (IAEA) laboratories, Seibersdorf, Austria. Atmospheric concentrations and detection limits (DLs) were determined and several of the elements below detection limits were excluded from analysis.

BC concentrations were determined by a Black Smoke Detector Model FH 621-N (ESM Emberline, Erlangen, Germany). This instrument is a reflectmeter that has light emitting diodes (LEDs) and photosensors enclosed in a completely black casing. The LEDs (red light emitting diodes for this case) illuminate the sample with optimized light that is tuned at a wavelength of 0.6µm. The reflected light intensity is sensed by the photosensors that translate the light intensity to electrical current. The voltage reading is related to the level of sample blackness and subsequently recalculated into BC concentrations. For QC/QA (quality control and Quality assurance) measures, appropriate filter substrate was selected and tested for sampling effectiveness prior to field sampling. The filters were pre-conditioned to removed contaminants and ensure quality of air sampled. Laboratory accredited program was used to assure the quality. The sensors in the instrument used were also calibrated for purposes of QC/QA.

Principal Component Analysis

Factor analysis with Principal Components as extraction method known as Principal Component Analysis (PCA) in air quality studies is widely used to provide information on PM or gaseous pollutant sources (Querol et al. 2001, Amodio et al. 2010). The PCA technique identifies components that explain the common variation pattern of the included variables (elements, and BC) based on the principle that elements with similar concentration patterns most likely originate from a common source. The components are identified by the PCA, and possible sources of the components ascribed. Values < 0.3 have low loading, those between 0.3 and 0.6 are considered to have moderate loadings, those with 0.8 are said to be moderately high loadings and values > 0.8 are considered as high loadings (Boman et al. 2009a).

Meteorological Conditions

Since $PM_{2.5}$ concentrations are strongly dependent on meteorological conditions, it is important to investigate the relationships between $PM_{2.5}$ and meteorological parameters (Lecoeur et al. 2012). The meteorological information during the measurement campaign was obtained from the Douala Meteorological centre which records such data for the entire city. The website "http:/wunderg round.com" was also valuable in getting certain daily variations for some climate parameters.

Results and Discussion

Mass and Mass Concentration

The mean mass and mass concentration of PM collected from the 3 sites is as shown in Table 1.

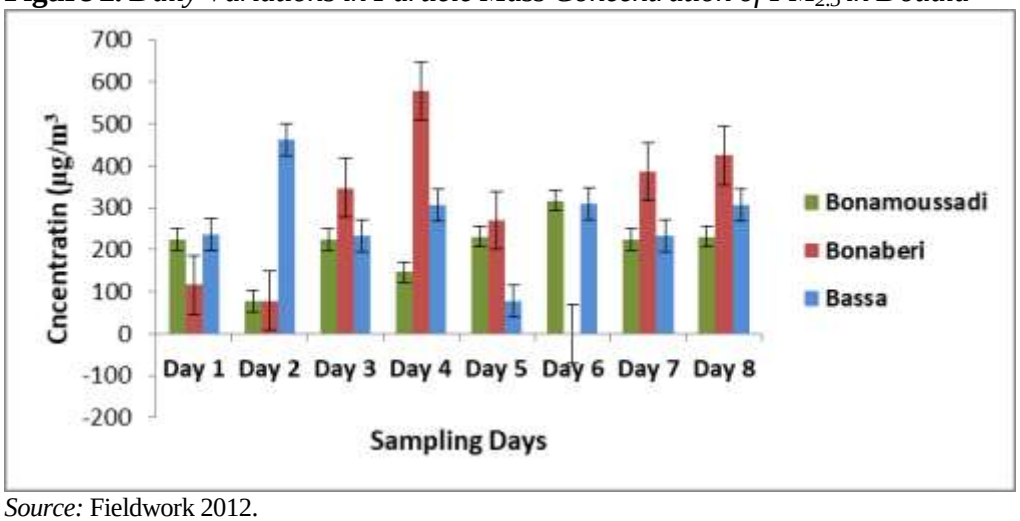
Table 1. *Mass and Mass Concentration for All Sampling Sites*

Sample Code	Mass(g)	Mass Conc ($\mu g/m^3$)	Sample Code	Mass(g)	Mass Conc ($\mu g/m^3$)	Sample Code	Mass (g)	Mass Conc ($\mu g/m^3$)
Bonamoussadi 1	0.0010	224	Bonaberi 1	0.0005	116	Bassa 1	0.0010	236
Bonamoussadi 2	0.0003	77.2	Bonaberi 2	0.0003	78.4	Bassa 2	0.0020	463
Bonamoussadi 3	0.0010	224	Bonaberi 3	0.0015	347	Bassai 3	0.0010	232
Bonamoussadi 4	0.0006	147	Bonaberi 4	0.0025	579	Bassa 4	0.0013	307
Bonamoussadi 5	0.0010	232	Bonaberi 5	0.0012	270	Bassa 6	0.0003	77
Bonamoussadi 6	0.0014	316	Bonaberi 7	0.0000	0	Bassa 7	0.0013	309
Bonamoussadi 7	0.0010	224	Bonaberi 8	0.0017	386	Bassa 8	0.0010	232
Bonamoussadi 8	0.0010	232	Bonaberi 9	0.0018	424	Bassa 9	0.0013	307
Mean	0.0009	209	**Mean**	0.0012	275	**Mean**	0.00115	271
Standard Dev.	0.000327	70.2	**Standard Dev.**	0.000856	197	**Standard Dev.**	0.000475	109
Range	0.0003–0.0014	77.2–316	**Range**	0–0.0025	0–579	**Range**	0.0003–0.002	77–463
Median	0.001	224	**Median**	0.00135	309	**Median**	0.00115	273

Source: Fieldwork 2012.

The cumulative mean concentration for all sites is 252 ± 130$\mu g/m^3$ which is relatively higher than the WHO Guideline of 25 $\mu g/m^3$ for $PM_{2.5}$ (24-hour mean), as stated by Heal et al. (2012). The daily variation in particle mass concentration of $PM_{2.5}$ in Douala is clearly shown in Figure 2.

Figure 2. *Daily Variations in Particle Mass Concentration of $PM_{2.5}$ in Douala*



Source: Fieldwork 2012.

The huge population of the city, the wide range of commercial and industrial activities, variety of old and new, maintained and poorly maintained vehicles, large scale two wheel activities, and the dependence of the population on biomass significantly contribute to the high value of $PM_{2.5}$ mass concentration. According to UN (2018), most vehicles imported into the country range are used or old vehicles (emit a disproportionate amount of pollutants) which between 6–9 years. Nonetheless, JV (2013) puts forward that some of these second hand vehicles are as old as 20 years, although the 2011 financial law of the country permits only the entry of cars of maximum 7years of age. Mercedes Benz MB 100 D that was first manufactured in 1981 is still being imported into the county. Named "cargo", this wagon carries up to 25 persons within the Douala city. Similarly, vehicles on Cameroonian roads such as taxis date between 1980 and 1990, states the paper.

Open burning and the high dependence on fuel wood and charcoal for domestic and commercial purposes significantly contributes the high BC concentrations for all sampling sites.

Elemental Analysis

EDXRF was run for 22 elements, and a total of 12 elements were identified (above detection limits as shown in Table 2), and quantified in most of the samples; Cl, K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Br, Sr, and Pb (Table 2).

Sample collection was done at a daily temporal resolution and temporal coverage from 30/10/2012–29/11/2012. The set up was mounted at each location for 9 sampling days after which it was mounted at the next location. Filters were changed after every 24h sampling period implying that after every 24 hours the filters were changed. Since the same setup was used during the whole campaign the different samples can be compared with each other without being influenced by possible differences in sampling flow.

Table 2. *Detection Limits (DL) in µg/m^3 for the Analysed Elements*

Elt	Cl	K	Ca	Ti	Mn	Fe	Ni	Cu	Zn	Br	Sr	Pb
DL	0.12	0.024459	0.017763	0.007277	0.002214	0.002029	0.002	0.00159	0.001724	0.0011	0.0011	0.001299
NB: Three axial geometry with Mo secondary target. X-ray tube operated with 50kV and 25mA. Lifetime of 1000s. A collection time of 24h.												

Source: Fieldwork 2012.

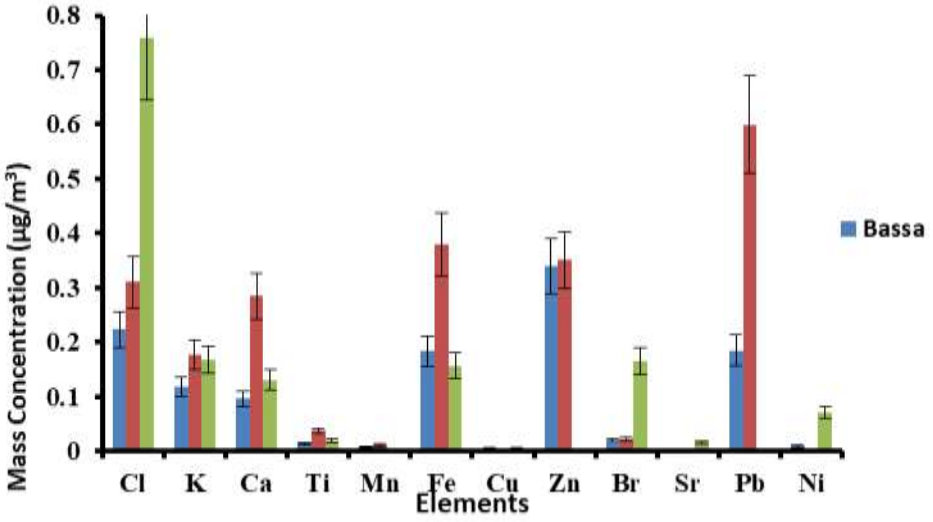
Full campaign concentration means with standard deviations in µg/m^3 for the analysed elements and the $PM_{2.5}$ mass concentrations at the three sites including BC concentrations in µg/m^3 are given in Table 3. Reported elemental concentrations are those above DL and blank filter concentrations while N is the number of samples with concentrations above DL. DL for analysed elements ranged from 0.0011µg/m^3 for Br and Sr to 0.12µg/m^3 for Cl as shown in Table 2 while Figure 3 shows how the elemental concentration varied at different sites.

Table 3. *Average Elemental Concentrations for the Entire City*

Parameter	Range	Average (µg/m^3)	N (Max = 24)
Particle mass concentration (µg/m^3)	0–578.7	251.4 ± 133.7	24
Black Carbon	0–7.0	1.9 ± 1.815	21
Cl	0.131–0.760	0.347 ± 0.189	9
K	0.048–0.507	0.164 ± 0.103	19
Ca	0.027–0.810	0.190 ± 0.195	23
Ti	0.008–0.085	0.029 ± 0.020	18
Mn	0.003–0.126	0.017 ± 0.033	13
Fe	0.035–0.917	0.248 ± 0.216	24
Ni	0.003–0.009	0.005 ± 0.002	4
Cu	0.002–0.013	0.005 ± 0.003	17
Zn	0.004–1.777	0.296 ± 0.469	24
Br	0.017–0.040	0.022 ± 0.005	24
Sr	0.001–0.022	0.004 ± 0.005	15
Pb	0.007–2.075	0.292 ± 0.48	24

Source: Fieldwork 2012.

Figure 3. *Variation of Elemental Concentration at Different Sites*



For Bonaberi, Ca, Fe, Zn, Br and Pb were present in all samples while for Bassa only Fe, Zn, Br and Pb were identified in all samples. Cl and Ni have the lowest frequencies of occurrence with Cl appearing only once in Bonamoussadi, Ni appearing twice in Bonamoussadi, once in Bonaberi and Bassa with the highest concentration recorded in Bassa.

All concentrations but for Fe, Zn and Pb have concentrations < 0.3µg/m^3 for Bonaberi. But for Cl, all other elements have concentrations < 0.3µg/m^3 for Bonamoussadi and Bassa. Ca presents relatively high concentrations in Bonaberi than for the other zones most probably due to the presence of the cement industry which is present in Bonaberi and absent in the other zones.

While the concentration of Br is relatively low for the other zones, Bonamoussadi presents a higher Br concentration. The high Br concentration could be explained by a high input of particles from biomass burning, since Br can be tracer element for pyrogenic biomass burning.

The possible contribution of Br from sea spray or some combustion source especially vehicle exhaust cannot be excluded (Boman et al. 2009b). Apart from Cl, K and Ca which are higher in Bonamoussadi than in Bassa, Bonamoussadi generally has lowest concentrations. It can then be concluded that Bonaberi has highest elemental concentrations followed by Bassa then by Bonamoussadi. The industrial zones therefore contain more $PM_{2.5}$ than the residential zone.

The lone appearance of Cl in Bonamoussadi indicates there is no local source in that locality. The high Cl concentration could either be from a sporadic source or blown in by the wind. PM concentrations here seem to be higher than for Bonamoussadi. Ca, Fe, Zn and Pb have highest concentrations as can be seen in Figure 3. Unlike in Bonamoussadi, Ca has peaks higher than the 0.3 line which can be explained by the presence of the cement industry in Bonaberi. Cl also presents concentrations higher than the other sites.

The relatively high concentration of Pb especially in Bonaberi can be accounted for by the presence of fuel from unofficial markets (locally known as "fungeh"). Leaded paint is also being scrapped from walls and spread in both old and new construction sites and also at the shipyard (eye witness account). Chronic exposure to low concentrations of Pb is very dangerous and can lead to reduction of intelligence, increased blood pressure and a range of behavioral and developmental effects (WHO 2005).

The results show a large variation in sample mass, BC concentration as well as in the concentrations of the analyzed elements. A look at the individual samples from the different sites (Figure 4) signifies that the variation of the different constituents does not show the same pattern. This adds to the picture of different sources for different pollutants and to the influence of meteorology on PM concentration. The different patterns are as shown in Figure 4(a–c).

Figure 4a. *Individual Element Pattern for Elements Found in $PM_{2.5}$ in Bonamoussadi*

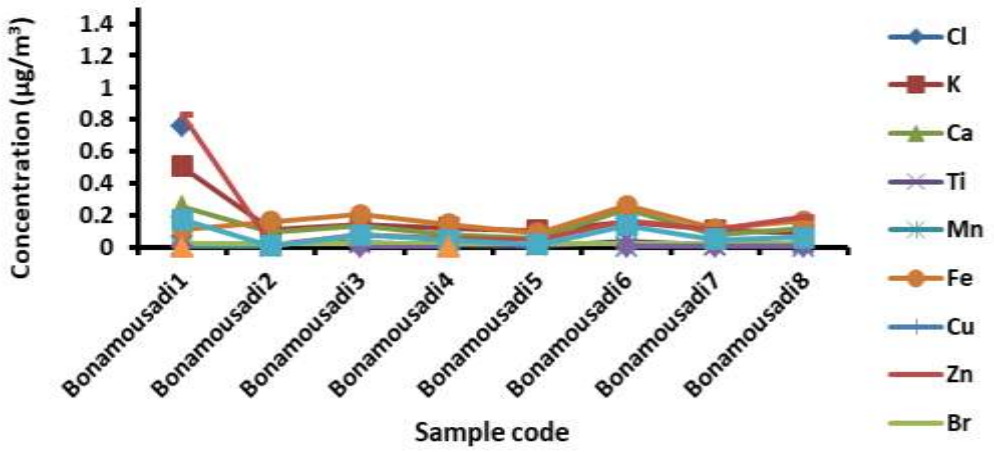


Figure 4b. *Individual Element Pattern for Elements Found in $PM_{2.5}$ in Bonaberi*

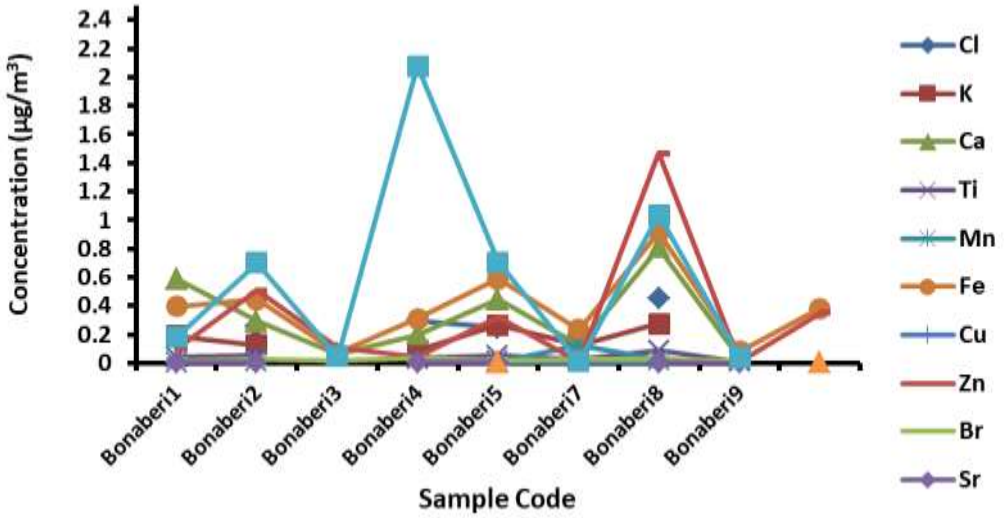
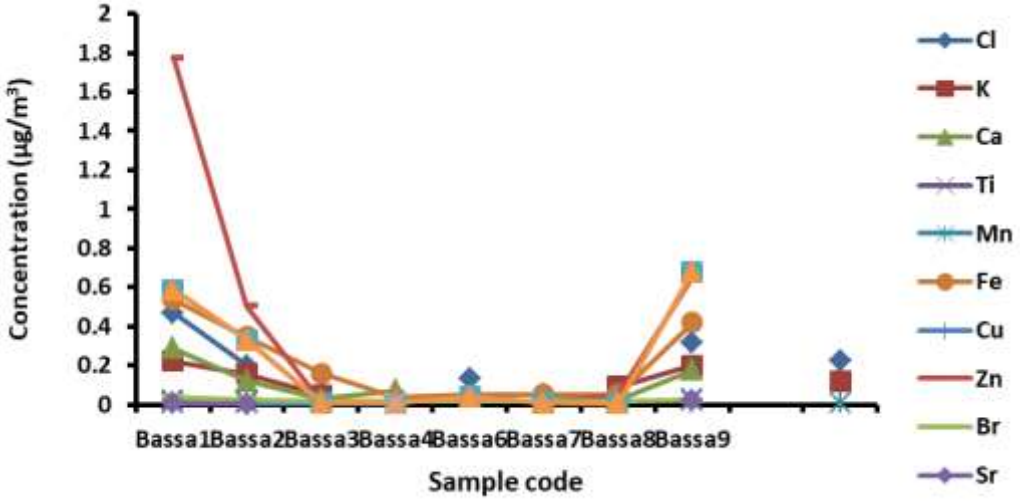


Figure 4c. *Individual Element Pattern for Elements Found in $PM_{2.5}$ in Bassa*



Black Carbon (BC)

Very high concentrations of BC are recorded for Bonaberi, high concentrations for Bonamoussadi and averagely high concentrations for Bassa. The mean concentration of Bonaberi, 3.17 ± 2.376 µg/m3 as opposed to 1.42 ± 0.459 µg/m3 for Bonamoussadi and 1.10 ± 1.566 µg/m3 for Bassa is relatively very high (there is high use of fuel wood for household and commercial purposes in the area hence the high BC concentration for Bonamoussadi). The sampling site for Bonaberi is the gateway to and away from the Wouri Bridge hence very dense traffic for most parts of the day hence emissions from vehicle exhaust can explain the high BC concentration. The industrial zone also has very high dependence on fossil fuel for energy production. Bonamoussadi concentrations can be due to the burning of biomass for domestic purposes while vehicle emissions cannot be ignored. Traffic also accounts for that of the Bassa area which is a gateway from Douala to

Yaoundé with high traffic at Ndokotti Market. Open burning and the high dependence on fuel wood and charcoal burning for domestic and commercial purposes significantly contribute the high BC concentrations for all the areas.

Factor Analysis

Three components were extracted by the analysis explaining a total of 76.8% variance for the whole data set as shown in Table 4. The first component is characterized by high loadings of Fe, K, Zn, and moderately high loadings for Cu, Cl, Sr, Br, Ti, and Ca. This component accounts for 50.5% of the total variance obtained. The component could be interpreted as a combination of geological (soil/crust) origin and combustion aerosols. There is a combination of high and moderately high loadings for elements which are derived from these sources. K and Fe for example have high loading and indicate soil originated aerosols, Ti and Ca have moderately high loadings and indicate soil originated aerosols while Zn with High loading indicate industrial activity (Boman et al. 2009a) especially metallurgical activities (Heal et al. 2012). The moderately high Cl and Br loadings also indicate industrial combustion. Zn and Fe could also be emitted from lubricating oil additives (used in two-stroke engine where engine oil is mixed with fuel), combustion of impure fuel, vehicle engine and brake tire wear.

Table 4. *Component Matrix for Source Apportionment for Elements in Air Samples from Douala*

	Components		
Elements	1	2	3
Cl	0.754	-0.021	-0.518
K	0.882	0.367	-0.130
Ca	0.668	0.538	0.141
Ti	0.721	0.050	0.517
Mn	0.345	0.748	0.289
Fe	0.946	-0.207	-0.063
Cu	0.779	0.147	-0.191
Zn	0.818	-0.158	-0.150
Br	0.727	-0.357	0.168
Sr	0.753	-0.242	-0.358
Pb	0.394	-0.730	0.394
BC	0.450	-0.049	0.581

The first component has high loading for all detected elements but for Mn, Pb and BC. Zn compounds are extensively employed as lubricants, antioxidants and as detergent/dispersant improvers for lubricating oils (Begum et al. 2007). The high and moderately high loadings are of more mixed character, possibly representing both soil and combustion origin. To confirm this mixed character, Fe, K, and Ca are characteristic to road dust attributed to diesel vehicle emissions. The industrial and petrochemical waste managing companies that incinerate most

of these wastes could also be a significant source for these elements in the atmosphere.

The second component is characterized by moderate loading from Mn, and this component accounts for 15.0% of the total variance obtained. Moderate loadings of Mn bear sign of aerosol from the metallurgical industry (Heal et al. 2012). This could be confirmed by the moderate loading of Ca in this component. Other activities generating Mn include vehicle engine, brake and tyre wear, and during combustion of impure fuel (particularly coal), and fuel and lubricating oil additives (Heal et al. 2012). Nonetheless, Mn and Ca are typical mineral elements and consequently, this factor could be associated with the crustal fraction of $PM_{2.5}$ (Heal et al. 2005). The presence of these elements in $PM_{2.5}$ could mainly be a result of local and regional dust re-suspension by wind, convection and other natural processes. However, if the emissions from incomplete and complete combustion of biomass have different sources, this could explain the appearance in two different components in the analysis.

The third component had moderate loading for BC accounting for 11.4% of the obtained variance. BC is a good marker for combustion – derived component of airborne particles. It is also a good marker for traffic-related PM pollution (Heal et al. 2012).

PCA for individual sampling sites showed same results as above implying that the individual sites have similar sources of particulate pollution.

Ni which was not included in the PCA due to its being below detection limits for most samples mainly comes from dust and re-suspended soil particles. It is also a tracer for the combustion of heavy fuel oil (Boman et al. 2010).

Influence of Meteorology on PM Concentration

Diurnal temperatures varied between 23°C and 31°C and relative humidity between 81 and 95%. Winds in Douala were westerly, showing a diurnal pattern with gusts of up to 10m/s during daytime, while evenings and nights were generally calmer with very stable atmospheric conditions.

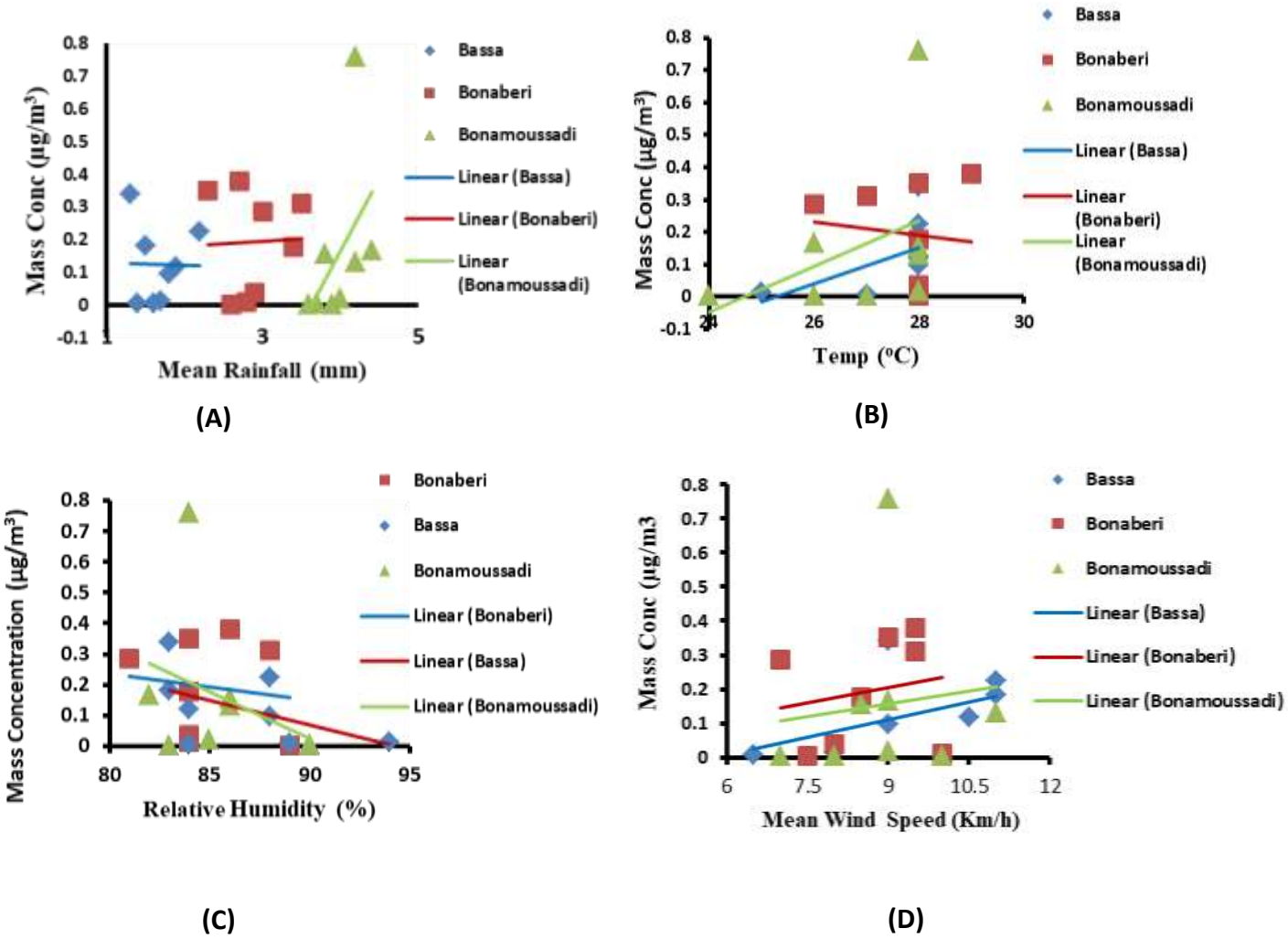
Scattered plots showing variation of meteorological variables with the elemental concentration for the sampling period are given in Figure 5.

Trends for the plot for temperature against mass concentration (A) show that as temperature increases in Bonaberi, the mass concentration reduces while mass concentration increases with increase in temperature for both Bonamoussadi and Bassa. These variations can be explained by the chemical species present in the $PM_{2.5}$. The mass concentration reduction with increasing temperature for Bonaberi could be explained using the species present in the $PM_{2.5}$. This trend may indicate the dominance of nitrates in this area since nitrates are semi-volatile. It could also indicate the dominance of primary particulates in this region (Seinfeld and Pandis 2007).

For Bonamoussadi and Bassa, mass concentration increases with increasing temperature indicating the probable presence of sulphates and dust. According to Seinfeld and Pandis (2007), the oxidation of SO_2 to SO_4^{2-} is temperature dependent and increases as temperature increases thus increasing the aerosol concentration. This also indicates that these two areas are dominated by secondary

particulates. From literature, one of the precursor gases for the formation of secondary particulates is SO_2 thus confirming the above assertion. On another hand, these variations can be explained by wind speeds and direction. The wind blows away from Bonaberi hence transporting away a bulk of the mass of particles with it, whereas for Bonamoussadi and Bassa, the wind blows to their direction bringing in more particles from the upwind. This confirms the theories of Brook et al. (2004), Dawson et al. (2007) and Tai et al. (2010).

Figure 5. *Variation of PM Mass Concentration with Meteorological Parameters: (A) with Temperature, (B) with Rainfall, (C) with Wind Speed and (D) with Relative Humidity*



Mass concentration of $PM_{2.5}$ shows a slight decrease with increasing rainfall for Bassa. A slight increase is noticed for Bonaberi and a sharp increase for Bonamoussadi. This can be explained by the nature of rainfall which is predominantly thunderstorms. Depending on the strength of the wind during the storm, the process of wet deposition can be counteracted and the particles blown away in the wind faster than they are deposited or washed out by the rain. In this case, the particles are blown downwind and mass concentration can then increase in the downwind area with increasing rainfall. This confirms Dawson et al. (2007)'s conclusion that changes in precipitation in upwind areas affect $PM_{2.5}$ concentrations in downwind areas and also explains the slight increase in PM mass concentration in Bonaberi as rainfall increases. The degree of change could be affected by the aerosol concentration of the upwind area.

PM mass concentration increases with increasing wind speed increases in all the locations contradicting the theories of Dawson et al. (2007) and Tai et al. (2010) which states that if the air is calm and pollutants cannot disperse then the concentration of these pollutants will build up. Conversely, if a strong, turbulent wind is blowing any pollution generated will be rapidly dispersed into the atmosphere resulting in lower pollutant concentrations in the air. This contradicting behaviour could be explained by the thunderstorm effect. However, it should be noted that the month of November which should be dry recorded quite some rainfall which could affect the behaviour of aerosols. In the dry season, there is the general tendency of particles to build up. And if suddenly strong winds and heavy rainfall come to play, patterns could be altered.

$PM_{2.5}$ mass concentration generally decreases as relative humidity increases. According to Dawson et al. (2007) this trend can be explained by the different species in the $PM_{2.5}$. Nitrates are semi-volatile thus, when relative humidity and temperature increase, they are taken out of the atmosphere by volatilisation hence reducing the mass concentration of $PM_{2.5}$. This trend could be an indication that the $PM_{2.5}$ in these areas is dominated by primary particulates. Tsigaridis and Kanakidou (2007) states that nitrates shift from particle phase to gas phase as temperature and relative humidity increase.

Comparing the average elemental concentrations in this study with selected studies from some African and European cities (Table 5), it can be seen that the concentrations of Ca, Ti, Mn, and Fe are much higher in Ouagadougou than in Douala, and lower for the other regions than for these two cities.

In the comparison, the concentrations of Br and Pb are relatively low for all the other areas indicating a low influence of leaded fuel. For this study Pb is present in all the samples and in relatively high concentrations (Mean value of 292 ng/m^3) indicating the influence of leaded fuel and leaded paints. Zn also presents higher concentrations in this study than for the others. Apart from Ouagadougou, elemental concentrations are higher for this study than for the other studies.

Table 5. *Summary of Selected Elemental Concentrations in Fine Aerosol Particles from Different Measurements in Cities in Africa and Europe*

Dataset	This study	Boman et al. 2009b	Gatari et al. 2006	Heal et al. 2005	Rodriguez et al. 2004
Location	Douala, Cameroon	Ouagadougou, Burkina Faso	Nairobi, Kenya	Edinburg, UK	Barcelona, Spain
Year	2012	2007	2001	1999–2000	1999–2000
Particle size range	d_a< 2.5µm	d_a< 2.5µm	d_a< 2.5µm	d_a< 2.5µm	d_a< 2.5µm
Cl	347	900	<DL		
K	167	290	730		229
Ca	190	690	70		516
Ti	29	240	8.7	0.4	16
Mn	17	61	12	0.7	14
Fe	248	3000	130	27.6	258
Zn	296	41	100	7.5	162
Br	22	8.7	36		
Pb	292	11	76	11.36	120

All Concentrations are in ng/m^3, year is the year of sample collection, <DL is below detection limit.

Conclusions

$PM_{2.5}$ for the city of Douala was collected over a 24-hour sampling period and analysed for mass, mass concentration and elemental composition. The cumulative mass concentration of 252 ± 130.8µg/m^3 which is critically higher than the WHO standard of 25µg/m^3 was recorded. Cl, K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Br, Sr, and Pb were identified in the PM collected. The high concentration of Pb indicated the possible use of leaded fuels and/or paints in the vicinity. The industrial zones exhibited higher PM concentrations than the residential areas. Meteorological parameters greatly influenced the PM concentration. However, the "thunderstorm effect" counteracted the normal variation of $PM_{2.5}$ with wind speed and precipitation.

Diurnal patterns in concentrations suggested a common PM source. From PCA it was concluded that anthropogenic activities like traffic, biomass burning and industrial activities were the major PM sources. Old fleet and poorly maintained vehicles exacerbate the situation. Despite the high emission from these sources, natural sources such as sea spray and windblown dust significantly contribute to the PM load of this city.

Conclusively, the results presented in this study indicate that the majority of the Douala inhabitants are exposed to high air pollution levels in their everyday life.

Recommendations

Given the high values of both elemental and PM concentrations in Douala, the following actions to reduce particulate matter and black carbon emissions are recommended:

- There should be very regular vehicle emissions tests, retirement, or retrofitting (e.g. adding particulate traps, including penalties for failing to meet air quality emissions standards, and heightened penalties for on-the-road "super-emitting" vehicles);
- The sale of certain fuels should be banned or strictly regulated. The use of cleaner fuels encouraged.
- The installation of a shore-based power/electrification of ships at port, regulating idling at terminals, and mandating fuel standards for ships seeking to dock at the Douala port.
- Banning or regulating slash-and-burn clearing of forests and burning of agricultural waste
- Biomas burning in urban and non-urban areas should be regulated and/or limited.
- Permits should be issued to operate industrial, and power generating, facilities, and periodic permit renewal and/or modification of equipment.
- Filtering technologies should be introduced together with high-temperature combustion for existing power generation plants. Annual emissions from such plants should also be regulated.

For BC it is necessary to focus on primary PM emission abatement measures such as:

- End-of-pipe technologies, i.e., diesel particle filters for road and off-road vehicles or machinery.
- Technologies allowing the reduction of emissions from medium- and small-scale combustion facilities, including domestic stoves (e.g., pellet stoves and boilers; product standards).
- Better implementation of the ban of open field burning of agricultural waste; such a ban has already been introduced in many EU Member States.

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Evaluation of Physicochemical Characteristics of Surface Water from Orashi River, Rivers State, Southern Nigeria

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Water samples were collected from four different stations bimonthly from the Orashi River for a period of one year. The samples were collected from the shores of selected communities along the Engenni axis of the river. The samples were treated and analyzed according to standard laboratory and analytical procedures for water physicochemical parameters. The parameters examined were pH, Salinity, chlorides (Cl^-), Conductivity, total dissolved solids (TDS), total suspended solids (TSS) turbidity, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrates (NO_3^-), sulphate (SO_4^{2-}) and phosphates (PO_4^{3-}). The results showed that the mean values of the evaluated parameters were; pH (6.91±0.11), salinity (9.79±0.27 mg/L), Cl^- (6.25±0.25 mg/L), conductivity (29.66±1.20 µS/cm), TDS (17.66±2.08 mg/L), TSS (16.83±1.15 mg/L), turbidity (11.84±1.50 mg/L), temperature (28.16±0.12 ^oC), DO (5.91±0.18 mg/L), BOD (7.30±0.60 mg/L), COD (9.41±0.70 mg/L), NO_3^- (3.42±0.27 mg/L), SO_4^{2-} (1.15±0.56 mg/L) and PO_4^{3-} (15.65±5.76 mg/L). The results of the different parameters showed that all of them fall within the WHO acceptable limit except turbidity, DO and BOD that were not within the recommended range, then COD and phosphates that were either within or above the recommended values at different instances. Based on the findings of this work, the water may not be particularly suitable for drinking purposes, but can be used for other household functions that do not require consumption and also for irrigation.

Keywords: *water, physicochemical property, human activity, environment, contamination*

Introduction

Water is an indispensable part of human existence. It is very crucial for agricultural processes, industrial processes, movement of transport of goods and services from one place to the other. Although water is notably important in the driving of human progressive processes, its management as a resource of utmost importance is very poor (Fakayode 2005). The concept and reality of the divers and numerous sources of water contamination, the attendant methods applied for its purification and the cost effects arising from these man made effects are worthwhile issues of concern all over the world. The level of water deterioration occasioned by human activities and natural causes is ever increasing. Even the natural factors which are supposed to occur on their own are now accelerated due to human incursions into the environment. These combined effects (human and natural) are now a threat to both plants and animals (Iyama et al. 2020).

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The health of any water system is a function of physicochemical properties of the water, which impacts on the general behaviour of the ecosystem (Dudgeon 2011). Interferences by humans can change the chemistry of the aquatic system which can cause a behavioural change in terms of migration, relocation of habitat, cannibalism and general feeding behaviour (Bere and Tundisi 2011). The cycles of water regeneration and natural purification processes is also dependent on the physicochemical roles of the different species present in the water, which if allowed can manipulated the characteristics of the species present (without human interferences) to preserve the natural state of the water. These parameters are responsible for both direct and indirect signs of the situation of the aquatic environment and its capability of supporting communities of biological organisms (Lawson 2011).

Rivers flow through naturally defined channels and with constant contact with its banks which is gradually washed off into the river water (Lawson 2011). Every river is fed by runoffs, from glaciers and ice melting at high temperatures, from adjoining streams, overflowing water logged swamps, lakes, springs, rain water, snow etc. (Nnamani et al. 2015). Due to the importance of water as a natural resource, human settlements have been by the banks of rivers right from ages past all over the world. The essence of settling by the riverside is for the numerous uses such as transportation, irrigation, fishing, power generation, waste disposal and farming (Lawson 2011, Edori, 2020). Moreover, every year rivers (especially fresh water) overflows their banks, thereby making the lands by the banks very fertile for cultivation. The nature of water contamination varies between rural and urban settlements. While water contamination in rural settlement is due to normal agricultural activities and runoffs, urban water pollution is majorly from industrial wastes (Wokoma and Edori 2017). All of which results in poor water quality that requires proper treatment before use (Edori and Nna 2018).

Therefore, this study was undertaken to examine the variations of some physicochemical properties of surface water from parts of the Orashi River.

Materials and Methods

Collection of Samples

The water samples were collected from the surface of the water to a depth of 30 cm with plastic jerry cans. The jerry cans were previously washed and dry. The samples were collected from four different positions and their geographic positions recorded. The points where samples were collected and the geographic coordinates are given in Table 1.

Table 1. *The Geographic Positions and Communities where Samples were Collected*

Serial Number	Geographic Location	Community
1	4^{o}107.3'N, 6^{o}30'6.6"E	Odau
2	5^{o}3'39.2"N, 6^{o}26'58.7"E	Mbiama
3	5^{o}9'5.2"N, 6^{o}25'47.6"E	Okarki
4	4^{o}59'10.1"N, 6^{o}27'2.5"E	Okparaki

The samples were collected at intervals of two months for a period of one year, beginning from December 2018 – October 2019. The samples were immediately put into ice packs containers and transported to the Chemistry Laboratory of the Ignatius Ajuru University of Education, Rumuolumeni, Port Harcourt, Rivers State, Nigeria.

Analysis of the Samples

The examination of the pH, conductivity and TDS were done insitu using a Jenway portable meter model 350. Turbidity of the water samples were also done on site with a turbidity meter, HACH Model 2100An, while salinity was analyzed with a digital electronic meter at the point of sample collection. Total suspended solid (TSS) was evaluated using the filtration method (APHA 1995) and the results calculated as follows:

$$\text{T S S} = \frac{post\ weight\ of\ filter - pre\ weight\ of\ filter}{Volume\ of\ Sample\ used\ (mL)}\ X\ 1000\ mL$$

The Winkler's method was used to determine the amount of dissolved Oxygen (DO) in the water and the values calculated as:

$$\text{Dissolved Oxygen} = \frac{Volume\ of\ sodium\ thiosulphate\ x\ 0.2\ x\ 1000}{Volume\ of\ sample\ taken}$$

Biochemical oxygen demand (BOD) of the samples were analyzed on the previously DO examined samples after being kept for a period of five days in the dark at a temperature of 20 ^{o}C. The result gotten was calculated and noted as BOD_5.

Chemical oxygen demand (COD) was determined using the oxidation method (APHA 1995) and calculated as:

$$\text{Chemical Oxygen Demand} = \frac{A - B\ x\ N\ x\ 8\ x\ 1000}{Volume\ of\ sample\ taken}$$

Where
A = Volume of ferrous ammonium sulphate for blank
B = Volume of ferrous ammonium sulphate for the sample
N = Normality of ferrous ammonium sulphate
V = Volume of sample.

For the determination of phosphates, mild acid hydrolysis method was used to convert phosphate present in the sample to orthophosphate and a colorimetric determination was done to find the concentration of phosphate in the sample. Phosphate concentration was calculated as:

$$\text{Phosphate concentration} = \frac{phosphate\ content\ x\ 1000}{Volume\ of\ sample}$$

Sulphates and nitrates concentrations in the water samples were determined using the HACH spectrophotometer (model 3900 DR, USA). This was achieved by dissolving analytical water test tablets Sulpha Ver®4 and Nitra Ver®5 in 25 ml into separate water samples. The final contents were determined at spectrophotpmetric wavelengths of 450 nm and 890 nm respectively and the results obtained by comparing with those of the respective blank in calibration curves from standard sulphate and nitrate solutions (APHA 1995).

Chloride concentrations in the samples were evaluated by titrimetric methods, which were compared with those of blank titrations. The concentration of chloride in the sample was calculated as:

$$\text{Chloride concentration} = \frac{(Vs-Vb)\,x\ nomality\ x\ 35.5\ x\ 1000}{Volume\ of\ sample\ taken}$$

Where
Vs = Volume of silver nitrate used for the sample
Vb = Volume of silver nitrate used for the blank

Results and Discussion

Chemical Parameters

The results of the chemical parameters are shown in Table 2 and Figure 1. The chemical parameters examined in this research work are pH, salinity and chlorides (Cl^-).

Table 2. *Chemical Parameters of Water Samples from Orashi River at the Different Stations*

Chemical Parameters	Stations				
	1	2	3	4	
pH	6.92 ± 1.17	6.90 ± 1.08	6.75 ± 0.89	7.07 ± 1.07	6.91 ± 0.11
Salinity (mg/L)	9.45 ± 1.30	10.10 ± 1.32	9.61 ± 2.39	10.01 ± 2.35	9.79 ± 0.27
Cl^- (mg/L)	6.45 ± 1.06	5.83± 1.62	6.27 ± 2.14	6.45 ± 0.06	6.25 ± 0.25

Figure 1. *Mean Monthly Variation of Chemical Parameters of Water Samples from Orashi River*

The pH varied from 6.75 ± 0.89 - 7.07 ± 1.07 in the stations, while variation in the months ranged from 6.66 ± 1.53 - 7.63 ± 1.29. The pH values observed in the river were within the WHO and NAFDAC value of 6.5 - 8.5 for drinking water. The values of pH observed in this work are in agreement with the observation of other authors in similar environment (Nnamani et al. 2015, Adewuyi et al. 2017, Edori and Kpee 2018). The value range of pH observed in the river falls within the range of good water quality (Adewuyi et al. 2017). This value range is common in a flowing river due to the fact that whatever is discharged into is carried away immediately and so may not have time to impact on it. Secondly, the volume of water is large and since it is always in constant motion renews itself almost immediately and finally, the near absence of industrial activities along the river can be a factor that may also be responsible for non-interference of ionic species with the pH, due to fewer concentrations present (Edori 2020).

pH specifies the strength of acido-basic behaviour of the water and is measured by the amount of dissolved substances and biochemical developments in the water medium (Saksena and Kaushik 1994). The pH of the water environment is often examined for valuations the health status of the ecological unit and its suitability for irrigation, drinking and other industrial and domestic uses (Mezgebe et al. 2015).

The salinity result obtained from the sampled stations varied from 9.45 ± 1.30 - 10.10 ± 1.32 mg/L, while those of the months varied from 7.85 ± 1.63 in April - 13.95 ± 3.29 mg/L in February. These values are lower than the WHO limit of 2000 mg/L. The values of salinity observed in the Orashi River were within the range of values observed in Elelenwo River, Rivers State, Nigeria (Edori et al. 2020), but lower than the values observed in the Silver River, Bayelsa State, Nigeria (Edori et al. 2019).

Salinity controls the mass to volume ration of water and is the major cause of water stratification. The presence of raised values of water salinity can lead to corrosion of technological equipment and structures such as bridges. Salinity provides a situation for increased electric charge carriers which help in the exchange of electrons between charged species. Again, the health status of aquatic biomes is greatly affected by quantity of salinity and in extreme situations these

are responsible for mortal consequences of aquatic flora and fauna (Edori et al. 2020).

Chloride values in the sampled stations varied from 6.45 ± 1.06 - 5.83 ± 1.62 mg/L. The values observed in 5.67 ± 1.04 mg/L in October to 8.67 ± 2.63 mg/L in February. The concentrations of chlorides observed in the river were lower than the stipulated limit of 250 mg/L in drinking water by NAFDAC and WHO. The concentrations of chlorides in the Orashi River at the time of analysis were lower than the value observed in Cauveri River, India (Chandra et al. 2011) and those of Iyama and Edori (2014), in brackish water environment in the Niger Delta, Nigeria.

The presence of high concentration of chloride in water shows a sewage imposed water pollution. Human intake of water which contains elevated levels of chlorides is likely to be purged. Food crops planted in soil irrigated with water that contains high levels of chlorides will not likely produce reasonably (suffer reduction in yield). The low results of chlorides observed in the present work might be due to complete absence of industries along the area that may likely discharge used water into the river and non-contaminated runoffs. Chloride in water enhances electrical conductivity and corrosion rate of metallic materials (Edori and Nna 2018). Metals reacts with chlorides to form soluble salts, which results in increased concentration of heavy metals in water (WHO 2003), which implies that chlorides in water promotes metal corrosion Bay et al. 2003).

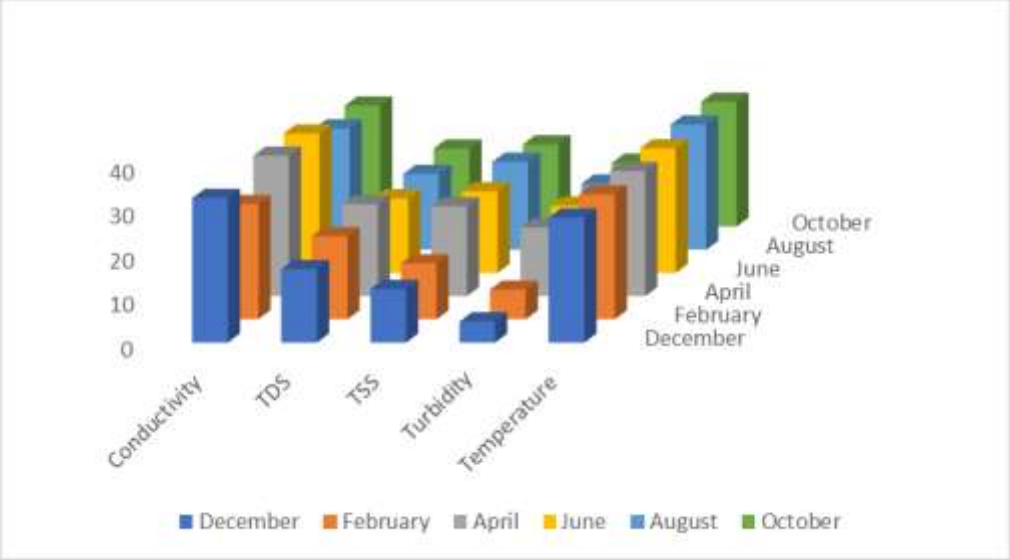
Physical Parameters

The values of the physical parameters are shown in Table 3 and Figure 2. These parameters include conductivity, total dissolved solids (TDS), total suspended solids (TSS), turbidity and temperature.

Table 3. *Physical Parameters of Water Samples from Orashi River at the Different Stations*

Physical Parameters	Stations				
	1	2	3	4	
Conductivity (µS/cm)	29.29 ± 4.64	30.51 ± 50.59	30.97 ± 6.66	27.87 ± 4.45	29.66 ± 1.20
TDS (mg/L)	17.42 ± 3.39	16.93 ± 2.43	21.00 ± 4.61	15.29 ± 2.39	17.66 ± 2.08
TSS (mg/L)	16.07 ± 2.36	18.29 ± 3.39	15.40 ± 2.38	17.55 ± 3.36	16.83 ± 1.15
Turbidity (NTU)	13.62 ± 1.36	13.03 ± 3.39	10.32 ± 4.37	10.40 ± 3.63	11.84 ± 1.50
Temperature (^{o}C)	28.04 ± 0.20	28.22 ± 0.22	28.32 ± 0.21	28.04 ± 0.20	28.16 ± 0.12

Figure 2. *Mean Monthly Variation of Physical Parameters of Water Samples from Orashi River*



The values of conductivity from the different sample stations ranged from 27.87 ± 4.45 - 30.97 ± 6.66 µS/cm. The monthly variations ranged from 25.98 ± 4.36 µS/cm in February to 32.53 ± 5.28 µS/cm in December. The conductivities of the different water samples from both stations and months were lower than the WHO and NAFDAC value of 1000 mg/L. The observed values of conductivity in the water were higher than those of Ukenye and Taiwo (2019), but lower than the values observed by other authors (Chandra et al. 2011, Nguyen and Cai 2019, Mbalassa et al. 2014). However, the observed values are in agreement with the observation of Edori (2020), in another water body that is a tributary of the Orashi River.

The conductance of any medium is referred to as electrical conductivity. It is used to evaluate the ability of water to transport electric current. It gives an overview of the quantity of salts in solution (Edori et al. 2020). The measured values of conductivity in the different stations and months were below the FAO limit fixed for agricultural irrigation (Ayers and Westcot 1994). The low values of conductivity can further be explained that the water from adjoining creeks, streams and runoffs which empties into the Orashi River contains very low amount soluble inorganic matter present in ionic forms. When the electrical conductivity is high, the implication is that little quantity of water will be made available to plants if used for irrigation. This is because the transpiration process of plants only requires water that is as pure as possible. The rate of water usage by plant in the soil solution decreases as the value of conductivity increases. Thus, the productivity of plants is reduced when planted in soil irrigated with water that has high conductance value (Mezgebe et al. 2015).

The values observed for total dissolved solids from the different stations ranged from 5.29 ± 2.39 - 21.00 ± 4.61 mg/L, while the variations within the months were16.52 ± 3.68 in December to 20.70 ± 4.11 mg/L in April. Values of TDS observed in the river were lower than the 1500 mg/L value recommended by

the World Health Organization (WHO). The values of this work were higher than those of Edori et al. (2020), in Elelenwo River, but within the range of values observed in Ishasha River and Lake Edward (Mbalassa et al. 2014), yet lower than those of Adewuyi et al. (2017) in Yewa River ogun and Badagry Creek Lagos, Southwest Nigeria and those of Chandra et al. (2011), in different water bodies in India.

The expression of the total amount of matter in solution of water is referred to as Total dissolved solids (TDS). The constituents that are summed up in this parameter are the inorganic salts and part of some soluble organic substances. Notable among the inorganic salts are calcium chloride, magnesium chloride, calcium nitrates and magnesium nitrates (Edori et al. 2019). The presence of elevated concentrations of these salts in the water will result in changes in the characteristics of several systems of water plants and animals. TDS positively correlates with conductivity in water media because of the dependence on each other. High levels of TDS imply the presence of high levels of ionic conducting species in water, which facilitators of conductivity (Thirumalini and Joseph 2009, Iyama et al. 2019). According to Nguyen and Cai (2019) increased content of TDS in water is toxicologically viewed as water contamination

Total dissolved solids present at values lower than 500 mg/L in water is safe for drinking and aquatic animal life, for example fisheries. Increase in concentrations of TDS reduces its sweetness and portability and when it has grown to levels above 1000 mg/L will introduce undesired taste to the water. Water with elevated levels of TDS is not good for irrigation, since it will negatively affect the yielding capacity of the soil due to excess salts (Which are conduction species that affects water uptake by plants root. Further to this even when the water has evaporated, the salts are left behind, which thereby increase the salinity of the soil (Chandra et al. 2011). TDS sources include rock weathering due to water current as it moves along its course and from runoffs laden with soluble metallic salts.

TSS concentrations within the stations varied from15.40 ± 2.38 - 18.29 ± 3.39 mg/L. Variations within the months ranged from 12.06 ± 2.08 in December – 20.25 ± 3.61 mg/L in April. All the values of TSS observed in this research were below the 500 mg/L recommended for drinking water by NAFDAC and WHO. The results of TSS in the present work is lower than the values observed in Agam River in Ethiopia (Mezgebe et al. 2015) and the values observed in Tano River, in Ghana (Nyantakyi et al. 2020).

High value of TSS in water decreases water transparency (Edori et al. 2019). Increased TSS in water can either be through anthropogenic or natural factors. Anthropogenic factors include dredging activities, which lead to resuspension of particles from sediment back to surface water and soil loosening activities such as farming, construction of road, erection of houses and other structures, quarrying, grubbing and direct discharge of wastes (Edori and Nna 2018). Natural factors include algal population, flow pattern of the river which may re-suspend particles from sediment to water, flooding and erosion. The extent of water contamination can be predicted through the amount of TSS present in the water and at very high concentrations will alter the organoleptic properties (taste, odour and colour) of the water and render it non-portable (Edori and Kpee 2016, Edori et al. 2020).

The values of turbidity in stations varied from 10.32 ± 4.37 - 13.62 ± 1.36 NTU. The variations of turbidity in the months ranged from 4.75 ± 1.02 in December to 15.16 ± 2.95 NTU in June. The observed values of turbidity in both stations and months were above the Nigerian NAFDAC and WHO standard of 5.0 NTU for drinking water. The observed values of turbidity in the Orashi River were in consonance with the observations of other authors in similar Niger Delta environment (Nduka et al. 2008, Edori 2020), whose values were equally higher than the 5.0 NTU maximum limit for drinking water. However, the present work values were at variance with those of Nnamani et al. (2015), in Isu and Calabar Rivers, where turbidity values were lower than 5.0 NTU.

Turbidity is used to describe the transparency of water. It is given by the extent of matter that is suspended in the water matrix. When the amount of suspended particles in water is high, the visibility of the water is reduced. At high turbidity, the vision of water inhabiting animals will be reduced and so affects their feeding characteristics and also causes some changes in the environment that are associated with turbidity, namely decreased amount of dissolved oxygen (Starkey and Karr 1984), light penetration, and photosynthesis, which affects primary productivity stages in water such as the growth of zooplanktons and other higher aquatic plants and thus the food chain of the environment.

According to Colman et al. (1992), the ability of fish to breathe and plants to perform photosynthetic activities is affected by turbidity. Turbid water helps to prevent juvenile fishes from attack by predators. This is because the water visibility is affected and so predators find it more difficult to see them for attack. Also, turbid water is more likely to offer more foods for fishes and then provide a path for migration of fishes to or from the river (Blaber 2000). Some of the negative consequences of highly turbid water are reduced number of eggs that are likely to survive, reduced hatchability of eggs, reduction in feeding capacity of filter feeders, reduction in growth rate and population of fish (Whitfield 1998).

The values of temperature in the stations ranged from 28.04 ± 0.20 - 28.32 ± 0.21 ^{o}C and in the months, the variation ranged from 28.09 ± 0.88 in June to 28.20 ± 1.63^{o}C in April. The observed values of temperature in all the stations and months did not vary significantly ($P > 0.05$). They all fall within the WHO and NAFDAC requirement for drinking water. The observed temperature range in the Orashi River is in agreement with observations of other authors on rivers (Edori et al. 2019, Edori et al. 2020) and creek (Edori 2020), in Niger Delta Nigeria.

The rate of metabolism of aquatic plants and animals is greatly affected by the prevailing water temperature. The extent to which the water is hot or cold is consequent on the growth and developmental form of aquatic biomes. Every living plant or animal in water has a range of organism has temperature range that can support optimum growth and survival of their various breeds. Other effects of temperature outside living organisms are alteration in the concentrations of dissolved oxygen in water, nutrients availability and viscous nature of the water. Others are changes in the body reactions of organism and fate of aquatic pollutants (Nguyen and Cai 2019). Generally, the temperature of a flowing water fluctuates slightly depending on variations of temperature during the day, but that of stagnant water is more stable and hotter, since the water do not mix properly (Ortiz-Zayas

et al. 2005, Dudgeon 2011) and also encourages more biochemical reactions and microbial activities and so stinks after a long period of non-regeneration through precipitation

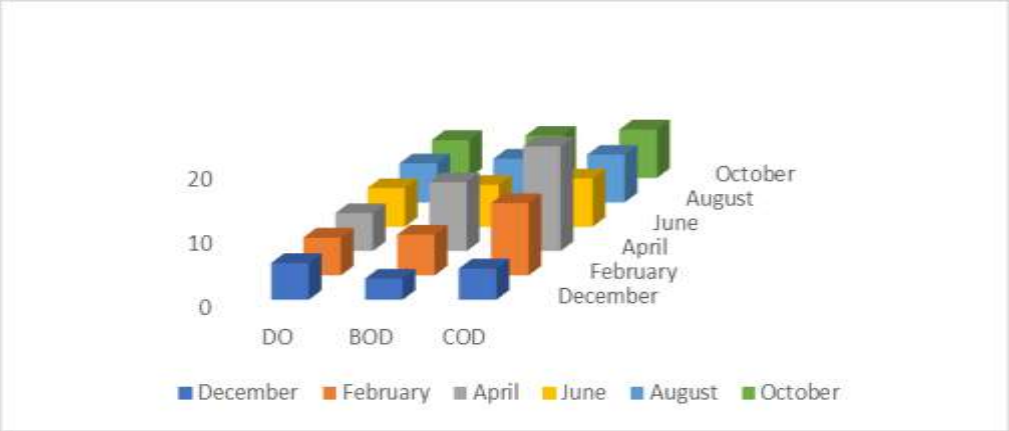
Gross Organic Pollutants

The concentrations of the gross organic pollutants are shown in Table 4 and Figure 3. These parameters include dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Table 4. *Gross Organic Pollutants of Water Samples from Orashi River at the Different Stations*

Gross Organic Pollutants	Stations				
	1	2	3	4	
DO (mg/L)	5.95 ± 1.10	5.71 ± 1.61	5.80 ± 0.90	6.18 ± 1.13	5.91 ± 0.18
BOD (mg/L)	7.73 ± 2.23	7.49 ± 1.25	6.26 ± 1.24	7.70 ± 2.23	7.30 ± 0.60
COD (mg/l)	8.28 ± 2.21	10.21 ± 1.21	9.60 ± 1.18	9.55 ± 2.17	9.41 ± 0.70

Figure 3. *Mean Monthly Variation of Gross Organic Pollutants Parameters of Water Samples from Orashi River*



The DO results obtained from the stations ranged from 5.71 ± 1.61- 6.18 ± 1.13 mg/L, while those months varied from 5.71 ± 1.04 in December to 6.06 ± 1.68 mg/L in August. The observed values of DO in the present work were lower than the standard requirement of 10 mg/L by the relevant agencies (WHO and NAFDAC). The values of DO in the present work fall within the range observed in River Tano in Ghana (Nyantakyi et al. 2020) and those of Ukenye and Taiwo (2019), in some coastal waters of some Nigerian Rivers, but were higher than the values observed in Tsaeda Agam River in Mekelle City, Tigray, Ethiopia (Mezgebe et al. 2015).

The amount of DO in water is dependent on the prevalent temperature of the water. The temperature of the water is inversely related to the temperature and so high temperature portends low oxygen solubility. However, the temperature of any water body varies at intervals during the day and also, the amount soluble oxygen in the water is likely to vary. The changes in the amount of oxygen in water are not

only affected by temperature but also the flow nature of the water, the amount and speed of wind that passes through the water surface, the pressure of the atmosphere (Nduka et al. 2008) and the nature of plants growing in the water which respire. According to Nguyen and Cai (2019) concentration of DO up to 5 mg/L can support aquatic life, when it is lower than 2 mg/L is lethal to fishes and adversely affect function and survival of biological communities, and below 2 mg/L can lead to death of fish that are not adapted to such conditions.

When the DO value is low (within 3 mg/L and below), it causes reduction in fish population through prolonged hatching time of fish eggs, reduction in the size of and strength of embryos. DO is responsible for redox reactions that take place in water and as a result of the redox reactions, changes the chemical and physical states of the species involved and as such can change the portability of the water (Nduka et al. 2008). The nature of life in natural aquatic surroundings is dependent on the quantity of DO present. Most microbes make use of available DO for replication (Edori and Nna 2018)

The values of BOD in the water samples from stations varied from 6.26 ± 1.24 - 7.73 ± 2.23 mg/L. in the months, the variations ranged from 3.28 ± 0.33 in December to 10.68 ± 2.64 mg/L in April. The BOD concentrations in the Orashi River were higher than the limit value given by WHO. The values of BOD in the present work fall within the range of values observed in a brackish water environment (Iyama and Edori 2014), but higher than those of Mezgebe et al. (2015), in Tsaeda Agam River in Mekelle City, Tigray, Ethiopia. However, these values were very low when compared with the values observed in a Ghanaian water body called Tano River, where BOD values ranged from 9–78 mg/L (Nyantakyi et al. 2020)

Biochemical oxygen demand (BOD) is a measure of the quantity of oxygen that is involved when bacteria is breaking down organic matter to simpler matter in aquatic medium. It gives underlying information on the available concentration of biological materials existing in water. The level of organic matter present in water is commensurate with the amount of oxygen demanded (Edori et al. 2019), which implies that BOD is dependent on the amount of biodegradable substances present in water, which when high cause a reduction in available DO (Ubwa et al. 2013). When substances decay, they make use the available oxygen in the water and so reduce its quantity and then the quality of water. Reduced oxygen content of water at certain level can cause the water to stink and thereby cause mortality of aquatic animal, but in stagnant water, the organisms may likely die.

The values of COD within the stations varied from 8.28 ± 2.21 - 10.21 ± 1.21 mg/L. In the months, the observed variation ranged from 4.85 ± 1.15 in December to 16.24 ± 3.22 mg/L in April. The observed values of COD in the river were either lower or higher than the 10 mg/L limit stipulated by NAFDAC and WHO for Drinking water. The values of COD in the present work were lower than those of Nyantakyi et al. (2020), in Tano River, Ghana and those of Kamal et al. (2007), in Mouri River, Khulna, Bangladesh.

The level of COD in water is a function of the amount of organic matter that is present in the water which undergoes chemical oxidation. The redox reaction of organic matter in water is dependent of the available DO in the water. The

oxidation-reduction possibility that can take place in any water body is factored on the volume of oxygen that can oxidize efficiently the organic substance existent in the water. COD is a measure of the quantity of DO that is consumed to complete oxidation (Sharma and Walia 2017), which is also responsible for reduction in the oxygen holding capacity of the water and detrimental to aquatic organisms (Hagai 2018). COD like BOD is a useful tool in health risk assessment before water is distributed to households for use (Edori et al. 2019).

The inputs of substance into water that are not subject to biodegradation give rise to elevated COD (Elayaraj and Selvaraju 2015). In most cases, higher values of COD are observed in rainy seasons as compared to dry seasons due to increased concentration of non-biodegradable matter discharged into the river through runoffs and used water into the river through runoffs and effluent discharges (Nyantakyi et al. 2020). Also during wet season, the rising tide due to flooding attracts more organic matter into the river which increases the organic water content and thus the COD of the water.

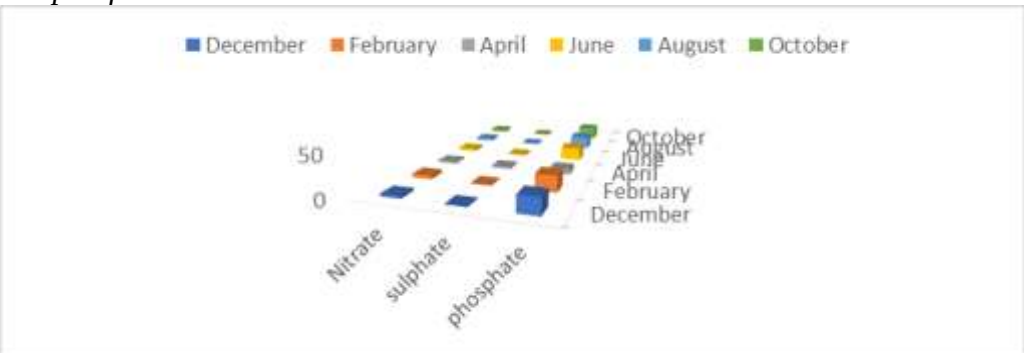
Nutrient Parameters

The values of the nutrient parameters in the Orashi River are shown in Table 5 and Figure 4. The nutrient parameters include nitrates (NO_3^-), sulphates (SO_3^{2-}) and phosphates (PO_4^{3-}).

Table 5. *Nutrient Parameters of Water Samples from Orashi River at the Different Stations*

Nutrient Parameters	Stations				
	1	2	3	4	
NO_3^- (mg/L)	3.19 ± 0.88	3.60 ± 0.97	3.75 ± 1.21	3.12 ± 0.11	3.42 ± 0.27
SO_4^{2-} (mg/L)	1.98 ± 0.09	1.18 ± 0.21	1.03 ± 0.10	0.41 ± 0.09	1.15 ± 0.56
PO_4^{3-} (mg/L)	6.89 ± 1.41	14.77 ± 2.44	18.36 ± 3.42	22.58 ± 4.40	15.65 ± 5.76

Figure 4. *Mean Monthly Variation of Physicochemical Parameters of Water Samples from Orashi River*



Stations variations in nitrates concentrations ranged from 3.12 ± 0.11 - 3.75 ± 1.21 mg/L. In the months the values varied from 2.67 ± 0.05 in April to 4.72 ± 1.01 mg/L in February. The values of nitrates observed in all the stations and months in the river were lower than the required value for drinking water by WHO

(10 mg/L) and NAFDAC (20 mg/L). The value of nitrates observed in water from the Orashi River is slightly higher than the values observed in brackish water environment in the Niger Delta Nigeria (Iyama and Edori 2014), but are within the range of values observed in surface water in Sagbama Creek, Bayelsa State, Nigeria (Iyama et al. 2019).

Nitrates originate from bacterial oxidation of organic nitrogen either in water or soil in the presence of abundant supply of oxygen. Nitrates are important plant nutrients and are useful for irrigation when present in water. However, increased values of nitrates in water lead to algal bloom, enhanced growth of aquatic plants, promotion of eutrophication and water pollution (Sinha and Biswas 2011). Ammonium nitrogen in wastewater is one source of nitrates in aquatic surroundings (Ali et al. 1996). Consumption of water with levels of nitrates greater than 45 mg/L can lead to methaemoglobinemia in children and expectant mothers (Kross et al. 1993).

Farming activities and burning of fossils can increase nitrate concentration (Iyama et al. 2019). When there is a sudden increase in nitrate concentrations, the biological dynamics of the waterbody is changed, turbidity is increased, more oxygen is consumed, increased presence of algae, increased growth of higher aquatic plants and increased harm to fishes (Edori et al. 2020).

The values sulphates observed in the sampled stations ranged from 0.41 ± 0.09 - 1.98 ± 0.09 mg/L. In the months the values varied from 0.83 ± 0.03 in December to 2.52 ± 0.00 in April. The observed values of sulphate were lower than the WHO and NAFDAC value of 500 mg/L. The amount of sulphates present in the Orashi River is lower than the WHO limit for drinking water. The value of sulphate in the present research were lower than the value of Ukenye and Taiwo (2019) in eleven (11) coastal waters in the Niger Delta, Nigeria and also those of Kamal et al. (2007), in Mouri River Khulna, Bangladesh, but within the value range observed in Ede Onyima Creek in Okarki Engenni, Rivers State, Nigeria (Edori 2020).

In water, sulphate is considered to be the least poisonous anions. Despite its low toxicity, it has been linked with some body disorders which include purging, lack of moisture and intestinal irascibility when present at concentration above the stipulated value of 500 mg/L (Bertram and Balance 1996). Sources of sulphate in water are discharges from industrial effluents, Sulphur mines, sulphuric acid production processes, heating of metals containing sulphur compounds (tanneries), paper mills and from precipitation by rain from atmosphere laden with Sulphur dioxide (Andrews et al. 2004). High content of sulphate in water increases acidity of the water and hence increased concentration of sulphate bound bacteria.

The values of phosphate observed in the stations in varied from 6.89 ± 1.41 - 22.58 ± 4.40 mg/L. The variation 6.74 ± 1.06 in April to 20.13 ± 3.88 mg/L in February. The values of phosphate observed in the present work at the different rivers showed that the values exceeded the WHO standard of 0.5 mg/L for domestic water use, but were either higher or lower than the NAFDAC requirement of 10 mg/L. The observed values of phosphate in Orashi River is higher than the values of Nduka et al. (2008), Nnamani et al. (2015) and Mezgebe et al. (2015), in different rivers.

Phosphates are introduced into the aquatic environment in the form of phosphorus. Although the presence of other chemical parameters may enhance eutrophication, yet the known major cause of eutrophication are the phosphates (Wagner 1974). Phosphorous as a vital nutrient required for growth and proper functions of cells is absorbed into cells and tissues in the form of phosphates. Phosphate compounds in cell set-up energy produced from food intake and transports them to actions that require it for some biological functions such as movement, replication and development. The absence of phosphorus (which are generated by phosphate reactions), it become difficult for high energy compounds such as ATPase to be formed (Edori et al. 2015), which will be deleterious for the continuation of cell life (Adeyemi et al. 2012, Edori et al. 2013).

Conclusions

The findings of this research revealed that the water from the Orashi River was slightly contaminated. This is evidenced from the observed values of turbidity, DO, BOD and partly those of COD and phosphates. Other parameters which include pH, salinity, Cl^-, conductivity, TDS, TSS, turbidity, temperature, NO_3^- and SO_4^{2-} were within the WHO acceptable limit required for drinking purposes. The contamination sources are likely of organic origin that may have originated from enormous amount or organic wastes discharged directly into the river by the inhabitants of the area investigated and flood water carrying plant materials during the rainy periods. Therefore, the water should be given some form of treatment before being consumed.

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Government Expenditure Data Exploration & Analysis Using Python

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The goal of improving cost efficiencies is a constant endeavor of all organizations. This is especially true for governments, where public perception often has the ability to affect budget allocations. The data used in this analysis consisted of publically available state expenditures from 2018 and 2019 for the state of Idaho. The dataset contains the record of over 2 million state expenditures across all state agencies. The data analysis was performed using Python and the Pandas library. Visualizations were created using the Matplotlib package. The data exploration showed that Idaho's Departments of Health and Welfare, Education and Transportation spent the most in this time period. The analysis also determined which Summary Objects, Sub-Object and Vendors experienced the greatest changes between the two years. Comparisons were also done using publicly available data on reported budget allocations by the states of Arkansas, California, Texas and Montana to see how spending differs between Idaho and these states based on percentage and per capita. Finally, suggestions for improvement in the areas of health care and employee transportation were given. These include methods of improving competition in health care, reducing travel through expanded teleconferencing and providing incentives to employees for reduced travel cost.

Keywords: *data science, budget analysis, python, pandas, government spending*

Introduction

Improving cost efficiencies is a goal that all organizations constantly seek to achieve. This is true for both private business as well as the public sector. In the United States, many of the individual states have laws that limit debt or require a balanced budget. This is different from the federal government which has the ability to carry a deficit, though there is a self-imposed debt ceiling. Due to these constraints, there is much incentive for state governments to analyze their respective budgets to identify areas for improvement and areas of waste. Still, this task can be very difficult, as even smaller states typically have hundreds of

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employees and potentially millions of different expenditures each year. The scope of these expenditures is also large; states typically have expenditures in infrastructure, education, public health, public worker's travel, etc. Analyzing this data can be extremely difficult and inefficient without the proper tools. The recent focus on the development and expansion of data science tools, such as the Pandas package in Python, presents a great opportunity for state governments to improve their fiscal spending. These tools can allow state governments to easily, quickly and efficiently analyze expenditures at a low cost. A comparison between the state of Idaho's spending and that of four different states will also be done. These states were chosen for the comparison due to each of the state's demographics and the availability of data from these states. Finally, this paper will analyze budget expenditures and identify areas of possible improvement for the state of Idaho, using data analytic and data mining techniques in Python.

Literature Review

The use of Big Data in business and finance has been expanding more and more in recent times. The reason for this is a belief that the more in depth analysis can result in better decision making and improve performance of the business and deliver a high return on investment. In a study done in 2011 by McKinsey Global Institute (MGI), it was estimated that the use of Big Data and analytics could save health providers over 300 million in annual value (Manyika et al. 2011). The study also estimated that Big Data could improve productivity growth by 0.5 percent in the European Union. Benefits cited by MGI in the use of Big Data include: improved automation, increased transparency and a quicker, more effective approach to identify vulnerability.

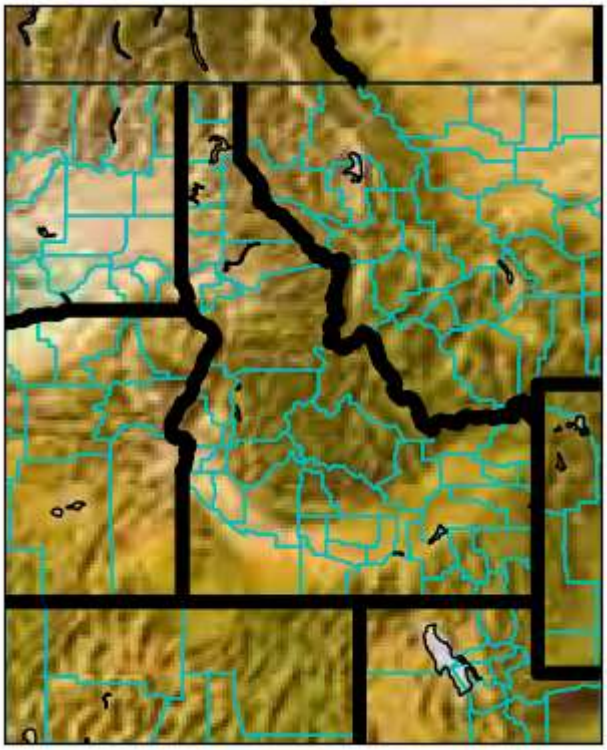
Big Data has also been used in many government applications. According to a publication in Communications of the ACM, The United States federal government began using Big Data in 2009 to help improve transparency. The focus of this was on transportation, health care and education related data (Gang-Hoon and Ji-Hyong 2014). Other government agencies that have taken advantage of big data include Singapore's Risk Assessment and Horizon Scanning, Japan's Ministry of Education and South Korea's Ministry of Public Administration.

State of Idaho Background

The state of Idaho is located in the northwest area of the United States. According to the United States Census Bureau, Idaho is ranked 13th in total area, approximately 83,569 square miles, but only has a population slightly below 1.8 million as of July 2019 (United States Census Bureau 2019a). This yields population density around 20 people per square mile, ranked 39th out of 50. The most populous area of the state is in the capital city, Boise and the surrounding towns. The state is divided into 44 counties, most of which are rural. The key industries of the state include energy, technology, agriculture, outdoor recreation

and tourism (Commerce Idaho 2020). Figure 1 shows Idaho's geographical location and county in the United States.

Figure 1. *State of Idaho*



In the last decade, Idaho has experienced major population growth. In 2010, the census reported the population of the state to be near 1.56 million, with the population in 2019 being reported around 1.8 million. The state has experienced an approximate 15% population increase in the last 10 years. This ranks very high within the United States, with the census bureau reporting that Idaho experienced the largest growth in the country in 2017 at 2.2% (United States Census Bureau 2017). Due to this large increase in population, it is likely the state will need to adjust its spending to ensure that public services are adequately funded and supported, and that infrastructure is maintained to accommodate the needs of the increasing population. This increases the need to use modern data analytic tools to reduce waste and monitor spending.

The State of Idaho employed 25,423 people in 2019 (Buxton 2020). This includes 13,070 employees listed as classified. Classified employees are subject to the state's evaluation process for promotion, merit and dismissal. The remaining employees are listed as non-classified. The average age of each state employee is 45 years, slightly above the national average of 42. The state government consists of 90 different agencies. These include areas such as health and welfare, defense, education, executive operations, etc. It should be noted that each department is divided differently. One example of this is the Industrial Commission. This agency is divided into three districts, while the Department of Agriculture is divided into four districts. Larger state agencies are typically organizationally structured

differently by region. According to the State Controller's office, most of the boundaries for these regional districts are county driven. It should be noted that not all state agencies have regions or districts through the state. For example, an agency may only have one office in Boise.

Methodology

State Controller's Office and Data

The data used for this analysis was obtained from the state of Idaho's Controller's office. This office is responsible for paying and managing all of the state's expenditures. This includes payroll for state employees, providing public access to state budget information and maintaining the state's accounting infrastructure. The Controller's office is required to collect data on every transaction that uses funds from the state. The head of this office is an elected office by the people of Idaho. Each term is four years in length and there are no term limits for this office. The current state controller for Idaho is Brandon D. Woolf who has been in the position since 2012.

The data from the State Controller Office was originally downloaded and saved as two CSV files. The two CSV files consist of all state expenditures from early July of 2017, beginning of the 2018 fiscal year, through June of 2019, end of the 2019 fiscal year. There were approximately 13.6 million transactions lines for expenditures during this time period between the two fiscal years. The data size of each CSV was approximately 2 gigabytes. Each expenditure in these datasets consists of 21 features including the data of the expenditure, the area of government where it occurred, the amount of the expenditure and the vendor who received the payment. The full list of features is given in Table 1. All data used in the project is publically available as part of the Transparent Idaho Program. As such, there are no issues with this dataset containing data that is confidential or otherwise covered by privacy laws.

Table 1. *Features from Expenditure Dataset*

Unnamed: 0	Fiscal Year	GL Account Code	GL Account Name	Agency Name
Agency Code	Amount	Effective Date	Process Date	Area of Government
Fund Name	Fund Code	Fund Category	Fund Detail	Fund Category
Object Name	Summary Object Name	Sub Object Code	Sub Object Name	Earn Ben Group
Vendor Name				

Pandas

In order to perform the analysis of the expenditure data it was necessary to make use of Python and the data science packages available. The majority of the analysis was done using the Pandas package. Pandas is a free open source package

designed to aid users in data analysis. Pandas is available standard or through download on most Python distributions, such as Anaconda. The package was developed in 2008 in response to the need for better data manipulation tools in Python. The project receives funding from many different entities, including the University of Paris Saclay Center for Data Science and Two Sigma. Python 3 is strongly recommended for use with Pandas, as all Python 2 support has been discontinued as of January 2020. Pandas only requires the use of the NumPy package in order to operate properly. The package is designed to work on Windows, Mac and Linux environments (McKinney 2011).

One of the most powerful aspects about Pandas is the ability to read and convert datasets into a structured form known as a DataFrame. A Pandas DataFrame is a 2-D Python list that stores values in a tabular form. As is the case with most Python packages, Pandas is considered high level and as a result, there are trade-offs in efficiency for improved ease of use. In addition to the ability to store values, Pandas has many tools for data analytics as well. This includes the ability to group data by user input, such as values present in the dataset or the data type of the values in the set. Also, Pandas can perform basic statistical analysis, such as standard deviation, mean, median, etc. Pandas is also designed with the ability to add, remove and combine groups of data between different datasets (McKinney 2019).

Data Exploration

In data science, one of the most crucial parts of any project is to explore the data that will be used for analysis. Figure 2 shows a portion of the header for the 2019 fiscal year DataFrame. It should be noted that none of the methods used in this project change the contents of the original CSV files.

Figure 2. *Sample of Header from Fiscal Year 2019 Dataset*

	Unnamed: 0	Fiscal Year	GL Account Code	GL Account Name	Agency Name	Agency Code	Amount	Effective Date	Process Date	Area of Government	...	Fund Code	Fund Name	Fund Detail
0	0	2019	4200	EXPENDITURES	ACCOUNTANCY, STATE BOARD OF	422	32.69	2018-07-05	2018-07-05	50	...	229	STATE REGULATORY FUNDS	NOT APPLICABLE
1	1	2019	4200	EXPENDITURES	ACCOUNTANCY, STATE BOARD OF	422	2285.24	2018-07-05	2018-07-05	50	...	229	STATE REGULATORY FUNDS	NOT APPLICABLE
2	2	2019	4200	EXPENDITURES	ACCOUNTANCY, STATE BOARD OF	422	7945.50	2018-07-05	2018-07-06	50	...	229	STATE REGULATORY FUNDS	NOT APPLICABLE
3	3	2019	4200	EXPENDITURES	ACCOUNTANCY, STATE BOARD OF	422	12.75	2018-07-05	2018-07-12	50	...	229	STATE REGULATORY FUNDS	NOT APPLICABLE
4	4	2019	4200	EXPENDITURES	ACCOUNTANCY, STATE BOARD OF	422	12.75	2018-07-05	2018-07-12	50	...	229	STATE REGULATORY FUNDS	NOT APPLICABLE

5 rows × 22 columns

Eight of the 22 features were found to be numerical. The remaining 14 columns consisted of string data. Figures 3 and 4 show the descriptive statistics for both fiscal year datasets.

Figure 3. *Descriptive Statistics from Fiscal Year 2018 Dataset*

```
In [552]: fy2018.describe()
```

Out[552]:

	Unnamed: 0	Fiscal Year	GL Account Code	Agency Code	Amount	Area of Government	State Objective	Fund Code	Sub Object Code
count	6.729250e+06	6729250.0	6729250.0	6.729250e+06	6.729250e+06	6.729250e+06	6.729237e+06	6.729250e+06	6.729250e+06
mean	3.364624e+06	2018.0	4200.0	3.418560e+02	1.459551e+03	3.630404e+01	3.899494e+01	2.064425e+02	4.451982e+03
std	1.942567e+06	0.0	0.0	1.578558e+02	2.807587e+05	1.551892e+01	1.558213e+01	1.865835e+02	7.120848e+02
min	0.000000e+00	2018.0	4200.0	1.000000e+02	-2.906680e+07	1.000000e+01	1.100000e+01	1.000000e+00	4.105000e+03
25%	1.682312e+06	2018.0	4200.0	2.450000e+02	7.920000e+00	2.000000e+01	2.400000e+01	1.000000e+00	4.210000e+03
50%	3.364624e+06	2018.0	4200.0	2.850000e+02	4.980000e+01	4.000000e+01	4.200000e+01	2.200000e+02	4.225000e+03
75%	5.046937e+06	2018.0	4200.0	4.500000e+02	2.686800e+02	5.000000e+01	5.300000e+01	2.900000e+02	4.255000e+03
max	6.729249e+06	2018.0	4200.0	9.570000e+02	6.052874e+08	6.000000e+01	6.500000e+01	6.600000e+02	8.400000e+03

Figure 4. *Descriptive Statistics for Fiscal Year 2019 Dataset*

```
In [600]: fy2019.describe()
```

Out[600]:

	Unnamed: 0	Fiscal Year	GL Account Code	Agency Code	Amount	Area of Government	State Objective	Fund Code	Sub Object Code
count	6.512520e+06	6512520.0	6512520.0	6.512520e+06	6.512520e+06	6.512520e+06	6.512518e+06	6.512520e+06	6.512518e+06
mean	3.256260e+06	2019.0	4200.0	3.403270e+02	1.582903e+03	3.615972e+01	3.897721e+01	2.055274e+02	4.457391e+03
std	1.880003e+06	0.0	0.0	1.575486e+02	2.957688e+05	1.558937e+01	1.561802e+01	1.850581e+02	7.190568e+02
min	0.000000e+00	2019.0	4200.0	1.000000e+02	-1.663463e+07	1.000000e+01	1.100000e+01	1.000000e+00	4.105000e+03
25%	1.628130e+06	2019.0	4200.0	2.450000e+02	8.210000e+00	2.000000e+01	2.400000e+01	1.000000e+00	4.210000e+03
50%	3.256260e+06	2019.0	4200.0	2.850000e+02	5.020000e+01	4.000000e+01	4.200000e+01	2.200000e+02	4.225000e+03
75%	4.884389e+06	2019.0	4200.0	4.440000e+02	2.746200e+02	5.000000e+01	5.300000e+01	2.900000e+02	4.255000e+03
max	6.512519e+06	2019.0	4200.0	9.570000e+02	6.287345e+08	6.000000e+01	6.500000e+01	6.600000e+02	8.400000e+03

The next step in the data exploration was to identify if any of the columns had consistent data entries. Three features were consistent throughout the set: Fiscal Year, GL Account Code and GL Account Name. Using the information from the Amount columns, it was found that Idaho's expenditures totaled over 9.9 billion USD in 2018 and 10.3 billion USD in 2019. It is important to note that many of these expenditures, while billed from the state, may come from sources other than tax payer funds. One example is retirement expenditures, where funds come from the state retirement program rather than the state budget.

It was now possible to begin exploring where the expenditures occurred. Idaho uses five different categories to classify an individual expenditure. The first is the state agency where the expenditure occurred. The next level is Object Name which is used to distinguish personnel costs versus capital outlays. Then Summary Object is used to determine what kind of expenditure is being billed for such as, employee benefits, computer services, supplies, etc. The next level is Sub-Object, the type of the expenditure. Some examples are employees, retirement/sick leave and worker's compensation. Finally, the last level is Vendor, which includes the individual employees or organization billing the state. One example would be

from an expenditure in July 2018. In this case the agency that created the expenditure was State Board of Accountancy. The summary object listed was administrator supplies and the sub-object was listed as office supplies. Finally, the vendor that billed the state was Treasure Valley Coffee INC. Table 2 shows this categorization as it appears in the dataset.

Table 2. *Expenditure Categorization Example*

Agency Name	Object Name	Summary Object	Sub-Object	Vendor
Accountancy, State Board of	Operating Expenses	Administrative Supplies	Office Supplies	Treasure Valley Coffee Inc.

Starting at the agency level it was found that the Department of Health and Welfare had the largest number of expenditures in both years with over 110,000 expenditures in both fiscal years. The Idaho Department of Corrections was second both years, with over 55,000 expenditures and the Idaho Department of Transportation was third with over 45,000 expenditures in each of the years. Figure 5 shows the top agencies for fiscal year 2018. In terms of dollar amounts, Health and Welfare spent the most, at over 2.5 billion USD in 2018 and nearly 3 billion USD in 2019. Department of Education was second at approximately 2 billion USD in both fiscal years. Department of Transportation was third, at approximately 1 billion USD in both years.

At the Summary Object level it was found that awards and claims and miscellaneous payments as agent made up the largest dollar amounts at this level. Both objects' total expenditures added up to over 2.5 billion USD in both fiscal years. Wages and employee benefits followed, with wages totaling close to 1 billion each year and benefits close to 500 million. It should be noted, that there were significantly more expenditures for employee benefits than wages. This is not unexpected, as there are many types of benefits that are billed each cycle. These include: dental coverage, unemployment insurance, retirement, medical, etc. Figure 6 shows the amounts spent by summary object for the 2018 fiscal year. At the Sub-Object level, employees and insurance made up the largest amount of expenditures across the two fiscal years by a large margin. Both had approximately 1 million USD in expenditures in both years. This is not surprising as medical benefits made up a large number of Summary Objects. Due to the large number of this category a graph could not be provided.

At the vendor level, it was discovered that the state paid out to 72,324 individual vendors during the 2018 fiscal year, and 76,371 vendors during the 2019 fiscal year. 1.5 billion USD of this was spent across 8,800 expenditures on vendors that are redacted. There are a number of reasons why a vendor may be redacted. This includes medical privacy issues relating to the federal Health Insurance Portability and Accountability Act (HIPPA), security concerns for the individual(s) or a vendor may be under the age of 18. Still, this could be an area of concern, as there are fewer accountability safeguards for redacted expenditures. It should be noted that the State Controller's office claims to have internal measures to allow internal auditors to evaluate these expenditures without violating privacy laws. Other vendors of note include: St. Luke's Regional Medical Center, the

largest hospital network in the state and United Behavioral Health. Both vendors had expenditures over 100 million in both fiscal years.

Figure 5. *Fiscal Year 2018 Expenditure Counts*

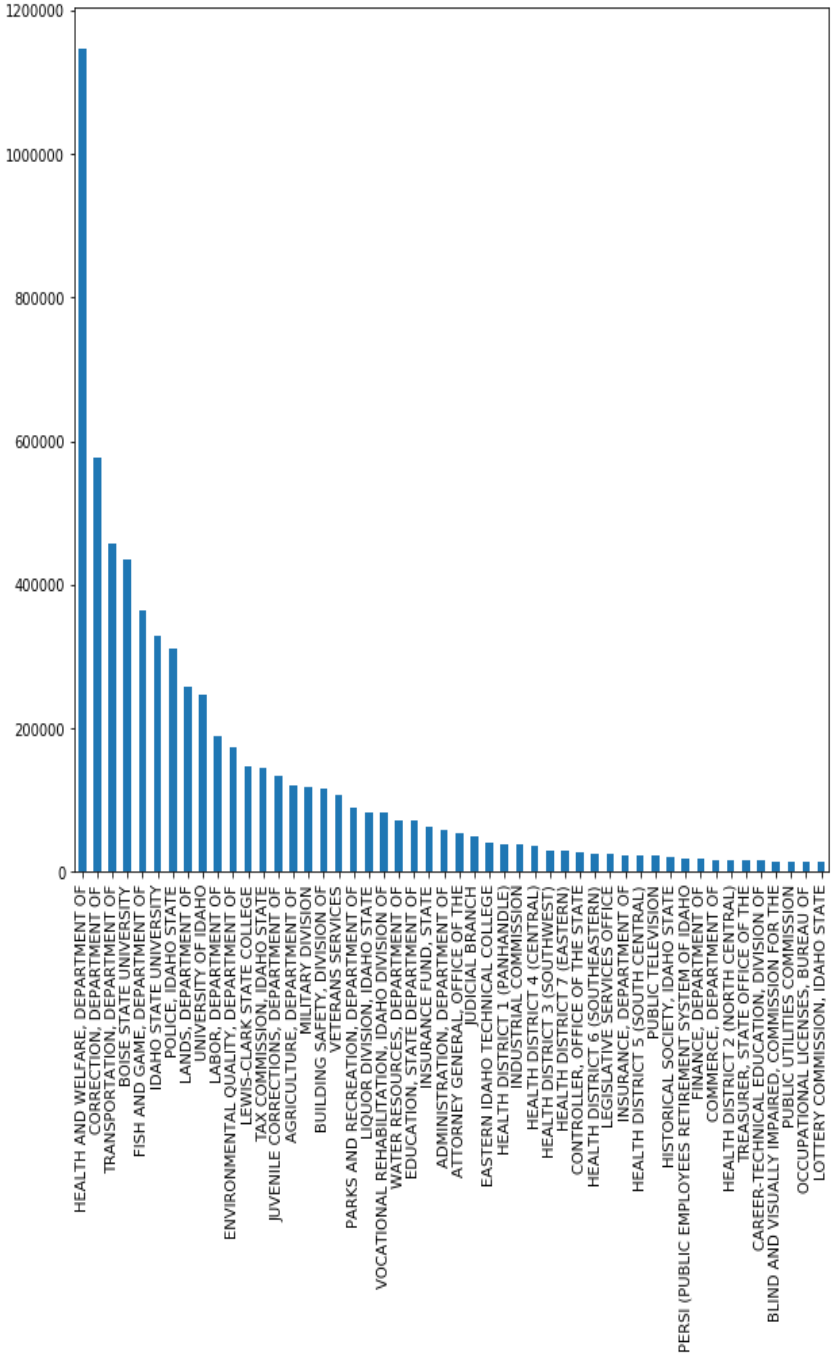
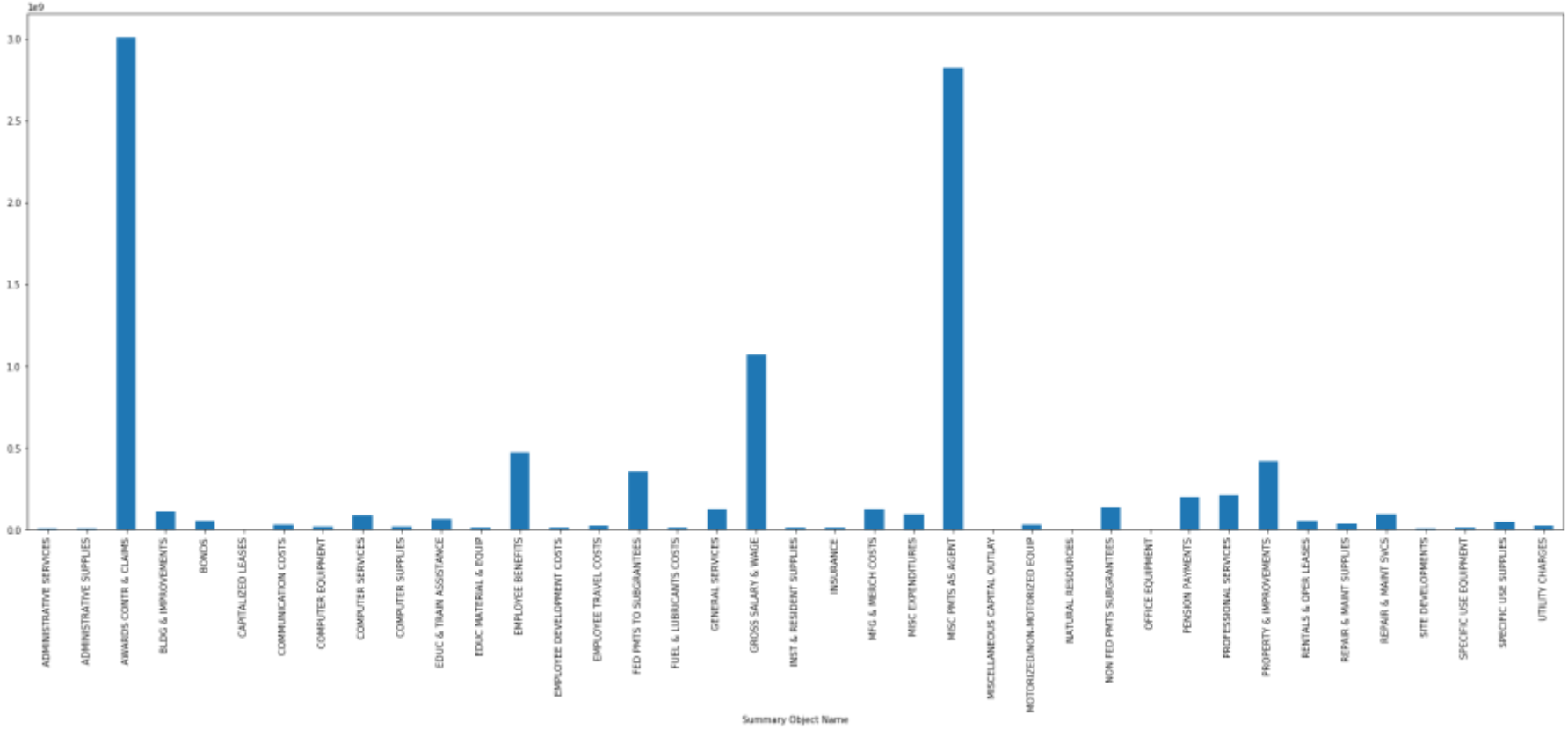


Figure 6. *Expenditure Amount for Individual Summary Objects*



The next objective of the data exploration was to determine where the largest changes had occurred between the two fiscal years. This process was done using all four categories for identifying expenditures. The first category examined was the agency category. Agencies as a whole spent 487 million USD more during the 2019 fiscal year than in 2018. On average, each agency's expenditure spending increased by 5.2 million USD or 3.8%. It was found that in terms of dollars, the Departments of Health and Welfare, Transportation, and Education had the largest increase. Health and Welfare was the largest with an increase close to 160 million USD. In terms of percentage, the Office of the Secretary of State, Department of Lands and Military Division experienced the largest increases. The Office of Secretary of State was the largest with an increase of over 54%, likely due to elections. Tables 3 and 4 summarize the largest agency increases by both percent and dollar amount. It should be noted that this process can be used to determine where the largest decreases occurred. This can be useful in identifying areas that are underfunded or have made significant efficiency improvements. Table 5 summarizes the largest agency decreases in terms of dollars.

Table 3. *Top 5 Greatest Year over Year Changes (by Dollars)*

Agency Name	Difference($)	Percent (%)
Department of Health And Welfare	1.595946e+08	5.601805
State Department of Education	9.317064e+07	4.541356
Department of Transportation	6.970577e+07	7.508004
Military Division	4.131726e+07	41.668744
Department of Lands	3.586630e+07	41.965609

Table 4. *Top 5 Greatest Year over Year Changes by Percent*

Agency Name	Difference ($)	Percent (%)
Idaho Office of the Secretary of State	2.254961e+06	54.023836
Department of Lands	3.586630e+07	41.965609
Military Division	4.131726e+07	41.668744
Department of Environmental Quality	1.605245e+07	32.710614
Correctional Industries	2.884625e+06	30.489316

Table 5. *Top 5 Smallest/Negative Year over Year Changes (in Dollars)*

Agency Name	Difference ($)	Percent (%)
Catastrophic Health Care	-2.429092e+06	-12.062386
Persi (Public Employees Retirement System of Idaho)	-2.771477e+06	-1.353824
Idaho State Historical Society	-2.916141e+06	-28.482509
Department of Labor	-8.692220e+06	-6.019738

The analysis of the other three categories showed similar results. The average increase for each Summary Object in 2019 was 12.8 million USD or an increase of 4.04% from 2018. In terms of Summary Objects, the largest increases in dollars were Awards & Claims, Property & Improvements, and Buildings & Improvements. Awards & Claims, was the largest, increasing by 141 million USD between the two fiscal years. In terms of percentage,

Buildings & Improvements, Computer Supplies and Specific Use Equipment experienced the largest increase. Tables 6, 7 and 8 summarize the top five Summary Object increases.

Table 6. *Top 5 Greatest Year over Year Changes (in Dollars)*

Summary Object Name	Difference ($)	Percent (%)
Awards Contr & Claims	1.410918e+08	4.693434
Property & Improvements	1.119937e+08	26.599756
Bldg & Improvements	6.569845e+07	59.706208
Misc Pmts as Agent	6.420825e+07	2.272240
Gross Salary & Wage	3.813386e+07	3.568694

Table 7. *Top 5 Greatest Year over Year Changes by Percent*

Summary Object Name	Difference ($)	Percent (%)
Bldg & Improvements	6.569845e+07	59.706208
Computer Supplies	4.841004e+06	28.262855
Specific Use Equipment	2.869434e+06	27.173937
Property & Improvements	1.119937e+08	26.599756
Capitalized Leases	2.014129e+05	14.745854

Table 8. *Top 5 Smallest/Negative Year over Year Changes (in Dollars)*

Summary Object Name	Difference ($)	Percent (%)
Educ & Train Assistance	-1.245134e+06	-1.896331
Pension Payments	-2.491714e+06	-1.265241
Motorized/Non-Motorized Equip	-2.607726e+06	-8.510727
Computer Equipment	-3.270671e+06	-16.140637
Employee Benefits	-2.209452e+07	-4.692094

The Sub-Object category experienced an average increase of 1.17 million dollars or a 208% increase between the 2018 and 2019 fiscal years, across all Sub-Objects. Many Sub-Objects experienced major increases in expenditure spending percentage-wise, which skews the arithmetic average. The machine and equipment Sub-Object had the largest percentage increase during this time, at over 45,000%. Other significant increases include the construction in progress and Land Non-1099 Reportable Sub-Objects, which also had increases of 13,129% and 7,929%, respectively. These are most likely due to the starting of major projects, as these amounts were relatively small in the previous year. In dollar amounts, the largest increase occurred with the Medical Assistance Vendors with an increase of 147 million dollars. Other significant increases include School Appointments, with an increase of 95.7 million USD, and Land Non-1099 Reportable, with an increase of 58 million USD. Tables 9, 10 and 11 summarize the Sub-Object increases.

Table 9. *Top 5 Greatest Year over Year Changes by USD Amount*

Sub Object Name	Difference ($)	Percent (%)
Medical Assistance-Vendors	1.472141e+08	6.484279
School Apportionment	9.579945e+07	5.386734
Land - Non 1099misc Reportable	5.804148e+07	7929.909276
Infrastructure - 1099m Reportable	4.951701e+07	12.079128
Employees	3.682643e+07	3.696804

Table 10. *Top 5 Greatest Year over Year Changes by Percent*

Sub Object Name	Difference ($)	Percent (%)
Machinery & Equipment	185692.00	45512.745098
Construction In Progress-Land-Building-Equipment	433548.08	13129.624537
Land - Non 1099misc Reportable	58041479.33	7929.909276
Educational Equipment-Furniture	39697.18	4411.680114
Non-State Employee-1099misc Box 3	37900.00	3661.835749

Table 11. *Top 5 Smallest/Negative Year over Year Changes*

Sub Object Name	Difference ($)	Percent (%)
School District-Federal Subgrant	-5.559486e+06	-2.554015
Environmental or Ecological Testing	-9.763956e+06	-90.027430
Premiums	-2.324098e+07	-7.160197
Group Insurance Health & Accident	-3.009131e+07	-12.228138
Refunds	-6.661183e+07	-14.849007

The vendor category experienced an average increase of 8,030 dollars per vendor in fiscal year 2019. This is an average increase of 6.6% with a median of 0.96%. The largest increase was Knife River Corporation Mountain West with an increase of over 79 million. It needs to be noted that Knife River Mountain West changed names from Knife River Northwest during this time period. As a result, there was a corresponding decrease of nearly the same amount from Knife River Northwest. The actual change was an increase of 137,000 dollars. In order to perform effective analysis of many vendors it will be necessary to learn the context of many of the vendors. Other significant vendor increases were from the State Treasures Office and The First American Title Company. Tables 12, 13 and 14 summarize the changes in vendor expenditures between the 2 fiscal years.

Table 12. *Top 5 Greatest Year over Year Changes*

Vendor Name	Difference ($)	Percent ($)
Knife River Corporation Mountain West	79270938.93	1289.430678
State Treasurers Office	51451052.14	3.695622
First American Title Company	43573135.43	3951.012729
Health & Welfare Department	35022656.15	78.447689
Blue Cross Of Idaho Care Plus, Inc.	31092732.75	77.237668

Table 13. *Top 5 Greatest Year over Year Changes by Percent*

Vendor Name	Difference ($)	Percent (%)
Nicholas And Company	58979.52	8.300630e+19
Home Depot	4747.30	6.681231e+19
Napa Parts Inc.	4083.55	5.747086e+19
Home Depot Store 1808	10295.49	4.829871e+19
Paypal Inc	12213.04	2.864721e+19

Table 14. *Top 5 Smallest/Negative Year over Year Changes*

Vendor Name	Difference ($)	Percent (%)
Veyo, Llc	-1.506158e+07	-98.122833
Staker And Parson Companies	-1.553464e+07	-38.048156
Diageo North America	-1.919531e+07	-99.997565
Knife River Corporation Northwest	-7.913310e+07	-99.924590
Redacted	-9.047389e+07	-6.184988

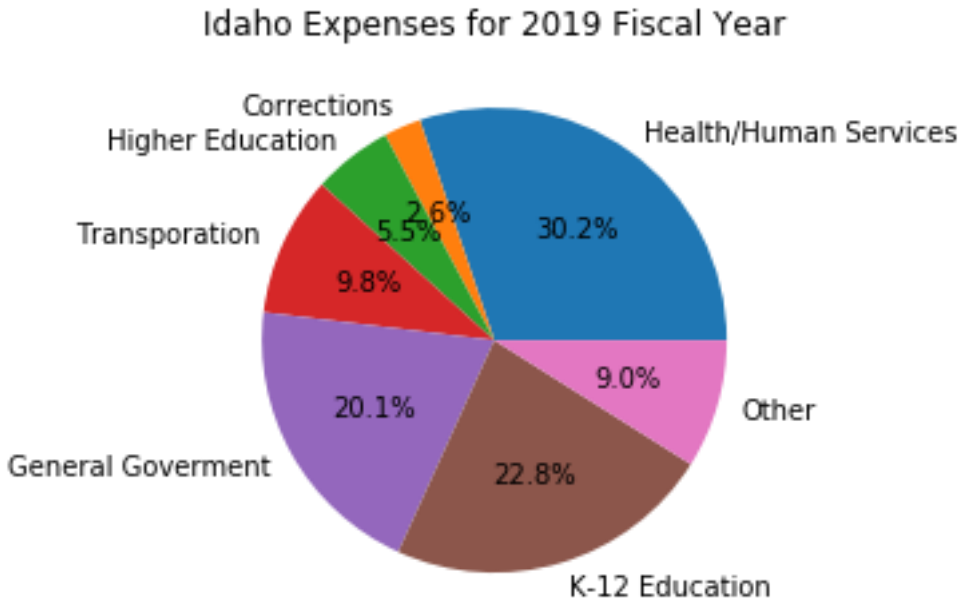
Exploring the expenditures using the four different categories can provide great insight into the expenditure data, especially as it changes from year to year. This analysis was able to show which categories had the largest increases and decreases both in terms of dollars and percentages, between both fiscal years. In terms of state agency and vendors, performing this analysis is useful in determining which groups are having the largest change in spending. This analysis showed that the Department of Health and Welfare was the agency with the largest dollar increase, while the Department of the Secretary of State had the largest percentage increase of all agencies. This allows for a quick determination if spending is trending according to expectations or if it is becoming out of control. Looking at the Summary Objects and Sub-Objects allows for analysis of what the expenditures are being spent on. Also, it can allow the state to make more informed decisions if an agency or summary object is adequately funded. In terms of Summary objects, it was found that Awards & Claims had the largest dollar increase, while Buildings and Improvements had the largest percentage increase. It is important to note that the decreases are just as important to analyze as the increases. Deeper analysis into the decreases can help identify methods that can help other groups improve spending efficiency. Also, it can be a useful tool for analyzing outside vendors to make better determinations of which vendors are performing the best.

Comparison to Other States

This section will compare Idaho's expenditures in different areas to that of several other states. The data will be compared against the states of Arkansas, Texas, Montana and California. Doing this comparison helps identify areas where Idaho's spending may be inefficient. Also, it may help identify areas of spending that are performing well in relation to other states. First, it is important to understand how Idaho total costs are distributed. According to the exploration of the expenditure data, 30.2% of Idaho's expenditure spending came from health and human services. 20.1% of expenditure spending was

from state government expenses. 9.8% was in transportation related expenses, 5.5% in higher education, 2.6% in corrections, 22.8% in kindergarten through 12th grade education (K-12), and the remaining expenditures are classified as other. Based on this data, the total per capita spending in 2019 for Idaho was approximately $6,129 per person. Figure 7 shows a visualization of this spending.

Figure 7. *Idaho Spending by Percent (Fiscal Year 2019)*

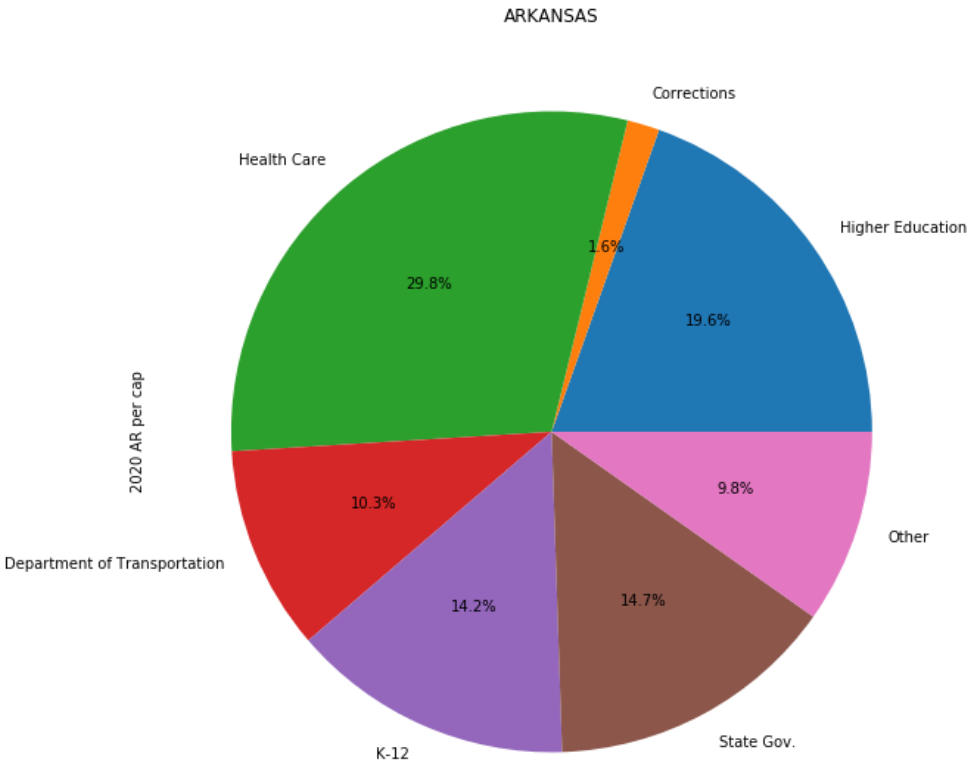


Arkansas

Arkansas is a smaller state in terms of land size, ranked 29th, and has a population of around 3 million. It was chosen for analysis in order to compare Idaho to a state that is very different in terms of size and population density. According to the state's appropriations for the 2020 fiscal year, the state has allocated 29.8% of its total allocations for healthcare (State of Arkansas 2020). This is close to Idaho's 30.2%. Areas of significant difference include state government expenditures, where Arkansas has allocated 14.7%, compared to Idaho's 20% in this area. Arkansas also has allocated more in the area of education. Arkansas allocated 33.8% in education. 14.2% for K-12 education and 19.6% for higher education. This is more than Idaho which allocated 28.3% for education, with 22.8% for K-12 and 5.5% for higher education. One possible reason for the larger higher education rates is that the universities in Arkansas have much higher endowments when compared to those in Idaho. For example, University of Arkansas has an endowment over 1 billion USD, while Boise State University has an endowment of 115 million (NACUBO 2019). Also, Idaho universities may rely more on federal funding due to the presence of the Idaho National Lab. Idaho and Arkansas have similar spending in the area of corrections, with Arkansas allocating 1.6% to Idaho's 2.6%. Also

similar are the state's allocations in the area of transportation, with Arkansas spending 10.3% of its allocations in this area and Idaho spending 9.8%. Figure 8 shows Arkansas' spending allocations in terms of percentage.

Figure 8. *Arkansas Spending by Percent (2020 Fiscal Year)*



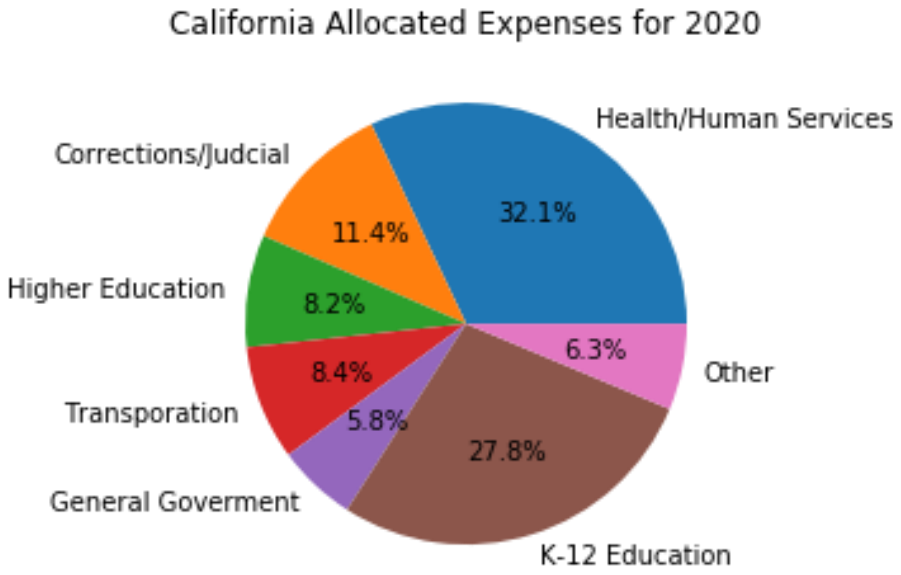
Using population estimates from the census bureau, it was also possible to determine estimates of Arkansas spending in terms of per capita and to compare these to Idaho's for another view on spending differences. Arkansas spent more in many areas than Idaho, on a per capita basis. These include education, K-12 and higher education combined, where Arkansas spent over $3,300 per person, compared to Idaho's $1,720. Transportation was another area with a noticeable difference, where Arkansas spent over $1,000 per person and Idaho spent $603. In terms of health care, Arkansas spent $2,900 per person, compared to Idaho at $1,865. Overall, Arkansas spent significantly more per capita than Idaho. Arkansas spent over $9,747 per person in total spending, while Idaho only spent $6,129. Figure 12 compares the per capita spending of Idaho and all the states analyzed.

California

California is the most populous state in the Unites States; its population is estimated to be over 39 million, and 3rd in terms of land size. California was chosen in order to compare Idaho's spending patterns to the state with the largest population in the country. According to the Governor's Budget Office

in California, the state allocated more in K-12 for 2020 with 27.7% of total expenditures allocated for K-12 education compared to 22.8% for Idaho. California was also higher in corrections, with 11.4% of spending going to this area. In higher education, California allocated 8.2% similar to Idaho's 5.5% (Newsom 2020). The two states also have allocated a similar amount in transportation with California allocating 8.4% compared to 9.8% for Idaho. California also allocated close to the same amount, percentage-wise, in 2018 in health and human services at 32%. State government allocations were significantly less at 5.3%. Figure 9 shows California's spending allocations for 2020.

Figure 9. *California Spending Distribution*



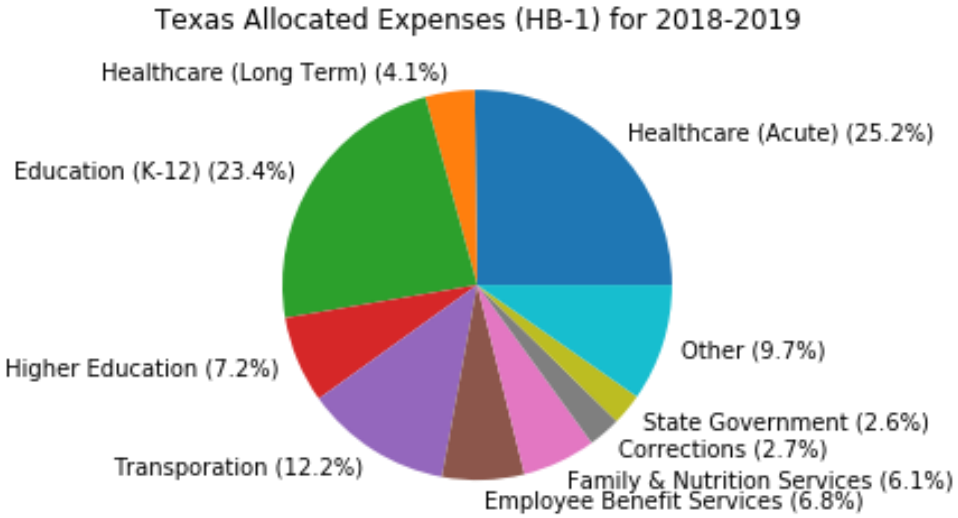
Data was also available to perform analysis on a per capita basis for expenditures in California. This is useful as Idaho and California are very different in terms of population and size. This analysis may help determine areas where either too much or too little may be allocated. In the area of transportation, California spent $473 USD per person, while Idaho spent $603 per person. In health care, California was similar, at $1,803 per person, while Idaho spent $1,865 per person. Finally in education, California spent approximately $2,018 per person, while Idaho spent approximately $1,720 per person. California's overall per capita allocation for 2020 was $5,625.

Texas

Texas is the second largest state in terms of size and it is also second in population, with approximately 29 million people living in the state. Texas was chosen for the same reason as California, to provide a comparison between Idaho and a large state. However, Texas is considered to be a very different state than California and is more similar to Idaho. According to data available

from the Texas' Legislative Budget Board, the state's budget from 2018–2019 was 221 billion in HB-1 (Texas Legislative Budget Board 2018). It should be noted that Texas divides up health care cost differently with spending for both acute health services and long term health services. These two services accounted for 29.3% of the budget, approximately 54 billion dollars. This is close percentage wise to Idaho's 30.2%. Texas's exact spending on corrections was found to be 2.7%, which compares close to Idaho's 2.6%. Higher education for Texas is close as well, with 7.2% allocated compared to Idaho's 5.5%. Also, transportation spending was similar, with Idaho spending, 9.3% of its allocations on transportation and Texas spending 12.1%. Idaho's state government expenses are higher in percentage than Texas at 20% compared to 2.6%, though Texas allocates its employee benefits separately. Texas spent a similar amount on K-12 education than Idaho, at 23.4%. Figure 10 shows how Texas allocated funds for 2018–2019 fiscal period.

Figure 10. *Texas Spending by Percent (2018–2019)*



On a per capita basis, Texas spent near $7,727 per capita overall. $980 was spent per capita in transportation, compared to $379 in Idaho. In the area of health care, Texas spent $2,351 on a per capita basis, compared to $1,865 for Idaho. Finally, in the area of education, Texas spent $1,816 per person on K-12 education and $514 per person on higher education. This gives Texas a per capita cost of education total of $2,362 per person, compared to Idaho's $1,720.

Montana

Montana is the 4th largest state in the United States and has an estimated population of slightly over 1 million. Montana's demographics are similar to Idaho in terms of population. According to Montana's fiscal report for 2019 budget, HB-2 accounted for over 86% of state expenses. The amount of HB-2 was approximately 10.31 billion dollars. Of this amount, HB-2 allocated

approximately 4.25 billion dollars, 42% of the total budget, to health and human services (Legislative Fiscal Division 2017). This likely includes the cost of health benefits to state employees. This is more than Idaho at 30.2% of total allocations for the same period. Idaho spent more in government expenses with 20% of the allocated budget, compared to Montana's 6%. Montana allocated close to the same amount in education, with Montana allocating 26% of the budget, approximately 2.65 billion dollars, between both K-12 and higher education. In comparison, Idaho allocated 28.3% toward education. Montana also spent more in the areas of transportation, and corrections at 18% and 8% respectively. Idaho spent 9.8% and 2.6% respectively in these areas. Figure 11 shows a visualization of Montana's spending allocations. Overall, Montana spent significantly more than Idaho, with a total of $10,140 per person.

Figure 11. *Montana Allocation Estimates for 2019*

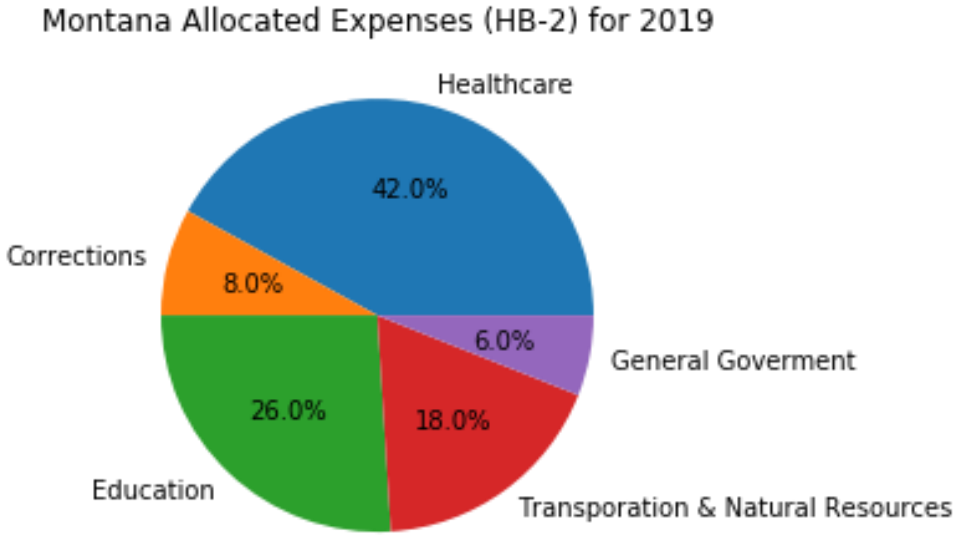
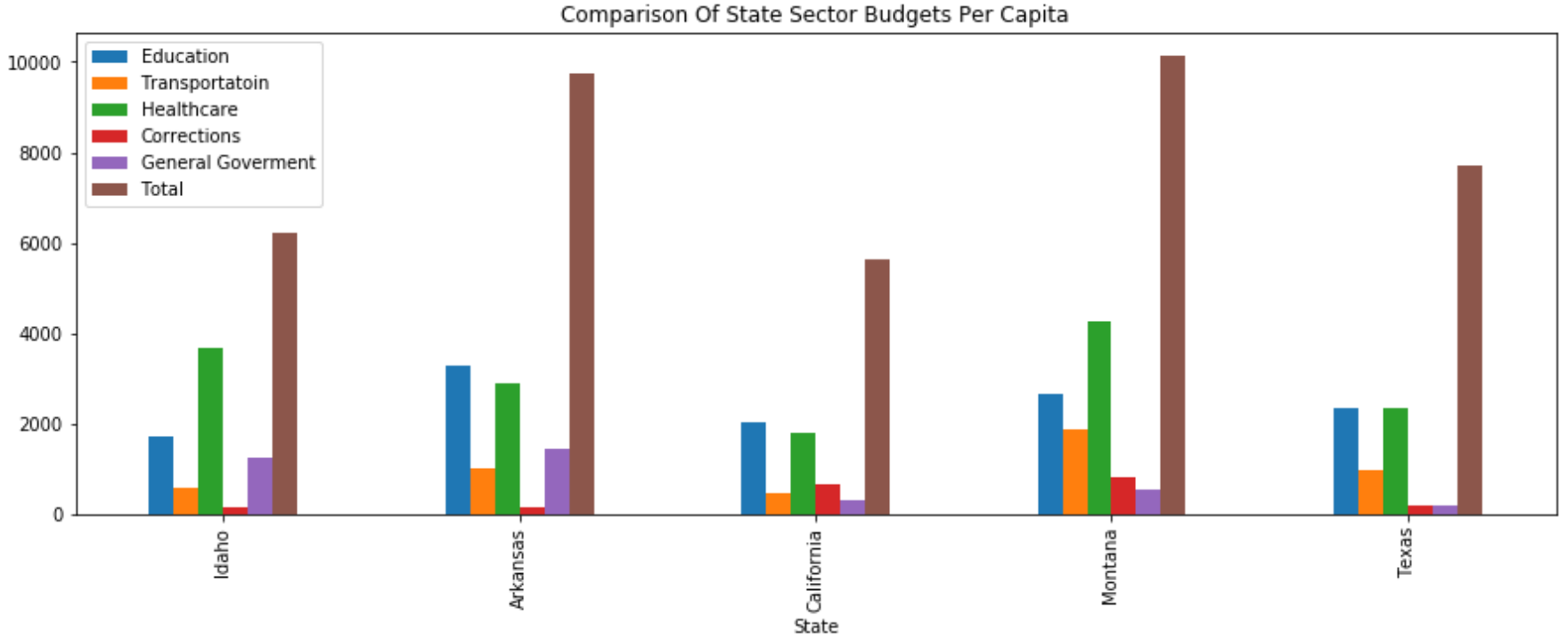


Figure 12. *Comparison of State's Expenditure Spending (per Capita)*



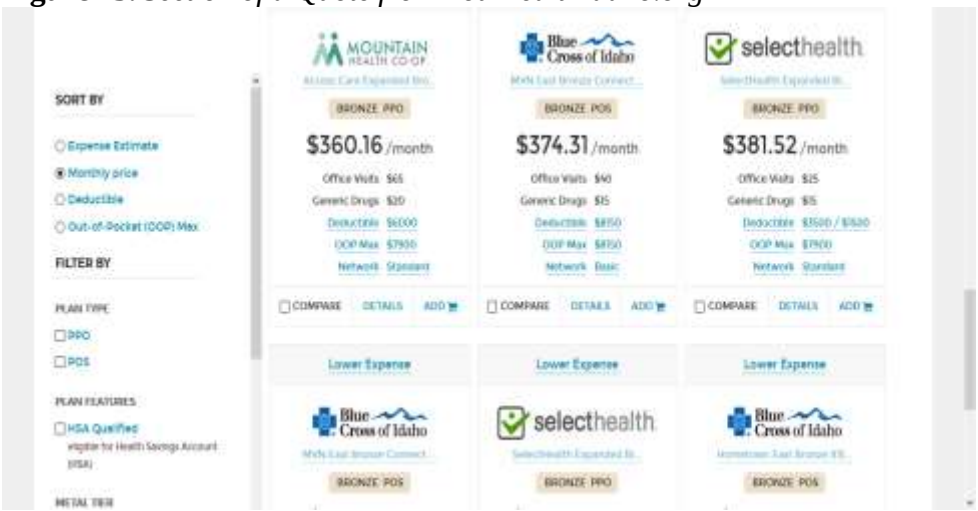
Areas of Improvement

The results of the data exploration show that there are many areas for possible improvements in reducing cost in Idaho. The analysis showed that there is a great deal of expense in both health care and transportation. As a result, these areas were further analyzed to see if suggestions could be offered to provide guidance on improvement. Health care was chosen as it is an important issue and employee transportation was chosen due to Idaho's large geographical area.

Health Care

Health care is a complex issue in the United States. In previous years, both state and federal governments have sought to reduce health care costs and allow more access. The results have been mixed, with more people having access to health care, but the costs of health care and health insurance have increased, in some cases dramatically. In Idaho for example, in 2019 Blue Cross of Idaho proposed a premium of $305 for a Bronze health plan, a 5% increase from the previous year (Dutton 2018). In 2020, the lowest priced Bronze plan from Blue Cross of Idaho was quoted at $374 per month according to the YourhealthIdaho.org. Figure 13 shows a screenshot from the Idaho health insurance website. The state government is facing similar issues, as a large percentage of its budget expenditures are from the areas of health care benefits provided to employees and health care services provided by the state. Again, the Department of Health and Welfare is Idaho's largest state agency and by far has the largest number of expenditures. According to the State Controller's Office, the reason for this is the growth and expanded use of Medicaid. While it is unlikely that the suggestions in this section will solve the issues surrounding health care, the savings could allow Idaho to continue providing health benefits to its employees and health services to its citizens without major cost increases in the short term.

Figure 13. *Section of a Quote from YourhealthIdaho.org*



The first issue that should be addressed is the issue of redacted vendors. These vendors made up over 1.37 billion USD of the state's expenditures in the 2019 fiscal year. It is true that there are likely good reasons for redactions and the state does claim to have measures to help internal auditors in this area. Still, transparency is questionable, especially to external parties. A system to classify redactions by reason, for example redacted for security, could go a long way in helping external auditors identify waste and improve accountability.

Another area that could be addressed is the issue of health cost transparency. This is an issue that is being evaluated not only at the state level, but at the federal level as well. In Idaho, both St. Luke's and United Health were among the top five vendors in terms of dollar amounts to the state of Idaho. Each had total expenditures valued over 100 million USD for the 2018 and 2019 fiscal years. Increasing the transparency of health cost to the consumer could provide incentive for them to search for alternatives that might better suit their individual needs and increase competition in health industry and reduce cost which would help Idaho maintain its ability to offer health insurance to its employees and health services to its citizens.

Employee Transportation

The next area to be examined for possible improvements was travel/ transportation for public employees. Idaho is a vast state, ranked 13th in the nation in terms of land size. Idaho also has a significant number of people that live in rural areas that are a number of hours from the major population centers in the state. As a result, many state employees are required to travel a large number of hours in order to perform their duties in these rural areas. For example, employees for the Department of Health and Welfare may have to travel from the city of Idaho Falls to the town of Victor, a drive of over an hour each way. To further complicate matters, Idaho's climate is very unpredictable. It is common for areas of the state to receive significant snowfall into the months of March and April. This can make travel more difficult and dangerous for the employees. It is very likely that an employee may spend half of their work day or more serving a single client in a rural area, for a routine task. According to the 2010 Census, Teton County has a significant Hispanic population, 16.7% (United States Census Bureau 2019b). Due to this, there is an increased chance that an interpreter may be needed to assist with services, which would further increase the costs of providing services.

A possible solution to this issue is expanding the use of teleconferencing technology where possible. The use of this technology would significantly reduce the need for state employees to travel to these rural areas. This would save hours of travel time, as well as reduce costs associated with travel, including expenditures needed to pay for gasoline, car maintenance, insurance, etc. Also, the cost of language translation could be reduced, as interpreters could also participate in the teleconferences from other locations. This would largely eliminate the need for interpreters to travel to rural areas and bill less hours. According to the Bureau of Labor Statistics, the median hourly rate of a translator/interpreter is 24.95 USD per

hour (United States Bureau of Labor Statistics 2020). Another benefit of the reduced travel requirements would be the possible increase in competition in the bidding for interpreting contracts with the state, as there would be fewer constraints for the contractors. This would have the benefit of reducing cost and improving the quality of the contractors.

Teleconferences could also be used for other applications as well. As noted, Idaho is a large state and travel to the capital, Boise, can take 4–5 hours from other areas inside the state. Expanding the use of teleconferences for things such as meetings, department trainings, etc. would also help reduce cost, by allowing state workers to attend these functions from their typical place of work, rather than having to travel. This not only would reduce cost in terms of travel, but may also improve productivity, inner department communication and allow for more training opportunities to improve operations.

It should be noted that there are issues that would need to be addressed with the expansion of teleconference technology. First, it is likely that lower income clients would need to be provided with a tablet or other device to participate in teleconferences. Still, the cost of devices that are needed for teleconferences are generally low when compared to the cost needed for travel. A formal and effective training service may also need to be provided to both clients and employees to ensure that the service can be used as intended.

The next area of possible improvement for travel/transportation involves reducing the cost of both in and out of state travel with the use of contracts. The data exploration showed that 40%, around 8–9 million dollars, was spent on out-of-state travel during both the 2018 and 2019 fiscal years while the remaining portion was used on in state travel. The benefit of contracts is that it would provide guaranteed income to travel vendors, such as hotels and airlines, while allowing the state employees to enjoy a lower rate for travel. This should be very effective in-state, as the contracts would be easier to negotiate, but out-of-state contracts would make sense in other areas, such as air travel.

Contracts could help in reducing the cost of both in-state and out-of-state travel, but it ignores an underlying issue with the travel system. As the system is set up now, there are no incentives for employees to participate in reducing the cost of travel. Travel can be difficult on employees and when making arrangements such as airfare, employees generally will plan for the most convenient arrangement, rather than the most practical. Examples of this are flying instead of taking a shuttle bus, or choosing a more expensive flight instead of a lower cost one. If the state was to determine a target price for types of travel and then reward employees for meeting this price, it would increase the probability that an employee would trade some convenience for cost reduction, as they also would benefit. This would also increase and incentivize employee involvement in the cost reductions.

Conclusions

The analysis done in this study shows the ability that data science tools, such as the Pandas package in Python, have in analyzing large amounts of data easily and in a reasonable amount of time. In this case, Pandas was able to read, display and order over 6 million different expenditures from the state of Idaho's controller office. Using basic Pandas functions with this data, it was possible to explore and determine which state agencies had the most expenditures, as well as which agencies spent the most during the 2018 and 2019 fiscal years. The data exploration was also able to group data by Summary Object and Sub-Object to determine what the use and the amount of these expenditures was. For example, Idaho spent near 5% more on health than Texas, but over 12% less than Montana. Also, using Pandas it was possible to see which vendors had billed the state the most times over the two fiscal years. This analysis allowed for comparison with other states such as, California and Texas, to see how Idaho's expenditure allocations varied from other states, on both a percentage and per capita basis. This was done successfully and the areas where Idaho's spending was significantly different from others were identified. This included incentives for employees to find savings during travel, expanded use of teleconferencing and remote technology and improved health cost transparency. Finally, using the insight gained from this data exploration, it was possible to identify areas where improvement could and should be made, specifically; health care and employee transportation. It is hoped that results from this study will help encourage state and local governments to make greater use of data analytic tools in order to improve spending efficiency and increase transparency. The Controller's Office has expressed interest in expanding this analysis to answer more questions regarding expenditures as well as performing regression analysis in the future.

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How Ontic Structural Realism would Formalize Scientific Progress

By Alex B Pablos[*]

This essay tries to make a tangential cut between the debate that seeks the most adequate definition of scientific progress (involving authors such as K. Popper, T Kuhn, A Bird or J Saatsi) and the debate on the viability of structural realism to be considered the best epistemological approach to the understanding of nature (B van Fraassen, J Ladyman, J Worrall, S Psillos...). Thus, we will first connect both debates by showing that they shared a common problem before their progressive distancing. Finally, we will outline a formulation of scientific progress inferred from the structural realism approach; in particular, our definition will be based on J. Ladyman's proposal in Every Thing Must Go as we will emphasize that it also provides an answer to the aforementioned original problem. Our conclusion is that this formulation of scientific progress differs from the three main ones, namely, truthlikeness, problem-solving, and accumulation of knowledge. This fourth form is necessarily linked to a speculative approximation of reality. Moreover, we want to suggest that this fourth conception is articulated under the shadow of the ideas of CS Peirce.

Keywords: *structural realism, scientific progress, J Ladyman, speculative realism*

Introduction

"Truths are fecund only if bound together"
(H Poincaré, The value of science, 1905)

Philosophical discussions, clearly in analytical philosophy, become more concrete and ramified due to the limits imposed by the (justified) academic requirements of rigor and formality. This leads to the generation of a microcosmos of debate which, despite being influenced by what sounds in the corridors, are alien to what happens in the next room, even though they may share themes, objectives and concerns. In view of this, the present essay tries to make a tangential cut between two prominent debates in contemporary philosophy of science: on the one hand, the debate that seeks to offer the most accurate formalization of scientific progress (held by authors such as K Popper, T Kuhn, A Bird, J Saatsi...); and on the other, the discussion regarding if structural realism, that is to say, the consideration that scientific theories expose *only* the structural or relational character of reality, is the best epistemological approach to understanding nature (involving B van Fraassen, J Worrall, J Ladyman, S Psillos...).

For this, our first objective is to make explicit the shared problematic underlying the two debates that we are dealing with. We will try to make this clear

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by showing that their problematic goes hand in hand with a conception of what the term "realism" means in its particular philosophical context. But our purpose does not end here. This contextualization will help us to offer an outline of how structural realism would formalise scientific progress. And we hold that this formulation of scientific progress will differ from the three main ones, namely, truthlikeness, problem-solving, and accumulation of knowledge, considering this fourth formulation as "speculative". Moreover, as we will see, the definition of scientific progress for structural realism that we will give is based mainly on J Ladyman's position as set out together with D Ross in *Every Thing Must Go* (2007). Due to that, we are aware of generalizing, among other things, over Ladyman's (1998) accepted distinction between epistemological structural realism (ESR), or "restrictive structural realism" (Psillos 2001), which understands that what science *can know* about reality is its structure, and ontic structural realism (OSR), or "radical structuralism" (van Fraassen 2006), according to which nature *is* structure. But the reason for our generalization is precisely part of the exposition, where we will argue that Ladyman's general project to support OSR is still related to a fundamental problem also shared by the debate on scientific progress: how to deal with the existence of theoretical entities.

It should be clarified, then, that this essay does not seek to argue for or against structural realism, and especially not for or against Ladyman's positions. Nor will it attempt to offer our positions on the debates which will be mentioned here and which are still ongoing: such as the new formulations of truthlikeness, the appropriateness or not of ramseyfication for structural realism, or the feasibility of certain structural models for explaining certain phenomena suggested by quantum mechanics. Instead, what we are dealing with here is the "is" and not the "should" of structural realism. Thus, we would like to reflect the channel through which structural realism has taken place and with which, according to the argument that we will explain, it can offer a different formulation of scientific progress.

For this, the first part of this essay contextualizes the emergence of structural realism in a broader philosophical problematic shared with the debate on scientific progress; this context holds a characteristic meaning of the term "realism". Then, the next part shows that the firsts formulations of structural realism, namely syntactic and semantic ones, did not overcome the aforementioned problematic. The following two parts offer the key points with which Ladyman in *Every Thing Must Go* attempts to be an alternative to those problems by endorsing OSR. Finally, it is offered an outline of the definition of scientific progress inferred from Ladyman's structural realism which we consider as "speculative", partly indebted to Q Meillassoux. In these last two parts we will deal with the presence of CS Peirce's pragmatic ideas in Ladyman's project.

Discussion Context at the Beginnings of Structural Realism

The history of thought shows that the term "realism" is equivocal, it didn't mean the same in the face of the problem of the realism of the universals in the Middle Ages, as it did in the face of the problem regarding the knowledge of the

external world in Modernist-Illustration, as it did in the different artistic realisms... and neither does it have a univocal meaning in contemporary positions: real are the transcendental instances of experience for phenomenologists, real is the void that promotes the symbolic creation in Lacan and some postmodernist... But despite this plurality of meanings, it turns out that structural realism has not made explicit what it understands by "realism". However, it does so with "structure" as shown by its awareness of different approaches that have prioritised knowledge of the law-like aspect of nature over its substantive knowledge: neokantians of the Marburg School, H Poincaré, M Schlick, B Russell…[1]. To that, my point is that by focusing on its concept of "realism" we will easily glimpse its connection with the debate on scientific progress.

Perhaps "structural realism" appears stated for the first time in *Structural realism and the meaning of theoretical terms* (1970) by G Maxwell, but in 1962 he already exposes the same ideas: science shows relational descriptions of phenomenal impressions (quoting P Feyerabend and Russell) and, moreover, we should not hold a distinction between the observable and the theoretical, as this distinction is contingent, that is, is an *a posteriori* distinction that could change together with our instrumental capacity (Maxwell 1962, p. 26). What we see in this G Maxwell's claim for the structural knowledge offered by science is an attempt of the late logical empiricism trying to overcome the problems of the preceding logicism, of which Kuhn is another direct reaction/escape. This more general problem, I maintain, is perfectly reflected in WVO Quine's *Word and the Object* (1960) regardless of its particular conclusions. In this work, Quine argues that all entities are theoretical (therefore his conventionalism). Science, as common sense, tends to inflate ontology (Quine 1951), but first order logic can clean and regiment scientific theories on bases that consider the whole set of theories (therefore his holism). With such rigour we can commit ourselves to the existence of theoretical entities (Quine 1960); that is, for Quine, there are "charm" quarks, but not tables, which are not scientific entities. As seen, these are similar problems to those approached by G Maxwell, but Quine does not stop here. Continuing with his metaphysical expurgation, Quine also attacks Peirce's idea of truth as unreachable limit[2]. "Limit", says Quine, must be applied exclusively to numbers (as is notion constructed from "near by"), applying it to objects such as theories is an incorrect extrapolation (Quine 1960, p. 23). This last critic hits precisely Popper's underlying ideas exposed in *Logik der Forschung. Zur Erkenntnistheorie der modernen Naturwissenschaft* (1934), one of the first texts focused on addressing scientific progress and rewrote in 1959 as *The Logic of Scientific Discovery*. In there, Popper exposes his theory of falsifiability which is supported on a notion of truth as an ideal ground on which to contrast theories, that will be recognised as a version of Peirce's in *Conjectures and Refutations* (1963, p.

[1]Addressed i.e., in Gower (2000), Demopoulos and Friedman (1989) and Massimi (2010). In the latter it is also addressed the structuralist perspective of scientists such as W. Pauli and N. Bohr.

[2]"Inquiry properly carried on will reach some definite and fixed result or approximate indefinitely toward that limit" (Peirce *CP 1.485*. [CP refers to the Collected Papers (1931-1958) of CS Peirce, C Hartshorne, P Weiss and AW Burks (eds.)])

229). Thus, Popper in 1963 endorses A Tarski's logico-semantic and metalinguistic formulation to restore the concept of "truth" against Quine's critic and to open science to an inventive capacity beyond its deductive systematicity (p. 221), as far as Tarski's system leads open the possibility of scientific examination by means of observational tests. So now, observational terms, if empirically adequate, can have truth content, so they can be part of a theory that can be contrasted with others equally constructed in terms of its verisimilitude, just as Popper wants. All in all, we see in Quine/Popper/Tarski the same problem we saw on G Maxwell: trying to know which entities can be justifiably invoked by science.

The previous example suggests that the *possibility* of dealing with the reality or not of theoretical entities is the general problem underlying the debate on scientific progress and scientific realism. This may seem obvious for some, but it is not redundant, as it implies a very concrete definition of "realism" far from the preceding debates in philosophy: *A realist is one who accepts the existence of the entities postulated by science*. Now, structural realism starts by endorsing this meaning of realism and accepts only the reality of the relationships between phenomena, and of no other entity. This gives us a basic insight on its notion of scientific progress, that is, unlike truthlikeness, problem-solving and knowledge accumulation proposals, it will need to endorse *the existence* of concrete entities, namely, structures. In the following section we will see why it would be necessary to commit to the reality of a structural nature (OSR) and not merely to structures as a descriptive tool (ESR) in order to justify progress.

Formal Structural Realism: Epistemic Insufficiencies

Ladyman, aware in *What is Structural Realism* (1998) that "the debate about how to characterise theories and their structure is of central concern" (Ladyman 1998, p. 415), defends precisely a semantic formalization for structural realism, as opposed to the insufficiency of G Maxwell's syntactic one[3]. This is partly because Ladyman relies on the critiques that Demopoulos (2003) and Demopoulos and Friedman (1985) did to G Maxwell's ideas. In fact, these authors saw in G Maxwell's re-adaptation of Russell 1927's project an approach that was already undermined by Newman (1928). In 1927, Russell left aside sense-data as a source of knowledge to focus on knowledge by description. Working on this, Russell

[3]The semantic approach consists of an isomorphic structural representation of a theoretical system, so it is not an axiomatization of the theory itself. This allows the same formulation to be isomorphic to several theoretical representations, which is equivalent to committing itself to the structure of the theory independently of its ontology (the elements to which it refers). For a clear exposition of Ladyman's points on the semantic approach see French and Ladyman (1999). Here it is sufficient to say that Ladyman's semantic approach is mainly based on the contributions of the physicist H. Weyl and his work on group theory in the theory of relativity and quantum mechanics (Ladyman 1998, Ladyman et al. 2007). According to group theory, objectivity can be explained in purely relational terms and without the need for substantiation, since it is the invariants under particular transformations that determine objectivity. Be that as it may, for our purpose it is not so necessary to expose Ladyman's semantic approach as to show his concerns about the formalization of structural realism.

used Ramsey's logical formalization, with which he translated theoretical terms into observational ones by transforming predicates into quantified variables that express type-relations. But Newman, in turn, considered that Ramsey/Russell were trivializing the empirical content of physics by reducing it just into its cardinality, so that two different sets with the same number of elements would be equal after being *ramseyfied* (Demopoulos 2003, Demopoulos and Friedman 1985)[4], or as Ladyman phrases it: "the *formal* structure of a relation can easily be obtained with any collection of objects provided there are enough of them" (Ladyman 1998, p. 412). So, ramseyfication ends up requiring an observational or valuative criterion that decides on the importance of one relationship over another in order to prioritise between two cardinal-identical Ramsey formalisations (Newman 1928, p. 147), that is, requires something beyond what's formalized.

Following similar paths, we can see that even the semantic approach does not fully hold. Russell/Maxwell faced similar problems as Popper's truthlikeness even though the latter endorses the Tarskian logico-semantic approach. For while it is true that Popper's work consists in realizing that "the contents of the theories play an important role" (Popper 1963, p. 232), Popper defines the scientific relevance of this content in terms of its improbability (p. 229), that is, in terms of its unexpected resistance to being falsified. But as pointed out by both Miller and Tichý (1974), Popper's equation to contrast the relevance of two promising theories falls into a problem, for it is possible to add absurd, invented or false sub-theories, but highly improbable, for the theory to gain in verisimilitude. So, although Popper is far from treating observations exclusively in terms of its cardinality, as for Popper the content is expressed by the natural language that then is formalized into a meta-language, there should be a prescientific criterion applied to the natural language regarding the appropriateness or not of the added sub-theory. Thus, these logical formulations (both Russell's and Popper's) always require extra-logical knowledge about which theory we are talking about, so, for the moment, these approaches fail to offer solutions for problems raised by the form/content distinction[5].

In a distinct way, Worrall (1989), another of the precursors of structural realism, insists on the mathematical capacity as an argument for structural realism, attributing this idea to H Poincaré. He considers that structural realism is the only perspective that can handle precisely two arguments related to scientific progress: gives an explanation for the non-miracles argument, according to which science predicts too well for all predictions be one miracle after another (Putnam 1975, p. 73); and avoids the pessimistic meta-induction argument, according to which, after seeing that scientific theories are rejecting the previously postulated entities (ether, caloric, atomic model, etc.), we should induce that our present scientific entities will be rejected in the future (Laudan 1981). For Worrall it is obvious: neither empiricism, nor Quineans, nor classical realist, face both arguments completely, but overcoming them is as simple as accepting that what survives from one theory

[4]Worrall and Zahar (2001) and Melia and Saatsi (2006) consider that it is possible to rehabilitate the ramseyfication.

[5]This and other problems of truthlikeness are trying to be overcome; see i.e., Niiniluoto (2003) and Oddie (2013).

to another is the mathematical representation of nature's structure. With structural realism we can see, for example, the theoretical continuity between Fresnel elastic ether to Maxwell's electromagnetic field (Worrall 1989, p. 108), as these representations can be expanded and nuanced but are not abandoned even in scientific revolutions. So, following Worrall we could say that, contrary to the opinion of Lakatos (1970), it is not that scientific practice tends to protect the mathematical hard core of theories by ascribing the inadequacies to the peripheral particularities of the theory, but that this core does persist by its own.

However, Worrall, and we could include here Maxwell and also Votsis (2004, 2010), limit themselves to pointing out retrospectively the continuities between the mathematical relations of theories that has been successful in predicting, and after that, they make an act of faith regarding the accuracy of the whole theory. This means, in the first place, that the content of the theory is ignored; in fact in the case that the theory postulates the existence of certain entities, these would be accepted for practical purposes, just as it happened with Quine. And secondly, it is suggested that what is retained as true is the structure that survives theory change, but it is not clear whether the whole structure is retained or only the successful part of it. In any case, what they see, for example, is that "the equations derived from Maxwell's equations using continuity principles in the dielectric interface are *formally identical* [emphasis added] to those derived by Fresnel from his mechanical principles" (French and Saatsi 2006, p. 555). But the problem with such emphasis on the continuity of *the representation* leaves open the possibility of considering that there are other real components underlying nature that are inaccessible or inexpressible of which we only know or can know their structure; that is, these positions in the scope of formal structural realism end up in an ESR (Ladyman 1998, 2018).

That is the interpretation behind the claims that structural realism seems deemed to support a distinction between structure and nature (Psillos 1995), and that, therefore, science cannot go beyond formal knowledge. So, in order to account for the two scientific phenomena that Worrall reminds us of and to combat the vagueness of *noumenical* considerations of nature, or of scepticism, mysticism or constructivism, the only alternative seems to be to engage radically with the reality of structures. For this, the transcendence of mathematical knowledge and the structural reality they are describing must be established. To do this, one can begin, for example, by taking a step further in understanding the insights of contemporary physics and see that the history of scientific improvements, beyond the example of Worrall's Fresnel-Maxwell, shows the structural continuity from one theory to another independently of any evolution in the entities postulated by them (Ladyman 1998, p. 415)[6]. In doing so, structural realism will be committed to the existence of a structural nature (OSR), and therefore will go a step further than simply considering that a logic-semantic approach can be used scientifically

[6]"For example, it is widely held that the equation (known as Ehrenfest's theorem) **F**(k**r**l) = md2k**r**l/dt2 exhibits continuity between classical and quantum mechanics; it certainly has a similar form to the equation **F** = m**a**. But the quantum equation has as its arguments the expectation values of Hermitian operators, whereas the classical equation features continuous real variables" (Ladyman 1998, p. 415).

to address physics in terms of structure as Ladyman (1998, 2007) and French and Ladyman (1999) continue to argue[7]. J Ladyman's project in *Every Thing Must Go* (2007), which he carries out together with D Ross, defends this position. They claim that neither objects nor intrinsic properties are ontologically fundamental. Even relationships do not presuppose related objects ("*relata*"), as Psillos (2001) criticised. As Ladyman argue, following Dennett's *Real patterns* (1991), objects are reified structures, that is, objects are patterns that are perceived on a relative scale for reasons of usefulness[8], but in a closer look: "'it's relations all the way down"[9]. The structure is the ground; or the non-ground, the *Abgrund*. So, let us focus now on how Ladyman bases OSR.

J. Ladyman and the commitment with the reality of the structures

Let us present some key points of the conception that Ladyman exposes in *Every Thing Must Go*, understanding that with them he establishes an alternative justification for the structural realism with which he seeks to overcome the errors of his predecessors.

Ladyman titles his project in *Every Thing Must Go* of "Naturalized Metaphysics". Under it, he offers a series of considerations/principles that systematically justify each other and whose evidence evokes the realisation that "Structure is all there is" (2007 p. 130). We summarize these principles into three: 1) The consideration that the results of physics, specially quantum physics and relativity theory, are those that contribute more to the understanding of any other branch of science and thought, ("Primacy of Physics Constraint" or "PPC") (Ladyman 2007, §1.4); 2) The interdependence of contributions of scientific fields, albeit asymmetric towards physics ("Principle of Naturalistic Closure" or "PNC") (§4.5); and 3) The continuous hypothesis, according to which all phenomena belong to the same cosmos (§1.5, §4.1). Assuming the consequences of one of these principles the others get justified, and OSR results to be the only coherent scientific approximation according to the latest contributions of physics and the applicability of the structural perspective to the rest of sciences. So to speak the statement of OSR becomes the fourth principle of his naturalized metaphysics and its resultant thesis excludes the existence of objects, causal relationships between objects[10], natural kinds[11] and intrinsic properties[12], which are just patterns generated, in our case, at an anthropomorphic scale.

[7]See note [3]

[8]This is a key point in Ladyman's conception. In Dennett's *Real patterns* (1991), patterns are projections that maximize information relative to the perceiver's ontological scale. Thus, they are projections, which means that could be otherwise if the needs or scale are different, but its effectiveness is real. In terms of philosophy of mind, Ladyman is subscribing a sort of instrumentalism; he does not endorse supervenience and his reductionism it wouldn't be a physicalism understood in classical terms. To all that, there is a strong Darwinism in this approach.

[9]Words by quantum physics theorist Saunders (2003). E Schrödinger, A Eddington, M Planck and H Weyl are other physicians referred by Ladyman.

[10]§5.1

We observe, then, that for Ladyman these principles necessarily exclude scepticism as a philosophical position, since these principles allow him to speak of the "truth" of certain theories or statements; this is so for at least two reasons: one is given by the consequences of the principles and another is given by the revisionist character of the principles; and both point to his pragmatist and "verificationist" conception. In the first place, Ladyman excludes scepticism because the applications or *practical consequences* of his principles offer fruitful explanatory and predictive rules about nature, the object in question; these applications, on the one hand, legitimize the truth of the other principles (remember: 1) physics as a more explanatory science, 2) contribution of all sciences, 3) continuism, and 4) OSR) and on the other hand, they solve doubts of the scientific practice at the same time that they generate new problems and the need of deeper investigations[13]. With that, see Ladyman's parallelism with Peirce's pragmaticism maxim: "Consider what effects, that might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of these effects is the whole of our conception of the object" (Peirce 1878b, p. 31). In short, for Ladyman there is truth knowledge, which in terms of metaphysical knowledge would be reflected in the knowledge of the principles. In fact, throughout the book, he refers to the "truth" of the theories and, consciously, not to the "approximate truth" of the theories, since he relates the latter to an objectifying worldview (Ladyman 2007, p. 84). For Ladyman there are no objects, but there are true structural formulations. However, we must stop for a moment at this explanation, since this use of the term "truth" should not confuse us: in Ladyman there is implicit a conception similar to that of Kant, Peirce and Popper about truth as an ideal limit and *ultimate end of the inquiry*[14]. Nevertheless, as I will also point out later, the ideal limit we attribute to Ladyman is not so much that of "truth" as that of the "unity" of the theories, which is strongly linked to the third of his principles. All in all, Ladyman would accept that knowledge is not total, but this does not make him a sceptic, since although true knowledge is not

[11]§5.6.

[12]Intrinsic properties presuppose the object that held such properties. So, what makes two logically identical individuals two and not one (Leibniz's Principle of Identity of the Indiscernible)? One candidate is its space-time location, but for different reasons in both quantum physics and general relativity theory, space-time does not exist independently of its components, and there's not emptiness in space-time. The other candidate is that there exists a principle of individuality transcendent to any intrinsic or extrinsic quality, a *haecceities*, according to Duns Scotus. Ladyman may consider this option due to one ambiguous case: bosons. Due to quantum entanglement a fermion and its antiparticle have a complementary electric charge relationship, they are complementary but asymmetrical (by this charge) so that makes them "*a posteriori*" discernible (weak PII), but this is not even the case with the bosons, whose antiparticle turns out to be absolutely identical as they do not have charge. It seems that there is no way to formalise the identity of a boson by reducing everything to structure. See §3.1, 3.2.

[13]"As it appeases the irritation of doubt, which is the motive for thinking, thought relaxes, and comes to rest for a moment when belief is reached. But, since belief is a rule for action, the application of which involves further doubt and further thought, at the same time that it is a stopping-place, it is also a new starting-place for thought" (Peirce 1878b, p. 28).

[14]"The opinion which is fated to be ultimately agreed to by all who investigate, is what we mean by the truth" (Peirce *CP 5.407*).

total, knowledge can still be justified, rational and predictive knowledge, that is, that knowledge could be not false and with the form of an *educated guess*.

The second reason why Ladyman can move away from scepticism help us to show one of the reasons why we prefer to treat his position as speculative and not as metaphysical or "naturalized metaphysical". We have already mentioned several times that for Ladyman, the principles are not justified because they are clearly and distinctly evident, but because they are coherent with the practical consequences of each other. Under this idea, we rely on what Meillassoux (2010) expresses against "dogmatic metaphysics", namely, that "to reject dogmatic metaphysics means to reject *all* real necessity, and *a fortiori* to reject the principle of sufficient reason" (Meillassoux 2010, p. 33). Thus, for Ladyman (2007), metaphysics and scepticism are comparable, since both start from the a priori assumptions of an entity that is the principle of reason of the other entities: in metaphysics this entity is considered known and in scepticism this entity is always unknown. But for Ladyman there is no such a priori; naturalized metaphysical knowledge is constituted as knowledge precisely through its practical consequences, because of its a posteriori. However, it can be argued that Ladyman seems to be conferring an a priori reality to an entity, namely, the homogeneous world, which would move away from Meillassoux's conception, who privileges the knowledge of the necessary contingency of it (Meillassoux 2010). But as far as we are concerned, Ladyman's world can also be seen as an asymptotic ideal or a transcendental illusion, just as Kant marked in his antinomies of pure reason. But we should not let pass that the homogeneity of Ladyman's world, in front of its possible discontinuity, can be considered one of the most debatable postulates of his theory. But be that as it may, he does not stop *pretending* to be coherent with his pragmatic and revisionist conception, that is, among other things, he does not stop pretending to be coherent with the insights of present physical theories.

Let us now turn to another feature of Ladyman's theory that is relevant to the OSR: according to the principles, scientific theories should be modal and not only real (Ladyman 2007, p. 123-). This is affirmed in contrast to van Fraassen's empirical constructivism and his criticism of structural realism, the thesis of empirical constructivism being the idea that we should only commit ourselves to what is empirically verifiable (van Fraassen 1980, p. 60); as can be seen, once again raising the problem of the scientifically observable/non-observable. For Ladyman, the modal does not refer to a metaphysics of possible worlds like that of D Lewis or S Kripke, but the modal must be understood as the possible, and the possible as the accessible. For Ladyman the human being is linked to a relative scale and to a technology and measuring devices that limit his observations. However, we can also have other ontological limits of access, as the Minkowski cone of light points out, for example, beyond which we cannot have access even in a possible sense. The limits of the possible are then a question of information connectivity (p. 278-), and the limits of research are marked by this. Therefore, realism is no longer linked only to what is observable precisely in other pragmatic terms[15].

[15]We repeat a quote from Peirce, to emphasize the aspect of Ladyman that we have just commented: "Consider what effects, *that might conceivably* [emphasis added] have practical

Finally, to finish with this general exhibition of Ladyman's project we want to mention one last aspect that ends in an open question. We have seen that Ladyman argues for the substantiation of the structure: structure now has formal properties and is at the same time its content. However, given that this structure is represented in theories in a mathematical way, it all seems that we should consider mathematical entities as real, in a Platonic or Pythagorean sense and as authors such as A Badiou and M Tegmark maintain or as Lewis exposed (1993). In an interview for *Collapse,* Ladyman answers to this question reflecting his principles: "Our metaphysics is directly motivated by the actual content of physics, and our review of the latter significantly undermines the distinction between mathematical and physical-nomological structure" (Ladyman [Collapse vol. V] 2009, p.166).

Scientific Practice according Ladyman: *Verificationism*

Anti-sceptical optimism, revisionist methodology and the modal aspect of the OSR are three other characteristic notes with which to attempt, along with the three principles, to extract a conception of scientific progress in line with structural realism. But before formulating a definition of this progress, we lack a last clarification regarding what Ladyman understands by scientific practice.

In *Every Thing Must Go* Ladyman states that the three principles are embodied by the scientific institutions, so that they show an epistemic superiority compared to other kind of knowledge mainly due to its process of revisability and iteration of critical filters (Ladyman 2007, p. 29); this is what Ladyman calls "verificationism" (which is the only one of his ideas that he attributes to Peirce (Ladyman 2007, p. 29). In light of this, we would like to make a remark here. Ladyman believes that scientific institutions already act consistently with the principles. But we refrain from believing that such a claim of scientific "*bona fide*" is justified. In fact, in an interview for *Collapse* (2009), Ladyman is asked about this point due to the fact that, paradoxically, Ladyman, is in clear favour of the quantum gravity theory, and he even suggest approximation to the Everett's interpretations against the Copenhagen one, and held the importance of developing Bohmian mechanics against classical quantum mechanics, all in all, Ladyman shares approximations which are strongly disregarded in scientific institutions in comparison, for example, to string theory or M-theory: His answer on why then to think that institutionalized scientific practice endorses the principles is elusive. So, we are inclined to say that institutional scientific practices do not necessary endorse this *bona fide* nor necessarily embody the three principles, so we would like to substitute Ladyman's *is* for a *should*. This will also serve to mark the normative and non-descriptive character of the definition of scientific progress.

Regardless of this point, what is important to note about Ladyman's verificationism is that he argues that scientific practice takes (or should take) a pragmatic attitude, that is, scientific institutions *should* only work with theories that fall under the modal scope (and see that we can say "modal" or structural/

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bearings, we conceive the object of our conception to have. Then, our conception of these effects is the whole of our conception of the object" (Peirce 1878b, p. 31).

mathematical/informational). That is, the criterion is neither empirical nor metaphysical, but speculative, or parallel to Peirce, neither inductive nor deductive, but abductive (Peirce 1878a). This *form* of speculation and abduction is the only conception that offers hypothesis with consequences, empirically treatable or not, that can appear anywhere in the scientific spectrum, in any scientific field, therefore, following principles 1), 2) and 3).

But be that as it may, with his perspective on scientific practice, Ladyman seems to reflect a very intriguing aspect of the history of the philosophy of science. It seems that it is no longer a question of justifying the truth or the adequacy of science on the basis of formal corroboration, nor is it enough to relativize it according to sociological characteristics (as Kuhn makes us reflect upon), but it seems that Ladyman supports basing the correctness of science on the virtues and good faith of scientists, namely, basing the rigor of science on honesty, open-mindedness, transparency, etc. In short, what Sosa (1980, 2007) calls "virtue epistemology" and which returns to Socrates. We find this thesis very interesting, but we will keep the discussion in parentheses and, on the contrary, argue that basing correction on virtuosity does not imply defending the idea that the subject contains some inherent values that make it a sort of guarantor of epistemological correction. On the contrary, we will read this *bona fide* practice, which we still think is a very important leg for scientific progress, as a necessary consequence of pragmatism and speculation. Thus, we understand that these values are not values in themselves, they are like empty forms, and they acquire meaning in the light of the conclusions of the three principles. That is, values like open-mindedness, sincerity, rigor and correction can be considered as translations of methodological conclusions such as research on what is possible or modal and not only on what is current or empirical or visible, importance of revisability, recognition of these revisions, place coherent and practical limits on our research, generate knowledge in the form of educated conjectures... in short, maxims that are not *a priori* but are promoted and justified by the principles and by the consequences of the principles.

Progress in OSR and the Principle of Continuity

We already have enough ingredients to infer a definition of scientific progress in line with the OSR.

At this point, it is worth quoting a claim that appears at the beginning of Ladyman's book anticipating many of his concepts that we already described and paving the path to a "*metaphysical* claim" such as "Structure is all there is":

> "Any new metaphysical claim that is to be taken seriously should be motivated by, and only by, the service it would perform, if true, in showing how two or more specific scientific hypotheses jointly explain more than the sum of what is explained by the two hypotheses taken separately, where a "scientific hypothesis" is understood as an hypothesis that is taken seriously by institutionally bona fide current science" (p. 30).

"Structure is all there is" can be successfully applied to two separate scientific theories or to two scientific fields and will show them a profound knowledge, namely its fundamental shared basis together with the *possibility* of explaining its mathematical or its nomological interdependence. Now, taking the contributions of our previous discussion, this last idea, which is not further developed by Ladyman, applied to the construction of scientific hypothesis gives us the cornerstone for the definition of scientific progress according to structural realism: *(Ontic) structural realism measures scientific progress according to the aim of epistemological continuity being equal to ontological holism.* Or what is the same, according to OSR, a theory would make scientific progress compared to another if it establishes an informational connection between patterns, where "patterns" can refer either to theories or phenomena. Note that as disconnection is for OSR not a justified idea, the only alternatives for science to progress is to either connect two patterns or to connect a pattern to a yet unknown and epistemologically unconnected pattern. Thus, aiming at unity is not the same as aiming at simplicity. All in all, one conclusion already anticipated in the previous section is that ontological holism, phrased primarily in the continuum principle, plays the homologue role of "truth" in the truthlikeness approach on scientific progress. However, ontological holism is not a principle formally based as truth for the truthlikeness approach, and neither it is considered as an a priori statement, but rather it is based on a speculative basis: ontological holism is the result of the interdependence of, on the one hand, a pragmatic rationality and, on the other, the successfulness of a modal approach according to empirically as well as mathematically verified structural analysis, as is represented in the insights of contemporary physics.

And leaving aside his continuist conception, we can go even deeper into what we mean by speculative. After all, what is special about our suggested formulation of scientific progress of OSR and what distinguish it from the other main accounts on progress matches perfectly with more reasons of why do we use the term "speculative":

a) As by speculative we also refer to daring to go beyond formalising just observational terms, and also to even holding the substantiality of theoretical ones (Opposed to truthlikeness)[16].
b) As by speculative we also refer to going beyond anthropomorphic and utilitarian problems. Progress is not just the variegated application of known laws to supposed different phenomena or objects, and even less to the generation of these. Knowing how to solve a problem, in some cases, may contribute nothing to the global understanding of reality. Thus, we can say that whereas progress entails more prediction, more predictions does not entail more progress. (Opposed to problem-solving and to accumulation of knowledge)[17].

[16]Paradigmatically held by Popper (1963) and Niiniluoto (1977), but also by van Fraassen (1980) and Saatsi (2019).
[17]The former is held by Kuhn (2012) and Laudan (1981), the latter by Barnes (1991) and Bird (2008).

Given this, and as during this brief essay we have already been dealing with the separation of Ladyman's position from the classic truthlikeness formulations, let's say one last thing in reference to β. As Ladyman explicitly states to follow non-utilitarian principles at the beginning of his book:

> "What we importantly wish to exclude that will not be obvious from anything said so far, however, are research projects that are primarily motivated by anthropocentric (for example, purely engineering driven) ambitions, as opposed to ambitions anchored around attempts to determine the objective structures in nature." (Ladyman 2007, p. 36)

Previously, we indicated that Ladyman's project cannot be understood completely, or at least without nuances, as a properly speculative project like the one that Meillassoux paradigmatically represents. Since, as we have mentioned, according to Meillassoux, Ladyman seems to consider in metaphysical terms the homogeneous world as the one and absolutely necessary entity. In the same vein, Ladyman's conception cannot be understood either as purely practical or consequentialist. It is, as in the difference with Meillassoux's notion of speculation, the thesis of the ideal continuum that rejects such anthropocentrism, as well as the attempt to abandon *correlationism*[18]. Such an ideal integrated by Ladyman's pragmatism, makes clear that pragmatism is a mechanism for resolving conflicts by understanding the truth and sense of a thesis by means of its practical consequences[19], but pragmatism does not prescribe what kind of ends should be pursued, and even less does it establish that these purposes must be utilitarian. In Ladyman, then, there is a pragmatism combined with some ideas that we consider speculative. In fact, our thesis is that we can extract a formulation of scientific progress according to the OSR, thanks to the combination of speculation and pragmatism of Ladyman's theory.

It seems opportune then to finish this essay commenting briefly on Ladyman's continuist conception, since, although it may seem coherent with the whole of his system, it does not cease to seem to us the fundamental point of his theory and a source of discussion. It is Meillassoux himself who takes from D Hume the scepticism regarding the absolute necessity of the temporal continuity of the physical laws, and with that, he launches a criticism against "the principle of the uniformity of nature"[20]. For Meillassoux the continuist hypothesis if it is not a

[18]"Correlationism" for Meillassoux includes all those philosophies that, establishing a relationship between subject and object, do not allow understanding one without the other. That is, this relationship, far from establishing conditions and motivations to knowledge, limits it. As far as we are concerned here, correlationism does not consider being able to know the world but just *the subject knowing it*. If this is one of the basic Kantian theses, Meillassoux calls it "correlationism" understanding that it is a whole philosophical conception present in authors such as M Heidegger, L Wittgenstein or M Merleau-Ponty. In fact, the book we are quoting, *After the finitude*, is an argument against this correlationist prison, showing that it is possible to know something about the external world independently of the subject.

[19]"Beliefs are distinguished by the different modes of action to which they give rise" (Peirce 1878b, p. 29).

[20]"But only the time that harbours the capacity to destroy every determinate reality, while obeying no determinate law – the time capable of destroying, without reason or law, both

metaphysical postulate is then based on an erroneous probabilistic analogy that insinuates that there is continuity and stability of the physical laws because induction shows us how infinitely improbable it is that the opposite occurs. In view of this, Meillassoux, taking up G Cantor's ideas, assures that this calculation is impossible to carry out unless a *complete* and absolute world is already presupposed as the denominator of the operation[21]. On a completely different line, the continuum hypothesis was also questioned by Plato. In *The Sophist*, an ontological discontinuity was argued in spatial terms with his famous epistemological principle of *symploké*: "if everything were linked to everything we could know nothing" (Platon 1992, 259e). "For if in order to know something, there was always the need to know something prior, and, even earlier, something previous, and thus *ad infinitum*, then we could not know anything" (Sierra 2000, [54: symploké])[22], which far from being understood as a principle of fallibilism, as we will mention that it is for Peirce, can be understood as the reason why there are different sciences dedicated to different supervenient phenomena.

Then, grant us to think that Ladyman's position may not be totally speculative in Meillassoux's terms, for although he shares many traits with him, we consider that a deeper discussion is pertinent about whether the considered Ladyman's ontological holism or continuist principle adheres to the speculative gesture or whether it introduces a metaphysical element. In any case, this does not take away from the fact that Ladyman's approach and the OSR's definition of scientific progress can be considered speculative in accordance with the characteristics we have been explaining. And the same is true of pragmatism. As we have mentioned, the aspiration to the continuist hypothesis as an ideal of progress is a challenge to utilitarianism or practicality, but not to pragmatism. And it is precisely in Peirce, a pragmatist *par excellence*, that we find support for the hypothesis of the continuity of the world (including the continuity between matter and mind) in what he called *synechism*: "Synechism is that tendency of philosophical thought which insists upon the idea of continuity as of prime importance in philosophy and, in particular, upon the necessity of hypotheses involving true continuity" (Peirce 1902, p. 354).

We cannot go into detail in Peirce's argument about synechism, but in general terms, Peirce considers that past ideas reappear or influence present ideas as long as they are not completely past. Ideas are infinitesimally linked (Peirce 1892, p.

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worlds and things – can be thought as an absolute. Only unreason can be thought as eternal, because only unreason can be thought as at once anhypothetical *and* absolute. Accordingly, we can say that it is possible to *demonstrate the absolute necessity of everything's non-necessity*. In other words, it is possible to establish, through indirect demonstration, the absolute necessity of the contingency of everything" (Meillassoux 2010, p. 62).

[21]"Thus, probabilistic reasoning is conceivable on condition that it be possible to conceive a totality of cases within which one can then calculate frequencies by determining the ratio of the number of favourable cases to the number of possible cases. If you revoke the notion of a set of cases and the idea of a total-universe from whence the events submitted to analysis are drawn, then aleatory reasoning becomes meaningless" (p. 102).

[22]Our translation.

341)[23], in turn, ideas reflect sensations (p. 344). And sensations are chains of stimuli reflecting parts of the infinitesimal infinitude of space[24]. We see then that in synechism the element of infinitesimal is present, as in Plato, but this time with a conclusion totally opposite to the one of Plato and that has repercussions on the model of scientific inquiry. In Peirce it is that ideal and absolute limit which, as we saw also in Ladyman, far from inducing to the relative scepticism or discontinuism in a Platonic way, it is an optimism that takes the form of fallibilism, of a well-constructed science that is always to be improved a bit more as far as it is structures all way down. Continuity, then, says Peirce, requires supporting, for example, the truth of the asymptotic value of number π, "the principle of continuity is the idea of fallibilism objectified (Peirce 1902, p. 356).

Be that as it may, we insist that the discussions on the coherence of the principle of continuity, or its justification or not in the light of the contributions of physics goes beyond the present essay. But we do want to point out that in its origin, such a thesis never supposed a metaphysical thesis, as clearly presented by Peirce himself: "Synechism is not an ultimate and absolute metaphysical doctrine; it is a regulative principle of logic, prescribing what sort of hypothesis is fit to be entertained and examined" (Peirce 1902, p. 355). If we trust Peirce, and Ladyman, we should say that if the continuist thesis is maintained or not, it is not because it is given over by metaphysics. On the contrary, to hold or not to hold the principle of continuity wrongly must be the fault of the "*bona fide*" of the current scientific practice. By correctly applying speculative and pragmatic conclusions we would get rid of these doubts, which for Ladyman is clear in favour of this principle and consequently of the truth of the OSR. However, if the latter were contradicted, the pragmatic and speculative principles will have led us to take another step towards progress.

Conclusions

The present text has attempted to provide a hypothetical formulation of scientific progress in line with structural realism. The first task in developing this formulation has been to offer a tangential review of the literature on structural realism in order to show that its problems are closely linked to the debate on scientific progress. We find its connection in a similar concern for how to account for the existence of theoretical entities, a problem thus made explicit in the philosophy mainly by the analytic philosophers of its context. Then, we have seen that structural realism could not be defended trough syntactic formulation and was also insufficient if it sustained semantic formulations that were accompanied by

[23]"This infinitesimally spread-out consciousness is a direct feeling of its contents as spread out" (Peirce 1892, p. 341).

[24]"Since space is continuous, it follows that there must be an immediate community of feeling between parts of mind infinitesimally near together" (Peirce 1892, p. 355). Outer space that is nothing but habituated ideas. "the reaction between mind and matter would be of no essentially different kind from the action between parts of mind that are in continuous union, and would thus come directly under the great law of mental association" (Peirce 1902, p. 353).

scepticism or *noumenism*, that is, what is called epistemological structural realism (ESR), according to which science knows structures, but there can always be something beyond those structures.

Thus we arrived at the work of J Ladyman in *Every Thing Must Go*, In there he offers a defence of ontic structural realism (OSR), which claims that structures are not only what we can know of reality but that *structures are reality.* Which such a claim it is possible to respond to the epistemological problems of the philosophy of science regarding the justification of theoretical entities and tries to overcome the inconsistencies of his structural realist predecessors. Its conception for arguing for OSR is pragmatist because it legitimizes knowledge in accordance with the practical consequences of other knowledge and clears up any hypothesis whose consequences are not conceivable. Furthermore, Ladyman is akin to the *speculative* elements with which we have defined progress: rational justification but not a priori, confidence in access to truths about the world, consideration of limits but not anthropocentric ones. In this way, his work is the basis of our proposal to define scientific progress in accordance with structural realism and which reads as follows: *(Ontic) structural realism measures scientific progress according to the aim of epistemological continuity being equal to ontological holism*. We have called this definition "speculative" influenced by the terminology of Q Meillassoux, since we maintain that both the content and the reason for its formulation respond to speculative criteria, and it is these same criteria that make it special with respect to other definitions of scientific progress that are formulated under the approaches of truthlikeness, problem-solving or accumulation of knowledge.

Along with this, we have found that Ladyman's work shows ideas already exposed by CS Peirce. With this we want to incite a reflection on the relevance of Peirce in contemporary pragmatist and speculative positions. Finally, we can draw two final conclusions: on the one hand, that the continuist hypothesis is still an incipient theme in the philosophy of science and, specifically, with Ladyman could be introduced in the debate on scientific progress. And finally, and perhaps above all, we think that through Peirce, Ladyman and Meillassoux we can describe scientific progress without taking into account utilitarian and anthropocentric considerations, but at the same time, without falling into metaphysical statements or logical formalisms. We believe that more discussion about this definition of progress is convenient to clarify how we catalogue progress in our epoch. Finally, the OSR's maxim of progress encourages inquiry along the lines of Poincaré in his fascination with the cosmos *per se*: "Would it be proper to ask what is the good of accumulating so much wealth and whether, to get time to acquire it, we are to neglect art and science, which alone give us souls capable of enjoying it" (Poincaré 1905, p. 93).

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