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Impacts of Air Pollution on Richness and Abundance of Bird Species in Phnom Penh Urban Habitats

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CHIM Samhaiy[1*], CHHIN Sophea[2] and YIM Raksmey[2]

[1]Hun Sen Kampong Chork High School, Chork village, Kampong Chork Commune, Romdul district, Svay Rieng Province.
[2]Minisrtry of Environment, Morodok Techcho (Lot 503), Tonle Bassac, Chamkarmorn, Phnom Penh 120101, Cambodia.

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*Corresponding author: Hun Sen Kampong Chork High School, Chork village, Kampong Chork Commune, Romdul district, Svay Rieng Province.
E-mail addresses: samhaiychim@gmail.com (CHIM SAMHAIY)
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សង្ខិត្តន័យ

រហូតមកដល់បច្ចុប្បន្ននេះ ប្រទេសកម្ពុជាមិនទាន់មានការសិក្សាអំពីឥទ្ធិពលនៃការបំពុលខ្យល់លើការរស់នៅ របស់សត្វបក្សីនៅឡើយទេ។ ការសិក្សានេះមានគោលបំណង៖ (1) វាយតម្លៃពីចំនួនប្រភេទនិងចំនួនឯកត្តៈបក្សី, (2) ពន្យល់ពីស្ថានភាពគុណភាពខ្យល់, និង (3) ប្រភពនៃការបំពុលខ្យល់ តាមរយៈការអង្កេតទំនាក់ទំនងរវាងអថេរនៃគុណភាពខ្យល់ (PM2.5, SO_2, NO_2, O_3)លើបម្រែបម្រួលចំនួនប្រភេទនិងចំនួនឯកត្តៈរបស់សត្វស្លាប់នៅជម្រកពីរផ្សេងគ្នានៅទីក្រុងភ្នំពេញ។ ការប្រមូលទិន្នន័យបានប្រព្រឹត្តទៅចាប់ពីថ្ងៃទី21 ខែកុម្ភៈ ដល់ថ្ងៃទី21 ខែឧសភា ឆ្នាំ2022 នៅទីតាំងសិក្សាចំនួនពីរគឺ៖ (1) សាកលវិទ្យាល័យភូមិន្ទភ្នំពេញ និង (2) សាកលវិទ្យាល័យភូមិន្ទកសិកម្ម។ សាកលវិទ្យាល័យទាំងពីរស្ថិតនៅរាជធានីភ្នំពេញ ហើយក្នុងបរិវេណនោះមានតំបន់បៃតងដែលសមប្រកបនឹងការរស់នៅរបស់សត្វស្លាប។ យើងបានប្រើប្រាស់វិធីសាស្ត្រការរាប់តាមចំណុច (Point count) សម្រាប់អង្កេត និងកត់ត្រាចំនួនប្រភេទ និងឯកត្តៈសត្វស្លាបក្នុងតំបន់ទាំងពីរ។ ជាលទ្ធផលយើងកត់ត្រាសត្វស្លាបបានចំនួន18334 ឯកត្តៈ ស្មើនឹង 50 ប្រភេទ, 40 ពួក, 25 អំបូរ, និង 9 លំដាប់។ នៅសាកលវិទ្យាល័យភូមិន្ទភ្នំពេញ យើងកត់ត្រាសត្វស្លាបបានចំនួន 11190 ឯកត្តៈ ស្មើនឹង34 ប្រភេទ, 29 ពួក, 21 អំបូរ, និង 7 លំដាប់។ នៅសកលវិទ្យាល័យភូមិន្ទកសិកម្ម យើងកត់ត្រាសត្វស្លាបបានចំនួន 7144 កឯកត្តៈ ស្មើនឹង 46 ប្រភេទ, 38 ពួក, 25 អំបូរ, និង 9 លំដាប់។ តាមការអង្កេតសកម្មភាព មនុស្សអាចជា ប្រភពនៃការបំពុលខ្យល់ ក្នុងនោះ មានប្រភពមកពីការដឹកជញ្ជូន ការអភិវឌ្ឍទីក្រុង ប្រភពពីស្ថានីយ៍ ការដុតដោយចំហរ។ល។ តាមការសិក្សាប៉ារ៉ាមែត្រនៃគុណភាពខ្យល់ នៅទីតាំងស្ថានីយ៍ទាំងពីរនៅមានកម្រិតទាបជាងស្តង់ដាការបំពុលខ្យល់ដែលបានកំណត់ដោយរាជរដ្ឋាភិបាលកម្ពុជា។ ក្នុងចំណោមអថេរនៃគុណភាព

ខ្យល់ មានតែ SO_2 និង O_3 ប៉ុណ្ណោះដែលមានការប៉ះពាល់ទៅលើបក្សី ប៉ុន្តែក្នុងកម្រិតភាគរយតិចតួចនៅឡើយ។ កត្តាដែលធ្វើឱ្យជះឥទ្ធិពលដល់បក្សី ប្រហែលអាចមកពី៖ (1) តំបន់បៃតងដែលមានដើមឈើតូចធំ (2) ប្រភពអាហារ និង (3) ការរំខានដោយមនុស្ស។

Abstract

In Cambodia, there has been no study on the effects of air pollution on birds. Accordingly, the purpose of this study aims to assess the species richness and abundance of birds, to understand air quality status and possible sources of air pollution, as well as to investigate the relationship between the variables of air quality (PM2.5, SO2, NO2, and O3), and bird diversity in two different habitats in Phnom Penh. The study was conducted from February 21 to May 21, 2022, at two study sites: 1) the Royal University of Phnom Penh (RUPP) and 2) the Royal University of Agriculture (RUA). Both universities are located in Phnom Penh. The two areas are structured by vegetation which suitable for birds. We used a point count method to observe and record the number and species of birds in both study areas. The study recorded 18,334 observation individuals (counting), arranged in 50 species, 40 genera, 25 families, and 9 orders. At the RUPP, we recorded 11,190 individuals (counting), arranged into 34 species, 29 genera, 21 families, and 7 orders. In the RUA, we recorded 7,144 observation individuals (counting), arranged into 46 species, 38 genera, 25 families, and 9 orders. An observation of human activities can be a source of air pollution, including transportation, stationary sources, urban development, open burning, etc. The air quality parameters at both study sites were still lower than the air pollution standards set by the Royal Government of Cambodia (RGoC). Among air quality variables, only SO2 and O3 affect birds, but to a lesser degree. Factors that affect birds may be due to green areas, including the number of small and large trees, food sources, and human disturbances.

1. Background

Birds are significant taxa of public interest and great environmental indicators (Tietze, 2019) because birds play a significant role in ecosystem services, including culture, art, philosophy, and economy (BirdLife International., 2004). As a result, birds provide benefits for people of all backgrounds, including biological pest control, pollinators, scavengers, seed dispersers, inspiring science, adding beauty quotient to the landscape (aesthetic value), engaging tourists, and sources of income (Kasambe., 2020; Whelan et al., 2008). Birds are a significant topic of public interest and great environmental indicators (Tietze, 2019).

Urbanization poses a significant threat to bird diversity through direct and indirect pathways (Xu et al., 2022). Urban expansion leads directly to severe habitat degradation and loss, depriving birds of essential resources (Xu et al., 2022). Additionally, pollution from various sources associated with urbanization, such as transportation and industry, disrupts abiotic factors like air and water quality, ultimately altering organism interactions and harming bird populations (Köhler & Triebskorn, 2013). Air pollution is particularly concerning, a global issue with detrimental effects on health and the environment, including respiratory diseases (D'Amato et al., 2010). Sources of air pollution include fuel burning for transportation, industry, and power plants, as well as open burning for waste disposal, agricultural purposes, and forest fires (WHO, 2021). In Cambodia, transportation, industry, and open burning are the primary culprits, emitting harmful pollutants like PM2.5, SO_2, NOx, and greenhouse gases (MoE., 2021). Therefore, addressing these various impacts of urbanization is critical for protecting and preserving bird diversity.

Air pollution casts a long shadow, impacting both human health and the environment. From terrestrial and aquatic ecosystems (Derwent & Hjellbrekke, 2019; Lovett et al., 2009) to the lungs of humans and the feathers of birds, its reach is undeniable. Air pollution alters the very composition of bird communities, shaping the types of birds found in urban landscapes (Toms, 2017).

Avian ecological indicators are very important for designing urban planning (Sanesi et al., 2009), while bird diversity is important for the assessment of air pollution in urban. The study of Bhowmick., in 2021 investigated a strong, significant correlation between increasing air pollution levels and decreasing bird diversity. Several documents focused on the impact of air pollution on bird diversity in forests as well as in urban habitats. Yet, there is no study to document the related air pollution impact on birds in Cambodia while the developing activities are dramatically increasing. Moreover, while the urban areas are expanding, the air pollution sources in Cambodia, such as transportation, factories-industries, construction, open burning, is also increasing. At the same time, the study of the effects of air quality concerning birds is very important in the management of public health and bird conservation.

This study aims to understand the correlation between the air quality and the species richness and abundance of birds within different urban habitats of Phnom Penh City, with the specific objectives including i) to assess the species richness and abundance of birds in different urban habitats in Phnom Penh, ii) to understand air quality status and possible sources of air pollution in two different urban habitats in Phnom Penh, and iii) to investigate the relationship between air pollution and species richness and abundance of birds in different urban habitats in Phnom Penh.

1.1. Diversity of Birds in Urban Habitats

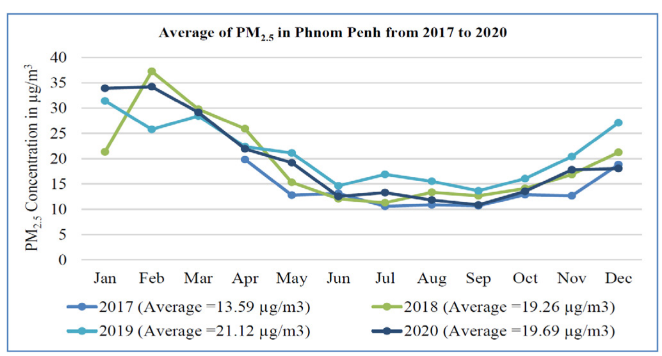
Birds recognize their environment by signals in the structure of the vegetation or general habitat. The decrease in bird species is perhaps due to human action, vehicle movement, landscape change due to offices, neighborhood blocks, residential buildings, continuous movement of vehicles, and so on (Chowdhury et al., 2014). Urban areas frequently create novel ecosystems that are characterized by fragmented regions with more disturbance than natural habitat and a significantly altered distribution of resources, but they can also present new opportunities. Birds return to ecosystems by avoiding cities or by adapting to and even making use of the urban environment. It is known that the city's topography and tree diversity influence the variety of birds that live there (Claro et al., 2020). Absolutely, urban has a negative impact as the disturbance and noise or light pollution cause the number of bird species to decline. However, some bird species could adapt to survive both physiologically (changes in stress hormones) and behaviorally (e.g., changes in foraging behavior, extending the breeding season) (Shochat et al., 2015). However, there are also some benefits. Urban always function as heat islands. Due to this provide warmer habitats even in winter, a rich source of food, and often safety from predators that are cautioned by human or domestic pets, and from parasites. Some bird species tend to live in urban through better-preserved themes (Filloy et al., 2019). Bird species such as *Passer domesticus*, and *Columba livia* domestica were positively related to human population density. These species can adapt well to the urban environment and have a close relationship with humans. Therefore, sometimes they benefit from human activities (Jokimäki & Suhonen, 1998).

In Cambodia, economic development is surely leading to an increase such the air pollutants level. The various sources, such as vehicles, motorbikes, factories, generators, open burning, etc., are contributors to increasing the concentration level of PM2.5, SO_X, NO_X, CO, CO_2, O_3, TSP and other substances. From the various parameters, in general, there is no noticeable variation in concentration of monitoring parameters except PM2.5. The annual mean concentration of PM2.5 in Phnom Penh kept increasing. In fact, in 2017, PM2.5 concentration was 13.59 and 19.26 μg/m^3 in 2018, and this concentration was reading 21.12 μg/m^3 which is above the WHO standard but still complying with the national standard (25 μg/m^3 annual average) (Fig. 1). PM2.5 is significantly higher in the dry season because of the relation to climate and the cycle of the season. In the dry season, it is observed that PM2.5 is generally high in the higher forest cover region (MoE, 2021).

Generally, the largest sources of air pollutants in Cambodia are the transport (Masami et al., 2005, 2009; Porsry et al., 2016) industry, residential and waste sectors, and electricity generation, industrial process emissions and charcoal making also contribute to the pollution for some specific pollutants, e.g., PM2.5, SO2, NOx, and greenhouse gases like CO2 (MoE, 2021). According to Hang, 2020 the source of air pollution from cooking and lighting, primarily using solid fuels for cooking, was shared about 95% in rural areas, 50% in urban, and 88% as the total national emission. The study by Furuuchi et al., (2005) illustrated that in Phnom Penh, the level of aromatic air pollutant, Polycyclic aromatic hydrocarbon is six times higher than in Bangkok and 40 times higher than in Kanazawa, Japan, and the sources of this pollutant are come from the combustion of diesel, and other generators for emergency electric supply, kerosene for light and biomass fuel for cooking, etc.

1.2. Effect of Air Pollution on Birds

Air pollution impacts the change of wildlife species, which leads to a decrease in the local animal population (Newman., 1979). Air pollutants affect bird diversity, such as illness, immunosuppression, increased detoxification effort, behavioral change, elevated stress levels, and impaired reproductive success that can reduce population, density, and species diversity in bird communities (Sanderfoot & Holloway., 2017). Furthermore, air pollution is affected bird direct mortality, disease, psychological stress, and bio accumulate (Newman., 1979). In contrast, the study of the effects of air quality on birds is important in the management of public



Source: Ministry of Environment (MoE), 2021

Fig. 1: Average of PM2.5 in Phnom Penh from 2017—2020

health and bird conservation. Therefore, the results of this research study reflect the amount of bird richness in micro-habitat in Phnom Penh, the Investigation of air quality and cause of air pollution, and the relationship between air pollution and birds in urban habitats, which allows us to identify the status air pollution level. Furthermore, this study would encourage maintaining green space in urban areas for, reducing air pollution as well as bird conservation. Birds can be used as indicators of good air quality.

1.3. Study Areas and Methodology

The study was conducted in Phnom Penh City at two different sites, estimated to be around 44 hectares (Fig. 2), located within the campus of the Royal University of Phnom Penh (RUPP) and Royal University of Agriculture (RUA). The RUPP and RUA are public universities with clear territories, and it is about 10 kilometers away from each other.

The RUPP is located at the coordination of (11°34'04.87''N, 104°53'30.49''E) estimated at around 21 hectares. The campus is around with a high human population, roads, and business buildings. The vegetation cover of RUPP is approximately 70% of the total area and is mostly covered by big-sized trees. Another one is at the RUA is located at the coordination of (11°30'43.57''N, 104°54'02.56''E) estimated at around 23 hectares. It is located in suburban areas with a less human population living around. About 40 percent of the surrounding is covered by mixed rice fields and houses, and the rest of part is present in roads, houses, small business buildings, and garment factories.

1.4. Birds Survey

The study was undertaken for 30 executive days from February 21 to May 21, 2022, by using the point count (Fig. 3) method to record bird species and abundance at both sites, six points from RUPP (Fig. 4) and five points from RUA (Fig. 5). To ensure the independence of points in each site, successive point counts were separated by at least 160 m. Point survey uses fixed search time of 15 to 18 minutes before moving to the next point, that a suitable time for searching birds and recording all birds. Overall, bird presence/absence at points is related directly to the habitat (Bibby & Burgess, 1992).

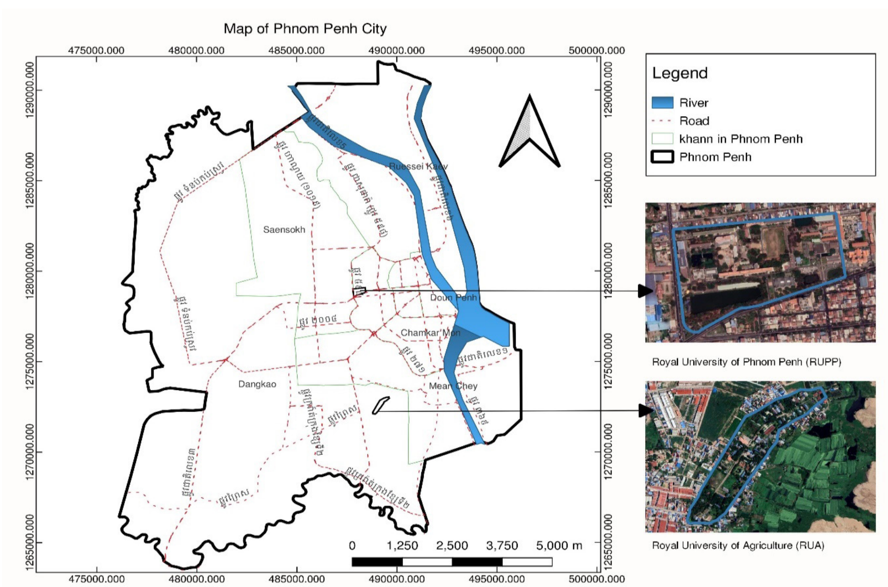
To aid the visualization, a pair of binoculars (Nikonmonarch 10x42) and bird identification were based on the "Birds of Southeast Asia" (Robson, 2005) and "The Birds of Cambodia An Annotated Checklist" (Goes & Furey, 2013).

1.5. Air Quality Sampling

The air quality data (PM2.5, SO_2, NO_2, O_3) were gathered from the station at the Institute of Technology of Cambodia (ITC), where it was placed at about 500 m from RUPP and it was used as air quality for RUPP and the station at Dang Kao, about 250 m from RUA was used for RUA.

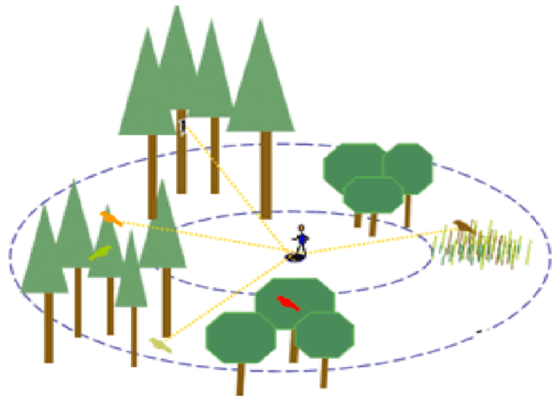
1.6. Data analysis was applied the following tools and procedure

Species richness (the number of taxa) is counting the number of bird species at each point of the site and adding new recorded species the following day.



Source: Authors' work

Fig. 2: Map of Phnom Penh Capital with study areas



Source: Bird Point Count Database (2011)

Fig. 3: Point count method in this research

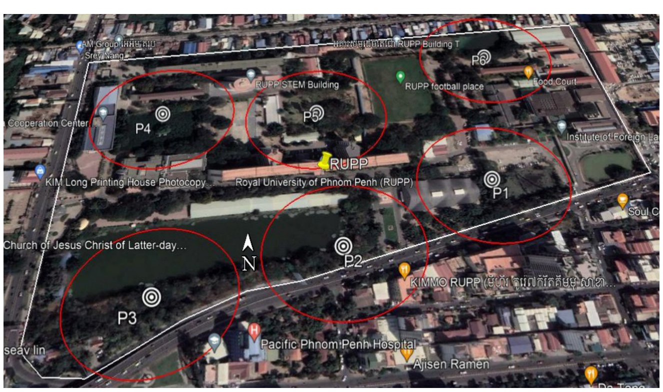
Abundances (number of individuals/species) are the number of individuals of each species at each point.

Diversity refers to Shannon winner's diversity index (H) is the value for each sampling of birds occupied in RUPP and RUA, and we use the vegan package of R (version 4.0.3 2020) for calculation with the formula below.

Shannon Diversity Index (H) = pi = (n = individual of given type/species, and N = total number of individuals in a community)

In order to select an appropriate statistical test for each data, the abundance, species richness, diversity index and air parameters were tested for normality using the Shapiro-Wilk normality test with the function Shapiro test. Data non-parameter test (Mann-Whitney test) was selected to test the statistical difference between bird (richness, abundance and diversity index) and air data between the RUA and RUPP by using R version 4.0.3 2020.

To determine the association between response data (bird data) and environmental data (air quality). We used a logistic regression model with a logit link function to determine the association between air quality and abundance and richness of bird location with the "Stats"



Source: Authors' picture

Fig. 4: Map of the RUPP with point count in this research

Source: Authors' picture

Fig. 5: Map of the RUA with point counts in research

package in R version 4.0.3 2020. First, we standardized the continuous variables by choosing each from its mean and dividing by twice its standard deviation: (x variable - mean of x)/2 (sd of x) (Gelman, 2008). Then, we test for multicollinearity between explanatory variables by creating a Pearson correlation matrix of all air quality variables and generating r values using the "GGally" package in R (Schloerke et al., 2018). We analyzed candidate models by running all possible combinations of explanatory variables, with the exclusion of highly correlated variables ($|r| > 0.5$) from the same regression model.

We selected fitness models by comparing each model's Akaike Information Criterion (AIC) value adjusted for a small sample size (Akaike, 1973): the difference between ΔAIC and AIC weight (AICwi) as the weight of evidence in favor of a model among all models being compared (Burnham & R.Anderson, 2002). We created a model selection table using the package "wiqid" version 0.2.2 (Meredith, 2019), and selected candidate models with cut-off criteria of $\Delta AIC < 2$ (Burnham & R.Anderson, 2002). If the difference in AIC values between the top models was less than 2, we averaged the models using the "AICmodavg" package in R (Mazerolle, 2019). We identified variables that strongly influenced air quality selection based on 95% confidence intervals.

2. Results and Discussion

2.1. Diversity of birds at the RUPP and the RUA

The avian survey conducted at the RUPP and the RUA yielded a total of 18,334 individual bird observations comprised of 50 distinct species belonging to 40 genera, 25 families, and nine taxonomic orders. Appendix 1 provides a detailed back down (Appendix 1). The most diverse order was Passeriformes, represented by 15 families. This initial analysis provides a snapshot of the avian community diversity present at the study sites (Fig. 6). This result seemed to be less number if compared to other studies done in the natural forest. The possible reasons should be there is a developed public place that was changing the environment, especially changing tree species. When trees specie was changed caused to loss of food resources and the original habitat, which led to the decline of native bird species (French et al., 2005). It was greater than studies in 10 urban parks in the Bangkok metropolitan area, Thailand in 2013, that prefer in bird presented a total of 50 bird species in a total area of 605.7 hectares (Chaiyarat et al., 2019). The study site was the green space area in Phnom Penh city. Urban green space (vegetation) was the most essential to increase the number of biodiversities, especially birds, which can reduce the loss of birds from urbanization and increase the concentration of higher bird density (Callaghan et al., 2018; Ciach & Fröhlich, 2017; Rodrigues et al., 2018).

From both study sites, we recognized *Passer montanus* (Eurasian Tree Sparrow) (4,507 observations), *C. livia* (Rock Dove) (2,237 observations), and *Pycnonotus* Olivier (Olive-winged Bulbul) (1,879 observations) as the dominant species (Appendix 1). These three species constituted a significant portion of the total observations, highlighting their prevalence within the study area. Several other species were observed but with lower frequency, including *Loriculus vernalis* (Vernal Hanging-parrot) (3 observations), *Ixobrychus cinnamomeus* (Cinnamon Bittern), *Pericrocotus cantonensis* (Canton Oriole), *Lonchura striata* (Striated Finch), and *Dicrurus leucophaeus* (White-bellied Drongo) (all with two observations each). At the opposite end of the spectrum, *Elanus caeruleus* (Black-shouldered Kite) and *Dendrocopos canicapilus* (Grey-capped Woodpecker) were the least recorded species, with only one observation each. This data provides valuable insights into the relative abundance of various bird species within the study area, aiding in the understanding of their ecological roles and potential conservation needs.

At the RUPP, the study had a total of 11,190 observations of 34 species, 29 genera, 21 families, and 7 orders (Fig. 7). *P. montanus* (3,512), *C. livia* (2,215) and *Pycnonontus goiavier* (1,007) was the dominant species in the study area. While, the following bird species were *P. aurigaster (3)*, *D. leucophaeus,* and *Oriolus chinensis (2).* Whereas, the least recorded bird species at RUPP were *D. canicapilus* and *Hypothimis azurea* (1) (Appendix 1).

For bird survey at the RUA, we collected and identified a total of 7,144 observations (count) arranged in 46 species, 38 genera, 25 families, and 9 orders (Fig. 8). *L. punctulate* (1,213), *P. montanus* (995), and *P.*

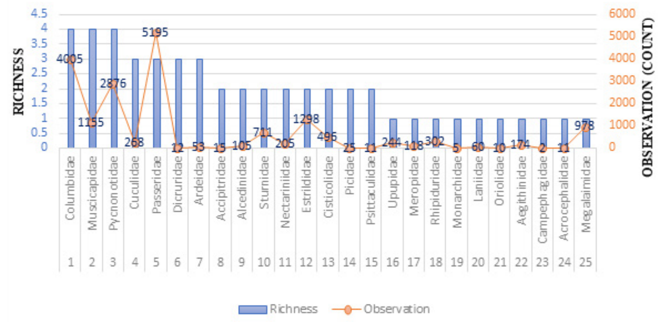


Fig. 6: Family, Richness, and Observations of birds at the RUPP and the RUA

goiavier (872) were dominant species in the study area. While, the following bird species were *L. vernalis* (3), *I. cinnamomeus, P. cantonensis, L. striata,* and *Ficedula parva* (2). Whereas, the least recorded bird species at RUPP was *Elanus caeruleus* (1) (Picture 2).

2.2. Comparisons of abundance, species richness, and diversity between RUPP and RUA

The mean number of birds ±SE per sampling point at the RUPP was 31.08 ± 19.44, while at the RUA was 23.81 ± 11.48, Mann-Whitney test p <0.0001 (Fig. 9/A). The number of observed abundances in RUPP is significantly higher than in RUA.

Refer to the possible reason is probably that RUPP is more covered by ponds and food sources vegetation than RUA. In fact, at the RUPP, the vegetation consists of the Fabaceae family, such as *Albizia procera, Cassia fistula, Pithecellobium dulce, Samanea saman, Peltophorum pterocarpum, Senna siamea,* and the genera of Ficus which was flowered and fruit during data sampling. The Fabaceae family offered a valuable food source for nectarivores and frugivores birds (Brown & Johnson, 2022; Mendonça & Dos Anjos, 2006). Especially, at the RUPP was a dominant abundance of synanthropic birds such as *P. montanus, C. livia,* and so on. So, synanthropic birds are avian endophytes of humans. (Dipineto et al., 2013; Johnston, 2001).

In contrast, the result showed that the bird species richness and diversity at RUPP was significantly lower than RUA. The mean of species of bird ±SE per sampling point at the RUPP was 7.93 ± 2.05, while at the RUA

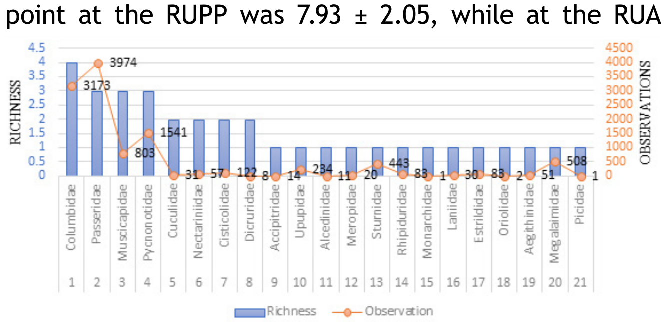


Fig. 7: Family, Richness and Observations of birds at the RUPP

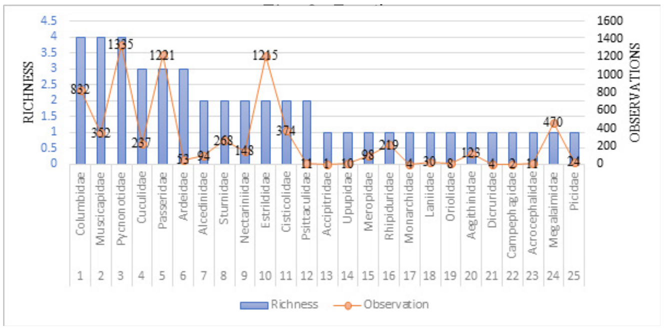


Fig. 8: Family, Richness, and Observation of birds at the RUA

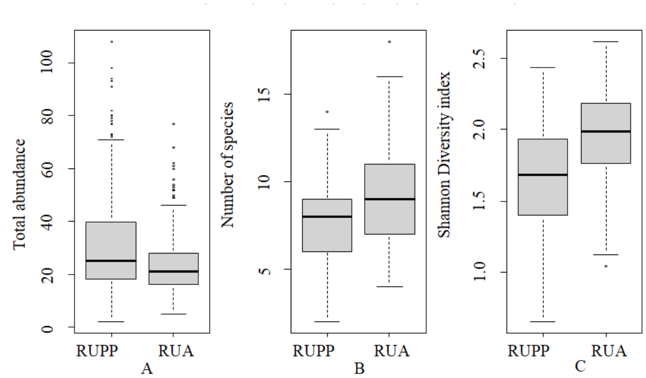


Fig. 9: Box plot of values for birds between the RUPP and RUA A. Total abundance, B. Number of species, C. Shannon Diversity index significantly different at $p < 0.05$

was 9.38 ± 2.50, $p < 0.0001$) (Fig. 9/B). The mean of the Shannon diversity index of bird ±SE per sampling point at the RUPP was 1.64 ± 0.35, while in the RUA was 1.96 ± 0.28. There was a significant difference (*p-value* < 0.0001) (Fig. 9/C).

The reasons are because of the existing variety of tree species and different habitat characteristics surrounding RUA, which is the habitat for many bird species. As the observation, the eastern of RUA was covered by aquatic plants in lowlands, rice fields, micro-grass land, and ponds, while the vegetation cover supported a higher richness of birds than the site without vegetation (Belcher et al., 2019). Green space management in the city significantly improves cities' capacity to support a wide variety of bird species (Hughes et al., 2022). Human disturbance is also a factor influencing the richness of bird species while RUA was a quieter place compared to RUPP. About 50% of the surrounding habitat at the RUA was covered by shrubs, micro-grass land, and water, while buildings, roads, and small businesses covered 100% of the surrounding habitat at the RUPP. Consistent with another study bird species richness is related to habitat reference and the percentages of disturbance (Waltert et al., 2004).

2.3. Air quality status and possible sources of pollution

Our analysis revealed statistically significant differences in air quality parameters (PM2.5, SO_2, NO_2, and O_3) between the RUPP and the RUA, with RUA exhibiting significantly higher levels ($p < 0.0001$). This suggests a potential difference in air quality between the two study sites, which could be attributed to various factors such as traffic volume, industrial activity, or proximity to pollution sources. Notably, temperature and humidity did not exhibit significant differences between the sites ($p > 0.05$), indicating that these parameters were relatively consistent across both locations during the study period. These findings highlight the importance of considering spatial variations in air quality when studying environmental impacts on ecological communities, such as bird populations. Table 1 provides details of the statistical analysis.

As detailed in Table 2, our analysis revealed variations in the concentrations of key air pollutants between the RUPP and the RUA. At the RUPP recorded a mean PM2.5 concentration of 13.56 μg/m³, complying with both the World Health Organization (WHO) 24-hour guideline (15 μg/m³) and the Cambodian standard (50 μg/m³). In contrast, at the RUA exhibited a higher concentration (28.76 μg/m³), exceeding the WHO guideline but remaining below the Cambodian standard.

Both sites recorded SO_2 levels within acceptable limits. RUPP had a mean concentration of 4.44 μg/m³, while RUA recorded 16.90 μg/m³, both falling below the WHO guideline (40 μg/m³) and the Cambodian standard (300 μg/m³ for 24 hours).

RUPP's NO_2 concentration (31.49 μg/m³) surpassed the WHO 24-hour guideline (25 μg/m³) but stayed below the Cambodian standard (100 μg/m³). Similarly, RUA's NO_2 concentration (48.84 μg/m³) exceeded the WHO guideline but remained under the Cambodian limit. Ozone levels at both sites were within acceptable ranges. RUPP recorded a mean concentration of 42.42 μg/m³, while RUA exhibited 49.80 μg/m³. Both values were below the WHO 8-hour guideline (100 μg/m³) and the Cambodian standard (120 μg/m³).

From the measurement, generally, the air quality status at two different sampling sites in Phnom Penh was good. In comparison, it was observed that the concentration of all air quality parameters was below the national standard set by the Ministry of Environment (MoE, 2021). However, some parameters exceeded the WHO guideline (WHO, 2021), such as NO_2, both at RUPP and RUA, and PM2.5 at RUA. As the result of continuous monitoring for three months in the dry season, it is observed that the trend of air quality status, focusing on PM2.5, tended to be stable if compared to the annual concentration of 2019 and 2020, while the PM2.5 concentration was always high in the dry season (Fig. 1). In addition, the result showed that air quality at RUPP was better than at RUA (p <0.0001).

Table 1: Summary air quality (PM2.5, SO_2, NO_2, O_3, Temperature, Humidity) record at the RUPP and the RUA

Variable	*RUPP*				*RUA*				*RUPP vs RUA (Mann-Whitney U-Test)*	
	Max.	*Min.*	*Mean*	*STD*	*Max.*	*Min.*	*Mean*	*STD*	*p-value*	*w-score*
PM2.5	50.3	2.1	13.56	8.32	72.05	6	28.76	14.55	<0.0001	16854
SO_2	7.3	0.6	4.44	1.84	66.94	0.79	16.90	10.25	<0.0001	103094
NO_2	86.1	8.1	31.49	14.50	70.44	28.2	48.84	9.04	<0.0001	16416
O_3	159.1	6.9	42.42	30.43	73.94	32	49.8	9.08	0.0001	36062
Temperature	37.1	19.4	29.06	3.36	35.9	23.6	29.51	3.36	0.26	51303
Humidity	97.5	50	73.31	13.31	98.5	49	74.60	13.76	0.13	50388

Table 2: Comparison of the RUPP and RUA air quality records with the WHO and Cambodian standards

Variable	*RUPP (μg/m^3)*	*RUA (μg/m^3)*	*Cambodia standard (μg/m^3)*	*WHO standard (μg/m^3)*
PM2.5	13.56	28.76	50	15 (24 hours)
SO_2	4.44	16.90	300	40 (24 hours)
NO_2	31.49	48.84	100	25 (24 hours)
O_3	42.42	49.80	120	100 (8 hours)

On the other hand, the industrial sector of Cambodia has seen significant growth over the last decades. Most industries rely directly or indirectly on fossil fuels and charcoal-making also contributes to the pollution of some specific pollutants, e.g., PM2.5, SO_2, NOx, and greenhouse gases like CO_2 (MoE, 2021). In addition, industrial air pollution in Phnom Penh, Dang Kao, and Meanchey Districts are the greatest emitters of air pollution among all districts in Phnom Penh from 1994 to 2014. The textiles and apparel sector is dominant more than other sectors among coke and petroleum refineries, basic metal (iron and steel), chemical products, and non-metallic mineral products. Volatile organic compounds (VOC) released grates compared with other harmful pollutants and then the second-ranked air pollutant was toxin chemical, while other air pollutants such as SO_2, NO_2, TSP, CO, FP, and toxin metals (San et al., 2018).

Based on these findings, combined with literature review and direct observations, we can infer potential sources of air pollutants at each site while the possible sources of air pollutants, such as stationary sources, mobile sources, and open burning (Fig. 10).

2.4. Relationship between birds and air quality

The data analysis identified significant autocorrelation between certain air quality and environmental variables, as indicated by an autocorrelation test (Fig. 11). Specifically, strong positive correlations (|r| > 0.5) were observed between ozone (O_3) and temperature (Temp.), ozone (O_3) and humidity, and temperature (Temp.) and humidity. To avoid collinearity issues and ensure model stability, we excluded these highly correlated variables from subsequent model-building processes. Based on this selection, we proceeded to evaluate 18 different logistic regression models to identify the most suitable model for predicting bird species richness and abundance based on air quality parameters.

For abundance, the analysis tested 18 models and the top one was the best model that explains the influencing of air quality parameters on bird abundance selection that ΔAIC < 2 (Table 3). The variables highlighted by the model were sulfur dioxide (SO_2) and humidity. This showed that the abundance of bird was a significant negative correlation with sulfur dioxide (SO_2), coefficient (-22%), and a positive correlation with the increase of humidity, coefficient (14%) (Table 3). We saw a sulfur dioxide (SO_2) negative correlation (p <0.001) with the abundant bird but a low coefficient of SO_2 (-22%) consistent with some species of bird were sensitive to sulfur dioxide (SO_2) by maybe impairing the bird immune response to inhaled antigens, making birds more susceptible to disease (Ukai et al., 1984).

For species richness, we tested 18 models and the top one was the best model that explains the influencing of air quality parameters on species richness of bird selection that ΔAIC < 2 (Table 3). The variables highlighted by the model were sulfur dioxide (SO_2) and humidity. This showed that the species richness of birds was a significant positive correlation with sulfur dioxide (SO_2), coefficient (10%), and a positive correlation with the increase of humidity, coefficient (10%) (Table 3). However, sulfur dioxide (SO_2) has a significant positive correlation with bird species richness but a low coefficient of SO_2 (10%) (Table 3). Through direct observation, some species have emerged, but less abundance in each species. Perhaps these species adapted to the air quality due to shelter. According to Muyemeki et al., 2017 showed the greenspace greater controlled bird population than sulfur dioxide (SO_2) pollution (Muyemeki et al., 2017).

Source: Authors' Picture

Fig. 10: Pictures showing the possible sources of air pollution in Phnom Penh. A). the black smoke from the garment factory's boiler, burning crush of fabric for energy supply. B). heavy black smoke from open burning at Dong Kao land fill, occasionally happening during the dry season. C). Traffic congestion is happening in Phnom Penh, especially in the early morning and evening. D). Open waste burning inside RUA. E). some smoke is produced by street food BBQ surrounding RUA, which occurs almost every morning and evening

In addition, the humidity had a low coefficient that indicated a positive correlation with either bird abundance or richness (14% and 10%) (Table 3), meaning it did not influence birds. There is a level of humidity that allows the bird to adapt. Referring to the level of

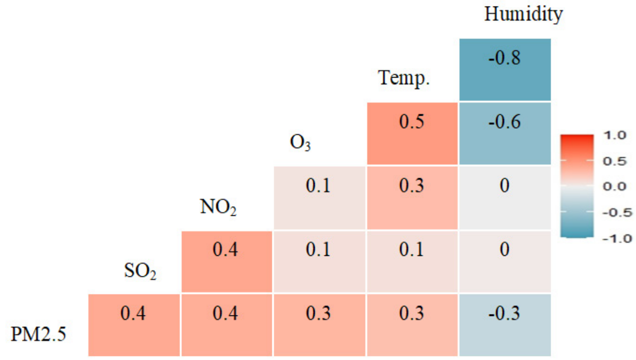


Fig. 11: Pearson's correlation matrix of air quality covariates showing r values

humidity in RUPP was 73.31% and RUA 74.60% (Table 1), while another study showed that birds were affected by humidity by 85% (Wei et al., 2015).

2.5. Air quality with abundance and species richness at the RUPP

Autocorrelation test showed that sulfur dioxide (SO_2) and humidity, ozone (O_3), temperature (Temp.), and humidity were strongly auto-correlating ($|r|>0.5$), so we exclude those variables in the same model building (Fig. 12). Thus, we evaluated air quality selection by testing 17 logistic regression models.

For abundance, the analysis tested 17 models and the top one is the best model that explains the influencing of air quality parameters on bird abundance selection that ΔAIC < 2 (Table 4). The variables highlighted by the model were PM2.5 and humidity. This showed that bird

Table 3: Logistic regression model building between air quality with bird abundance and species richness in RUPP & RUA; ΔAIC, the difference in relation to the best model within the AIC

Model	*Variable*	*K*	*AIC*	*ΔAIC*	*AIC-W*	*Coefficient*	*SE*	*P-value*	*95% CI*	
									Lower	*Upper*
Abundance (18 model tested)										
1	SO_2	3	8756.8	0.00	1	-0.22	0.02	<0.001	-0.26	-0.19
	Humidity					0.14	0.02	<0.001	0.12	0.18
2	NO_2	3	8893.3	136.47	0	-0.16	0.01	<0.001	-0.19	-0.13
	O_3					-0.06	0.01	0.00	-0.09	-0.03
3	PM2.5	3	8926.7	169.95	0	-0.14	0.02	<0.001	-0.18	-0.11
	Temperature					-0.04	0.02	0.02	-0.07	-0.01
Species richness (18 model tested)										
1	SO_2	3	3031.6	0	0.55	0.10	0.03	0.00	0.05	0.15
	Humidity					0.10	0.03	0.00	0.04	0.15
2	NO_2	3	8893.3	136.47	0	-0.16	0.01	<0.00	-0.19	-0.13
	O_3					-0.06	0.01	0.00	-0.09	-0.03
3	PM2.5	3	8926.7	169.95	0	-0.14	0.02	<0.00	-0.18	-0.11
	Temperature					-0.04	0.02	0.02	-0.07	-0.01

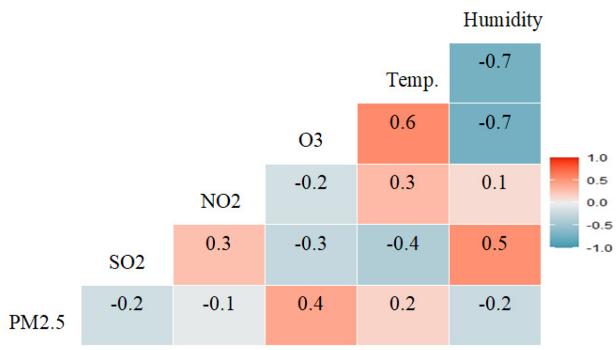


Fig. 12: Pearson's correlation matrix of air quality covariates showing r values at the RUPP

abundance was significantly positively correlated with PM2.5, coefficient (13%), and positive correlation with the increase of humidity, coefficient (13%) (p = 0.001) (Table 4).

While the PM2.5 concentration during data sampling was much lower than the national standard (Table 2), it was explained that at this concentration, PM2.5 does not impact birds. Furthermore, the humidity was a significant positive correlation (13%) (Table 4) that allowed good the bird to adapt to humidity at 73.31% (Table 1), while other studies that birds were affected by humidity from 85% (Wei et al., 2015). Furthermore, RUPP is a good green space for birds to adapt.

For species richness, we evaluated air quality selection by testing 17 logistic regression models. A best model had a ΔAIC < 2 (Table 4). The variables highlighted by the model were PM2.5 and O_3. This showed that bird species richness was a significant positive correlation with PM2.5, coefficient (11%) and a negative correlation with the decrease of ozone (O_3), coefficient (-8%) (Table 4). This study found a significant correlation between PM2.5 (p = 0.01) and Ozone (O_3) (p = 0.04). The major variable with a positive link to species richness was PM2.5 (11%) as well as abundance. Bird species richness had a significant negative correlation with ozone (O_3) (-8%) (Table 4). Based on ROMBOUT et al. (1991) O_3 affected health risks to birds by causing morphological and physiological changes in the avian respiratory system.

2.6. Air quality with abundance and species richness at the RUA

Autocorrelation test showed that PM2.5 and humidity, nitrogen dioxide (NO2) and ozone (O3), temperature (Temp.), and humidity were strongly auto-correlating (|r| > 0.5), so we excluded those variables in the model

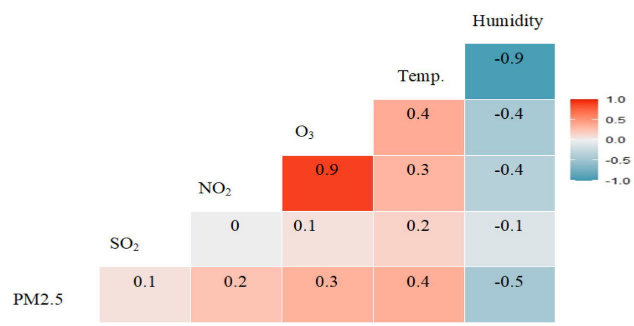


Fig. 13: Pearson's correlation matrix of air quality covariates showing r values in RUA

Table 4: Logistic regression model building between air quality with abundance and species richness of birds in RUPP; ΔAIC, the difference in relation to the best model within the AIC

Model	Variable	K	AIC	ΔAIC	AIC-W	Coefficient	SE	*p-value*	95% CI	
									Lower	Upper
Abundance (17 model tested)										
1	PM2.5	3	5681.3	0.00	1	0.13	0.02	0.001	0.10	0.17
	Humidity					0.13	0.02	0.001	0.09	0.16
2	NO_2	3	5742.2	60.89	0	-0.02	0.02	0.25	-0.06	0.02
	Temperature					0.07	0.02	0.001	0.03	0.11
3	SO_2	3	5752.5	71.16	0	-0.02	0.02	0.24	-0.06	0.02
	O_3					-0.03	0.02	0.09	-0.07	0.01
Species richness (17 model tested)										
1	PM2.5	3	1595.2	0.00	0.39	0.11	0.04	0.01	0.03	0.19
	O_3					-0.08	0.04	0.04	-0.16	-0.003
2	NO_2	3	1602.6	7.40	0.00	0.02	0.04	0.50	-0.05	0.10
	Humidity					0.02	0.04	0.66	-0.06	0.09
4	SO_2	3	1603.1	7.84	0.00	-0.02	0.04	0.67	-0.10	0.06
	Temperature					0.00	0.04	0.99	-0.08	0.08

Table 5: Logistic regression model building with abundance and species richness of birds in RUA; ΔAIC, the difference in relation to the best model within the AIC

Model	Variable	K	AIC	ΔAIC	AIC-W	Coefficient	SE	*p-value*	95% CI	
									Lower	Upper
Abundance (18 model tested)										
1	O_3	3	2855.3	0.00	0.55	_-0.05	0.03	0.04	-0.003	-0.11
	Temperature					-0.27	0.03	<0.001	-0.32	-0.22
2	NO_2	3	2867.7	12.40	0.00	0.02	0.03	0.37	-0.03	0.07
	Humidity					0.25	0.03	<0.00	0.19	0.29
3	PM2.5	3	2946.4	91.13	0	-0.11	0.02	0.00	-0.15	-0.06
	SO_2					-0.03	0.02	0.29	-0.07	0.02
Species richness (18 model tested)										
1	Humidity	2	1403.3	0.00	0.25	0.16	0.04	0.00	0.09	0.24
2	Temperature	2	1404.2	0.87	0.16	-0.15	0.04	0.00	-0.23	-0.08
3	PM2.5	3	1404.9	1.61	0.11	-0.05	0.04	0.26	-0.13	0.03
	Temperature					-0.14	0.04	0.00	-0.22	-0.06
4	SO_2	3	1405.2	1.84	0.10	0.02	0.04	0.69	-0.06	0.09
	Humidity					0.16	0.04	0.00	0.09	0.23
5	O_3	3	1405.2	1.84	0.10	0.02	0.04	0.69	-0.07	0.10
	Humidity					0.17	0.04	0.00	0.09	0.25
6	NO_2	3	1405.3	1.99	0.09	0.005	0.04	0.91	-0.07	0.08
	Humidity					0.16	0.04	0.00	0.09	0.24

building (Fig. 13). Thus, we evaluate air y testing 18 logistic regression models.

For abundance, the analysis tested 18 models and the top one is the best model that explains the influencing of air quality parameters on bird abundance selection that ΔAIC < 2 (Table 5). The variables highlighted by the model were ozone (O_3) and temperature. This showed that bird abundances had a significant negative correlation with ozone (O_3), coefficient (-5%), (p = 0.04) and a negative correlation with decreasing temperature, coefficient (-27%) (p < 0.001) (Table 5).

This result of ozone (O_3) affected bird abundance as well as revealed by on ROMBOUT et al. (1991) showed O_3 affected health risks to birds by causing morphological and physiological changes in the avian respiratory system. In addition, the abundance of birds had a negative correlation with temperature, but it was a lower coefficient (-27%) (Table 5) that confirms temperature does not strongly affect the abundance of birds and is consistent with another study of numerous bird abundance counts are related to temperature, that meaning bird have not affected temperatures unless it is extremely high (Robbins, 1981). Furthermore, the average temperature record at our study site is 29.51, which is not below the range of effect (44-56) as stated by Gerson et al., 2014.

For species richness, the analysis tested 18 models which are the six best models that explain the influencing of air quality parameters on bird abundance selection that ΔAIC < 2 (Table 5). A difference in AIC value between

Table 6: Model averaging of all logistic regression models with delta AIC < 2 for richness at the RUA

Variable	*Beta_coef*	*uncond. SE*	*Adjusted SE*	*p-value*	*95% CI*	
					Lower	*Upper*
Intercepts	2.24	0.02	0.02	<0.0001	2.19	2.27
Humidity	0.16	0.04	0.04	0.0001	0.09	0.24
Temperature	-0.15	0.04	0.04	0.0001	-0.23	-0.07
PM2.5	-0.05	0.04	0.04	0.27	-0.13	0.04
SO_2	0.02	0.04	0.04	0.69	-0.06	0.09
O_3	0.02	0.04	0.04	0.69	-0.07	0.10
NO_2	0.005	0.04	0.04	0.91	-0.08	0.08

these six models was < 2. When AIC can't be the thing selected as the best-fit model, we averaged them (Table 6). The present bird species richness of birds is the most significant positive correlation with humidity, coefficient (16%), followed by a negative correlation with temperature, coefficient (-15%), and no significant correlation with SO_2, PM2.5, O_3, and NO_2 (Table 6).

The result in this site we observed the richness of birds was a negative correlation (-15%) (Table 6) with temperature as well as abundance. It was a lower coefficient that confirmed temperature is not strongly affect the richness of birds and is consistent with another study that shows that temperature determines the species abundance in the environment (Carrascal et al., 2016). Furthermore, humidity always had a significant positive correlation (16%) (Table 6) with the richness of birds that it was not affected on birds. The average humidity record at our study site is 74.60%, which is not below the range of 85% by Wei et al., 2015.

Conclusion and policy implication

This study was new, yet it documented important knowledge of birds in an urban area, air quality status, and the relationship between air pollution and birds. For this study, we recorded 50 species of 40 genera, 25 families, and 9 orders. RUPP, we recorded 34 species belonging to 29 genera, 21 families, and 7 orders, while at RUA 46 species belong to 38 genera, 25 families, and 9 orders and share 30 species in both study areas. We observed abundance of birds at RUPP was significantly higher than at RUA. Based on RUPP is more covered by ponds and food sources vegetation (Fabaceae families, such as *A. procera, C. fistula, P. dulce, S. saman, P. pterocarpum, S. siamea* and the genera of Ficus) than RUA. Especially, RUPP was dominated by synanthropic birds, eg. *P. montanus, C. livia,* and so on. Species richness and diversity at RUPP were significantly lower than at RUA. Refer to, RUA in the suburbs is existing of a variety of tree species and different habitat characteristics surrounding RUA, which is the habitat for many bird species. As the observation, the eastern of RUA was covered by aquatic plants in lowlands, rice fields, micro-grass land, and a pond.

Based on our study, air quality status at both study sites is below the national standard settled by the Ministry of Environment; however, NO_2 of both RUPP RUA is higher than the WHO's standard and PM2.5 at RUA is also higher than WHO. Anthropogenic could be a suggestion of the sources of air pollutants through stationary sources, transportation, and open burning. Among the air quality parameters (PM2.5, NO_2, SO_2, O_3), only SO_2 and O_3 were found to affect the bird's community (both richness and abundance); however, with a lower rate (SO_2 = - 22%, O_3 = -5--8%). This finding may suggest that the study areas are covered with dominance of green vegetation and clean water ponds, which reduces the rate of negative data within air quality as referencing with the level of air quality in both study areas is lower than the National Standard. We noted that in general, birds adapt to the current weather with suitable temperature (mean 29.06 ±3.36°C) and humidity (73.31 ± 13.31%) in RUPP and (29.51 ± ss3.36°C) and (74.60 ±13.76%) in RUA.

For further study, we should have longer periods of data collection that are conducted in both seasons (dry and rainy) and along the bird observation; vegetation study should not be ignored. Furthermore, we should be organizing urban green space areas as much as possible to provide available habitat for wildlife, especially the existing forest birds. Keep some green spaces, as well as a variety of trees for the development plan to conserve biodiversity, as well as birds. Public education and awareness-raising programs should be implemented at educational institutions and this provides information on birds within the urban area. Especially for air quality management, we should be reducing fossil fuel consumption by replacing it with alternative energy sources for example, electric cars, solar energy, and some others.

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Declaration of competing interest

The authors have no competing interests to declare. All authors have read and approved the final, published version of the manuscript.

Credit authorship contribution statement

Chim Samhaiy: Research design, data collection, sample identification, data interpretation, visualization, drafting, reviewing, and editing. Chhin Sophea: advised in research design, data interpretation, visualization and reviewing. Yim Rasmey: advised in research design, data interpretation, visualization, and reviewing. All authors have read and agreed to the published version of the manuscript.

Data Availability statement

The data on bird species and it abundance were collected at the RUPP and at the RUA that surveyed by author, while the related air quality data was measured by the professional air quality monitor, belong to the Ministry of Environment , once was installing at the institute of Technology of Cambodia (ITC), located at about 500 m from RUPP and another was installing at Dang Kao commune located about 250 m far from RUA.

Author's biography

Chim Samhaiy: Teacher at high school, and currently graduated swith Master of Science in biodiversity conservation at Royal University of Phnom Penh.
Chin Sophea: Chief Official, Department of Biodiversity, General Directorate of Policy and Strategy, Ministry of Environment
Yim Rasmey: Deputy Director, Department of Air Quality, Noise and Vibration Management Protection, Ministry of Environment.

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Appendix

(Photo by Mr. Ieng Pisey)

Picture 1: a) P. montanus, b) D. canicapilus at the RUPP

Photo by Mr. Ieng Pisey

Picture 2: a) L. punctulata, b) Elanus caeruleus at the RUA.

Appendix 1: Birds recoded at the RUPP and the RUA

Orders	*Family*	*Genera*	*Species*	*IUCN status*	*RUPP*	*RUA*	*Total*
Accipitriformes	Accipitridae	Butastur	liventer	LC	14	0	14
		Elanus	caeruleus	LC	0	1	1
Bucerotiformes	Upupidae	Upupa	epops	LC	234	10	244
Columbiformes	Columbidae	Geopelia	Striata	LC	619	493	1112
		Columba	livia	LC	2215	22	2237
		Streptopelia	chinensis	LC	250	300	550
			tranquebarica	LC	89	17	106
Coraciiformes	Alcedinidae	Alcedo	atthis	LC	11	7	18
		Todiramphus	chloris	LC	0	87	87
	Meropidae	Merops	philippinus	LC	20	98	118
Cuculiformes	Cuculidae	Eudynamys	scolopacea	LC	11	16	27
		Cacomantis	merulinus	LC	20	187	207
		Centropus	sinensis	LC	0	34	34
Passeriformes	Passeridae	*Passer*	montanus	LC	3512	995	4507
			domesticus	LC	449	111	560
			flaveolus	LC	13	115	128
	Muscicapidae	*Copsychus*	malabaricus	LC	0	12	12
			saularis	LC	671	211	882
		Musicapa	dauurica	LC	117	127	244
		Ficedula	parva	LC	15	2	17
	Sturnidae	Acridotheres	tristis	LC	443	249	692
		Sturnus	malabaricus	LC	0	19	19
	Pycnonotidae	*Pycnonotus*	goiavier	LC	1007	872	1879
			blanfordi	LC	531	427	958
			aurigaster	LC	3	28	31
			jocosus	LC	0	8	8
	Rhipiduridae	Rhipidura	Javanica	LC	83	219	302
	Monarchidae	Hypothymis	Azurea	LC	1	4	5
	Nectariniidae	Cinnyris	jugularis	LC	19	51	70
		Anthreptes	malacensis	LC	38	97	135
	Laniidae	Lanius	cristatus	LC	30	30	60
	Estrildidae	Lonchura	punctulata	LC	83	1213	1296
			striata	LC	0	2	2
	Oriolidae	Oriolus	chinensis	LC	2	8	10
	Aegithinidae	Aegithina	tiphia	LC	51	123	174
	Cisticolidae	Prinia	inornata	LC	91	254	345
		Orthotomus	sutorius	LC	31	120	151
	Dicruridae	*Dicrurus*	leucophaeus	LC	2	0	2
			macrocercus	LC	0	4	4
		Dicaeum	cruentatum	LC	6	0	6
	Campephagidae	Pericrocotus	cantonensis	LC	0	2	2
	Acrocephalidae	Acrocephalus	orientalis	LC	0	11	11

Pelecaniformes	Ardeidae	Ardeola	speciosa	LC	0	16	16
		Mesophoyx	intermedia	LC	0	35	35
		Ixobrychus	cinnamomeus	LC	0	2	2
Piciformes	Megalaimidae	Megalaima	haemacephala	LC	508	470	978
	Picidae	*Dendrocopos*	canicapilus	LC	1	0	1
			macei	LC	0	24	24
Psittaciformes	Psittaculidae	Psittacula	alexandri	LC	0	8	8
		Loriculus	vernalis	LC	0	3	3