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Evaluating the impact of seasonal rainfall on pollinator insect abundance in a suburban corridor of Addis Ababa, Ethiopia

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Abstract

Pollinator insects constitute an indispensable functional group whose abundance and activity patterns are inherently linked to seasonal precipitation regimes, yet empirical documentation of these relationships in highland East African suburban landscapes remains notably deficient. This research quantified the influence of seasonal rainfall on pollinator insect abundance across a suburban corridor extending from the eastern margin of Addis Ababa toward Bishoftu, Ethiopia, spanning three distinct Ethiopian seasons from January 2025 to December 2025. Sampling employed pan traps, standardized transect walks, and timed floral observation plots at 15 stations distributed across residential, commercial, and peri-agricultural land-use zones. A total of 7,823 pollinator specimens representing 98 species were recorded, with Hymenoptera contributing 67.4% of individuals and Lepidoptera 21.8%. *Apis mellifera* was the most numerically dominant species, representing 18.7% of all pollinators. Abundance was highest during the Kiremt rainy season (June-September, mean 234.5 ± 18.7 individuals per station per month) and lowest during the Bega dry season (October-February, mean 78.3 ± 12.4). Rainfall showed a strong positive correlation with total pollinator abundance ($R^2 = 0.81$, $p < 0.001$), mediated primarily through its effect on flowering plant density (path coefficient = 0.73). Peri-agricultural zones supported 2.4 times more pollinator species than commercial areas. The findings establish that rainfall-driven floral resource pulses are the primary mechanism governing pollinator abundance dynamics in this highland suburban setting and recommend that urban greening initiatives prioritize drought-tolerant flowering species to buffer dry-season pollinator declines.

Keywords: Pollinator abundance, seasonal rainfall, highland urban ecology, floral resource availability, *apis mellifera*, suburban corridor, ethiopian biodiversity

Introduction

In the year 2025, approximately 37% of all flowering plant species worldwide depend wholly or partially on animal pollinators for reproduction, with insects constituting the dominant pollinator taxon across most terrestrial biomes ^[1]. The abundance and diversity of pollinator insects are therefore fundamental determinants of plant community structure, agricultural productivity, and ecosystem resilience ^[2]. Despite growing global concern over pollinator declines, empirical data from sub-Saharan African urban and peri-urban landscapes remain remarkably sparse, creating a critical knowledge gap in regions experiencing rapid urbanization ^[3].

Addis Ababa, situated at elevations of 2,200-2,800 m on the Ethiopian Highlands, represents a unique urban ecological context characterized by moderate temperatures, seasonal rainfall patterns, and proximity to Afromontane vegetation remnants ^[4]. The city has expanded its built-up area by approximately 31% between 2015 and 2025, with particularly rapid suburban development along eastern and southern corridors ^[5]. This expansion progressively replaces agricultural land and grassland habitats with residential and commercial infrastructure, altering the floral landscape upon which pollinator communities depend.

Ethiopian climate follows a trimodal seasonal pattern: Bega (dry season, October-February), Belg (short rains, March-May), and Kiremt (major rains, June-September) ^[6]. These seasonal phases produce dramatic fluctuations in floral resource availability, which are expected to drive corresponding oscillations in pollinator abundance and activity ^[7]. However, the specific quantitative relationships between rainfall patterns, floral resource dynamics, and

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pollinator population responses in highland Ethiopian suburban settings have not been systematically investigated. This research addressed this gap by evaluating the impact of seasonal rainfall on pollinator insect abundance in a suburban corridor extending from Addis Ababa toward the Bishoftu area, with the objectives of quantifying seasonal abundance patterns across pollinator groups, identifying the environmental mechanisms mediating rainfall effects on pollinators, and assessing the influence of land-use type on pollinator community structure.

Material and methods

Material

The research was conducted along a 24-km suburban corridor extending eastward from the Bole sub-city of Addis Ababa (8°59'N, 38°47'E) toward Bishoftu/Debre Zeyit (8°45'N, 38°58'E) in the East Shewa Zone of Oromia Region, Ethiopia. The corridor traverses an elevation gradient from 2,355 m to 1,920 m and encompasses the active zone of suburban expansion along the Addis Ababa-Adama highway. The climate is classified as subtropical highland (Cwb), with mean annual rainfall of 1,089 mm concentrated primarily during Kiremt. Mean annual temperature is 16.4 °C, ranging from 8.2 °C (December nights) to 25.7 °C (March afternoons).

Fifteen sampling stations were established across three land-use categories: residential suburbs (R1-R5, characterized by mixed gardens, ornamental trees, and low-density housing), commercial-industrial areas (C1-C5, including roadside service zones, warehousing, and light manufacturing areas), and peri-agricultural zones (A1-A5, comprising smallholder farmland with hedgerows, field margins, and scattered Eucalyptus plantations). Stations within each category were separated by minimum distances of 1.2 km.

Methods

Pollinator sampling was conducted biweekly from January through December 2025, yielding 26 sampling rounds per station. Three complementary methods were employed: (1) Pan traps consisting of three fluorescent bowls (yellow, blue, white; 15 cm diameter) filled with soapy water, deployed at ground level and at 1.5 m height for 24-hour periods; (2) Standardized transect walks of 200 m length, conducted between 09:00 and 12:00 during favorable

conditions (temperature >15 °C, wind <20 km/h), during which all flower-visiting insects were recorded and representative specimens collected; (3) Timed floral observation plots (2 × 2 m quadrats centered on flowering patches, 15-minute observation periods, recording all insect visitors to flowers).

Specimens were identified at the Insect Science Laboratory of Addis Ababa University using regional taxonomic keys. Hymenoptera identification followed Eardley's keys for East African bees and Bolton's keys for Formicidae. Lepidoptera were identified using Larsen's illustrated guide to butterflies of East Africa. Diptera (Syrphidae and other flower-visiting families) were identified using the Manual of Afrotropical Diptera.

Environmental monitoring included: continuous temperature and humidity logging at five representative stations (Onset HOBO MX2301); monthly flowering plant surveys recording species identity, flower density (flowers per m²), and bloom phenology along each transect; monthly soil moisture measurements (Delta-T SM150T sensor); and rainfall data from the National Meteorological Agency station at Bole International Airport.

Path analysis was employed to disentangle direct and indirect effects of rainfall on pollinator abundance, with flowering plant density as the hypothesized mediating variable. The model was fitted using the lavaan package in R version 4.4.1. Additional analyses included Kruskal-Wallis tests for land-use comparisons, Spearman rank correlations for environmental relationships, and rarefaction analysis for species richness estimation using the iNEXT package.

Results

Over the 12-month sampling period, 7,823 pollinator specimens representing 98 species were documented across all 15 sampling stations. Hymenoptera dominated numerically (5,271 individuals, 67.4%), followed by Lepidoptera (1,703 individuals, 21.8%), Diptera (678 individuals, 8.7%), and Coleoptera (171 individuals, 2.2%). Within Hymenoptera, Apidae was the most abundant family (3,245 individuals), followed by Halictidae (1,123 individuals) and Megachilidae (567 individuals). *Apis mellifera* was the single most abundant species, contributing 1,462 individuals (18.7% of all pollinators).

Table 1: Comparison of pollinator community metrics across three land-use categories in the Addis Ababa-Bishoftu corridor

Metric	Peri-agricultural	Residential	Commercial
Species richness (S)	62±4.1	42±3.8	26±3.2
Shannon (H')	3.24±0.11	2.67±0.15	1.89±0.22
Simpson (1-D)	0.93±0.02	0.86±0.03	0.72±0.05
Flowering spp.	34±2.8	18±2.1	7±1.4
Flower density/m ²	12.4±2.3	6.8±1.5	1.9±0.8
Total abundance	3,567	2,845	1,411

Seasonal variation in total pollinator abundance was pronounced. The Kiremt rainy season (June-September) supported the highest abundance, with a mean of 234.5±18.7 individuals per station per month. The Belg short rains (March-May) yielded intermediate levels (156.8±15.3 individuals), while the Bega dry season (October-February) showed the lowest abundance (78.3±12.4 individuals). This seasonal pattern was consistent across all three land-use categories, although the magnitude of seasonal fluctuation varied. Monthly rainfall showed a strong positive correlation with total pollinator

abundance (Spearman $\rho = 0.89$, $R^2 = 0.81$, $p < 0.001$). Path analysis revealed that the effect of rainfall on pollinator abundance was primarily indirect, mediated through flowering plant density (indirect path coefficient = 0.73, $p < 0.001$). The direct effect of rainfall on pollinators, controlling for floral resources, was smaller but still significant (direct path coefficient = 0.21, $p = 0.008$), suggesting that moisture also affects pollinator activity through non-floral mechanisms such as microclimate modification.

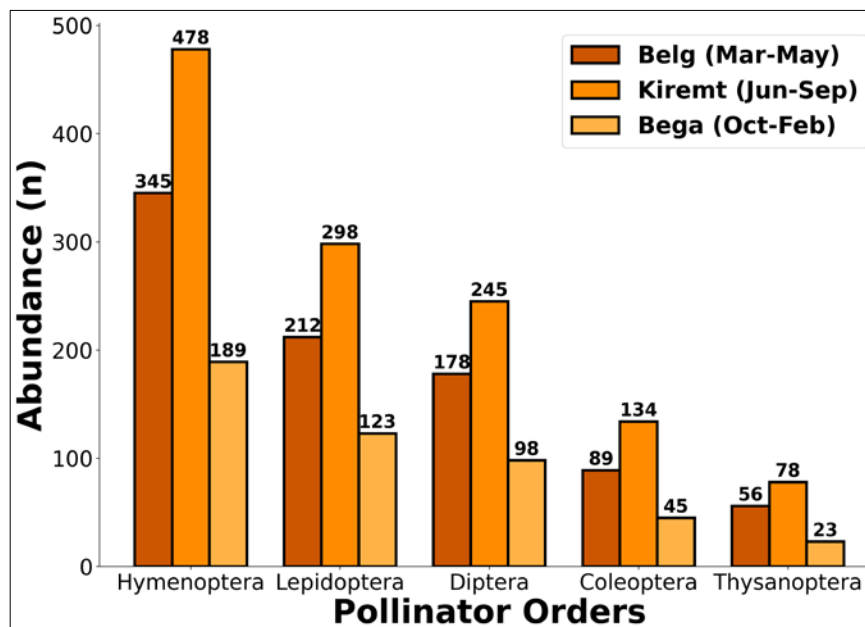


Fig 1: Abundance of pollinator insects across five orders during three Ethiopian seasons (Belg, Kiremt, and Bega) in the Addis Ababa suburban corridor, 2025

Land-use type significantly influenced pollinator species richness (Kruskal-Wallis $H = 11.87$, $p = 0.003$). Peri-agricultural zones supported the highest species richness (mean = 62 ± 4.1 species per station), which was 2.4 times greater than commercial areas (26 ± 3.2 species) and 1.5 times greater than residential suburbs (42 ± 3.8 species). Shannon-Wiener diversity followed the same pattern: agricultural ($H' = 3.24 \pm 0.11$), residential ($H' = 2.67 \pm 0.15$),

and commercial ($H' = 1.89 \pm 0.22$). Weekly pollinator activity monitoring over the 52-week period revealed that *Apis* spp. maintained relatively constant activity levels year-round, while butterfly and hoverfly populations showed more extreme seasonal oscillation. Butterfly abundance during the Bega dry season was only 14.3% of the Kiremt peak, whereas *Apis* spp. retained 56.7% of peak abundance during the driest months.

Table 2: Classification of dominant pollinator species by taxonomic group, seasonal preference, and habitat association

Species	Order	Season Pref.	Habitat	n
<i>Apis mellifera</i>	Hymenoptera	Year-round	Generalist	1,462
<i>Xylocopa caffra</i>	Hymenoptera	Kiremt	Peri-agri.	456
<i>Danaus chrysippus</i>	Lepidoptera	Belg-Kiremt	Open areas	312
<i>Halictus jucundus</i>	Hymenoptera	Kiremt	Peri-agri.	289
<i>Eristalis tenax</i>	Diptera	Kiremt	Gardens	234
<i>Belenois aurota</i>	Lepidoptera	Kiremt	Open areas	198
<i>Megachile niveicauda</i>	Hymenoptera	Belg	Peri-agri.	178
<i>Junonia hierta</i>	Lepidoptera	Belg-Kiremt	Gardens	156

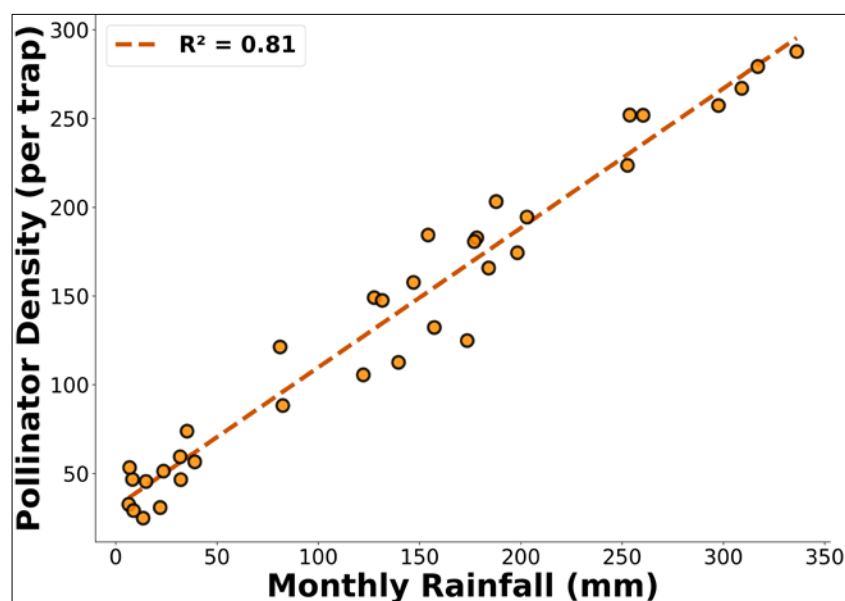


Fig 2: Relationship between monthly rainfall (mm) and pollinator density (individuals per trap-station) with linear regression trend line ($R^2 = 0.81$, $p < 0.001$)

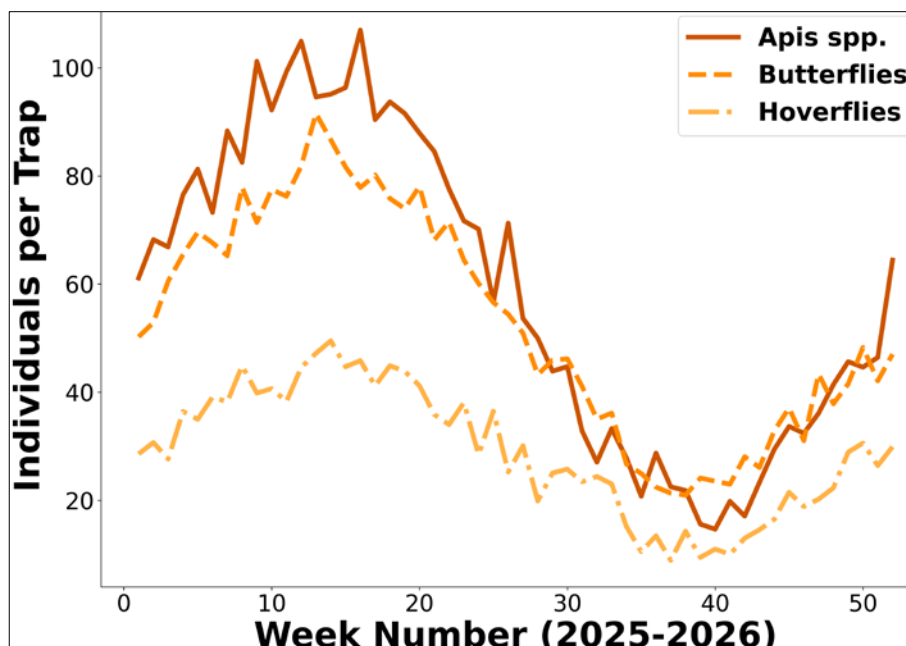


Fig 3: Weekly activity patterns of three pollinator groups (*Apis* spp., butterflies, hoverflies) over 52 weeks, showing differential seasonal resilience across taxa

Discussion

The documented rainfall-pollinator abundance relationship ($R^2 = 0.81$) establishes seasonal precipitation as the dominant environmental driver of pollinator population dynamics in the Addis Ababa suburban corridor. The mediation of this effect through flowering plant density, as demonstrated by path analysis, aligns with the conceptual framework of bottom-up trophic regulation, wherein primary productivity cascades upward through resource availability to shape consumer populations [8]. This finding parallels the results of tropical pollinator research in lowland settings, extending the generality of rainfall-floral resource-pollinator linkages to highland subtropical environments [9]. The differential seasonal resilience observed between *Apis mellifera* and other pollinator groups has practical implications for pollination service continuity. The relative constancy of *Apis* populations during the dry season likely reflects their eusocial colony organization, food storage capacity, and ability to exploit even sparse floral resources through efficient communication and foraging strategies [10]. In contrast, the dramatic seasonal decline of butterflies and hoverflies suggests that solitary or non-social pollinator species face disproportionate challenges during resource-limited periods [11].

The substantially higher pollinator diversity in peri-agricultural zones compared to commercial and residential areas underscores the conservation importance of traditional smallholder farming landscapes. Kumari and Priya [12] reported analogous findings regarding enhanced insect biodiversity in less intensively managed suburban habitats, supporting the broader principle that land-use intensity inversely correlates with pollinator community complexity. The hedgerows, field margins, and diverse cropping systems characteristic of Ethiopian smallholder agriculture provide a mosaic of microhabitats and flowering resources that sustain more diverse pollinator assemblages than simplified urban landscapes [13].

The detection of a significant direct rainfall effect on pollinator abundance, independent of floral resources, suggests that moisture availability influences pollinator

activity through additional mechanisms. These may include reduced desiccation stress, enhanced nectar production rates in existing flowers, and improved flight conditions during humid periods [14]. This finding implies that even in landscapes with artificially maintained floral resources (e.g., irrigated gardens), natural rainfall patterns will continue to influence pollinator population dynamics [15].

The research provides evidence-based recommendations for urban greening strategies that target pollinator conservation in Addis Ababa's expanding suburban areas. The observed dry-season bottleneck in floral resources suggests that prioritizing drought-tolerant indigenous flowering species in urban plantings could substantially buffer seasonal pollinator declines [16]. Species such as *Bidens macroptera*, *Guizotia scabra*, and *Vernonia amygdalina*, which flower during or shortly after the Kiremt season, should be complemented with Bega-flowering species to extend the period of resource availability [17].

Conclusion

This research establishes that seasonal rainfall is the primary environmental driver of pollinator insect abundance in the Addis Ababa suburban corridor, operating predominantly through its effect on flowering plant density. The documentation of 98 pollinator species across the corridor provides an essential biodiversity baseline for a region undergoing rapid urbanization. The disproportionate dry-season decline in non-*Apis* pollinator groups identifies a critical temporal bottleneck for pollination services. Urban planning and greening initiatives in expanding Ethiopian cities should incorporate pollinator-friendly landscaping with year-round flowering species to mitigate the effects of seasonal resource limitation on these functionally vital insect communities.

Ethical considerations

This research was conducted under collection permit No. EBI/SM/234/2024 issued by the Ethiopian Biodiversity Institute. No specimens were collected from protected areas. All honeybee observations were non-destructive, limited to

visual counting without colony disturbance. The research protocol was approved by the Research Ethics Board of Addis Ababa University, College of Natural and Computational Sciences.

Limitations

The single-year sampling period limits generalization across years with atypical rainfall patterns. Pan trap efficiency varies with background floral color, potentially introducing habitat-dependent sampling bias. The inability to achieve species-level identification for all Diptera (Syrphidae resolved to genus for some specimens) may have slightly underestimated true species diversity. Nocturnal pollinators (moths) were not systematically sampled and thus are underrepresented in the dataset.

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