

HONEY BEE AS A BIOINDICATOR OF ECOSYSTEM HEALTH

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Abstract: Protection of agriculture, human, animal and overall ecosystem health is ensured through proper assessment of environmental pollution, contaminants, pesticides and pathogens. The interdependence of human, animal and ecosystem health is now widely recognized by the One Health Concept. To quantify contaminants in our ecosystem, researchers often utilize naturally available biomonitors. Honey bees are widely admired for their ability to act as potential biomonitors because they are intrinsically linked to their residential habitat. Honey bees, being foraging creatures, are extensively exposed to various kinds of contaminants and pathogens from air, water and soil. Contaminants such as heavy metals, microplastics, persistent environmental pollutants, pesticides and pathogens are then carried into their hives, which can be easily used for ecosystem quality assessment studies. Although individual bees are susceptible to environmental stressors, the whole colony can respond to environmental pollutants without collapsing. Thus, bees prove to be very useful for conducting long-term environmental monitoring studies over large spatial and temporal scales. This review highlights the versatility of using honey bees as a biomonitoring species. It provides practical insights into ecosystem health and also raises awareness among beekeepers and policy makers regarding sustainable hive management practices. Finally, we must incorporate sophisticated methodologies, widespread geographical monitoring and interdisciplinary research to improve the detection capability of environmental health using this nature-gifted monitoring tool.

Keywords: Honey bee, *Apis mellifera*, bioindicator, environmental pollutants, microplastics, heavy metals, pesticides, pathogens, antimicrobial resistance genes, airborne particulate matter.

1. INTRODUCTION:

The prevalence of metal contamination in and around industrial, urban as well as agricultural areas have become a great field of interest among recent researchers (Ciszewski & Aleksander-Kwaterczak, 2015; Skorbilowicz et al., 2018). When excess amount of these contaminants, accumulate into environment they can cause drastic effects by moving through soil, water and air. From the environment these pollutants concentrate in body causing neurotoxic damage, reproductive failure and even death (William et al., 2015; Moro'n et al., 2014). Not only that, several instances of respiratory illness as well as cancer were also observed (Carpenter, 2006; Lambert et al., 2012; Briffa et al., 2020). Again, plastic pollution is well recognized as a rising concern of the 21st century. Microplastics being very small in size can easily penetrate into the food chain and thus create extreme toxic effects in living organisms. For this reason, real time monitoring of environmental quality has proved to be a very vital requirement for maintaining food safety, diversity maintenance and human health (Cunningham et al., 2021).

Several biotic and abiotic systems can be used for conducting environmental monitoring (Kienzl et al., 2003; Cordier et al., 2020). A bioindicator is generally referred to as a species that can effectively predict environmental quality (McGeogh, 1998) whereas a biomonitor is recognized as a species that can not only indicate ecosystem but also measure ecological changes through numerical and statistical data (Markert and Wünschmann 2011). In this context, both bioindicator and biomonitor terms are utilized widely and interchangeably. Selection of bioindicator must follow by the following criterias: abundance in large populations, occurrence must be in several different habitats, specific compounds accumulation capacity, simplicity of identification, ease of chemical analysis (Pendias & Pendias, 1999).

Honey bees fulfill all the above criteria and thus considered as an excellent biomonitoring tool (Sadeghi et al., 2012). (Table 1). Honey bees widely interact with the environment and considered as a microlivestock of the world. (pic.1). In spite of, honey bee being sensitive to environmental stressors a whole colony can recover from these changes and accumulate these stressors without collapsing. Honey bees are long range foragers and can cover an area of approximate 7 m² during a single foraging trip (Crane, 1984; Martinello et al., 2020). During these foraging flights honeybees come in contact with several pollutants (Devillers, 2002). Pollutants from air, water or soil adhere directly into the body hair of honey bees and also get consumed by them while collecting pollen and honeydew, drinking nectar or harvesting resin (Devillers, 2002; Negri et al., 2015; Porrini et al., 2002; Celli et al., 2003). These forager bees upon their return into the hive introduce these contaminants into the hive by converting them into products like honey and wax (Leita et al., 1996; Satta et al., 2012; Negri et al., 2015). Thus, several matrices of honey bee such as pollen, honey, beeswax etc. can be effectively utilized for measuring pollutant accumulation. (Table 3).

The concept of "One Health" coined by the WHO has developed as a very essential strategy for addressing worldwide challenges by interconnecting human, animal and ecological health (Lerner et al., 2015). Honeybees have been vividly recognized for their indispensable role in maintaining environmental ecosystems and diverse species well-being (de Jongh et al., 2022). (Explained with a flowchart in fig. 1). This review work provides proven and potential up-to-date information about the importance of honeybees as proactive samplers for demonstrating ecosystem health. We conclude with a discussion showing the potential of honey bees in improving human, animal and ecosystem health and to improve the performance of food safety and agricultural sector.



pic. 1: western honey bee / european honey bee

source: <https://www.activewild.com/wp-content/uploads/2019/12/Honey-Bee-On-Flower-768x512.jpg>

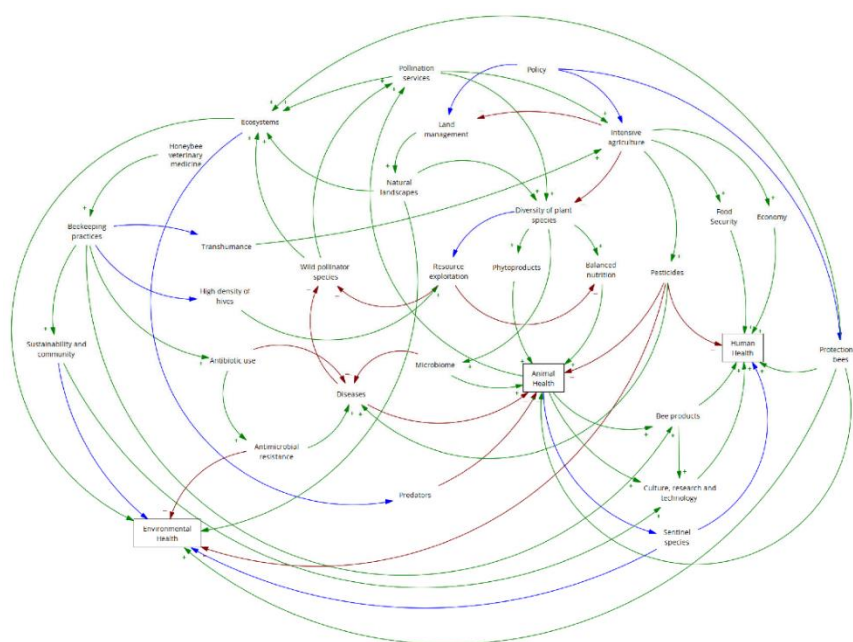


fig. 1: flow diagram representing one health concept with honeybee as model organism

source: (Prata and da Costa, 2024)

1.1. CRITERIAS FULFILLED BY HONEY BEES FOR BEING RECOGNISED AS BIOINDICATOR

Table 1: criteria for considering honey bee as an ideal bioindicator

Factors	Fulfillment
Broad localization	Versatility in utilizing wide range of habitats (Crane, 1984)
Social behaviour	Single colony composed of foragers of nearly 20,000 – 50,000 members (Michener, 1974)
Foraging	Covers approximately a distance of 7 km ² per flight (Greenleaf et al., 2007)
Accumulation of contaminants	Pollutants adhere to body hair, contaminants ingested and carried on to hive (Negri et al., 2015)
Easy handling	Non- invasive strategy for environmental health analysis (Porrini et al., 2002)
Resilience	Colony is resistant to environmental stressors (Cunningham et al., 2022)
Utilization of water	Used to maintain thermoregulation (Fuente-Ballesteros et al., 2025)

2. ENVIRONMENTAL POLLUTANTS

The various types of environmental contaminants encountered by the bees essential for biomonitoring are as follows: a) Heavy metals, b) Microplastics, c) Persistent environmental pollutants, d) Pesticides, e) Pathogens. (fig. 2). Further categorized in Table 2.

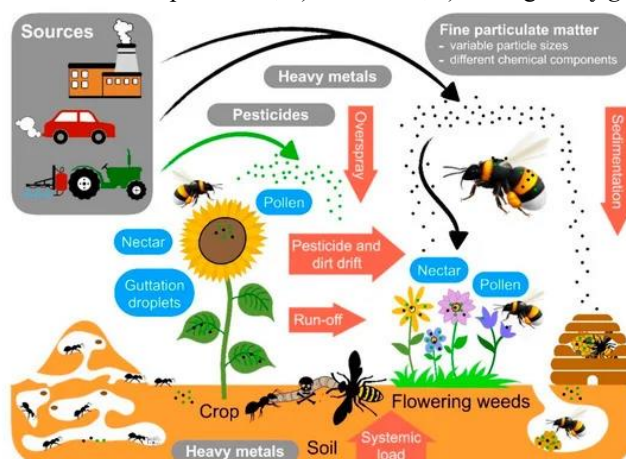
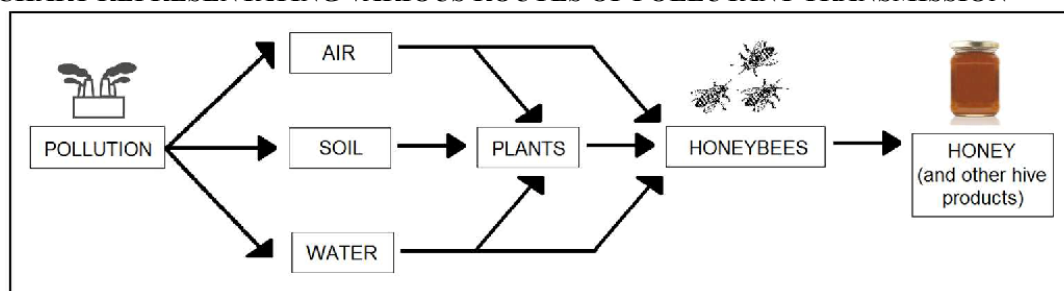


fig. 2: exposure of several environmental pollutants to social insects

source: (Abdel-Aziz, 2021)

2.1. FLOWCHART REPRESENTATING VARIOUS ROUTES OF POLLUTANT TRANSMISSION



Source: (Herrero-Latorre et al., 2017)

2.2. Categories of Environmental Pollutants that can be monitored through Bees

Table 2: several categories of environmental pollutants assessed through honeybee

Pollutants	Example	Bee matrices	Methods
Heavy metals	Pb, Cd, Zn, Cr, As, Cu	Body hair, honey, pollen, beeswax, propolis	AAS, ICP-MS (Perugini et al., 2011)
Microplastics	Polyethylene, Polypropylene	Body hair, honey, pollen, beeswax, larvae	FTIR, μ FTIR (Edo et al., 2021)
Persistent environmental pollutants	PAHs, PCBs	Body hair, propolis, beeswax	GC-MS (Conti & Botrè, 2001)
Pesticides	Organophosphates, Pyrethroids etc.	Body hair, honey, pollen, beeswax	LC-MS/MS, GC-MS (Niell et al., 2017)
Pathogens	Plant viruses, AMR genes, Enterobacteriaceae	Bee gut, pollen	PCR, HTS, ELISA (Tremblay et al., 2019)

2.3. Use of several Bee Matrices for Environmental Health Assessment

Table 3: bimonitoring using different bee matrices

source: Balayiannis & Balayiannis, 2008.

Bee Matrices	Contaminants
Body hair	Heavy metals, Airborne particles
Honey	Microplastics, Pesticides, Pathogens
Bees wax	Persistent Organic Pollutants, Polycyclic Aromatic Hydrocarbons
Pollen	Microplastics, Pesticides, Pathogens
Propolis	Heavy metals

2.1.1. Heavy metals

Heavy metal pollution is a rising environmental concern in densely populated areas mostly due to urbanization, heavy industrial activities, vehicle exhaust, fossil fuel burning, smelting and agrochemical use (Hu et al., 2013). Trace heavy metals like lead (Pb), chromium (Cr), cadmium (Cd), mercury (Hg) can prove to be extremely toxic (Jyothi, 2021; Mahurpawar, 2015). In humans, these toxic heavy metals can cause neurological disorders, kidney damage, disruption of endocrine system as well as cancer and malignancies mostly linked to upper gastrointestinal tract (Khan et al., 2008; Alloway, 2013; Rehman et al., 2018). In honey bees, these toxic metal contaminations can deteriorate brood production, survival rate as well as navigation abilities (Moron et al., 2014; Burden et al., 2019; Di et al., 2016). However, in spite of being lethal to single individual there is no significant effect of these

heavy metals on bee colony (Cunningham et al., 2022; Burden et al., 2011). This resilience provides an opportunity for using bees as environmental monitors. (fig. 3).

It was seen that honey bees and their hive products collected from the center of Rome contained a higher level of heavy metals in comparison to other areas outside the city which might be caused due to heavy vehicle traffic (Conti & Botrè, 2001).

The highest levels of Pb were also detected from hives located in Campino river (Rome) next to the airport (Perugini et al., 2011). Again, in another independent research in Northern Iraq it was seen that pollen samples collected from Duhok/ Semel/ College of Agriculture also contained highest level of Pb which might be caused due to the presence of nearby petroleum refinery stations (Hussein et al., 2024). According to Grousset et al. (1994) multiple isotopes of some heavy metals like Pb can be used to indicate sources of pollution. Higher isotopic ratio of 208 Pb/206 Pb was observed in honey samples collected from locality close to Vancouver's main shipping port in comparison to rural areas which might be caused to shipping emissions from the port (Skorobilowicz, 2018). Moreover, local Pb isotopic compositions and gradients in honey associated with human activities throughout the world was presented in a recent report provided by Smith et al. (2021) which can be utilized in future studies for estimation of Pb contaminations in several places. When newly constructed hive combs were compared to that of old reused combs it was seen that reused combs had higher lead composition (Gajger et al., 2019).

Again, beehives which were exposed to higher agricultural or industrial activities contained highest amount of Pb and Cu (Gajger et al., 2019). In a study of heavy metal prevalence in relation to seasonal variations, it was seen that Cu content was highest in summer (Skorobilowicz et al., 2018). Cu content in bees from urban areas were higher as compared to that of farmlands and forests (Roman, 2003). Similar results were also seen in test bees from Bulgarian city Stara Zagora (Zhelyazkova, 2012). This result coincided with a study conducted in Siberia also (Zari'c et al., 2016). The increase in copper level in urban areas can be explained with the prevalence of heavy traffic and industrial activity. The main source of copper in urban areas is the use of frequent breaks in vehicles of urban environments (Li et al., 2001).

In the seasonal study, the average concentration of Cr was highest in June and lowest in September (Skorobilowicz et al., 2018). Similar study was seen in a study of Italy's urban and rural areas (Perugini et al., 2011). Cr levels exceeded the threshold levels in seasons lacking rainfall (Cunningham et al., 2021). This was supported by other studies which revealed that rainy season reduces metal concentration in honey bees (Lambert et al., 2012; Zari'c et al., 2017; Satta et al., 2012).

According to Skorobilowicz et al. (2018) maximum concentration of Fe was recorded in June whereas lowest concentration was found in March. Similar results were found in several independent studies conducted in three Bulgarian regions (Zhelyazkova, 2012), Moldova (Eremia et al., 2010), Siberia (Zari'c et al., 2016). In Bialystok city, the apiary was located close to a small river where the bees collected water for maintaining hive thermoregulation. Since, iron is one of the most mobile elements it must have somehow contaminated the water body. Another possible Fe source in the city area must be coal combustion.

Zn content was also sampled with highest concentration in the month of June. Similar observations were made in studies performed by Eremia et al., (2010), Zhelyazkova (2012) and Zari'c et al., (2016). On the survey of Northern Iraq Zn was recorded to be maximum in Duhok/ Ahmed/ Gri village whereas minimum value was recorded in Duhok/ Akre. This little amount of Zn explained that the pollen samples were collected from apiary located far away from human residence (Hussein et al., 2024).

Just like other studied metals in seasonal data the highest content of Mn was observed in the month of June while the lowest amount was sampled in March. Similar results were also observed in surveys carried out in vicinity of Stara Zagora city (Zhelyazkova, 2012) and Siberia (Zari'c et al., 2016). The possible source of Mn in these collected samples of nearby apiary must be from transport and coal combustion. A similar conclusion was drawn from the study conducted in Duhok which is situated close to the highway (Hussein et al., 2024). Overall results from several studies conducted throughout the world showed that Pb, Zn, Cu, Fe, Mn, Cr in bee products were highest at urban or semi urban sites and lowest at rural areas (Hussein et al., 2024). (Table 4).

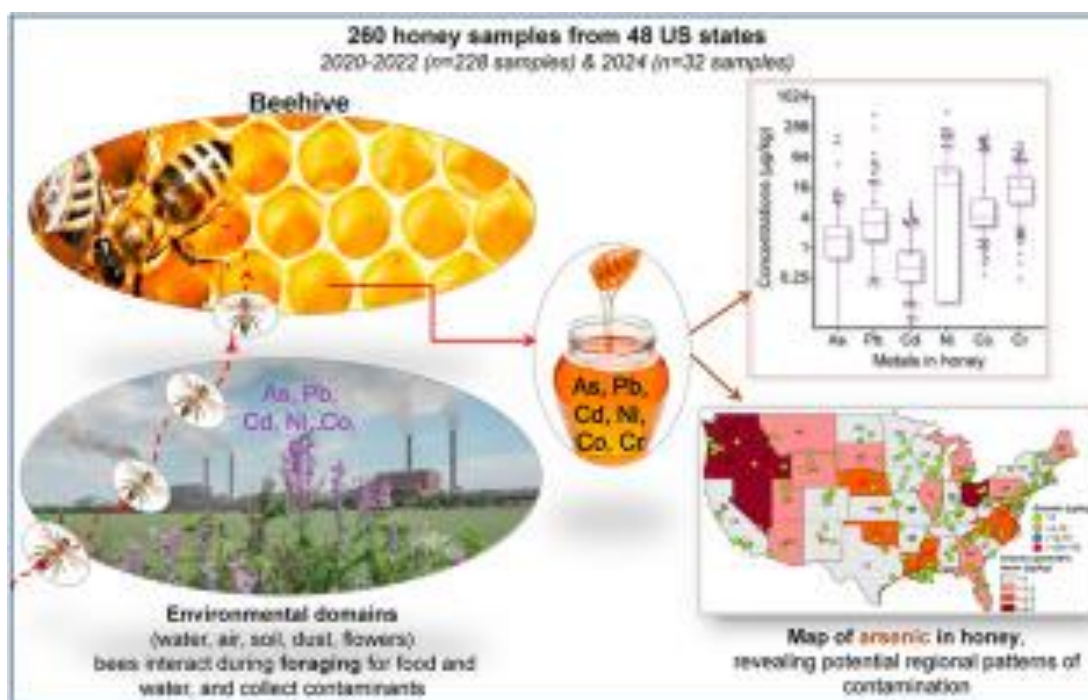


fig. 3: Honeybee products serve as bioindicator of heavy metal Contamination
source: (Godebo et al., 2025)

Table 4: detection of heavy metals through honey bees and their findings

Heavy metal	Analysis	Source
Cr, Pb, Cd, Hg	Urban areas showed higher incidence	Perugini et al., 2011
As, Cd, Pb	Higher in agricultural fields	Balayiannis and Balayiannis, 2008
Pb, Cr, Hg, Cd	Seasonal fluctuation was observed	Conti & Botrè, 2001
Zn, Pb, Cd	Urban area highly contaminated	Skorbiłowicz et al., 2018

2.1.2. Microplastics:

On the 21st century plastic pollution has been a rising concern but this concern was initially focused on visible plastic contamination which accumulated in our environment. But now global concern has been increasingly shifted towards hazardous effects caused by microplastics. Microplastics (MPs) are small, 1µm to 5 mm sized particles which remains suspended in air, soil, water, food and human resources (Basaran et al., 2024). Primary MPs are produced from commercial sources whereas secondary MPs are produced through environmental degradation of larger plastic particles (Edo et al., 2021).

As MPs are small in size, mobile and persistent in environment for longer time they pose a high risk by infiltrating biological systems and entering food chain (Martin Gomez et al., 2024). These MPs even contaminate edible plants which serve as food source for humans (Li et al., 2020). MPs not only infiltrate food chain but also enter into the life of honeybees and its products (Naggar et al., 2021). This vast distribution of MPs in ecosystem has led it to be referred as “contaminants of emerging concern” and “everywhere chemicals” (Liu et al., 2021; Vighi et al., 2023).

As honeybees forage over long distances by interacting with all environmental factors (Martin Gomez et al., 2024) and anthropogenic sources (Papa et al., 2024) they serve as natural vectors of environmental pollution (Fuente-Ballesteros et al., 2025). FITR images showing microplastic residues on bee body parts are shown in *pic. 2*. Detection of microplastics through several bee matrices are shown in *Table 5*.

Though MPs are believed to have limited impact on honeybees according to recent studies but it can induce a range of sublethal effects (Ferrante et al., 2024; Bashir et al., 2024; Shavali Gilani et al., 2025). Some impacts include restricted growth, abnormal genetical effect on immunity and detoxification, altered oviposition and foraging behaviour, endocrine disruption, morphological abnormalities, increased contaminants toxicity (Alma et al., 2023). However, these impacts widely depend on the specific type of MP polymer incorporated. This diversification in toxicity is mainly caused due to the variety of additives used in plastics as well as factors including particle size and shape (Fuente-Ballesteros et al., 2025). (*fig. 4*).

In a study of using honey as bioindicators of microplastic pollution with special insights into industrial and special honey types Bilecen and Altunışık (2026) it was seen that among 93% of the honey samples analyzed MPs were detected Detection by FITR showed that the abundance of MPs in industrial honey was significantly greater in special honey than industrial honey. This study also demonstrated that EVA was the most dominant polymer, followed by PET, PE, HFFR and PA. In spite of MPs being more abundant in special honeys as compared to industrial honey, there is no such difference of size distribution in MPs within both the honey types (Bilecen and Altunışık, 2026).

Enivornmental factors such as industrialization, tourism and population density have a high impact on the abundance of MP levels within honey (Edo et al., 2021; Altunışık et al., 2025; Borges et al., 2024; Toussaint et al., 2019; Gilani et al., 2025). In a study predominance of fragments over fibers were seen in honey samples which suggested contamination due to processing equipment, packaging procedure, environmental deposition and most importantly beekeeping practices (Bilecen and Altunışık, 2026). This hypothesis is supported by the presence of higher levels of EVA and PET polymers. Again, the higher abundance of MPs in special honey as compared to industrial honey can be explained by the use of less standardized processing, diverse packaging materials and potential contaminations during harvesting and storage practices in case of special honey. The predominance in EVA and PET in the samples studied by Bilecen and (2026) suggested MP contamination because of packaging related issues which coincides with findings from Turkey and Kosovo where food-grade plastics were the major sources of contamination (Basaran et al., 2024; Özçifçi et al., 2025).

All these findings demonstrate the vitality of using honey bees as monitoring tools on a global scale to raise consumer awareness and minimize too much plastic usage during processing and packaging (Kumar et al., 2025). These efforts can be brought into result by incorporating glass or stainless steels equipment in apiary practices. Minimizing plastic usage can potentially reduce contamination issues. Food safety and consumer trust can be improved by incorporating standardized guidelines in food processing and packaging industries.

Mechanism and key results of microplastics in honey

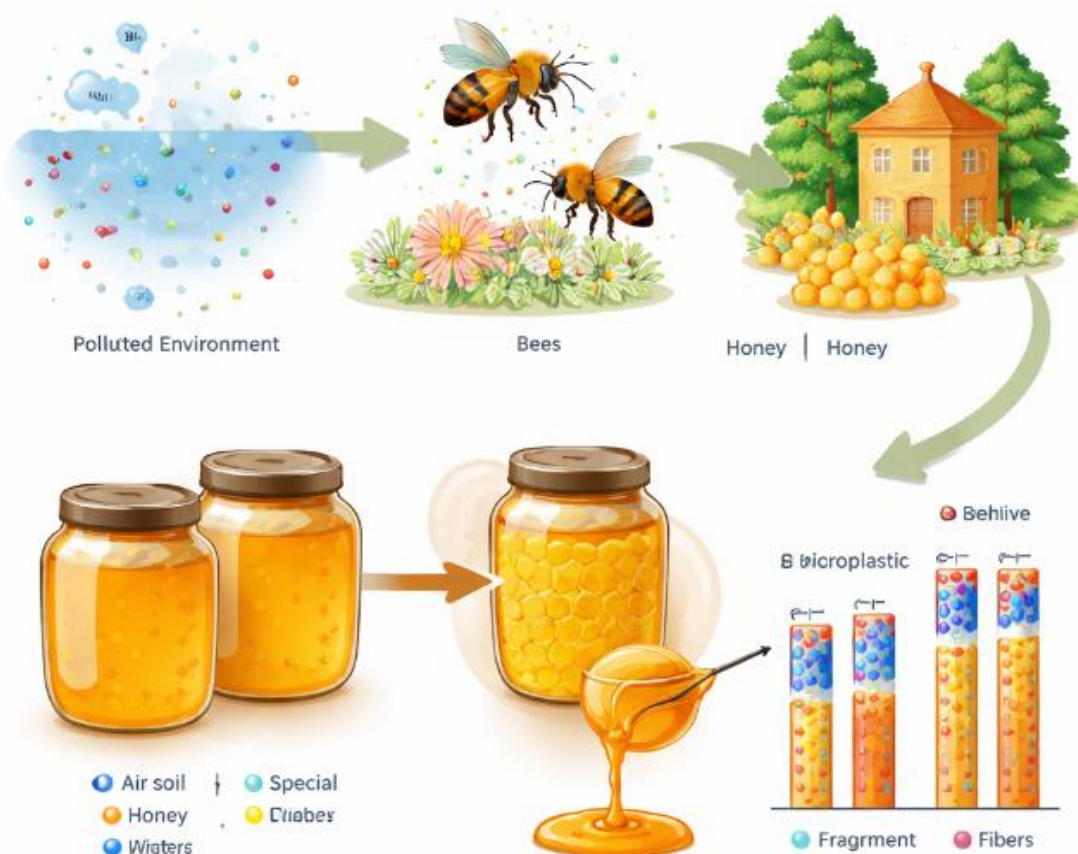
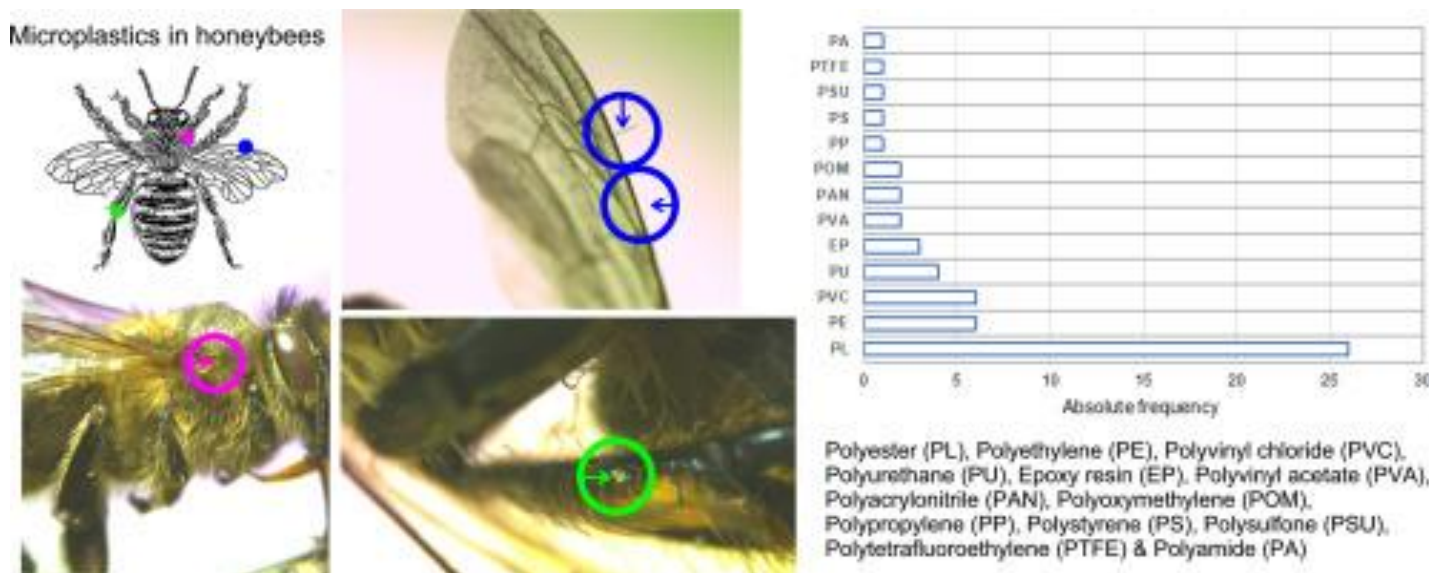


fig. 4: honey as a bioindicator of microplastic contamination

source: <https://www.clearskyscience.com/en/10.1038/s41538-026-00720-y/graphic2.png>



pic. 2: ftir images showing microplastic residues on bee body parts

source: (Edo et al., 2021)

Table 5: detection of microplastics through several bee matrices

Component	Matrices	Source
Microplastics	Body hair, honey, pollen	Edo et al., 2021; Martin-Gomez et al., 2024; Özçifçi et al., 2025
Bisphenols	Honey, pollen, royal jelly	Zhang et al., 2021; Zhou et al., 2019
Plasticizers	Pollen, honey, royal jelly, propolis	Zhou et al., 2019

2.1.3. Persistent environmental pollutants

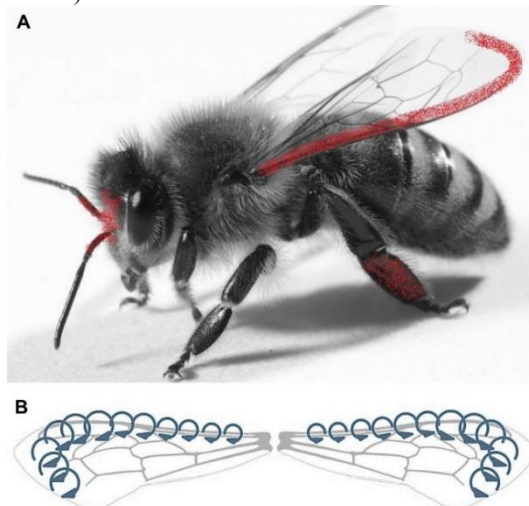
Air pollution caused by persistent chemicals and airborne particulate matter poses significant health risk such as respiratory diseases, lung cancer and other chronic diseases (Dockey et al., 1993; Bala et al., 2021). Among the most concerning pollutants are Persistent Organic Pollutants (POPs) which can travel long distances in air or water and even resist degradation for longer periods of time within the environment (Wania and MacKay, 1996; Ma et al., 2011).

The use of honey bee and their hive matrices prove to be very much effective in measuring two major classes of POPs: polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Tulini et al., 2020; Villalba et al., 2020).

PCBs are a group of environmentally persistent synthetic organochlorines which are released from burning of municipal waste, contaminated water bodies and most importantly from old electrical equipment in landfills (Faroon et al., 2003). These PCBs concentrate in human bodies and cause immune system dysfunction, cardiovascular diseases, cancer (Carpenter, 2006). Recent studies revealed that PCBs accumulate in honey bees, honey and to a lesser extent in pollen (Cunningham et al., 2022). PCBs are less soluble in water and not readily absorbed within plant vascular tissues. For this reason, their concentration is low in pollen. Thus, pollen measurements generally represent PCBs on the pollen surface (Roszoko et al., 2016; Sari et al., 2020). According to Cunningham et al. (2021) PCB content was highest in forager bees during warm dry weather. This is mainly caused due to evaporation of PCBs from soil and high incorporation into air (Sari et al., 2020).

Another major group of POPs is polycyclic aromatic hydrocarbons (PAHs) which are found in gasoline, crude oil and coal (Lag et al., 2020). Source of PAH emissions include vehicular emission, fumes from asphalt roads, cement production industry and iron-steel manufacturing industry (Control for Disease Control, 2017). In humans these toxic compounds are considered to be carcinogenic and can also irritate the eyes as well as affect lungs (De La Torre-Roche et al., 2009). In a study PAH levels were examined in pollen, honey and bees in French apiaries (Lambert et al., 2012). It was demonstrated that bees were the best agents for measuring PAH contamination level and that the concentration of PAHs depended largely on the apiary location. PAH sources, such as petrol or diesel emissions could be calculated by measuring honey's PAH content which was proved in a survey conducted across Lebanon (Al-Alam et al., 2019). The PAH concentration on honey is largely correlated with anthropogenic factors as higher levels of PAHs are present in densely populated areas in comparison to less dense regions (Cunningham et al., 2021).

Pollution caused by particulate matter can act as catalyst for change in climatic conditions (Seaton et al., 1995; Kyotani and Iwatsuki, 2002). To identify target areas where remediation efforts are necessary, measurement of persistent chemicals and air pollutants in bees and hive matrices prove to be very much fruitful (Cunningham et al., 2021). (*pic.3* shows accumulation air borne particulate matters in different body parts of bee).



Pic. 3: A) accumulation of air borne particulate matter observed along the medial plane of head, coastal margin of forewings and inner surface of hind legs.

B) fore wings' leading edge showed presence of LeadingEdgeVortex (LEV)

source: (Negri et al., 2015)

2.1.4. Pesticides:

Another major environmentally persistent contaminant which proves to be hazardous for humans as well as pollinators is agrochemical pesticides. Due to the variety of bee related testable matrices, sensitivity of individual bee and rapid recovery of community, bees are widely used as bioindicators of pesticide pollution (Balayiannis and Balayiannis, 2008; Ruschioni et al., 2013; Bargańska et al., 2016; de Oliveira et al., 2016). Again, honey bees tend to overlap with other bee species and insect pollinators during their flights. This quality enables the opportunity for getting information about contamination incorporation level within other species (Paini, 2004; Quigley et al., 2019; Bishop et al., 2020). (*fig. 5*).

One remarkable research in this field was run in the early seventies to determine the effect of Endosulfan, a chlorinated hydrocarbon insecticide on foraging bees. According to Giordani et al., (1978) Endosulfan proved to be highly toxic to the bees which spread not only through contact but also through ingestion of contaminated nectar. This critically increased the risky period of the bees. The main objective of this research was to create a stricter regulation on pesticides and lead legislators for decrementing pesticide's toxicity towards these beneficial pollinators of our ecosystem.

Another worldwide used insecticide is neonicotinoids (Simon-Delso et al., 2015). Several studies showed that this class of insecticide can destroy bee colony and also impact immunity, memory and foraging activities of bees (Wu et al., 2011; Scheidner et al., 2012; Tsvetkov et al., 2017; DesJardins et al., 2021; Tosi et al., 2021). (*Table 6*).

Lethal levels of pesticides can utilize bees as indicators of extreme stress. However, this stress doesn't cause bee colony collapse and thus bee along with their associated matrices can be utilized for long term studies. In northern Italy a largescale monitoring project was run from 1983 to 1986 in which hundreds of monitoring stations were installed. Each sampling station consisted of two hives situated at different places. One hive was located in the center of the sampling station which was more or less intensively farmed and thus under constant chemical pressure. Another hive was positioned near the periphery i.e., low contamination zone. Each hive had a gray cage for collecting dead bees. Whenever the count of the dead bees crossed the threshold of 500-700 individuals per station per week then the dead bees were analyzed. The number of pesticides peaked at 581 during the years from 1983 to 1986. It was possible to determine the molecules responsible for bees' death in about 76% of the instances. The responsible compounds responsible for these mass deaths were recorded to be parathion (15%), dimethoate (15%), zinphos-methyl (12%), carbaryl (11%), methyl-parathion (10%) (Celli et al., 1988). Among 70% of the deaths dithiocarbamateS were frequently detected. These significantly ubiquitous fungicides were listed as most hazardous compounds in the U.S academy of sciences report of 1987 (Triolo, 1988).

As many as 120 active ingredients of agrochemicals were found to be present in bee's pollen from a U.S study (Traynor et al., 2021). This indicated the ability of using bee-collected pollen as an efficient bioindicator. Measurement of the pesticides depends largely on the chemical nature of pesticide being detected and utilization of specific hive matrices for indication. In a survey done by Neill et al. (2017), number of forager bees actively involved in transfer of three most abundant nicotinamides (acetamiprid, imidacloprid, thiamethoxam from soyabean crops to colony was measured. He also investigated the amount of accumulation of these toxic compounds within hive matrices: pollen, honey and beeswax. Beeswax contained all three nicotinamides. Though, transfer ratio of thiamethoxam was highest and transfer ratio of acetamiprid was lowest, which might be due to high volatility nature of acetamiprid (Neill et al. 2017).

In another study, it was seen that beeswax contained the highest concentration of agrochemicals whereas the greatest diversity of insecticides was found in pollen (Calatayud-Vernich et al., 2018). It was also demonstrated that pesticide concentration in pollen was much higher in intense agricultural fields compared to rural or grassland areas. This vitalized the use of pollen in monitoring spatial differences in environmental pesticide pollution (Calatayud-Vernich et al., 2018). A great discovery in this field is the utilization of non-biological in-hive strip for passive sampling of pesticides in honey bee colonies (Murcia-Morales et al., 2020).

All these approaches can be used for determining the negative impacts caused by pesticides in pollinator health or creating toxic conditions for humans. Potential indicators of pesticide pollution can be used to quantify the effect on human, animal and ecosystem health, and also integrated as part of One Health Approach (Martinello et al., 2021).

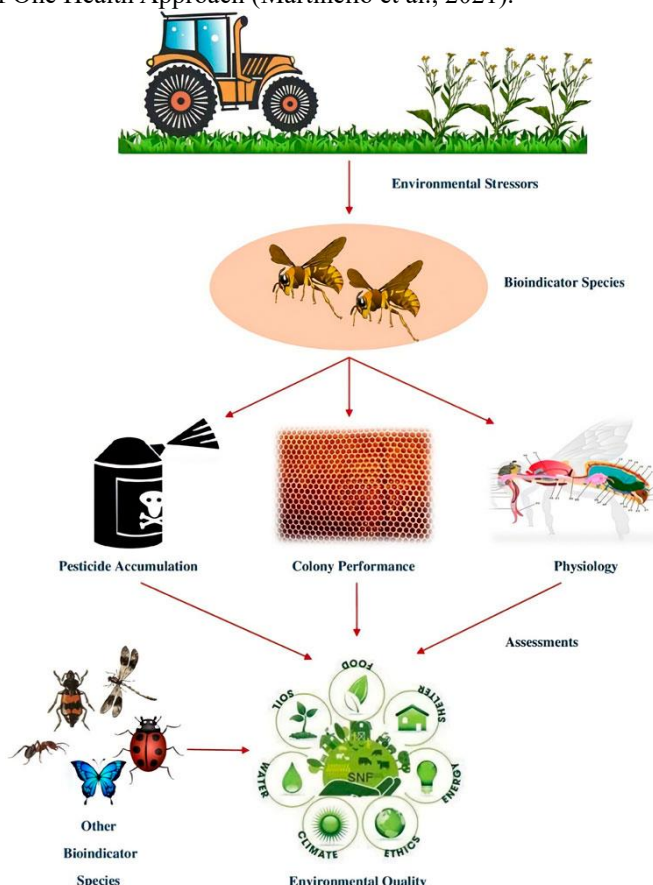


fig. 5: honeybee as bioindicator of pesticide contamination

source: (Chowdhury et al., 2023)

Table 6: detection of pesticides through honeybees

Pesticides	Country	Source
Neonicotinoids	USA, Canada	Traynor et al., 2021
Fungicides	USA	Des Jardins et al., 2021
Organophosphates	Italy, Spain	Calatayud-Vernich et al., 2018; Martinello et al., 2020

2.1.5. Pathogens:

A variety of bacterial, fungal and viral pathogens significantly affect agricultural plants. These pathogens can pose severe challenge to the economy by declining crop yields. Pathogens associated with plant diseases are easily transmitted by horizontal as well as vertical transmission. In this transmission, honey bees play a pivotal role while performing their foraging flight (McArt et al., 2014; Patemore et al., 2014). Till date there are as many as 45 viruses of genera *Tobamavirus*, *Ilarvirus*, *Nepovirus*, *Sobemovirus*, *Idaeavirus* which are transmitted through pollen (Levitzky et al., 2019; Bhat and Rao, 2020).

In plant surveys, modern techniques such as PCR or ELISA need to be used (Roberts et al., 2018; Beaver-Kanuya and Harper, 2019). Since, the cost and complexity of these techniques are very high honey bees can provide distinct advantage over these conventional methodologies. Again, collection of pollen pellets from honey bee colonies is very simple which makes this biological technique a very effective sampling device (Tremblay et al., 2019). Colonies of *Apis mellifera* might contain 20,000-50,000 foragers that act as biosurveillance tools by foraging over long distances around their hives and collecting affected pollen from a large variety of species in a very short time span (Michener, 1974; Greenleaf et al., 2007). To reduce the quantity of samples usually needed to survey plant pathogens and for early detection, bees and bee collected samples can be widely used (Roberts et al., 2018; Tremblay et al., 2019). Actively pollinating plants of bees such as corn, rice etc. can be effectively monitored for presence of pathogens (Malebro-Souza, 2011; Roberts et al., 2018; Pu et al., 2014). Furthermore, the virus reservoirs and transmission pathways in managed and non-managed plant species can be monitored with the involvement of using honey bees as biomonitor.

In a survey conducted on pooled honey bee samples from commercial hives two plant viruses namely, cucumber green mottle mosaic virus (CGMMV) and Tomato Ringspot virus (ToRSV) which were not detected by conventional screening methods at that time. The researchers suggested that undiscovered exotic plant viruses can be detected by performing high throughput sequencing (HTS) on pooled samples of honey bee. Thus, plant biosecurity programs can be improved by utilizing honey bee assisted surveying (Roberts et al., 2018). Greenhouses have longer pollination windows which can employ bees to pollinate on the crops. This greenhouse sector has a high potential to frequently utilize bees for pathogen detection. Two major greenhouse vegetables affected by tobamovirus infections (tomato brown rugose fruit virus, ToBRFV) are tomatoes and cucumbers. This was first detected in 2014 in Jordan. Later it spread worldwide. Pollen transmitted infections such as CGMMV and ToBRFV (Liu et al., 2014; Levitzky et al., 2019) can cause wide level destruction of crops. To check this bee-based bio surveillance within greenhouses is very much essential.

Honey bees are also utilized for detecting pathogens affecting other bee species. When healthy forager honey bees forage on flowers that have earlier been visited by diseased bee of same or other species, this disease can spread to the wild through the healthy bee. This mechanism helps in assessing disease prevalence between managed and wild honey bees (Grassl et al., 2018; Di Prisco et al., 2016). In a study, honey bees with deformed wing virus (DWV) was found to be infected by viral and fungal pathogens (de Sousa Pereira et al., 2019). In other studies, DWV in bumble bees has been correlated with that in honey bees (Fürst et al., 2014; Manley et al., 2019). For this reason, honey bees can be used as bioindicators for detecting pathogen prevalence in a local environment and determine when surveillance of other pollinator species is required.

3. SENSITIVITY TO CLIMATE CHANGE AND ANTIMICROBIAL RESISTANCE

A variety of animals ranging from humans to honey bees are affected by climate changes (Luber and McGehehin, 2008; Switanek et al., 2017). Since, honey bees are social insects they are less adversely threatened by climate change in comparison to solitary species. They can maintain constant hive temperature which ensures colony survival during winter (Fahrenholz et al., 1989). However, wide fluctuations in global temperature can disrupt survival, growth and homeostasis of honey bee colonies. Not only that, the overall reproductive output of honeybees are also reduced due to extreme weather conditions (Hansen, 2009; Zeh et al., 2012; Sales et al., 2018; Walsh et al., 2019). Studies revealed that honeybees grown in high as well as low temperatures under laboratory conditions showed reduction in fertility (Pettis et al., 2016; McAfee et al., 2020). Measuring specific biomarker proteins such as HSPs and changes in queen's reproductive success can be used for biomonitoring temperature fluctuations in different habitats (McAfee et al., 2020). Another study revealed that amount of stored honey and bee bread, hive weight, adult populations are decreased due to increased heat (Flores et al., 2019).

A rising concern in agriculture and medicine is antimicrobial resistance (AMR). AMR bacteria have a wide range of hosts such as plants and animals including humans. As honeybees carry AMR genes they may serve as essential indicators of AMR genes' prevalence in the environment (Cunningham et al., 2021). (fig. 6). Analysis of honey bees collected from 35 different sites in Umbria showed AMR genes against antimicrobials generally used in human and animal medicines (Cenci-Goga et al., 2020). Piva et al. (2020) in a different study observed the prevalence of AMR in Enterobacteriaceae which was isolated from the gut of honey bees of different locations. Thus, the presence of AMR genes in honey bees suggest their environmental origin which suggests the usefulness of honeybees as potential monitors of environmental AMR (Piva et al., 2020).

ANTIMICROBIAL RESISTANCE GENES (ARGS) MONITORING AND GUT MICROBIOTA PROFILING IN HONEY BEES FROM AN INTENSIVE LIVESTOCK FARMING AREA

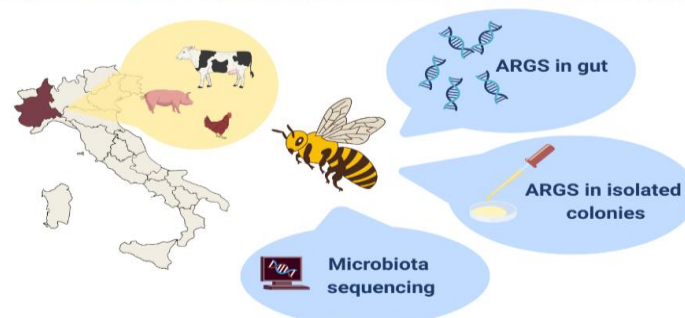


fig. 6: detection of amr genes in bees
source: (Oliveria et al., 2026)

4. KNOWLEDGE GAP

The role of honeybee as bio indicators of our ecosystem health is undeniable, but the question still remains: which body part of bee must be utilized for a specific study? Despite advances in research the answer to this question still remains unanswered. External contaminants can accumulate in wings and legs whereas internal contaminants accumulate in intestinal tract which indicates ingestion. Full body homogenates might increase the sensitivity of a test but the specificity of the route of exposure might be reduced. Again, stored hive products may serve as indirect indicators of environmental contamination. Thus, for the study of a particular environmental problem not only bees' body parts but also the surrounding environment is analyzed by researchers (Fuente-Ballesteros et al., 2025).

There is a clear gap of evidences where bees can be used as bio monitors throughout the whole year as studies are mostly conducted during the active foraging period of honey bees. Specially, the unavailability of utilizing bee hive matrices for several studies during winter season identifies the lack of knowledge in this field. Again, use of alternative bee matrices, such as bee bread is also under studied (Mair et al., 2023).

Multidisciplinary studies including involvement of industries, policymakers and scientists can effectively improve future studies.

5. CONCLUSION

Unique ecological and biological traits make honey bees effective proactive samplers for monitoring ecosystem health. Using honey bees as bioindicators provides a promising approach for continuous pollution monitoring and strengthening monitoring stations. The introduction of analytical techniques linked to bee matrices has facilitated the effective estimation of MPs, heavy metals, persistent environmental pollutants, pesticides and pathogens. However, there is a wide research gap in this field. This highlights the need to expand global research, standardize the use of honey bees in biomonitoring studies and foster interdisciplinary collaboration. These steps will not only improve our knowledge of environmental health but also help in developing widely applicable monitoring frameworks. This narrative review discusses a new perspective on the utilization of honey bees as active bioindicators, highlighting their ecological role and future potential within ecological assessment techniques.

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