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Research Article

Perceptions of farmers and government officials towards the effects of air pollution on honey bees in Bhutan

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Abstract

Bees interact with the environment, mainly the atmosphere, during foraging, and collect a wide range of airborne suspended particulate matter. Integrating beekeeping into farming operations is an important initiative for improving livelihoods, but little is known about the perceived impacts of air pollution on honey bees in Bhutan. This study aims to examine the perspectives of Bhutanese farmers and Department of Livestock (DOL) officials on the effects of air pollution on honey bees. $PM_{2.5}$ concentrations of Thimphu from 2018 to 2024, collected by the National Environment Commission (NEC) and made available by the National Statistical Bureau (NSB) were utilised for the data analysis. Questionnaire survey was undertaken from 85 farmers and 85 DOL officials to acquire information on air pollution and its impact on bees. Between 2018 and 2024, $PM_{2.5}$ concentrations revealed a twofold rise, with levels above the WHO 2021 Air Quality Guidelines (AQG) of 5 µg/m³, indicating a continual worsening in the quality of the air in Thimphu as well as in Bhutan. Almost 55% of farmers and DOL officials reported an increase in air pollution, while 48% indicated a decline in Bhutan's bee populations over time. It was found that 77% of the respondents felt that bees and bee products are negatively impacted by air pollution. Similarly, 61% believe that apiculture will reduce rural-urban migration in Bhutan. Re-enforcing current laws and regulations is necessary to reduce air pollution and its impacts on honey bees in Bhutan.

Keywords: Air pollution impact, apiculture, Bhutan, honey bees

Introduction

Bhutan possesses exceptional beekeeping potential relative to other countries, attributed to its 69.8% forest coverage and extensive variety of flowering plants (MoAF, 2020). With such richness and diversity, the floral species, Bhutan has the potential to become a veritable land of honey (Bhujel, 2022; MoAF, 2020; Sherpa, 2020). Among honey bee species, namely *Apis cerana* and *Apis mellifera* species are managed in the traditional and modern hives while many exist in wild state in Bhutan (NBC, 2017). The apiculture developmental in Bhutan, however, have faced multiple constraints and challenges and some of these are weak institutional linkages, low adoption of improved technologies, indiscriminate use of pesticides and weedicides in agriculture, high rate of pests and predation, and air, water and soil pollution (MoAF, 2020). However, earlier studies revealed that bees face several difficulties, including those related to agrochemicals, and contaminants that may have an impact on honey quality (Balos et al., 2021; Christen et al., 2019; Mayack et al., 2023). When there is poor air quality, honeybees find it difficult to find sources of nectar and pollen, which reduces their productivity (Cunningham et al., 2022; Puiu, 2016; Thimmegowda et al., 2020;). It is ascertained that air quality is a significant predictor of honeybee mortality (Coallier et al., 2025).

Open fires at building and road construction sites, burning of household and agricultural waste, wind-blown dust from unpaved roads, emissions from petrol and diesel vehicles, wood-burning stoves and forest fires are the main causes of air pollution in Thimphu, however, there are very few quantitative studies on the sources of these emissions (Dorji, 2019; NEC, 2010; NECa, 2020). In rural areas of Bhutan, household air pollution from cooking with firewood adds to outdoor air quality that often exceeds WHO standards (Dendup et al., 2022; IRENA, 2019; NECa, 2020; Wangchuk, 2017). Because of its complexity and small size, $PM_{2.5}$ is more damaging than PM_{10}, which can cause respiratory and cardiovascular diseases (WHO, 2016). In Bhutan, the prevalence of respiratory and cardiovascular disorders has increased over time (MoH, 2020; NSB, 2023; UNDP, 2018).

Rising levels of air pollution may have effects on honeybees and their products in both the rural and urban areas in Bhutan. It is widely acknowledged that honeybees may play an important role in crop pollination, considerably enhancing agricultural yields while also supplying beneficial products such as honey, beeswax, pollen, and propolis (Devkota, 2020; Isaacs & Kirk, 2010). Due to the direct involvement in beekeeping, DOL officials and beekeepers in Bhutan are especially concerned about the health and welfare of the bees as well as the environment in which they forage. Hence, the perspectives and opinions of local beekeepers and DOL officials were collected in order to find out unknown impacts of air pollution on bee status. Indigenous beekeepers are well-known due to their wealth of local knowledge, perspectives, records, and

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expertise (Potts et al., 2016). This study, the first of its kind in Bhutan, intends to examine the perception of air pollution and to discuss its effects on honeybees based on the perspectives of the Bhutanese farmers and DOL officials.

Materials and Methods

Air pollution data acquisition

$PM_{2.5}$ concentrations of Thimphu town from 2018 to 2024 collected by NEC was used for the analysis. To date, comprehensive data collection on air pollution in other districts besides a few districts in Bhutan is lacking. The NEC maintains several air pollution monitoring stations in urban areas of Bhutan, but long-term data availability and analysis are still erratic. Due to inadequate human resources, current air pollution rules and follow-up procedures are not adequately followed (Kunzang, 2015, NEC,2016; RGoB, 2021). Thimphu District lies in the western part of Bhutan (Fig. 1). Regular air quality monitoring started more than ten years ago in Thimphu city in the Thimphu District (Fig. 1), Thimphu has experienced increased air pollution due to its rising population and vehicle density. Pollution in Thimphu is caused by the large number of vehicles, car workshops, small industries, and wastewater treatment facilities to name a few (NEC 2016; MoWHS, 2008). As such, other districts in Bhutan are anticipated to have lower air pollution levels than Thimphu District.

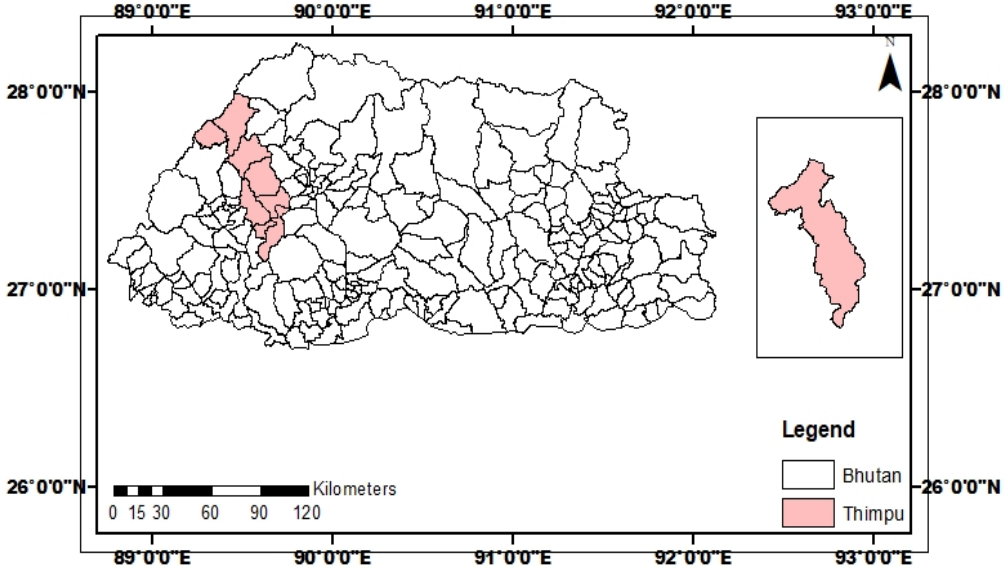

Figure 1. Systematic particulate matter data collection in Thimphu District

Methods of survey

In Bhutan, some farmers raise bees in addition to other agricultural pursuits. To determine their perceptions on bees and air pollution in Bhutan, 85 farmers and 85 DOL staff members were randomly selected for the questionnaire survey. DOL extension agents communicated to contact farmers and arranged interviews. The farmer group responders were primarily from districts where bee farming is widespread, such as Bumthang, Thimphu, Haa, Samtse Chukha, Sarpang, Samdrupjongjonkhar, Tsirang and Dagana. At least one farmer from each district of Bhutan responded to the questionnaire survey. Nearly every district had a DOL official representation in the poll, with at least two responders per district. Although most responders completed the questionnaire, some farmers were illiterate, thus the surveys were completed in person. The questionnaire consisted mainly of close-ended questions. Verbal consents from respondents were obtained before starting the survey. Data obtained were utilized only for the purposes of this study, and participants were ensured the confidentiality of their information. Permission to conduct field surveys was also obtained from Bhutanese Government (Applicant ID: 164121115862B57625C5E74 dated 2022-06-29).

Statistical analysis

Both descriptive and inferential statistics were used for the analysis. Chi-squared test was performed to comprehend the status of response given to bee populations by farmers and DOL officials. Perspectives on the quality of the air, now and five years ago, impact of air pollution on bees, and DOL officials and farmers' combined responses on air pollution and beekeeping were explained using the Likert scale. Graphs and charts were used to explain farmers' and DOL officials' perceptions on air pollution causes, air pollution effects on human, awareness creation on beekeeping, strength and weakness for beekeeping, and existing information dissemination methods.

Results and Discussion

Annual $PM_{2.5}$ over recent years

Thimphu recorded annual mean $PM_{2.5}$ readings of different years higher than 5 μg/m³ WHO 2021 guidelines (Table 1). The $PM_{2.5}$ concentrations of 14.23 μg/m³ and 16.21 μg/m³ in 2020 and 2021 were very low

due to Covid-19 lockdowns in Bhutan. The concentrations of $PM_{2.5}$ in 2022 was 19.43 µg/m³, which revealed again upsurge in $PM_{2.5}$ when lockdown was lifted (Table 1). In 2018, the $PM_{2.5}$ level was 15.92 µg/m³, and by 2024, it was 32 µg/m³, demonstrating that air quality in Bhutan is continuously deteriorating. In comparison to neighboring cities, Guwahati in the east and Gangtok in the west had $PM_{2.5}$ readings of 50.63 µg/m³ and 29.27 µg/m³, respectively (IQAir, 2023). In Thimphu, $PM_{2.5}$ concentrations in winter months (December, January, February, and March) consistently exceeded Bhutan's 40 µg/m³ threshold (NECb, 2020; NSB, 2021; NSB, 2023). Transboundary air pollution, temperature inversion, and firewood burning for heating in some houses contribute to increased particulate matter concentrations in Thimphu District during the winter months (Saikawa et al., 2019; Sharma et al., 2022). The second most significant risk factor for poor health in rural and urban parts of South Asian countries, including Bhutan, is exposure to air pollution (Jabbar et al., 2022). According to studies, air pollutants, particularly $PM_{2.5}$, can worsen air quality, raising the risk of respiratory and cardiovascular diseases, as well as mortality (Kulshrestha, 2018; Miri et al., 2016; WHO, 2021).

Table 1. Thimphu city annual mean $PM_{2.5}$ concentrations from 2018-2024

Year	$PM_{2.5}$ (µg/m³)	Ratio of $PM_{2.5}$ to WHO 2021 AQG
2018	15.92	3.18
2019	16.95	3.39
2020	14.23	2.85
2021	16.21	3.24
2022	19.43	3.95
2023	11.00	2.20
2024	32.00	6.40

(Source: NSB , 2022; NSB, 2023; NSB, 2025; Sharma et al., 2024; WHO 2021)

Perceptions on air pollution and bees by farmers and DOL officials

Comparing air quality now and five years ago

Bhutan is a world's first carbon-neutral country, but population growth, transportation, and construction activities all contribute to increase in air pollution. Figure 2 indicates that 46.5% of the participants thought that the quality of the air is slightly worse, whereas 8.4% thought that it is much worse. Only 19.4% of participants responded that there had been no change in air quality, whereas 25.9% reported that it has improved (Fig. 2). While comparing the concentrations of air pollution now with those from five years ago, 54.8% of the respondents claimed that the air quality has deteriorated (Fig. 2). The findings align with a study conducted by ICIMOD, which confirmed that air pollution in Bhutan is increasing (ICIMOD, 2019; NEC, 2016).

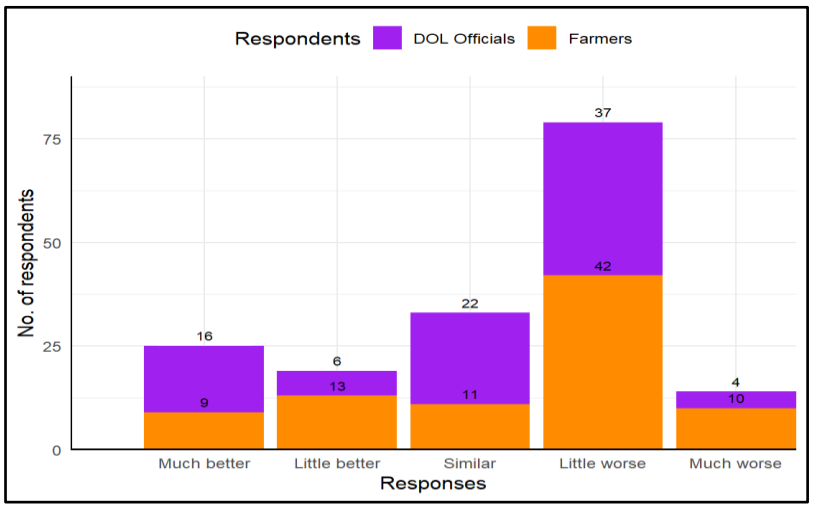

Figure 2. Respondents response towards air quality now and five years ago.

Causes of air pollution

Farmers and DOL officials identified construction, manufacturing, cooking and heating, power plants, waste burning, and transboundary air as the primary causes of air pollution, among others (Fig. 3). According to Romanello et al. (2024) residential buildings, industry, anthropogenic dust, agriculture, transportation, and waste are the main sources of particulate matter ($PM_{2.5}$) in Bhutan.

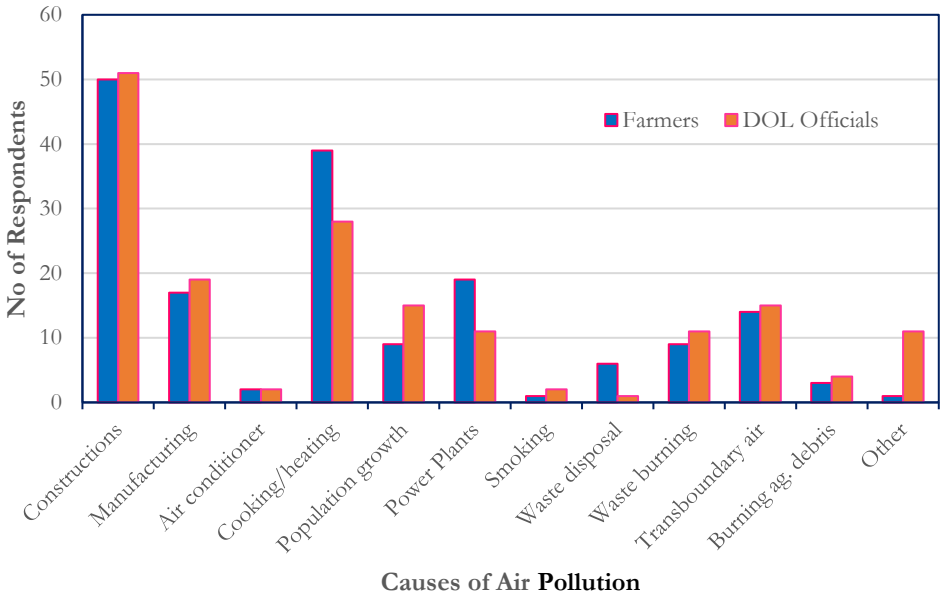

Figure 3. Causes of air pollution responses from farmers and DOL officials (*Note:* ag = agricultural)

During 2021, ambient air pollution was responsible for roughly 25% of particle air pollution ($PM_{2.5}$) deaths per 100,000 people in Bhutan (Romanello et al., 2024). Burning fossil fuels caused 28% of these deaths, coal burning alone caused 17%, and biomass burning caused 29% (Romanello et al., 2024). Sharma et al. (2022) reported transboundary air pollution as a contributing factor of air pollution in Bhutan, particularly during the winter and pre-monsoon seasons.

Air pollution impact on individuals

Considering the various effects of air pollution, responses of farmers' and DOL officials were essentially identical (Fig. 4). Most DOL officials and farmers who mentioned the negative effects of air pollution mentioned ENT irritation, depression, breathing difficulties, and concern for future generations (Fig. 4). Although air pollution in Bhutan is now minimal, there are numerous subtle consequences witnessed by the people, necessitating immediate action. With 770276 residents in 2023, Bhutan has a motor vehicle to population ratio of 164/1000 which is reportedly higher than that of other nations (DECC, 2023). As Bhutan's human population and number of cars increased, so was observed with air pollution, which has been associated with an increase in respiratory morbidity and mortality over time (DECC, 2023NEC, 2016). The occurrence of asthma, acute pharyngitis, tonsillitis, chronic obstructive pulmonary disease (COPD), cold, and other respiratory diseases in Bhutan has increased over the years (MoH, 2021; UNDP, 2018). Bhutan is committed to lowering its transport sector's dependency on fossil fuels and switching to more eco-friendly and alternative energy sources; however, implementation has not accelerated (RGoB, 2021).

Status of the bee populations in Bhutan

Bee populations around the world are declining due to variety of reasons (Christen et al., 2019). The study by Zattara and Aizen (2021) found that there was an almost 25% decrease in bee species between 2006 and 2015 compared to before 1900. Opinions were solicited from farmers and DOL officials to determine if bee population in Bhutan is decreasing, remaining the same, or increasing in comparison to five years ago. 40% of the farmers who participated in the survey reported that the bee population is declining, 40% reported that it is increasing, and 20% reported that there has been no change. According to DOL officials, the bee population has decreased by 56.5%, while 22% claimed an increase and 21.5% said there was no change. There was no association between type of response and category of respondents ($\chi^2_{df\,2,\ 0.05}$, p=5.15).

The variety and abundance of honeybee species in the Hindu Kush Himalaya are decreasing, which is having a detrimental effect on pollination (Partap et al., 2012). According to a study done in Jumla District of Nepal, 76% of beekeepers perceived a decrease in honeybees, and 86% indicated a decrease in honey production between 2012 and 2022 (Kortsch et al., 2024). The study demonstrated that Bhutan is not an exception to the

trend of declining bee populations. As a result, diminishing bee populations in Bhutan may eventually have detrimental effects on a range of crops, potentially reducing productivity, particularly in areas with high air pollution.

Effects of air pollution on bees

Of the total respondents, 51.8% stated that there is greater effect, and 21.2% stated that there is only slight effect of air pollution on bees (Fig. 5). It indicates that just over 77.1% of participants agreed that bee and bee products are adversely affected by air pollution.

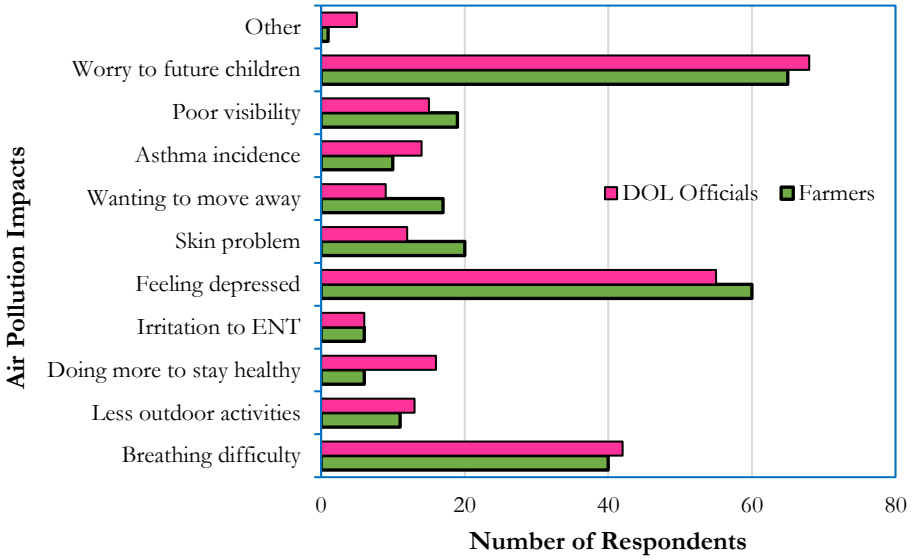

Figure 4. Impacts of air pollution on individuals

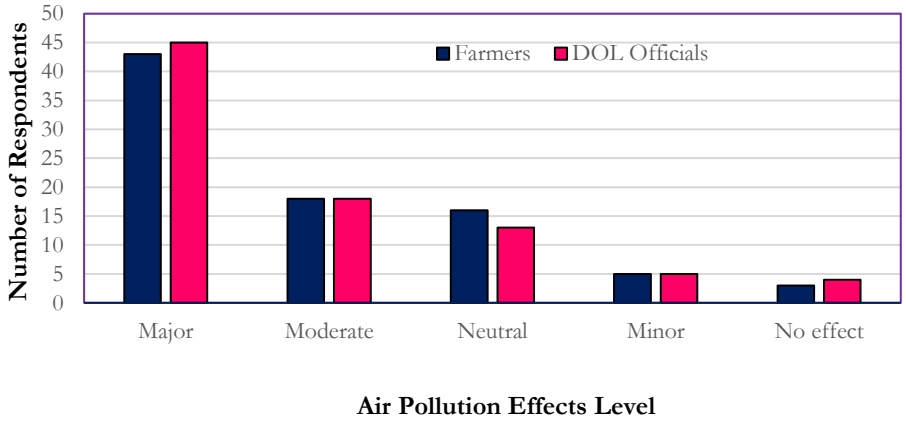

Figure 5. Effects of air pollution on bees

Of the responders, 17.1% expressed no opinion about how air pollution affects bees. Farmers and DOL officials provided practically identical assessments of the extent of the negative effects of air pollution on bees (Fig. 5). Numerous studies have proven that honey bees and their products are impacted by increased air pollution. (Leonard et al., 2019; Pellecchia & Negri, 2015; Porrini et al., 2002; Thimmegowda et al., 2020). Reductions in worldwide bee populations are endangering pollination benefits upsetting sustainable development of any nation (Patel et al., 2021). This makes it reasonably evident that air pollution is impacting bee populations in Bhutan which may affect the sustainable development.

Strength and weakness of beekeeping

The common resources necessary for establishing and raising bees are availability of floral species, technical inputs from extension agents, availability of hive materials, government incentives and market demand of honey. The increased demand for honey, as reported by 44% of respondents, is clearly the main strength of beekeeping (Fig. 6).

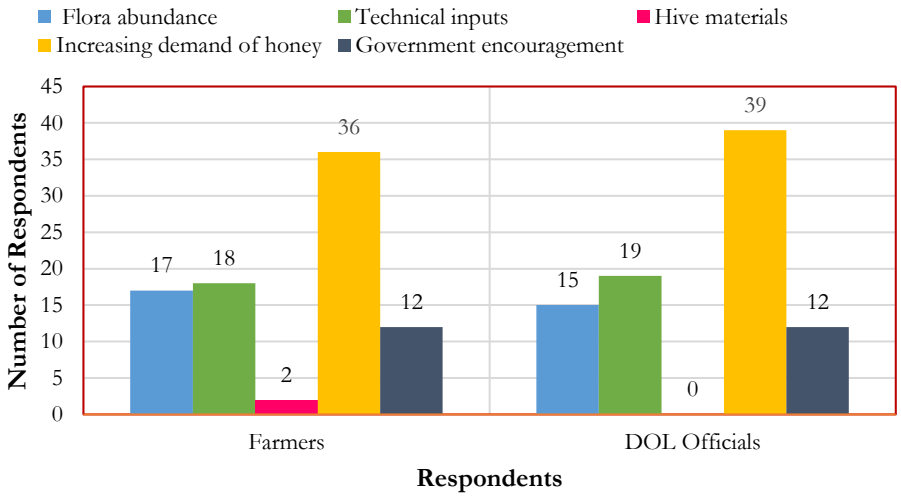

Figure 6. Strength and opportunities of beekeeping in Bhutan

Due to the extremely restricted supply of hive materials, the Department of Livestock of Bhutan may work with farmers and the wood-based industries to meet the demand. Though technology inputs and government support are available to beekeepers (Fig. 6), additional reassurance is required to ensure that locals stay in their communities, increasing revenue and reducing rural-urban migration (Bhujel, 2022; MoAF, 2020). Despite Bhutan's dense forests and plenty of flowering plants for bees, the forest is receding from communities where bees could not obtain enough nectar and pollen. Encouragement is required to cultivate a range of seasonal agricultural crops in farmer fields where bees may easily access them throughout the year.

Awareness creation on beekeeping

Farmers and DOL officials were interviewed on whether or not any organizations planned campaigns to raise awareness of beekeeping. 46% farmers and 53% DOL officials reported that beekeeping awareness campaigns were held to raise awareness and promote beekeeping in Bhutan (Fig. 7). However, 32% of farmers were unaware that programs to raise awareness were carried out. According to Devkota et al. (2022), creating awareness to the beekeepers and providing training can boost the honey production and incomes. Panchani et al. (2019) noted that apiculture is a highly lucrative enterprise that can be undertaken either as a supplementary activity or as a full-time profession, without the requirement of land ownership. It is vital to educate people about beekeeping, which provides a lucrative income and assists in pollination of agricultural/horticultural crops, consequently increasing crop quantity and quality. Farmers should emphasize the importance of beekeeping for agricultural prosperity since it matches the biotic relationship between insects, pollination, and seed production (Panchani et al., 2019).

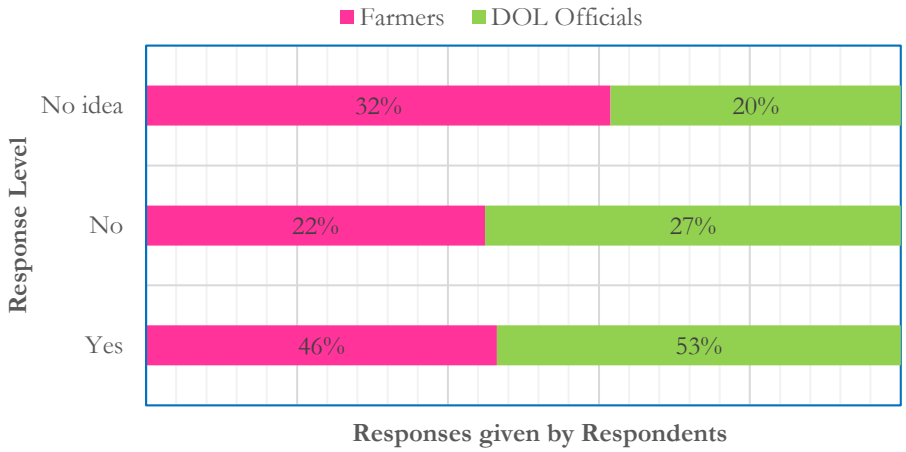

Figure 7. Raising awareness of beekeeping

Methods to disseminate information on air pollution and beekeeping

The collection, dissemination, and accessibility of environmental information are considered very advantageous for activities such as the establishment and enhancement of national environmental information systems (UIA, 2025). When asked which media they prefer for conveying information about air pollution and

bees, respondents gave the internet and television the highest importance, with 27.7% and 45.3%, respectively (Fig. 8). Compared to DOL officials, farmers were more eager to obtain knowledge from experts.

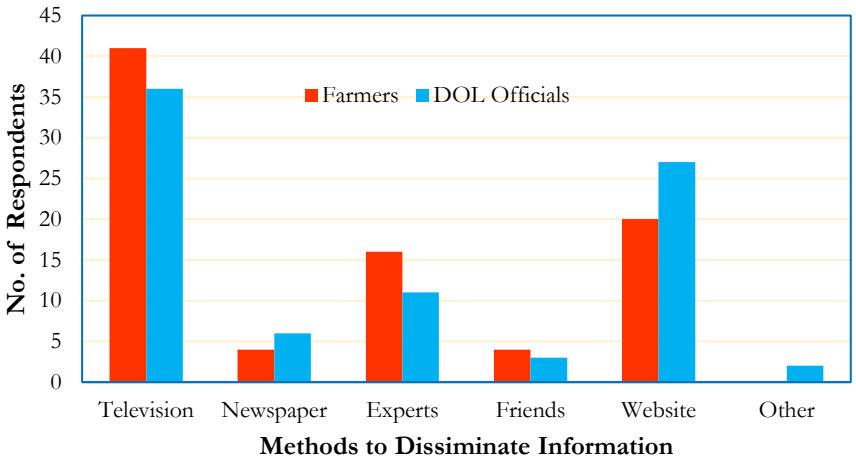

Figure 8. Information dissemination methods on air pollution and beekeeping

According to the survey, websites and television are the main methods of disseminating information on bees and air pollution (Fig. 8). Hence, it would be advantageous to work in conjunction with the Bhutan Broadcasting Services (BBS) to systematically disseminate information after acquiring it from the NEC and the Department of Livestock. As stated by UIA (2025), a well-informed public can participate in decision-making more effectively and is more likely to support policies that promote environmental health.

Combined response from DOL officials and farmers on beekeeping and air pollution

A total of 89.4% of the respondents said that beekeeping could increase agricultural output and the income of Bhutanese people, whereas 94.1% of those surveyed thought it may help create jobs in the country (Fig. 9). According to the survey results, 61.1% of respondents believe that bee farming will reduce rural-urban migration in Bhutan. In Bhutan, over 21.7% of people migrate to urban centers (NSB, 2018), which could possibly be reduced by boosting beekeeping in rural areas. Slightly more than 77.1% of the respondents agreed that air pollution has an impact on bees and bee products (Fig. 9). The data indicates that only a small proportion of respondents (3.5%) strongly agree with the air pollution measurements adopted by the Bhutanese government, while 34.1% agree, and a significant 46.5% remain neutral. Conversely, 15.9% disagreed with the measures (Fig. 9). These findings align with previous studies by NEC (2010) and Kunzang (2015), highlighting ongoing concerns about the enforcement of air quality regulations in Bhutan. This suggests that to prevent future negative impacts on Bhutan's ecosystems, agriculture, employment, and public health, the government must strengthen adherence to and effective implementation of current air pollution laws and policies.

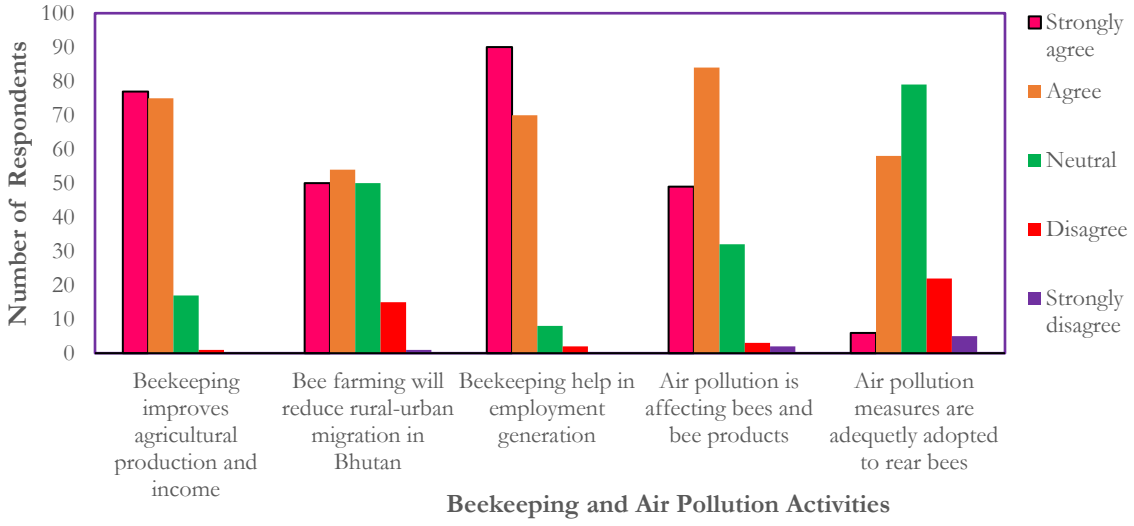

Figure 9. Combined responses of DOL officials and farmers to beekeeping and air pollution

Conclusions

About two-thirds of the respondents believed that honeybees and their products are impacted by air pollution. According to the survey, almost all the respondents agreed that beekeeping would enhance agricultural productivity and income. The overwhelming majority of respondents felt that beekeeping may help create jobs in Bhutan and reduce rural-urban migration. The poll suggested that websites and television are the main channels for disseminating information on bees and air pollution. According to the survey, the most common methods of sharing information on bees and air pollution include websites and television, among others. In the current situation, it has been urgent that Bhutan requires to put effort to preserve clean air for the prosperous health and livelihood of its citizens and environment. The authors recommend collecting air pollution data from urban and rural areas across all 20 districts to establish a baseline for academicians, researchers, lawmakers, politicians, and the general public.

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Author contributions: Govinda Prasad Sharma: Data collection, manuscript writing; Ramesh Prasad Sapkota: statistics-data analysis, editing; Tulsi Gurung: data collection; Siva Praveen Puppala: data validation; Rejina Maskey Byanju: editing, supervision.

Conflict of interests: The authors declare no conflict of interest.

Data availability statement: The data can be provided upon request.

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