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Research Paper

Assessment of Pesticide Exposure due to Residential Proximities among the Horticultural Population of Kashmir Valley

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ABSTRACT

Kashmir valley is a horticultural hotbed with intensive pesticide consumption across the region. The expanding horticultural land use and residential construction within orchard spaces has triggered the concerns regarding residential pesticide exposure. While occupational exposure among the horticultural population has been widely studied, minimal attention has been given to the exposure emerging out of residential proximity. To assess these dynamics in the region, a quantitative cross-sectional method was followed. A set of six indicators were selected based on their relevance to pesticide exposure arising from closeness to pesticide treated areas. The indicators included; orchard-residence distance, buffer zone availability, storage pattern of pesticides, awareness of pesticide toxicity, disposal mechanism of pesticide trash and Post spray health symptoms. A composite Residential Proximity Index (RPI) was developed to assess exposure potential across the valley out of these indicators. The study finds unavailability of buffer zones is the prominent cause of residential exposure followed by unsafe dumping of pesticide leftovers. 68.5 % of the households reside within critical (500-100) meter limits with no intercepting buffer zone. RPI scores indicate three-fourth (75.6%) of the households fall within moderate to high-risk categories. The indicator specific and composite assessment of the residential exposure underscores the importance of multi-layered vegetative buffers around residential houses. Alongside labelling of pesticide treated areas as "no entry zones'' for few days could reduce the exposure.

Keywords: *Pesticide Exposure, Residential Proximities, Horticultural Population, Kashmir Valley*

Pesticides are the substances used to protect crops from the large number of pests by stopping their growth or eliminating them completely. Pesticides have been used since ancient times, however their consumption gained momentum with the discovery of

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DDT. The contemporary agricultural activities largely depend on the use of pesticides. Pesticide traces have become ubiquitous and the people are susceptible to exposure almost everywhere. Pesticides are the chemical substances that are sprayed on a various farm crop to guard them against harmful bugs and pests (García et al., 2022; Rani et al., 2021). Pesticides have the role in increasing the food production and feeding the increasing population by preventing the loss of cereal, vegetable and fruit production (Tudi et al., 2021). Nevertheless, pesticides are used in various other sectors, agriculture is being recognized as the significant source of negative effects (Sattler et al., 2007). Alongside the agrarian societies, the residues of pesticides are a potential danger for the entire population of the world. (Vera-Herrera et al., 2021) The footprint of pesticide exposure and the seriousness of this issue can be highlighted with this fact that three-fourths of the world's population face exposure to pesticides (Maggi et al., 2021). Pesticide overuse and exposure go hand in hand with farmers' perception about risks, knowledge and training (Xu et al., 2008). Pesticide application was instrumental in enhancing the crop yield during 20th century (Aktar et al., 2009). The downside of pesticides was recognized throughout the history.(Abubakar et al., 2020) Humans have strived against pests right from the ancient times with age-old practices to the contemporary times with synthetic chemicals, the breakthrough in agriculture and health was achieved by the Paul Muller's discovery of dichloride-diphenyl-trichloroethane (DDT) in 1939, nevertheless, it was banned in many countries for its drastic side effects (Abubakar et al., 2020).

Pesticides are commonly classified on the basis of their target pest viz., fungicides, insecticides, rodenticides, herbicides, weedicides etc., and may be organic or inorganic with respect to their origin (Abubakar et al., 2020). From the perspective of molecular composition, pesticides are categorized as organochlorines, carbamates, organophosphates, and Pyrethrins/pyrethroids. (Kaur et al., 2019). However, the most important classification has been presented by WHO which classifies the pesticides on the basis of their toxicity level as; Extremely hazardous, highly hazardous, moderately hazardous, slightly hazardous and Unlikely to present acute hazard in normal use. A multitude of factors for the outdoor workers determine the level of exposure to pesticides notably environmental conditions like moisture, wind direction and temperature, quantity of spraying and time taken, and use of protective gear (gloves, googles, apron, no protection, etc.,) (Damalas & Eleftherohorinos, 2011).

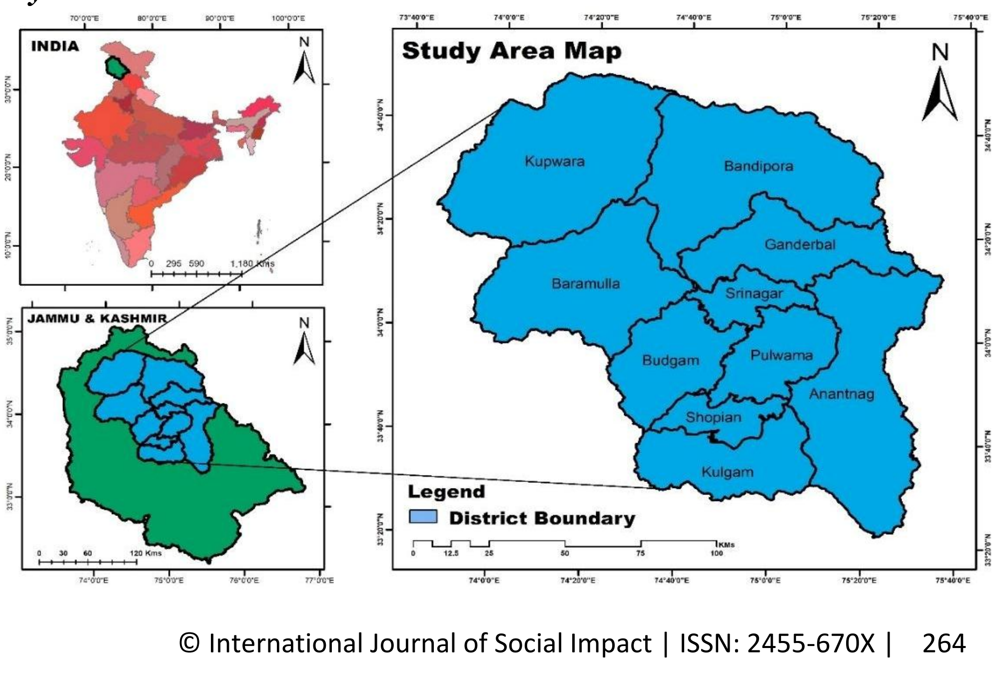
Pesticides find their way inside the human bodies via inhalation, ingestion and dermal proximities and contact to them may happen at home, orchard, or during handling at the work, other indirect ways of exposure include coming in contact with pesticide-contaminated water, food, soil and air. (Hernández et al., 2013; Tudi et al., 2022). Thus, pesticides pose dreadful effects on human health and environment; pollute the important resources and perturb the ecological balances. Pesticide exposure has possible repercussions on health conditions including psychological, immune system, behavioural abnormalities, neurological diseases, hormonal abnormalities and even cancer progression (Garud et al., 2024; Gundogan et al., 2018; Jokanović, 2018). Pesticide exposure has also been linked with cardiovascular problems, renal problems, diabetes, Parkinson, Alzheimer, multiple sclerosis and aging (Mostafalou & Abdollahi, 2013). Despite regulations in manufacturing to minimize their impact, pesticides drew attention to raising concerns of occupational exposure, dietary exposure and exposure due to unsafe handling (Gebretsadkan et al., 2025). Residential proximity to the pesticide treated sites has been linked with reproductive problems among the female adolescents, childhood cancers, neuroblastoma risk, breast cancer, chronic rhinosinusitis (Doná et al., 2025; Mancini et al., 2026; Paul et al., 2026; Van Deventer et al., 2025; Yang et al., 2023)

The expansion of agricultural activities in the mountainous terrain often results in the spatial convergence of residential and cultivated land. In the valley of Kashmir, horticulture has become the backbone of its economy. By the Directorate of Horticulture, Govt. of Jammu & Kashmir, in 1970-71, the total area under horticultural crops was 48 thousand hectares which has now increased to 212 thousand hectares (2022) (Sharma et al., 2023). This shift has amplified the pesticide consumption for pest management. While the agricultural land remains largely separated from the residential areas in the plains, apple orchards in hilly terrains exhibit strong spatial adjacency to the residential spaces. The risk of exposure is comparatively higher among the communities living within or adjacent to the actively cultivated farms often aggravated by the intensity of chemical use (Felisbino et al., 2025). The exposure is primarily influenced by the wind guided spray drift, a process determined by atmospheric, terrain and behavioral variables (Teysseire et al., 2023). Thus, the occupational exposure is not the sole cause, residence and movements within the actively cultivated land accounts for the exposure among communities. Studies have shown the escalated concentrations of pesticide traces among the people living in the vicinity of pesticide-treated areas (Teysseire et al., 2021). Evidences indicate that pesticide induced contamination can go beyond 4 kilometres in the residential interiors (Madrigal et al., 2024).

The widespread use of pesticides and the frequency of application increase the chances of exposure among the population residing in proximity of pesticide application sites. Here we report an in-depth study regarding the residential proximity to the pesticide treated orchards as prevalent risk factor of pesticide exposure. The closeness to the pesticide treated areas. Residential proximity determines the spatial aspect of risk, whereas a temporal aspect of risk is also associated with it in the form of re-entry period post pesticide application. The important steps to tackle this problem from further exacerbation include the demarcation of buffer zones around the residential spaces, closing of windows and doors particularly during the active spraying periods and usage of safety gears.

METHODS AND MATERIALS

Study area



Kashmir valley is a bowl-shaped depression surrounded by Pir-Panjal range in the south-west and the Greater Himalayas in the north-east. Its distinctive geographical settings and unique agro-climatic conditions support the horticulture. With a total area of 15,948 kilometers square, it extends over a length of 135 km and is 45 km broad at its center (Lone et al., 2021). The Southern section of the valley is a hotbed of horticultural activities. As reported by the Directorate of Horticulture, J&K horticultural land area is increasing and is largely impacted by the present land use land cover (LULC) changes. Apple cultivation is crucial in the region and contributes significantly to local economy and employment generation (Malik & Choure, 2014).

Apple orchids are the backbone of the economy of Jammu and Kashmir, the northern UT of India. The cultivation of apple in Kashmir is heavily dependent on the use of pesticides. Multiple carcinogenic pesticides including *chlorpyriphos*, *mancozeb, captan,* are being used in the region, other heavily used pesticides include *dithane, democron, carboxin, synthetic pyrethroids, and endosulphan* (Bhat, Wani, Bhat, Kachroo, et al., 2020; Riyaz et al., 2020). Pesticides constitute the bulk of the agro-chemicals used in horticultural settings. (Bhat, Wani, Bhat, Qadir, et al., 2020). Apple industry is the primary consumer of pesticides (83%); fungicides 71.1%, insecticides (15.4%) and acaricides sales around (7.7%). (Naqash et al., 2019). Farmers are but ill-informed about the negative effects of pesticide usage, particularly the risks posed in occupational settings. (Ara et al., 2024)

Research Design

A quantitative, cross-sectional survey design was implemented for the systematic assessment of residential proximity risk within the study area. Baseline sample size was determined by Cochran's (1977) formula (equation 1 given below) at 95% confidence level. However, the calculated sample size approximately 385 was expanded to 509 samples for better inter-district representation of sample size. A multistage stratified sampling technique was adopted to ensure that the final sample adequately represents the spatial and agricultural variations across the region. All the ten districts of the valley were stratified and based on the consumption of pesticide villages were selected and finally households were chosen by employing systematic sampling.

$$n_0 = \frac{Z^2pq}{e^2} \qquad 1$$

Where $'n_0'$ is required sample size, 'Z' standard normal deviate at chose confidence level, 'p' is assumed population proportion, 'q= (1-p)' is complement of p and 'e' is allowable sampling error

For primary data collection, a structured questionnaire was developed that covered the questions primarily capturing the risk emerging out of residential proximity. It included sociodemographic characteristics, residential distance from the orchard, buffer zone presence or absence, storage/disposal of pesticides, awareness of pesticide induced toxicities and post spray health symptoms. The instrument was designed after extensive survey of existing knowledge regarding spatial proximity exposure and risks. To quantify the risk associated with exposure due to orchard proximity, a composite Residential Proximity Index (RPI) was formulated by using six indicators. The index was formulated to integrate all the indictors into a single measurable value. Each indicator was allocated a score of 0 or 1 based on the presence or absence of a risk condition. The overall index was computed by aggregating the values of the six chosen indicators by employing a formula $RPI = \sum_{i=1}^{6} X_i$, which produced values between 0 and 6. Based on the cumulative score, the residential proximity risk was classified into three categories: low risk (0-2), moderate risk (3-4) and high risk (5-6). Cronbach's alpha was employed to assess the internal consistency of the indicators, producing a value of 0.78, which suggests an acceptable degree internal consistency. Descriptive statistics and exploratory data assessment by Microsoft excel and SPSS 23 software. ArcGIS 10.8 and Google Earth Pro were used to generate geospatial data.

Measurement of Indicators

- **Residential distance from the orchard:** Residential distance of a household is the shortest linear distance between a household and the nearest orchard margins in terms of metres. It represents how close a household is and the potential for direct exposure. Measuring tape and motorcycle odometer readings were used to record these distances.
- **Buffer zone**: A buffer spraying zone refers to the specified area surrounding a residential space to protect it from the spray drift emerging out from the nearby treated areas. It is a radial distance (e.g., 0-50m, 50-100m), implying the presence or absence of potential risk of exposure within a given radius.
- **Storage of Pesticides**: Pesticide storage represents the way agrochemicals are kept within or near the domestic settings. Households close to orchards may store pesticides for frequent use, thus increasing the likelihood of indoor exposure. This indicator measured through survey questions (e.g., inside/outside the house), and classified to reflect safe or unsafe storage practices.
- **Disposal of Pesticides**: It represents the practices used to discard leftover packets, containers and containers, which can contribute to pollution and contamination around the residential spaces. It was measured using survey-based responses on disposal practices (e.g, open dumping, burning, disposal in water) and were accordingly classified ads safe and unsafe disposal practices to assess associated exposure risk.
- **Awareness of pesticide toxicities**: It represents the knowledge of pesticide induced diseases and toxicities among the residents. This knowledge is crucial for the populations dealing with pesticide application. This indicator was measure through questionnaire responses. It was categorised into two classes low to moderate awareness and high awareness levels among the residents.
- **Post-spray health symptoms**: It refers to the occurrence of short-term health condition immediately after spray. The populations residing close to the active pesticide treated areas are more vulnerable to the drift. This indicator was measured whether the residents experience the symptoms after pesticide application.

RESULTS

Socio-demographic profile

Demographic profiling was recorded for 509 samples. The surveyed population largely composing of males falls in the age group of (30-60) years. More than half of the respondents fall in the age bracket of (35-45) years followed by (25-35) and (45-55) year cohorts. The horticultural manpower largely composed of female workers comprising 76.23 % of the sample, compared to female workforce of 23.77%.

Household composition coupled with the land use tenure determine the potential exposure within the region. The family size of the all the study participants stands at 6.64 members.

This comparatively large family structure indicates the proximity-based pesticide exposure does not only affect the occupants but the residents living in the orchid proximity. Additionally, the population exhibits high expertise in horticultural practices; the highest proportion of the workers (41.26%) reported 15 years of farming experience.

In terms of education, majority of the participants possess limited educational status, with 41.26 % having attained only primary education and nearly one-third reporting no formal schooling at all. Representation peaks down at the higher education levels, which accounts for just 6.49 % of the population. The socio demographic characteristics of the surveyed population are outlined in the below given table. (**Table 1**)

Table 1:

Variable	Category	Frequency	Percentage (%)
Age	25–35	118	23.18
	35–45	262	51.47
	45–55	104	20.43
	55–65	25	4.91
Gender	Male	388	76.23
	Female	121	23.77
Education	No Education	156	30.65
	Elementary	210	41.26
	Secondary	110	21.61
	Higher Education	33	6.49
Farming Career (Years)	5	32	6.29
	10	138	27.11
	15	212	41.65
	20	75	14.74
	25	31	6.09
	30	21	4.13

Residential pesticide exposure assessment:

The analysis of proximity-based exposure indicators reveals significant vulnerability to pesticide exposure within the study population. A considerable proportion of the surveyed population (41.06%) were located within 0-200 meters of orchards. This physical proximity to the pesticide treated areas increases the likelihood pesticide drift reaching residential areas. Protective buffer zones are largely absent around the houses situated within the orchard settings. An overwhelming majority of (88.80%) of the contain no buffer zones, reflecting insufficient spatial barriers to the incoming wind guided pesticide drift. Household-level practices of pesticide management augment the residential exposure, as 70.73% of the surveyed population reported unsafe domestic storage. These practices largely include open dumping of pesticide packets, containers and chemical leftovers. The study observed that 61.30% of the respondents had limited to moderate knowledge of pesticide hazards, potentially hindering the adherence to safety procedures. Furthermore, majority of the surveyed population (55.01%) reported pesticide induced health symptoms, suggesting a crucial link between pesticide exposure other than occupational settings. Collectively, the coexistence of physical settings, household practices, awareness gaps and health related factors indicate a widespread and cumulative residential pesticide exposure burden across the study area. The percentage and frequency of various categories of the indicators selected for this study are summarized in Table 2 and graphically shown by figure 1.

Table 2: Percentage Distribution of the Residential Pesticide Exposure Conditions

Indicator	Frequency (n)	Percentage (%)
Residential distance (meters)		
0-200	209	41.06
200-1000	300	58.94
Buffer Zone		
Presence of buffer zone (yes)	57	11.20
Absence of buffer zone (No)	452	88.80
Storage of pesticides		
Safe storage (outside garage)	278	54.62
Unsafe storage (domestic setting)	231	45.38
Disposal practices (leftovers, containers)		
Unsafe (open dumping near orchards)	360	70.73
Safe (Burial)	149	29.27
Awareness of pesticide toxicity		
Low to moderate awareness	312	61.30
High awareness	197	38.70
Post spray health symptoms		
Experienced symptoms	280	55.01
Did not experience symptoms	229	44.99

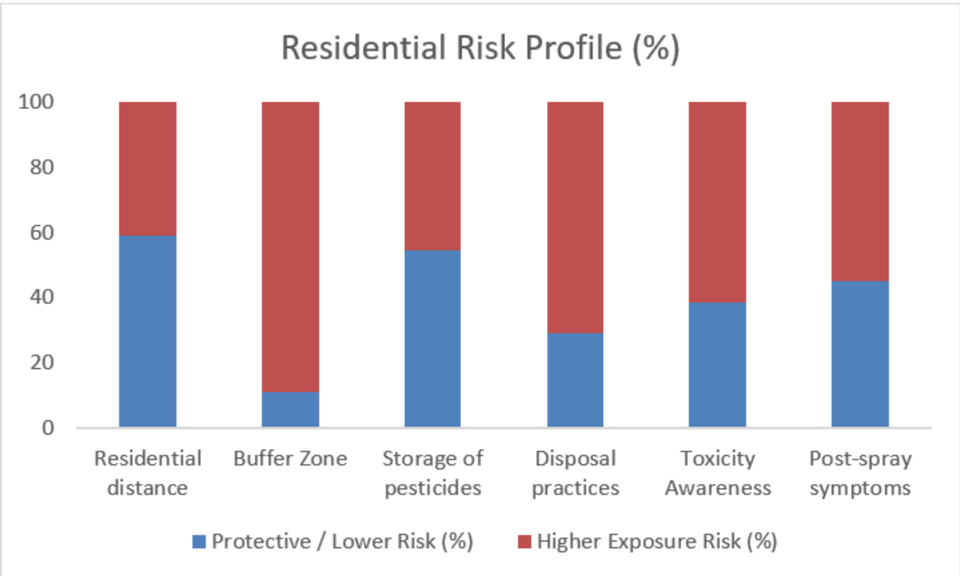


Figure 1: Patterns of pesticide exposure conditions in the residential settings

Composite Assessment of the residential proximity indicators

While the selected indicators independently represent the exposure at household level, it was crucial to assess the cumulative exposure burden across the study area. Therefore, for this purpose a composite Residential Index was developed from the chosen indicators which were merged to yield a measurable score. The cumulative exposure profile showed that a majority of the respondents experienced moderate to high exposure risk, emphasizing the overlap of various exposure determinants across the study area. Around One- fourth of the households were identified in a high-risk category (5-6), indicating the exposure arising out of close orchard adjacency, missing buffer zones, pesticide handling malpractices, unawareness about pesticide hazards and occurrence of health symptoms post pesticide application. Over half of the surveyed households were categorized in moderate exposure risk (3-4), showing that multiple exposure risks are prevalent in a significant share of population. In comparison only a small share of the surveyed households belonged to the low-risk category of (0-2), having comparatively safer residential locations. The higher prevalence of moderate and high-risk category is largely due to the multiple overlapping residential exposure conditions. The index formulation approach provided an integrated insight into the cumulative exposure across the study area beyond the indicator-based assessment. The distribution of Residential Proximity Index (RPI) scores across the study area is shown in the Figure 2 given below.

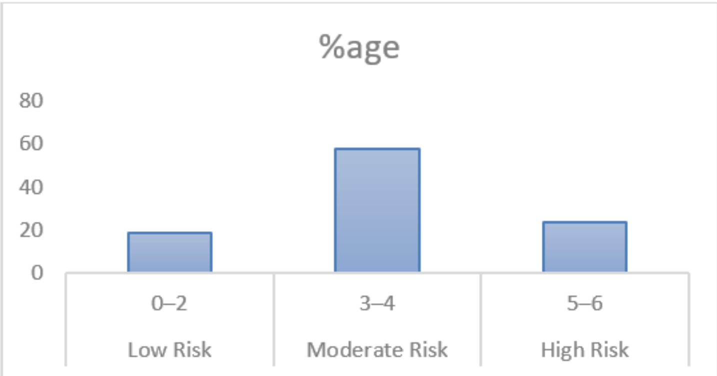


Figure 2: Percentage distribution of RPI classes across the study area.

DISCUSSION

The spatial vicinity to the pesticide treated areas forms an important risk factor of exposure among the horticulture dominated population (Rotkin-Ellman et al., 2025). By integrating the exposure indicators with the composite risk index, the study explores the spatial variations of pesticide induced risk due to the residential proximities of pesticide treated orchards. The study shows that a major proportion of the horticultural population live in their proximity, thus amplifying the risk of non- occupational exposure among them. Such exposure pattern is largely witnessed in the agricultural settings where the farmers live within or very close to their farmlands (Aparicio et al., 2025).

The analysis shows that the households with intensive horticultural land use tend to exhibit higher exposure than others. The structural aspects of the Kashmiri horticulture in terms of coexistence of orchards, crop fields and residential settlements are largely reflected in the spatial risk distribution. The wind movements bring chemical traces, vapours and droplets of pesticides and thus expose the populations irrespective of their location (Afandi et al., 2025; Herkins et al., 2025). Without being directly involved with the horticultural activities, the residents may thus experience exposure even in the absence of direct occupational contact.

The findings of the present study also support the existing literature that identifies residential proximity to the pesticide treated areas as prominent determinant of environmental exposure among the farming and non-farming communities. Several studies concerning epidemiology have linked pesticide induced exposure due to residential proximity to wind guided drift, toxified soil particles and homely dust. This kind of exposure is prevalent among the regions characterized by intensive and frequent pesticide applications alongside non demarcation of buffer zones between horticultural and residential land uses.

This study largely indicates that the varying cropping pattern, land use and residential structure account for concentrated residential risk in certain geographical pockets of the valley. The number of pesticide treatments in the horticulture dominated areas has increased recently aggravates this problem (Bhat, Wani, Bhat, Kachroo, et al., 2020). Thus, the populations are exposed to repeated exposures of pesticide which has the long-term implication on the farmers' health.

Methodologically, the implementation of composite index in this study provides the roam for incorporating all the indicators that are crucial for exposure in proximity settings. The method of combining several indicators clearly reflects the multidimensional nature of exposure risk. However, it has to be noted that it does not account for the risk imparted on the part of soil, water and biological means. Despite these limitations, the indicator specific framework used in this study offers multiple advantages, particularly the identification of distribution of proximity-based risk among the population.

Based on the findings of this study, the future research should integrate geospatial data with the environment and biomonitoring approaches. The assessment of pesticide traces in soil, water and food in the vicinities of active pesticide treated areas might provide concrete evidence of pesticide contamination. At the same time the pesticide residues could be traced via biological samples like urine, blood and saliva for bioaccumulation. This multidisciplinary approach will improve the overall understanding regarding spatial proximity and the health risk.

CONCLUSION

The production and consumption of pesticides is critically important to check the food crisis in the contemporary societies of the world. Alongside, their positive change in terms of economy and food surplus, they have garnered concerns particularly among the horticultural communities. The populations living close to the orchards are among the most vulnerable entities. They are occasionally exposed to the pesticide drift thus exposing them to short- and long-term toxicities. Kashmir valley is a horticultural hub, a large proportion of the population reside in the vicinities of the active pesticide treated lands. Thus, they are constantly exposed to the wind guided chemical drift. They often develop allergy symptoms particularly respiratory issues. The effect on the cohort is amplified due to the outdoor works within the vicinities. This population is affected irrespective of being occupationally engaged with horticulture or not. Various studies have linked the residential proximity exposure with multiple diseases particularly among children and pregnant women. It is impossible to relocate such huge populations, therefore buffer zones must be developed to intercept the wind brought pesticide drift and vapors. The outdoor activities must completely be thwarted during the active pesticide application operations. The doors and windows must also be closed during peak hours. The new constructions within the orchard spaces should be engineered from the perspective of pesticide induced exposure in the neighborhood.

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