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Spatial Vulnerabilities: How Geography Shapes The Health Burden Of Pesticide Use On Farmers

[1]Lokesh K C
[1]Post Doctoral Fellow
[1]Department of Geography,
[1]Osmania University, Hyderabad, India

Abstract: The toxic effects of chemical factors i.e., pesticides exposure of farmers is a continuous health concern worldwide especially in regions of intensive agriculture. This impact deciphered the type of pesticides and its effects on farmers' health based on exposure levels in detail to the research world. In this process of mitigating the adverse effects of farmers health the geographical factors that include climate, land use, rural health infrastructure access, topography & altitude, proximity to water bodies, crop type, regional practices influencing the farmers health were given less priority in most of the regional health investigation studies and not documented properly on a regional global scale. To cover the spatial determinants influencing health outcomes internationally a literature review synthesizing the research of a span of past 25 years is performed. 45 peer reviewed unique research studies were selected and analysed. The outcome of the findings are regions of high temperature, slope gradient, monoculture farming, poor healthcare mobility, nearness to contaminated water bodies are under higher influence of both exposure levels and chronic health effects across the world. It proves the need for geographical dimensions by Geographical Information Systems (GIS) modeling in advocating regional specific policies that address spatial health problems in relation to pesticide exposure.

***Index Terms* - Pesticide exposure, farmers, environment, land use, and health impacts**

I. INTRODUCTION

Application of synthetic pesticides in modern agricultural systems has increased worldwide as they were effective in controlling pests, weeds and also in boosting the yield of the crop. On the other hand it also created the health disorders that range from mild acute symptoms (headaches, dizziness, eye irritation, nausea, skin rashes) to chronic illnesses (respiratory & reproductive issues, cancers, neurodegenerative & immunologic diseases, hormonal imbalances, endocrine disruption's d organ failures) (Ahmad et al., 2024; Alavanja et al., 2004; Alavanja et al., 2012; Mostafalou & Abdollahi, 2017; Sanborn et al., 2007; Shekar et al., 2024) to the environmentally exposed farmers and also who handles them directly by occupational means. This difference in health disorders severity was influenced by the geographical dimensions (Aktar et al., 2009; Boedeker et al., 2020; Van Maele - Fabry et al., 2011) such as 1. Physical parameters which include slope gradient (Dasgupta et al., 2007), terrain, wind direction, altitude, climate, temperature, soil, & rainfall type (Jaga & Dharmani, 2006), proximity to treated fields, land use & crop patterns and nearness to water bodies (Gunnell et al., 2003) 2. Socio Geographic parameters which are safe education, poverty, literacy rates (Nalwanga & Ssempebwa, 2011) distance from health centers (Atreya, 2008), cultural norms, rural infrastructure, agricultural practices, traditional knowledge systems and access to protective equipment as evident from the geographical approach pesticide exposure studies (Damalas & Koutroubas, 2016). They also revealed that non uniformity in geographical settings also influences the amount, distribution, persistence and intensity of pesticide exposure that has been inflicted on health outcomes in farmers for decades. All these empirical research studies are from diverse global regions that took into consideration of environmental, geospatial data, public health assessments and spatial epidemiology analytical frameworks which appears to be fragmented as they focused on specific area or region thus creating a gap to understand on similar influence of geographical factors on pesticide exposure in similar regions of farmers present worldwide. This research paper aims to fill that analytical gap by segregating these evaluations into several geographical themes which will provide clear pesticide exposure pathways in diversified geographical context, facilitate in mitigating the pesticide exposure health challenges and formulating geographically based location specific policies in concern to human and environmental health and pushing to new research directions.

II. Methodology

A systematic literature review to identify and analyse studies related to spatial determinants influencing severity of pesticide exposure health impacts among farmers was conducted by following PRISMA 2020 guidelines using leading academic databases JSTOR, Web of Science, Google Scholar, Science Direct, Scopus and PubMed for the time period January 2000 - December 2024. Keywords included for searching in above databases were “geography”, “pesticide exposure”, “health impacts”, “farmers”, “climate”, “proximity”, “topography”, “landscape” rural health” “crop type” and few combinations of these keywords “pesticide exposure” AND “farmer” AND “health impacts” AND “rural infrastructure”; “topography” OR “climate” AND “pesticide impact”, were also applied using Boolean logic to refine the results and exclude irrelevant studies. Further, inclusion criteria conditions 1. It should be an English language peer reviewed empirical research study 2. Deals with farmers exposed to pesticides 3. One or more of the influencing spatial factors (e.g., climate, topography, altitude, proximity to water bodies & agricultural fields, land use, access to healthcare) are examined from the pesticide exposure health impacts in the research and exclusion criteria rules 1. Non geographic analysis lab toxicological study 2. Studies focusing on non-occupational health impacts of pesticides exposure 3. Reviews, theoretical frameworks and studies not linking geography with health, were applied to the retrieved research studies. After that full text screening is done to ensure that quantitative and qualitative methodologies such as observational, modeling, cross-sectional studies, longitudinal analyses, case control studies, meta analyses, spatial mapping studies were considered from Asia, Africa, Latin America, North America, Europe and presented original research findings. Finally, 45 studies were included for the final review.

III. Results & Discussion

All the finalised studies were analysed thematically and geographically based on findings to identify commonalities, unique findings and methodological frameworks and are grouped into major geographical determinants or factors: Climate, topography & altitude, proximity to water bodies, land use patterns, access to health care.

3.1 Climatic Factors

Climatic variation in factors rainfall, temperature and humidity alter the intensity of exposure on humans and pesticide behavior (drift, volatilisation and persistence) in the environment. Warmer climatic regions experience high temperatures which accelerates the volatilisation rate of pesticides in the environment causing inhalation risks to the farmers applying and nearby communities as demonstrated from few studies in tropical agricultural zones (Aprea et al., 2002; Keifer & Firestone, 2007). This effect is observed more in farmers of Southeast Asia, South Asia, sub-Saharan Africa & Central America as the reported health symptoms (skin rashes, fatigue, nausea, neurological, dizziness) were frequent in the summer or pre-monsoon planting seasons because farmers in these regions apply pesticides directly under the intense sunlight (Gunnell et al., 2007; Lekei et al., 2014; Boateng, 2023; Shammi et al., 2020).

Level of humidity is linked to sweat production there by influencing the dermal absorption rate. High humid conditions exacerbates the sweat intensity in farmers causing rapid skin exposure to pesticide compounds and followed by chronic health conditions as concluded from findings in studies in tropical climates of Ghana, Bangladesh, India, Thailand, Srilanka and Brazil (Gunnell et al., 2003; Ntow et al., 2006; Alam et al., 2020). It also decreases the efficiency of PPE's.

Rainfall patterns significantly affect the pesticide runoff. Uneven rainfall in regions of long dry spell promoted the heavy transportation of pesticide residues to nearby aquatic ecosystems and settling of pesticide dust in the soil causing contamination of both soil and water. The above phenomenon is noticed in semi-arid zones of Central India, South Africa and parts of Kenya (Ajayi et al., 2007).

On contrary, Arid climatic zones of parts of Africa and Australia pesticide particles show longer persistency in air and soil of the agricultural fields due to lack of rainfall thus, presenting another form of climatic vulnerability causing elevated risks of respiratory illness in elders and children's near fields (Camacho & Mejia, 2015) likewise, in cooler European climates too.Global warming induced climate change patterns in unaffected temperate zones of parts of the Mediterranean, Northern India has driven for the continuous use of pesticides (Cocco et al., 2013).

3.2 Topography and Altitude

Topographical features relate with the movement and accumulation of pesticide residues to low lying regions (Tudi et al., 2022). Regions of steep slope like Andes in Colombia, Himalayan foothills, Western Ghats (India), Ethiopia highlands had enhanced runoff creating concentration of pesticide residues in the low level areas water catchments, atmosphere and soil which caused the chronic health impacts because of the indirect exposure of communities to pesticides (Mekonnen & Agonafir, 2002; Poudel et al., 2020).

In contrast, flat terrain facilitates strong wind movements which drift the pesticide particles dispersed in the air to several kilometers into residential areas or non-farming communities enabling for the pesticide related health consequences because of inhalation exposure as reported in Brazil, Argentina, Northern Kenya, Punjab & Rajasthan of India (Bhandari et al., 2020).

Similarly in valleys or floodplains though they are linear with less geographical feature barriers the pesticide drift is low because of the stagnant water bodies acting as sink for pesticide residue accumulation and presence of poor drainage system which is revealed in studies conducted in Vietnam Mekong Delta, Ganges basin, Nepal, Indonesia and Malaysia.

Altitude controls the rate of degradation, persistence and usage in perspective to the colder regions of high altitude as confirmed in the research zones of Himalayan and Andes mountains. These regions have short growing seasons leading to heavy spraying of persistent pesticides by farmers which accumulates in soil causing prolonged environmental contamination and bioaccumulation in food chains because of the poor microbial degradation and photo decomposition posing severe health risks as shown in farming communities in the mountainous zones of Bhutan and Colombia.

3.3 Proximity to Water Bodies

It is one of the prominent geographical determinants in the severity of pesticide exposure among farmers. Agricultural runoff of pesticide residues into the nearby or low lying water bodies, canals, rivers, wells spreads the indirect exposure of pesticides to farmers, residents using it for irrigation, bathing, drinking and washing exacerbating severe threat to chronic health hazards (cancer, endocrine disruption). This was highlighted from the studies conducted in Telangana, Rural Bangladesh, Tamil Nadu, Srilanka, Parts of Latin America, and Pakistan (Sultan, 2023). The severity increases with the proximity to water bodies as proven in high-input agriculture zones of Godavari and Nile Basins (Jayasumana et al., 2014) irrigation canals in Mexico and paddy water in Indonesia's Banten Province.

3.4 Land use patterns

The type and intensity of agricultural practices define the pesticide amount, frequency and exposure level (Habran et al., 2024). Regions of monoculture agriculture require regular and heavy volumes of pesticides as they are highly vulnerable to pest infestations. Studies from cotton fields in Telangana (India), tea in Kenya, tobacco farming in Malawi, rice cultivation in Vietnam, banana plantations in Costa Rica (Murphy et al., 2000; Kishi, 2005; Marete et al., 2021; Brühl et al., 2023) reported intensive and regular usage of pesticides. This is a continuous process resulting into cumulative toxicity like chronic neurotoxicity, behavioural disturbances (Mittal et al., 2013), leukaemia, dermatological, infertility, bronchitis (Subhash et al., 2013; Ngowi et al., 2001)

Structural land use factors like fragmented landholdings also influence the pesticide usage pattern (Ali et al., 2020). Intensity of the land tenure and small size of the land held by the farmer drive them to enormous and multiple times of pesticide application to maximize short-term yields which is also observed particularly in peri-urban agricultural zones (Yadav et al., 2015) linked to health complications because of drift in the pesticide dust (Atreya et al., 2011) to nearby non targeted exposure communities or by the bioaccumulation in local ecosystems.

3.5 Access to Healthcare

Geographic disparities determine the state of healthcare infrastructure thereby, health outcomes in farmers. Peri urban agriculture farmers receive proper health treatment when exposed to pesticides as they are near to well-equipped healthcare services of urban centers reducing the severity of effects as mentioned in the peri-urban regions studies of Brazil and China. In contrast, rural farmers undergo poor treatment because of ill equipped primary health centers having no proper diagnosis or chronic condition health problems treatment services for pesticide exposed farmers increasing the severity of health disorders (Rother, 2008) and even lack of proper transportation also delays the access to treatment especially in remote regions of India, Ethiopia, Indonesia, Bangladesh and Latin America.

IV. CONCLUSION

The literature review of diversified geographical factorial studies in various regions proves that geographical factors (climatic stress, topographical flow patterns, regional agricultural practices, land use practices, water body proximity, health infrastructure access) also have a key role for the similar & direct influence on similar geographical settings in terms of nature and intensity on the detrimental pesticide related health effects on farmers across the world. Thus, showing the necessity of spatial determinants in bringing the GIS infused tailored regional pesticide policies for decreasing the threat of pesticide exposure in world's vulnerable agricultural regions. Policy recommendations are 1. Region specific safe pesticide handling training programs, PPE designs & distributions, ban on specific pesticides 2. Incorporation of Geographical Information Systems (GIS) mapping in pesticide monitoring systems 3. Reinforcing the rural health infrastructure in accessibility and health care services. In Addition to the above a dynamic system that combines GIS, land use, climatic data, toxicology and health surveillance should be developed for real-time prediction of pesticide exposure risk in vulnerable geographies.

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