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An alarming presence of carcinogenic pesticide residues above recommended maximum residual limit (MRL) in fruits and vegetables in Tamilnadu, India causing a public health catastrophe

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Abstract

Chemical pesticides have become an integral part of modern agriculture. This study analyses the levels of carcinogenic pesticide residues and their maximum residual limit (MRL) in fruits and vegetables consumed daily in Tamilnadu, India. A total of 24 samples of commonly used fruits and vegetables which are consumed by the general population of Tamilnadu were collected from the major markets of Tamilnadu for analysis of pesticide residues. The sampling technique followed was the multistage cluster random sampling technique. Pesticides were extracted by the Modified QuEChERS method, and the residue pesticides were analysed using gas chromatography-mass spectrometry (GC-MS). The carcinogenic link of the reported pesticides is as follows: ϒ-HCH has a direct link to non-Hodgkin's lymphoma risk. o, p-DDT causes pancreatic cancer, liver cancer, and it is a marker for breast cancer. o,p-DDD is linked to lung, liver and thyroid cancers. Dichlorvos causes prostate cancer. Cypermethrin is related to lung tumours in mice. Phorate has a direct link to prostate cancer. Propargite is related to intestinal tumours. Chlorpyrifos is linked to several cancers like rectal, lung, brain, breast, prostate cancer, and non-Hodgkin's lymphoma. Carbendazim causes hepatic tumours. Thiacloprid is linked to thyroid, uterine, and ovarian tumours. Malathion causes non-Hodgkin's lymphoma and prostate cancer. Tebuconazole is related to liver tumours. Dicofol causes liver adenoma and carcinoma. Monocrotophos increases the growth of breast cancer cells. Dimethoate has a direct link to adrenal, thyroid and pituitary cancers. Diazinon has a direct link to lung cancer and non-Hodgkin's lymphoma. Heptachlor is related to thyroid, pituitary, and reproductive system cancers. The prevalence of widespread contamination of fruits and vegetables consumed in Tamilnadu by carcinogenic organochloride and organophosphate pesticides has been found. To prevent these cancers, strict preventive measures like adhering to laws managing pesticides, consuming organic fruits and vegetables, and using biopesticides should be implemented by the government authorities.

Keywords: fruits and vegetables, pesticide residues, carcinogenicity, maximum residual limit (MRL), Food Safety and Standards.

Full length article **Corresponding Author*, e-mail: researchphdsrm@gmail.com

1. Introduction

Pesticides are mainly used in agriculture to control pests and have become an indispensable component of modern agriculture [1, 2]. The gross use of pesticides causes significant damage to the environment and public health. Pesticides have been dispersed in the environment widely, through air, soil, and water [3]. Pesticides contaminate water, soil, and air, which in turn get accumulated again in the crops. They are mainly transported through rain to running waters near the agricultural field or through wind [4]. The pesticide contamination of any region depends on the pesticide application practices and the extent of cultivable lands in that region. Fruits and vegetables are highly nutritious components of the human diet. A high intake of fruits and vegetables has been recommended to reduce the incidence of several major diseases like obesity, cancer, and cardiovascular diseases. Like any other crop, fruits and vegetables are also attacked by pests during cultivation which leads to damages that ultimately decrease the yield. To reduce the loss and to maintain the quality of harvested fruits and vegetables, pesticides are used together with other pest management techniques during cultivation. Pesticide usage during cultivation causes the retention of pesticide residues in harvested fruits and vegetables. Chemical pesticides are broadly classified into four types depending on their sources: carbamate, organophosphate, organochlorine, and pyrethroid pesticides [5]. The major proportion of pesticide usage is confined to fruits and vegetables than other crops which are used for human consumption. Pesticide residue leads to major health problems in humans like acute poisoning, neurotoxicity, respiratory disorders, skin irritation, etc. [6]. One such important human health risk is the carcinogenicity of pesticides. The association between cancer and pesticides has been a huge concern over time. According to the World Health Organization (WHO), cancer is the topmost cause of death in humans globally, accounting for nearly 10 million deaths in 2020 [7]. The National Cancer Registry Programme of India 2020 reported that the cause of death of 9% of the population was due to cancer [8].

The pesticides are regulated by two government bodies in India. They are the Central Insecticides Board and Registration Committee (CIBRC) and the Food Safety and Standards Authority of India (FSSAI). The CIB committee regulates the entry of new pesticide formulations in India. Registration processes are carried out by RC. The FSSAI has constituted a scientific panel with experts which recommends the maximum residue level (MRL) of pesticides according to the Food and Safety Act, 2006. Because of the many disadvantages associated with the improper usage of pesticides in agriculture, there is an immediate need to minimise the use of chemical pesticides in the prevention of pests. This study analyses the levels of carcinogenic pesticide residues in fruits and vegetables used daily in Tamilnadu and their harmful effects on general health. It was also done to create awareness on the toxicity of chemical pesticides and set futuristic goals such as starting of complete organic farming in Tamilnadu for a healthy future generation.

2. **Materials and methods**

2.1 Sample collection

A total of 24 samples of commonly used fruits and vegetables which are consumed by the general population of Tamilnadu were collected from the major markets of Tamilnadu for analysis of pesticide residues of which 12 samples were fruits, and 12 samples were vegetables. The study was conducted from October 2022 to February 2023. Samples were collected in zip-locked polybags and brought to the laboratory within 24 h and stored in a refrigerator at 4 ℃ until the analysis. About 500 grams of each sample was collected. The sampling and preservation protocol was as per the manual of the Food Safety and Standards Authority of India (FSSAI). The sampling technique followed was the multistage cluster random sampling technique.

2.2 Sample preparation

The modified QuEChERS method, as proposed by Anastassiades *et al*. (2003), was used for sample preparation and pesticide extraction. According to this method, 10 g of ground composite sample was mixed with 10 mL of acetonitrile (ACN) in a 50 ml Teflon centrifuge tube and shaken well manually and then homogenized in a vortex shaker. 5 ml of water and 4 g anhydrous magnesium sulphate (MgSO4) with 1 g sodium chloride (NaCl) were added to the mixture and shaken vigorously for 1 minute. The mixture was again homogenized in a vortex shaker for 1 min and centrifuged for 5 min at 3000 rpm. 5 ml supernatant was transferred to 15 ml Teflon centrifuge tube, which contained the mixture of 750 mg anhydrous MgSO4, 125 mg primary secondary amine (PSA) and C18 sorbent. The mixture was shaken manually, then homogenized in a vortex shaker for 1 min and centrifuged at 3000 rpm for 5 min. A fraction of 2 ml of the extracted sample in glass tubes was evaporated in Turbo Vapevaporator at 30 ℃ using nitrogen gas of 10 psi pressure. The residues were reconstituted using n-hexane for GC MS/MS analysis [9].

2.3 Pesticide residue analysis in GC-MS/MS

Pesticide residues were analysed using gas chromatography triple quadrupole mass spectrometry (GCMS-TQ8040 Shimadzu, Japan). Samples extracted were auto-injected into the 2 ml capillary column SH-Rxi-5Sil MS (30 m long, 0.25 mm ID, 0.25 mm df). The injection mode was splitless with high pressure of 250 kPa (1.5 min) and 250+ ℃ temperature. Ultrapure helium (with a purity of 99.999%) was used as the carrier gas, and the collision gas used was argon. Gases were passed through gas purification filters that contained an oxy trap and a moisture trap. The operating condition for the column oven was programmed starting from 50+ ℃ (kept for 1 min), increased to 125 ℃ (at the rate of 25 ℃ per min), then from 125 ℃ (at the rate of 10 ℃ per min) increased to 280 ℃. The detector which was used to detect pesticide residues was a triple quadruple mass spectrometer (MS) [10].

3. Results

3.1 Carcinogenic pesticides reported in fruit vegetables

The carcinogenic pesticides reported in lady's finger collected from the Ottanchathiram market are Delta-HCH (Delta-Hexachlorocyclohexane), o, p-DDT (Dichlorodiphenyltrichloroethane), o,p-DDD (Dichlorodiphenyltrichloroethane), dichlorvos, cypermethrin, and phorate. ϒ-HCH (Delta-Hexachlorocyclohexane) (0.032 mg/Kg) level was 3 times higher than the maximum residual limit of 0.01 mg/Kg. o,p-DDD (Dichlorodiphenyltrichloroethane) level (0.022 mg/Kg) was 2 times higher than the maximum residual limit of 0.01 mg/Kg. Phorate level (0.025 mg/Kg) was 2 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in brinjal collected from the Ottanchathiram market are cypermethrin (0.024 mg/Kg), Propargite (1.02 mg/Kg), Chlorpyrifos (0.038 mg/Kg), Carbendazim (0.042 mg/Kg), and Thiacloprid (0.31 mg/Kg). The carcinogenic pesticides reported in snake gourd collected from the Ottanchathiram market are Delta-Hexachlorocyclohexane, o, p-DDT (Dichlorodiphenyltrichloroethane), Malathion, dichlorvos, and carbendazim. Delta-Hexachlorocyclohexane level (0.021 mg/Kg) was 2 times higher than the maximum residual limit of 0.01 mg/Kg. o, p-DDT (Dichlorodiphenyltrichloroethane) level (0.039 mg/Kg) was 3 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in bottle gourd collected from the Ottanchathiram market are Chlorpyrifos (0.027 mg/Kg), and Carbendazim (0.18 mg/Kg). The carcinogenic pesticides reported in chilli collected from the Ottanchathiram market are Propargite (0.12 mg/Kg), and Chlorpyrifos (0.025 mg/Kg). The carcinogenic pesticide reported in tomatoes collected from the Ottanchathiram market is Tebuconazole (0.77 mg/Kg). The carcinogenic pesticides reported in beans collected from the Ottanchathiram market are Alpha-HCH (Alpha-Hexachlorocyclohexane), and Monocrotophos. Monocrotophos level (0.11 mg/Kg) was 10 times higher than the maximum residual limit of 0.01 mg/Kg.

3.2 Carcinogenic pesticides reported in leafy vegetables

The carcinogenic pesticides reported in corriander collected from the Ottanchathiram market are o,p-DDD (Dichlorodiphenyltrichloroethane), Malathion, Dimethoate, and Monocrotophos. o,p-DDD (Dichlorodiphenyltrichloroethane) level (0.021 mg/Kg) was 2 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in curry leaves collected from the Ottanchathiram market are Dicofol and Monocrotophos. Monocrotophos level (0.1 mg/Kg) was 10 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in spinach collected from the Ottanchathiram market are Delta-Hexachlorocyclohexane, o, p-DDT (Dichlorodiphenyltrichloroethane), o, p-DDD (Dichlorodiphenyltrichloroethane). Delta-Hexachlorocyclohexane (0.021 mg/Kg) was 2 times higher than the maximum residual limit of 0.01 mg/Kg.

3.3 Carcinogenic pesticides reported in flower vegetables

The carcinogenic pesticide reported in cauliflower collected from the Metupalayam market is Dichlorvos (0.059 mg/kg). The carcinogenic pesticide reported in cabbage collected from the Metupalayam market is Cypermethrin (0.12 mg/Kg). The carcinogenic pesticide reported in ginger collected from the Ottanchathiram market is Monocrotophos (0.11 mg/Kg), the level of which was 10 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in big onion collected from the Ottanchathiram market are Malathion (0.025 mg/Kg), and Monocrotophos (0.012 mg/Kg).

3.4 Carcinogenic pesticides reported in tropical fruits

The carcinogenic pesticides reported in guava collected from the Ottanchathiram market are o,p-DDD (Dichlorodiphenyltrichloroethane) (0.018 mg/Kg), Malathion (0.018 mg/Kg), Dimethoate (0.027 mg/Kg), and Monocrotophos (0.021 mg/Kg). The carcinogenic pesticides reported in sapota collected from the Ottanchathiram market are Chlorpyrifos (0.041 mg/Kg), and Carbendazim (0.15 mg/Kg). The carcinogenic pesticides reported in mango collected from the Ottanchathiram market are ϒ-HCH (Gamma- Hexachlorocyclohexane), Malathion, Dichlorvos, and Carbendazim. ϒ-HCH (Gamma-Hexachlorocyclohexane) level (0.029 mg/Kg) was 2 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in banana collected from the Ottanchathiram market are Diazinon (0.11 mg/Kg), the level of which was 10 times higher than the maximum residual limit of 0.01 mg/Kg, Phorate (0.065 mg/Kg), the level of which was slightly higher than the maximum residual limit of 0.05 mg/Kg, and Cypermethrin (0.10 mg/Kg) the level of which was 10 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in pineapple collected from the Ottanchathiram market are Dicofol (0.58 mg/Kg), and Carbendazim (1.58 mg/Kg). The carcinogenic pesticides reported in jackfruit collected from the Ottanchathiram market are Heptachlor level (0.071 mg/Kg) was 6 times higher than the maximum residual limit of 0.01 mg/Kg.

3.5 Carcinogenic pesticides reported in sub-tropical fruits

The carcinogenic pesticides reported in lemon collected from the Ottanchathiram market are Dicofol (0.042 mg/ Kg), Dimethoate (0.092 mg/ Kg), and Monocrotophos (0.10 mg/Kg) whose level was 10 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in grapes collected from the Ottanchathiram market are Malathion (0.11 mg/Kg), Dichlorvos (0.11 mg/Kg), Carbendazim (1.58 mg/Kg), and ϒ-HCH (Gamma-Hexachlorocyclohexane) (0.34 mg/Kg) whose level was 3 times higher than the maximum residual limit of 0.01 mg/Kg. The carcinogenic pesticides reported in pomegranate collected from Koyambedu market are Carbendazim (1.34 mg/Kg), ϒ-HCH (Gamma-Hexachlorocyclohexane) (0.10 mg/Kg) whose level was 10 times higher than the maximum residual limit of 0.01 mg/Kg, Chlorpyrifos (0.031 mg/Kg) whose level was 2 times higher than the maximum residual limit of 0.01 mg/Kg, and Propargite (0.12 mg/Kg) whose level was 11 times higher than the maximum residual limit of 0.01 mg/Kg.

3.6 Carcinogenic pesticides reported in temperate fruits

The carcinogenic pesticides reported in watermelon collected from the Koyambedu market are Carbendazim (0.042 mg/Kg), and Chlorpyrifos (0.038 mg/Kg).ϒ-HCH (Delta-Hexachlorocyclohexane) has a direct link to non-Hodgkin's lymphoma risk. o, p-DDT (Dichlorodiphenyltrichloroethane) causes pancreatic cancer, liver cancer, and it is a marker for breast cancer. o,p-DDD (Dichlorodiphenyltrichloroethane) is linked to lung, liver and thyroid cancer. Dichlorvos causes prostrate cancer. Cypermethrin is related to lung tumours in mice. Phorate has a direct link to prostate cancer. Propargite is related to intestinal tumours. Chlorpyrifos is linked to several cancers like rectal, lung, brain, breast, prostate cancer, and non-Hodgkin's lymphoma. Carbendazim causes hepatic tumours. Thiacloprid is linked to thyroid, uterine, and ovarian tumours. Malathion causes non-Hodgkin's lymphoma and prostate cancer. Tebuconazole is related to liver tumours. Dicofol causes liver adenoma and carcinoma. Monocrotophos increases the growth of breast cancer cells. Dimethoate has a direct link to adrenal, thyroid and pituitary cancer. Diazinon has a direct link to lung cancer and non-Hodgkin's lymphoma. Heptachlor is related to thyroid, pituitary, and reproductive system cancer.

Table1 represents vegetables and their respective collection market.Table2 represents fruits and their respective collection market. **Source for Carcinogenicity:** United States Environmental Protection Agency. Research fact sheet [11]. Table 3 represents the pesticide residues reported in the vegetables and their carcinogenic effects from the vegetables consumed in Tamilnadu. **Source for Carcinogenicity:** United States Environmental Protection Agency. Research fact sheet [11]. Table 4 represents the pesticide residues above MRL level reported in the vegetables and their carcinogenic effects. **Source for Carcinogenicity:** United States Environmental Protection Agency. Research fact sheet [11]. Table 5 represents the pesticide residues reported in the fruits and their carcinogenic effects from the vegetables consumed in Tamilnadu. **Source for Carcinogenicity:** United States Environmental Protection Agency. Research fact sheet [11]. Table 6 represents the pesticide residues above MRL reported in the fruits and their carcinogenic effects. Figure 1 represents graphical representation of pesticide samples in Tamilnadu compared with normal limit of WHO standards. Figure 2 represents Number of cancer cases recorded in Dindigul district compared with Tamil Nadu Average count. [12]. Figure 3 represents Number of cancer cases recorded in Coimbatore district compared with Tamil Nadu Average count. [12]. Figure 4 represents Number of cancer cases recorded in Chennai district compared with Tamil Nadu Average count [12].

4. Discussion

Several studies over time have indicated a positive relationship between pesticides and the development of some cancers, particularly brain, prostate, liver, and breast cancers, as well as non-Hodgkin's lymphoma and leukaemia. Carcinogenic effects of pesticides are examined by studying the type of pesticides used and measuring the exposure at various follow-up times. Carcinogenic pesticides may increase the risk of cancer through a variety of mechanisms, including immunotoxicity, genotoxicity, hormonal action and tumour promotion. Contrary to genotoxic compounds, carcinogens acting through other mechanisms (tumour promoters) are assumed to have a threshold, i.e., a dose level below which no effects occur. Complete carcinogens have both genotoxic and tumour-promotive potential [13, 14]. In the US National Cancer Institute (NCI) and the National Toxicology Program (NTP), 47 pesticides have been tested in rats and mice as of 1991, with evidence of carcinogenicity for 23 of them [15]. Of those, 18 also had been evaluated by the International Agency for Research on Cancer (IARC); nine were classified as having 'sufficient' and nine 'limited' evidence of carcinogenicity. The other four pesticides were not evaluated by IARC. Fresh documentation from the manufacturer is frequently required since many of them have undergone insufficient testing. Most countries ban pesticides if there is sufficient evidence of carcinogenicity from occupational exposure in humans. The principal justification for banning a pesticide, however, frequently comes from evidence of carcinogenicity in animal experiments, despite the fact that the levels examined were at least one or two orders of magnitude more than the exposure experienced by humans. Phenoxy acid herbicides do not appear to be genotoxic or carcinogenic in experimental animals, but based on epidemiologic studies, they are classified by IARC as carcinogens with limited evidence of carcinogenicity in humans. The documentation on the carcinogenicity of DDT and its metabolites in experimental animals is extensive. In mice, exposure to p,p'-DDT increased the occurrence of hepatoma, malignant lymphoma (in females) [16] and leukaemia and lung carcinoma [17]. DDT exposure increased liver tumour incidence, which has been documented in many animal studies. Although IARC considered some studies inadequate, mainly due to short follow-up time, there is yet sufficient evidence of carcinogenicity. Several organochlorine pesticides (aldrin, benzene hexachloride [BHC], chlordane, chlordecone, DDT, dieldrin, hexachlorobenzene [HCB], heptachlor, lindane and mirex) have been reviewed with respect to carcinogenic properties. The dominating tumour types in rodents exposed to these organochlorines are carcinomas and adenomas of the liver. The compounds reviewed could increase (DDT) or reduce (TCDD) the risk of estrogen-related cancers through hormonal mechanisms, but they also can act through non-hormonal mechanisms. Among organophosphates (OP), phorate has a direct link to prostrate cancer. Monocrotophos increases the growth of breast cancer cells [18].

The present study demonstrates the carcinogenic capability of the fruits and vegetables consumed in Tamilnadu. The purchase of fruits and vegetables is through different modes, such as directly from farmers or from markets or maybe even from transporters. These varied modes of purchase may be due to the different geographical locations of the residing population as well as their convenience. Unlike Europe and the United States [19, 20], India does not have a strict law regarding identification of the source of food products sold on markets, which makes tracing of the source of the contamination difficult or impossible. The lack of strong policies to regulate food products has led to less knowledge about food handling strategies that minimize pesticide use, residues and exposure while maintaining good food hygiene and safety standards. Our laboratory findings also confirm the widespread contamination of fruits and vegetables by carcinogenic pesticide residues. There could be many reasons for pesticide residue contamination in these crops such as farmers' failure to monitor the pesticide application interval between exposure and harvest [21]. In fact, some market vendors reported that they apply pesticides, especially on tomatoes; so visible residues would appeal to consumers. Handling methods including washing, peeling, cooking, blending and drying and other practices have also been shown to increase or decrease the concentration of pesticide residues in fruits and vegetables [22-27]. The present study highlights the need for farmers to ensure the hygiene of the fruits and vegetables sold on markets by observing the proper handling and processing throughout the food chain. Applying pesticides to fruits and vegetables to increase shelf life and reduce loss across the supply chain is potentially a significant source of dietary pesticide exposure. Several studies highlight physical (heating, irradiation and edible coating), chemical (antimicrobial, antioxidants and anti-browning agents, nitric acid and sulphur dioxide), and gaseous (ozone, controlled atmospheric storage and ethylene) [28] methods as safe post-harvest treatment strategies for fresh produce. Some farmers and market vendors have resorted to using pesticides as a treatment to increase the shelf life of fruits and vegetables along the food chain. This increases the potential for dietary pesticide exposure and health risks among consumers.

Table 1: Vegetables and their respective collection market

S. No	VEGETABLES	MARKET
1.	Lady's Finger	Ottanchathiram
2.	Brinjal	Ottanchathiram
3.	Snake gourd	Ottanchathiram
4.	Bottle gourd	Ottanchathiram
5.	Chilli	Ottanchathiram
6.	Tomato	Ottanchathiram
7.	Beans	Ottanchathiram
8.	Coriander	Ottanchathiram
9.	Curry Leaves	Ottanchathiram
10.	Spinach	Ottanchathiram
11.	Cauliflower	Metupalayam
12.	Cabbage	Metupalayam
13.	Ginger	Ottanchathiram
14.	Big Onion	Ottanchathiram

Table 2: Fruits and their respective collection market

S. No	FRUITS	MARKET
1.	Guava	Ottanchathiram
2.	Sapota	Ottanchathiram
3.	Mango	Ottanchathiram
4.	Banana	Ottanchathiram
5.	Pineapple	Ottanchathiram
6.	Jackfruit	Ottanchathiram
7.	Lemon	Ottanchathiram
8.	Grapes	Ottanchathiram
9.	Pomegranate	Koyambedu
10.	Watermelon	Koyambedu

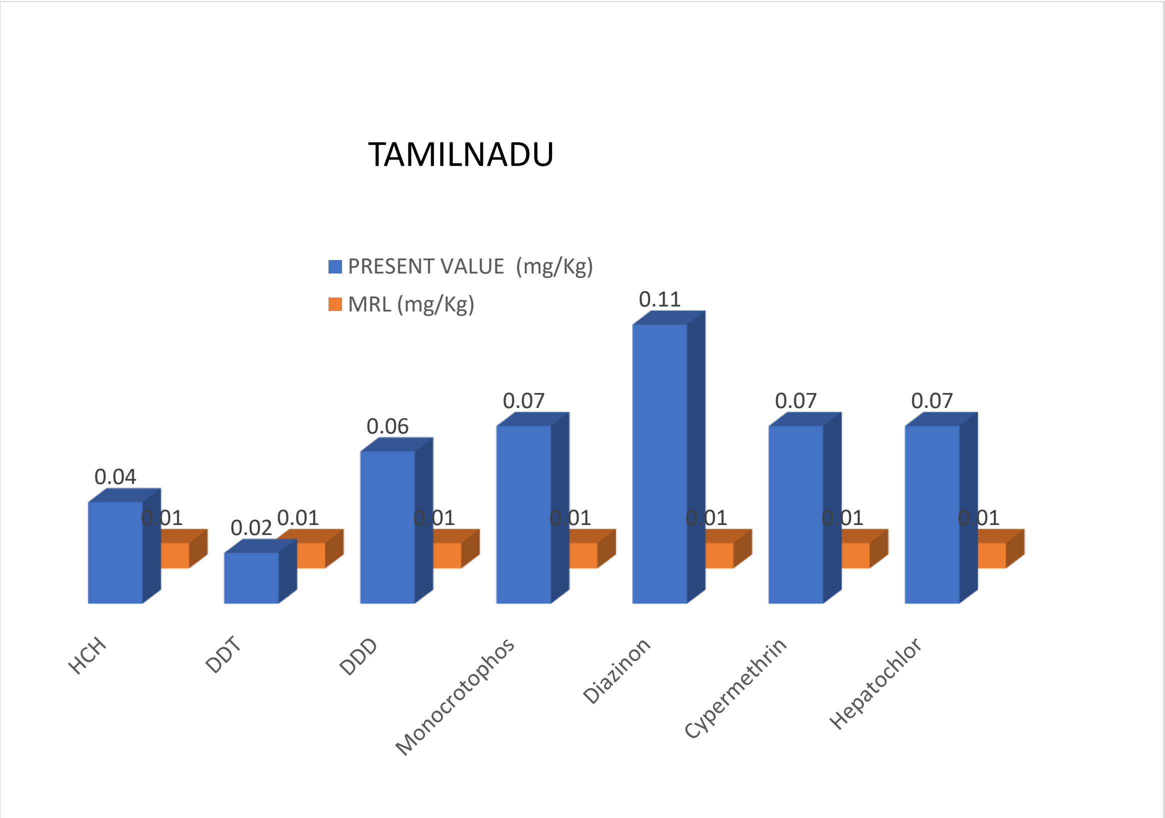

Figure 1: Graphical representation of pesticide samples in Tamilnadu compared with normal limit of WHO standards. [12]

Table 3: Pesticides residues reported in the vegetables and their carcinogenic effects.

	S. No	Vegetables	Pesticides reported	Classification	Type	Present value mg/Kg	MRL* mg/Kg	IARC/ US EPA Classification	Carcinogenicity [11]
Fruit vegetables	1)	Lady's Finger	Delta-HCH (Delta-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.032	0.01	1- IARC	Non-Hodgkin's Lymphoma
			o, p- DDT (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.019	0.01	2A- IARC	Pancreatic Cancer, Liver Cancer, a marker for breast cancer
			o,p-DDD (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.022	0.01	2B- IARC	Lung, Liver, and Thyroid cancer
			Dichlorvos	Organophosphate	Insecticide	0.031	0.15	2B- IARC	Prostate Cancer
			Cypermethrin	Pyrethroid	Insecticide	0.039	0.5	2B- IARC	Lung Tumour in Mice
			Phorate	Organophosphate	Insecticide	0.025	0.01	B4- US- EPA	Prostate Cancer
	2)	Brinjal	Cypermethrin	Pyrethroid	Insecticide	0.024	0.2	2B- IARC	Lung Tumour in Mice
			Propargite	Acaricide	Insecticide	1.02	2	2B- IARC	Intestinal tumours
			Chlorpyrifos	Organophosphate	Insecticide	0.038	0.2	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non-Hodgkin's Lymphoma
			Carbendazim	Others	Fungicide	0.042	0.5	Group C- US EPA	Hepatic tumour
			Thiacloprid	Others- Neonicotinoid	Insecticide	0.31	0.7	Likely to be carcinogenic in humans	Thyroid, Uterine, Ovarian tumour
	3)	Snake Gourd	Delta-HCH (Delta-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.021	0.01	1- IARC	Non- Hodgkin's Lymphoma
			o, p-DDT (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.039	0.01	2A- IARC	Pancreatic Cancer, Liver Cancer, a marker for breast cancer
			Malathion	Organophosphate	Insecticide	0.021	3	2A- IARC	Non- Hodgkin's Lymphoma, Prostate cancer
			Dichlorvos	Organophosphate	Insecticide	0.032	0.15	2B- IARC	Prostate Cancer

			Carbendazim	Others	Fungicide	0.14	0.5	Group C- US EPA	Hepatic tumour
	4)	Bottle Gourd	Chlorpyrifos	Organophosphate	Insecticide	0.027	0.2	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non-Hodgkin's Lymphoma
			Carbendazim	Others	Fungicide	0.18	0.5	Group C- US EPA	Hepatic tumour
	5)	Chilli	Propargite	Acaricide	Insecticide	0.12	2	2B- IARC	Intestinal tumours
			Chlorpyrifos	Organophosphate	Insecticide	0.025	0.2	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non-Hodgkin's Lymphoma
	6)	Tomato	Tebuconazole	Others	Fungicide	0.77	2	Group C- US EPA	Liver tumours
	7)	Beans	Alpha-HCH (Alpha-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.012	0.01	1- IARC	Non- Hodgkin's Lymphoma
			Monocrotophos	Organophosphate	Insecticide	0.11	0.01	NC	Growth of breast cancer cells
Leafy vegetables	8)	Corriander	o,p-DDD (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.021	0.01	2B- IARC	Lung, Liver, and Thyroid cancer
			Malathion	Organophosphate	Insecticide	0.10	3	2A- IARC	Non- Hodgkin's Lymphoma, Prostate cancer
			Dimethoate	Organophosphate	Insecticide	0.11	2	GROUP C- US EPA	Adrenal, Thyroid, and Pituitary cancer
			Monocrotophos	Organophosphate	Insecticide	0.014	0.01	NC	Growth of breast cancer cells
	9)	Curry Leaves	Dicofol	Organochlorine	Insecticide	0.045	5	Group C- US EPA	Liver adenoma and carcinoma
			Monocrotophos	Organophosphate	Insecticide	0.10	0.01	NC	Growth of breast cancer cells
	10)	Spinach	Delta-HCH (Delta-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.021	0.01	1- IARC	Non- Hodgkin's Lymphoma

			o, p-DDT (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.014	0.01	2A- IARC	Pancreatic Cancer, Liver Cancer, a marker for breast cancer
			o,p-DDD (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.014	0.01	2B- IARC	Lung, Liver, and Thyroid cancer
Flower vegetables	11)	Cauliflower	Dichlorvos	Organophosphate	Insecticide	0.059	0.15	2B- IARC	Prostate Cancer
	12)	Cabbage	Cypermethrin	Pyrethroid	Insecticide	0.12	2	2B- IARC	Lung Tumour in Mice
Bulbous vegetables	13)	Ginger	Monocrotophos	Organophosphate	Insecticide	0.10	0.01	NC	Growth of breast cancer cells
	14)	Big Onion	Malathion	Organophosphate	Insecticide	0.025	3	2A- IARC	Non- Hodgkin's Lymphoma, Prostate cancer
			Monocrotophos	Organophosphate	Insecticide	0.012	0.01	NC	Growth of breast cancer cells

Table 4: Pesticide residues above MRL level reported in the vegetables and their carcinogenic effects.

	S. No	Vegetables	Pesticides reported	Classification	Type	Present value mg/Kg	MRL* mg/Kg	IARC/ US EPA Classification	Carcinogenicity [11]
Fruit vegetables	1)	Lady's Finger	Delta-HCH (Delta- Hexachlorocyclohexane)	Organochlorine	Insecticide	0.032	0.01	1- IARC	Non- Hodgkin's Lymphoma
			o,p- DDD (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.022	0.01	2B- IARC	Lung, Liver, and Thyroid cancer
			Phorate	Organophosphate	Insecticide	0.025	0.01	B4- US- EPA	Prostate Cancer
	2)	Snake Gourd	Delta-HCH (Delta- Hexachlorocyclohexane)	Organochlorine	Insecticide	0.021	0.01	1- IARC	Non- Hodgkin's Lymphoma
			o, p-DDT (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.039	0.01	2A- IARC	Pancreatic Cancer, Liver Cancer, a marker for breast cancer
	3)	Beans	Alpha-HCH (Alpha-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.012	0.01	1- IARC	Non- Hodgkin's Lymphoma
			Monocrotophos	Organophosphate	Insecticide	0.11	0.01	NC	Growth of breast cancer cells
Leafy vegetables	4)	Corriander	o,p-DDD (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.021	0.01	2B- IARC	Lung, Liver, and Thyroid cancer
	5)	Curry Leaves	Monocrotophos	Organophosphate	Insecticide	0.10	0.01	NC	Growth of breast cancer cells
	6)	Spinach	Delta-HCH (Delta- Hexachlorocyclohexane)	Organochlorine	Insecticide	0.021	0.01	1- IARC	Non- Hodgkin's Lymphoma
Bulbous vegetables	7)	Ginger	Monocrotophos	Organophosphate	Insecticide	0.10	0.01	NC	Growth of breast cancer cells

Table 5: Pesticide residues reported in the fruits and their carcinogenic effects.

	S.No	Fruits	Pesticides reported	Classification	Type	Present value mg/Kg	MRL* in mg/Kg	IARC/ US EPA Classification	Carcinogenicity [11]
Tropical fruits	1)	Sapota	Chlorpyrifos	Organophosphate	Insecticide	0.041	0.5	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non-Hodgkin's Lymphoma
			Carbendazim	Others	Fungicide	0.15	5	Group C- US EPA	Hepatic tumour
	2)	Guava	o,p-DDD (Dichlorodiphenyltrichloroethane)	Organochlorine	Insecticide	0.018	0.01	2B- IARC	Lung, Liver, and Thyroid cancer
			Malathion	Organophosphate	Insecticide	0.018	4	2A- IARC	Non- Hodgkin's Lymphoma, Prostate cancer
			Dimethoate	Organophosphate	Insecticide	0.027	2	GROUP C- US EPA	Adrenal, Thyroid, and Pituitary cancer
			Monocrotophos	Organophosphate	Insecticide	0.021	1	NC	Growth of breast cancer cells
	3)	Mango	ϒ- HCH (Gamma- Hexachlorocyclohexane)	Organochlorine	Insecticide	0.029	0.01	1- IARC	Non- Hodgkin's Lymphoma
			Malathion	Organophosphate	Insecticide	0.11	4	2A- IARC	Non- Hodgkin's Lymphoma, Prostate cancer
			Dichlorvos	Organophosphate	Insecticide	0.032	0.1	2B- IARC	Prostate Cancer
			Carbendazim	Others	Fungicide	1.01	5	Group C- US EPA	Hepatic tumour
	4)	Banana	Diazinon	Organophosphate	Insecticide	0.11	0.01	2A- IARC	Lung cancer, Non-Hodgkin's Lymphoma
			Phorate	Organophosphate	Insecticide and acaricide	0.065	0.05	US EPA- B4	Prostate Cancer
			Cypermethrin	Pyrethroid	Insecticide	0.10	0.01	2B- IARC	Lung Tumour in Mice
	5)	Pineapple	Dicofol	Organochlorine	Insecticide	0.058	5	Group C- US EPA	Liver adenoma and carcinoma
			Carbendazim	Others	Fungicide	1.58	5	Group C- US EPA	Hepatic tumour

	6)	Jackfruit	Heptachlor	Organochlorine	Insecticide	0.071	0.01	2B- IARC	Thyroid, Pituitary, Reproductive system cancer
Sub-tropical fruits	7)	Lemon	Dicofol	Organochlorine	Insecticide	0.042	5	Group C- US EPA	Liver adenoma and carcinoma
			Dimethoate	Organophosphate	Insecticide	0.092	2	GROUP C- US EPA	Adrenal, Thyroid, and Pituitary cancer
			Monocrotophos	Organophosphate	Insecticide	0.10	0.01	NC	Growth of breast cancer cells
	8)	Grapes	ϒ-HCH (Gamma- Hexachlorocyclohexane)	Organochlorine	Insecticide	0.034	0.01	1- IARC	Non- Hodgkin's Lymphoma
			Malathion	Organophosphate	Insecticide	0.11	4	2A- IARC	Non- Hodgkin's Lymphoma, Prostate cancer
			Dichlorvos	Organophosphate	Insecticide	0.11	0.1	2B- IARC	Prostate Cancer
			Carbendazim	Others	Fungicide	1.58	3	Group C- US EPA	Hepatic tumour
	9)	Pomegranate	ϒ-HCH (Gamma- Hexachlorocyclohexane)	Organochlorine	Insecticide	0.10	0.01	1- IARC	Non- Hodgkin's Lymphoma
			Chlorpyrifos	Organophosphate	Insecticide	0.031	0.01	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non-Hodgkin's Lymphoma
			Carbendazim	Others	Fungicide	1.34	5	Group C- US EPA	Hepatic tumour
			Propargite	Acaricide	Insecticide	0.12	0.01	2B- IARC	Intestinal tumours
Temperate fruits	10)	Watermelon	Carbendazim	Others	Fungicide	0.042	5	Group C- US EPA	Hepatic tumour
			Chlorpyrifos	Organophosphate	Insecticide	0.038	0.5	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non-Hodgkin's Lymphoma

Table 6: Pesticide residues above MRL level reported in the fruits and their carcinogenic effects.

	S. No	Fruits	Pesticides reported	Classification	Type	Present value mg/Kg	MRL* in mg/Kg	IARC/ US EPA Classification	Carcinogenicity [11]
Tropical fruits	1)	Mango	ϒ-HCH (Gamma-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.029	0.01	1- IARC	Non- Hodgkin's Lymphoma
	2)	Banana	Diazinon	Organophosphate	Insecticide	0.11	0.01	2A- IARC	Lung cancer, Non-Hodgkin's Lymphoma
			Phorate	Organophosphate	Insecticide and acaricide	0.065	0.05	US EPA- B4	Prostate Cancer
			Cypermethrin	Pyrethroid	Insecticide	0.10	0.01	2B- IARC	Lung Tumour in Mice
	3)	Jackfruit	Heptachlor	Organochlorine	Insecticide	0.071	0.01	2B- IARC	Thyroid, Pituitary, Reproductive system cancer
Sub-tropical fruits	4)	Lemon	Monocrotophos	Organophosphate	Insecticide	0.10	0.01	NC	Growth of breast cancer cells
	5)	Grapes	ϒ-HCH (Gamma-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.034	0.01	1- IARC	Non-Hodgkin's Lymphoma
	6)	Pomegranate	ϒ-HCH (Gamma-Hexachlorocyclohexane)	Organochlorine	Insecticide	0.10	0.01	1- IARC	Non-Hodgkin's Lymphoma
			Chlorpyrifos	Organophosphate	Insecticide	0.031	0.01	GROUP E- US EPA	Rectal, Lung, Brain, Breast, Prostate cancer, Non- Hodgkin's Lymphoma
			Propargite	Acaricide	Insecticide	0.12	0.01	2B- IARC	Intestinal tumours

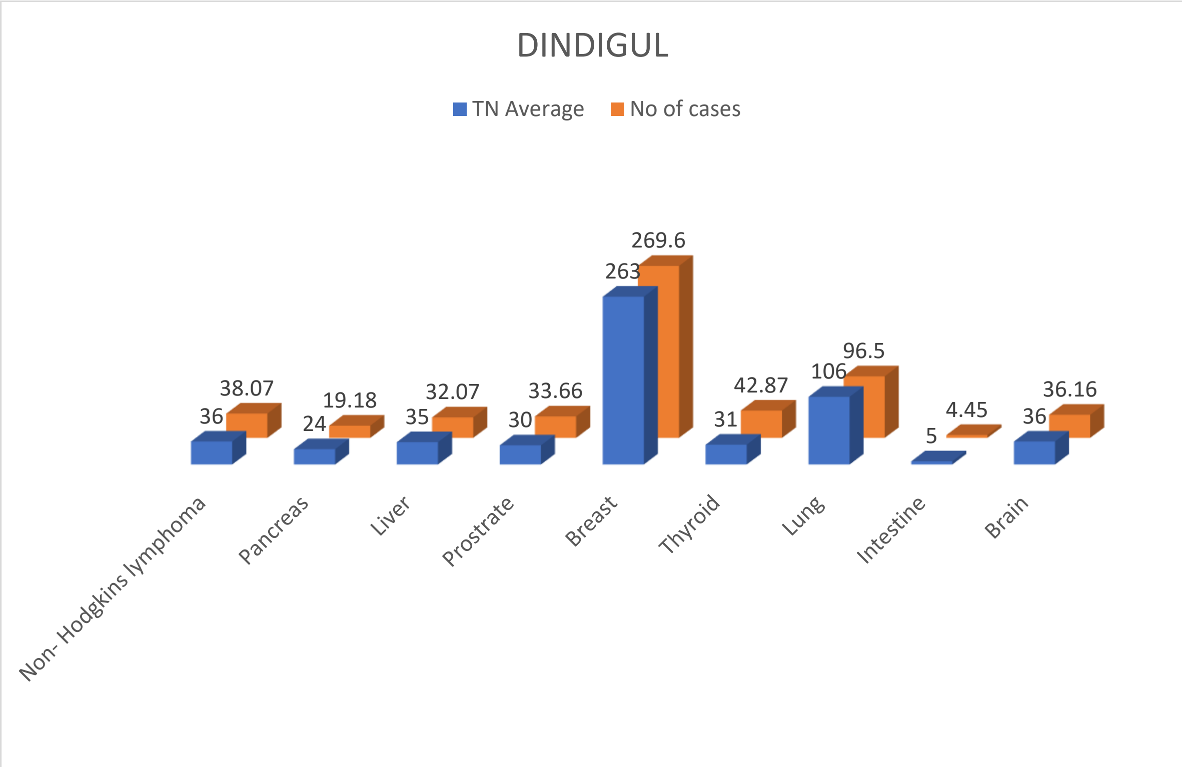

Figure 2: No. of cancer cases recorded in Dindigul district compared with Tamil Nadu Average count. [12]

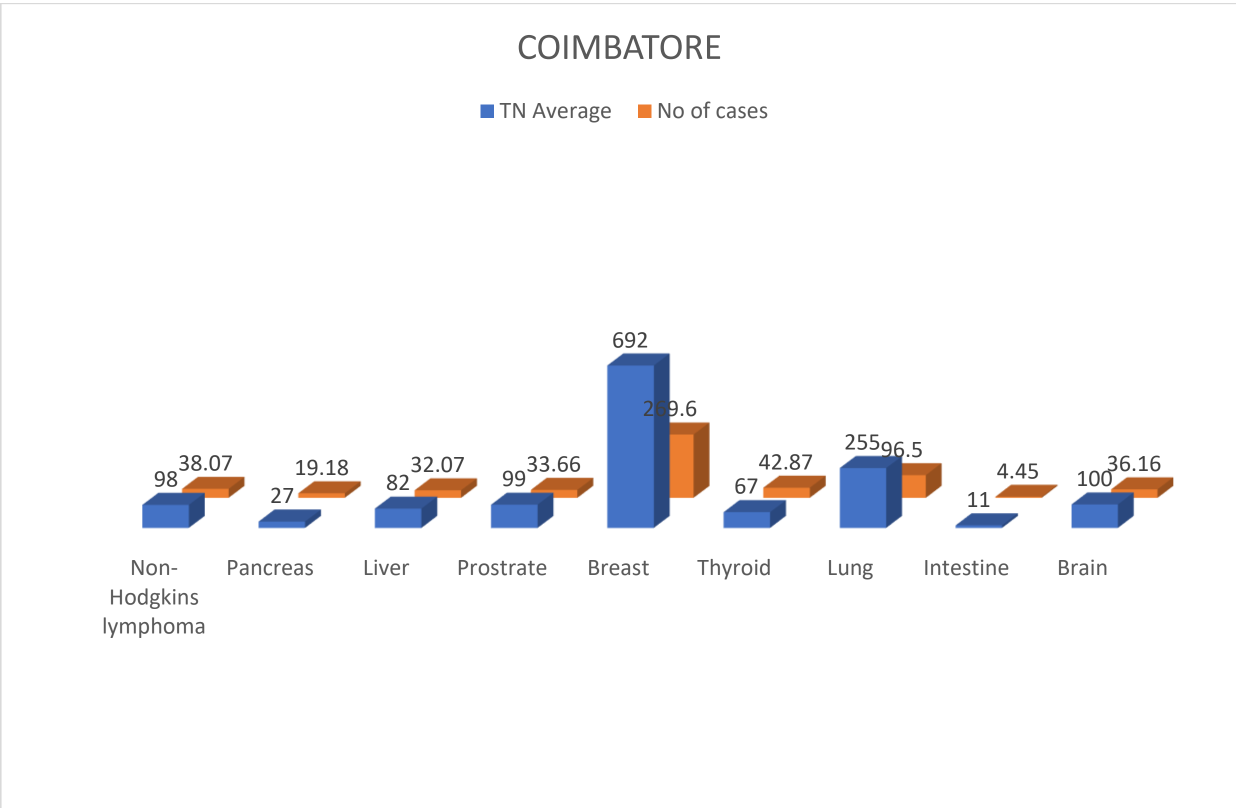

Figure 3: No. of cancer cases recorded in Coimbatore district compared with Tamil Nadu Average count. [12]

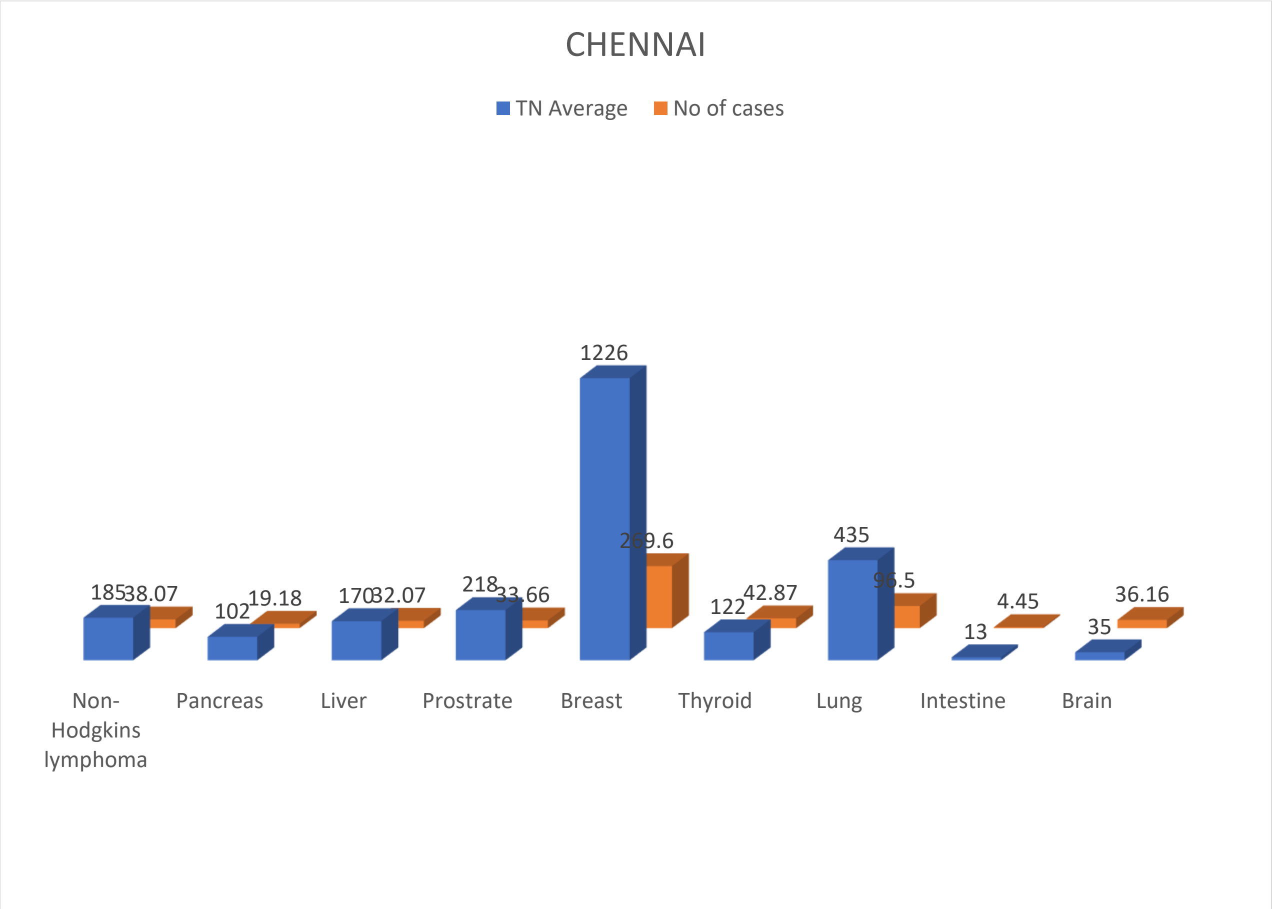

Figure 4: No. of cancer cases recorded in Chennai district compared with Tamil Nadu Average count [12].

However, the state government cannot single-handedly take action to regulate carcinogenic pesticide usage. Since pesticides are governed by agencies like the Central Insecticide Board (CIB), banning the product will need a decision from the Union agriculture ministry [29].The Pesticides Management Bill, 2008 was introduced in the Rajya Sabha on October 21, 2008. The Bill seeks to regulate the manufacture, quality, import, export and sale of pesticides to control pests, ensure the availability of quality pesticides and minimize contamination of agricultural commodities with pesticide residue. It repeals the Insecticides Act, of 1968 [30]. The CIB committee regulates the entry of new formulations of pesticides in India. As per the Food Safety and Standards Act, 2006, the FSSAI recommends the maximum residue level (MRL) of pesticides. In India, several controlled field trials are conducted by the Indian Council of Agricultural Research (ICAR) and agricultural universities to collect data on pesticide residues. The CIB periodically scrutinizes all pesticides and their usage – some can be banned after the registration when it causes serious health effects whereas some pesticides are banned from registration [31]. Some of the banned pesticides are reported in our study. They are Gamma- Hexachlorocyclohexane (banned in 2011), DDT (banned in 2004), Dichlorvos (banned in 2020), Cypermethrin (banned in 2009), Phorate (banned in 2018), Monocrotophos (banned in 2005), and Heptachlor (banned in 2020) [32]. Strong regulations should be made by FSSAI and their compliance should be ensured by state-appointed inspectors. They have the authority to test food products for adherence to MRL and take appropriate action. Imported food products should comply with MRL established by the Food Safety and Standards Regulations, 2010. At the port of entry, custom authorities work with FSSAI appointed officials and The Ministry of Agriculture works at the harbour through the Plant Quarantine Office to check and prevent the import and export of restricted pesticides [33]. Despite these strong regulatory and supervision methods, unauthorised pesticides are still a continuing public health concern. Health of a population plays an influential role in the development of the country. [34] In the future, biochemical pesticides could be utilised in place of chemical pesticides along with natural treatments and remedies, which result in more sustainable elimination of pests and insects. The recommended bio-pesticides by ICAR are Trichoderma, Gliocladium, Paecilomyces, Pseudomonas, Trichogramma, NPV and Bacillus. For sustainable development of economics, based on our limited knowledge of inferential information, the domain of pesticides illustrates a certain ambiguity in which people are undergoing lifelong exposure while also minimising human exposure to pesticides. [35].The limitation of this study is that the samples were collected only from the markets near the geographic locations where the fruits and vegetables are grown. The samples could be gathered throughout various timeframes. for a detailed analysis of pesticide residues and their carcinogenic activity.

5. Conclusion

The prevalence of widespread contamination of fruits and vegetables consumed in Tamilnadu by carcinogenic organochloride and organophosphate pesticides has been found. They are mainly related to deadly cancers like non-Hodgkin's lymphoma, breast cancer, liver cancer, prostate cancer, etc. To prevent these cancers, strict preventive measures like consuming organic fruits and vegetables, and usage of bio-pesticides should be implemented. Our study may serve as a basis for the national regulatory authorities to take proper measures to ensure that pesticide residues in fruits and vegetables are within the acceptable limits for safe consumption. Basic research on public perception towards risk assessment and analysis of pesticide residues in food products and examining their health hazards promotes knowledge on the carcinogenic effects of pesticides. Therefore, additional field research is necessary along with precise exposure assessments for each pesticide and appropriate MRL measures to reduce health risks. Thus, eating can be either the safest and most effective type of medicine or may be the slowest form of poisoning.

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Nil.

Conflict of interest statement
Nil.

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