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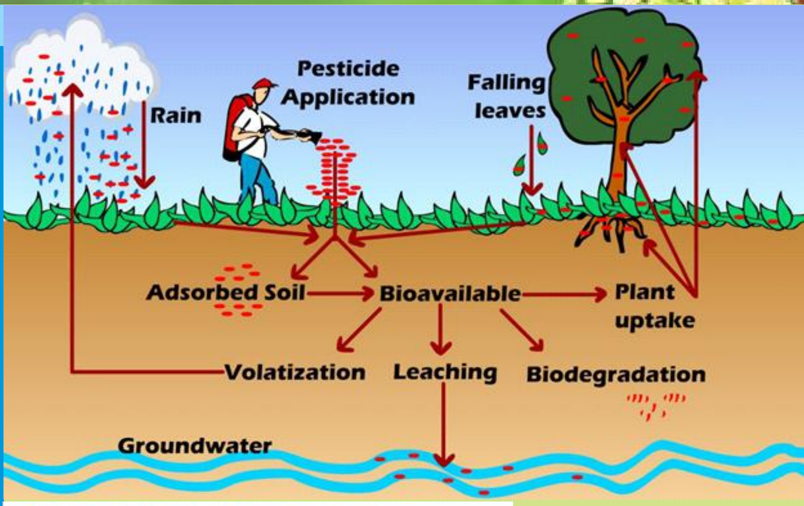

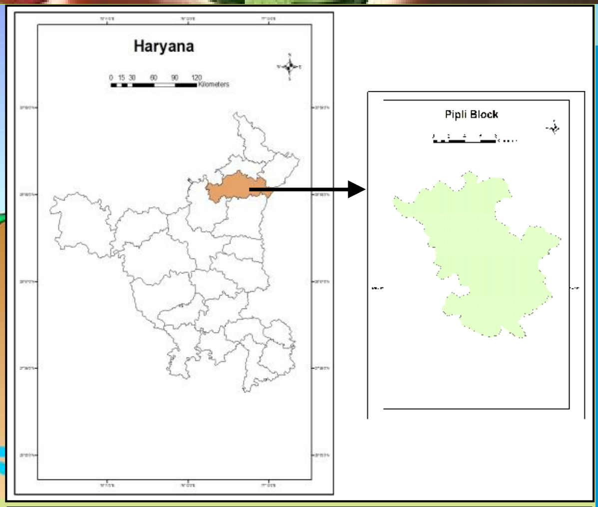

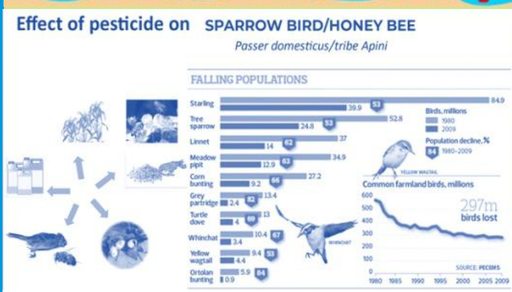

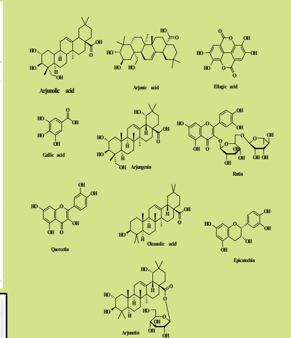

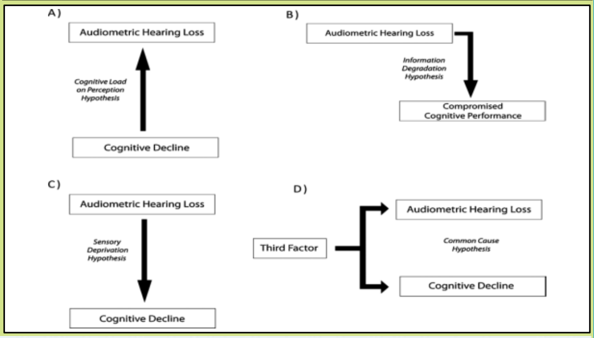

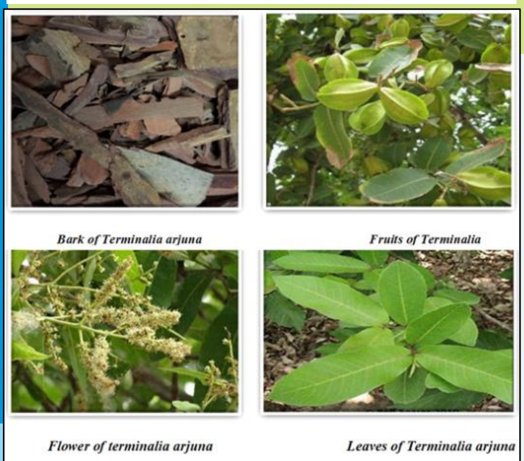

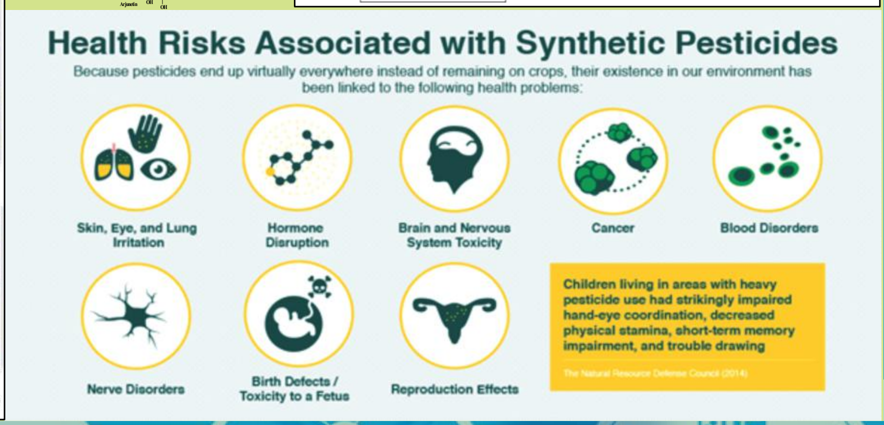

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The IJEHS is an official publication of Save The Environment (STE). It publishes peer reviewed quarterly, original articles (Research paper, Review articles, Short Communication, Case studies, etc.) related to all fields of Environment and Health Sciences. It disseminates the scientific research and recent innovations.

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International Journal of Environment and Health Sciences

From The Editor's Desk…

As we welcome the New Year 2024, the time has come to work together for creating a sustainable and environment-friendly earth around us by making the most of this recovery phase. New policies are being formulated for improving air, soil and water quality which will further improve the health status of public as well as the environment quotient. Undoing the economic losses and health crisis incurred in the past two years, by implementing more responsible actions will be the main pledge.

One important aspect of the 75th year of Indian independence under 'Azaadi ka Amrit Mahotsav' theme has been designated as repurposing natural compounds for therapeutic functions by harnessing the vast knowledge about traditional medical systems available in our ancient texts. Also, another major focus will be necessitating agricultural reforms in order to reduce gaps in crop production, while ensuring benefits of farmers, who are one of the most important pillars of nation-building.

In view of this, all of us have to act more responsibly by 'life management' such that we move a step closer towards achieving the goal of sustainability, as suggested by The United Nations.

Striving to achieve the aforesaid, The International Journal of Environment and Health Sciences (IJEHS) proposes to provide a reliable platform to discuss relevant technologies and strategies. IJEHS will be quintessential to academicians, industry professionals and researchers who are actively engaged in the areas of environmental issues and related health effects. We are pleased to inform that ISSN for IJEHS is available as 2582-5283. IJEHS is referenced in Crossref, the official Digital Object Identifier Agency (doi 10.47062). IJEHS is now also indexed in the International Scientific Indexing (ISI).

We invite original research articles, short communications and critical reviews directed towards an academic, clinical and industrial audience. The first section of the journal focuses on burning environmental issues like pollutants and their fate, waste management, resource conservation, remediation technologies, etc. The second section includes all topics relevant to physiological impact of environmental risk factors and application of alternative medicinal approaches as remedial measures. Detailed scope can be found in the home page of the journal (www.stenvironment.org/journals). Notes on development of any novel and validated strategy or tool to address environmental challenges are welcome. Discussion on proceedings of conferences conducted on environmental themes and related health aspects will also be considered.

All submissions will be meticulously scrutinized by pioneers in the field to ensure publication of only articles of high quality and relevance. Authors are requested to take special precautions to avert plagiarism and redundancy. It is high time that we realize the gravity of circumstances and take potent steps to undo the adversities already triggered. In this pursuit, IJEHS expects to be the ideal platform to discuss sustainable ideas and potential solutions.

We thank all authors who have contributed to the journal and have consistently been with us in the past years. With this, I wish all our readers a Very Happy New Year, 2022 and I hope our audience and patrons shall come together in this effort to promulgate their part in resurrecting our valuable environment.

Kshipra Misra

Dr. Kshipra Misra
Executive Editor-In-Chief

International Journal of Environment and Health Sciences

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A.
Environmental Sciences Section

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STUDY OF GROUNDWATER QUALITY FOR DRINKING PURPOSE IN HANSI-I BLOCK, HISAR DISTRICT, HARYANA

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[1]Haryana Space Applications Centre (HARSAC) CCS HAU Campus, Hisar
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Abstract

Groundwater is a vital source of water for domestic, agricultural, and industrial utilization. Due to non availability of surface water everywhere people rely on groundwater because of availability. In arid to semi-arid regions of the world groundwater is the main source for drinking, iriigration and industrial utilization. In the present study groundwater quality in Hansi-I block has been studied for srinking purpose. In this study, 18 groundwter samples were collected from different locations in the study area. Groundwater samples were analysed for 12 chemical parameters- pH, TDS, Cl, Zn, K, HCO3, CO3, Ca, Mg, Fe, TH, and Mn. BIS 10500:2012 drinking water standards were used for assessment of suitability of groundwater for drinking purpose. In the study area pH ranges 6.9 to 8.3 and desirable at all the groundwater samples.TDS ranges 118 mg/l to 2640 mg/l. TDS is desirable in groundwater samples -Dhnderi School (214 mg/l), Daple (118 mg/l), Sainipura (171 mg/l), Bhidfarm (450 mg/l), Sisai (270 mg/l), bhatla (308 mg/l), Chanak (175 mg/l), Masoodpur (149 mg/l), Dhata (209 mg/l), Sindhar (146 mg/l), Rajli (268 mg/l), Sulakhni (153 mg/l), permissibe in Dhani Qutub (1165 mg/l), Lalpura (1360 mg/l), Majood Temple (1525 mg/l), Ghiraye (1075 mg/l) and non-potable in Civil Hospital (2640 mg/l), Khanpur (2295 mg/l).Manganese ranges 0.02 mg/l to 0.15mg/l and desirable in all groundwater samples. In the study area zinc ranges 4.96 mg/l to 64.82 mg/l. In the study area zinc is non-potable in groundwater samples at Dhnderi School (64.82 mg/l), Daple (62.43mg/l), Dhani Qutub (60.71 mg/l), Civil Hospital (58.23 mg/l), Lalpura (57.09 mg/l), Sainipura (55.62 mg/l), Bhidfarm (53.67 mg/l), Sisai (49.53 mg/l), Bhatla (45.70 mg/l), Chanak (38.94 mg/l), Majood Temple (35.49 mg/l), Masoodpur (29.27 mg/l), Dhata (24.68 mg/l), Khanpur (20.68 mg/l), Sindhar (15.81 mg/l), permissible in Rajli (11.74 mg/l), Ghiraye (7.84 mg/l) and desirable in Sulakhni (4.96 mg/l) groundwater sample. Iron ranges 0.07 mg/l to 0.92 mg/l. Iron is desirable in groundwater samples in Masoodpur (0.29 mg/l), Dhata (0.20 mg/l), Khanpur (0.14 mg/l), Sindhar (0.20 mg/l), Rajli (0.20 mg/l), Ghiraye (0.07 mg/l), Sulakhni (0.07 mg/l) and non-poyable in groundwater samples in Dhnderi School (0.92 mg/l), Daple (0.89 mg/l), Dhani Qutub (0.71 mg/l), Civil Hospital (0.77 mg/l), Lalpura (0.72 mg/l), Sainipura (0.72 mg/l), Bhidfarm (0.64 mg/l), Sisai (0.71 mg/l), Bhatla (0.53 mg/l), Chanak (0.33 mg/l) and Majood Temple (0.36 mg/l). In the study area chloride ranges 2.7 mg/l to 38.2 mg/l and desirable in all the groundwater samples. Hardness ranges 2.8 mg/l to 32.2 mg/l and desirable in all the groundwater samples. In the study area potassium ranges 2.9 to 65 mg/l and desirable in all groundwater samples except Civil Hospital (18.4 mg/l), Lalpura (14.6 mg/l), Majood Temple (65 mg/l), Khanpur (19.3 mg/l), Sulakhni (14.1 mg/l) groundwater samples in which potassium is non-potable. In the study area bicarbonate ranges 0.2 mg/l to 0.5 mg/l and desirable in all the groundwater samples. In the study area carbonate ranges nil to 0.1 mg/l and desirable in all the groundwater samples. In the study area calcium ranges 1.87 mg/l to 21.47 mg/l and desirable in all the groundwater samples. In the study area magnesium ranges 0.93 mg/l to 10.73 mg/l. and desirable in all the groundwater samples. The study is highly useful for planning of groundwater quality for drining purpose in the study area.

Keywords
Groundwater, drinking, non-potable, Hansi-1, Hisar, Haryana.

INTRODUCTION

Groundwater is the water that exists in the surface of the earth and fills all voids in soils and geologic strata. Groundwater in the upper portion of 2 km of the Earth's surface is estimated to contain 22.6 million cubic km. The most often used groundwater reservoirs are unconsolidated (sand and gravel) or carbonate hard rock reservoirs and mostly found in alluvial plains, valleys, coastal plains and high-temperature deserts. Groundwater is highly expoited for drinking, irrigation and industrial purposes. Suitability of groundwater for drinking purpose must be assessed to avoid health issues. Many workers (Chatterjee et al. (2010), Singh and Khan (2011), Adhikary et al. (2012), Konkey et al. (2014), Logeshkumaran et al. (2015), Nagalakshmi et al. (2016), Ali and Ali (2018), Tiwari et al. (2018), Deepika et al. (2020), Gaikwad et al. (2020), Vaiphei et al. (2020)) studied groundwater quality for drinking purpose in different types of terrains.

CONTACT *Corresponding author: *anup0106@yahoo.com*
Color versions of one or more of the figures in this article can be found online at www.stenvironment.org

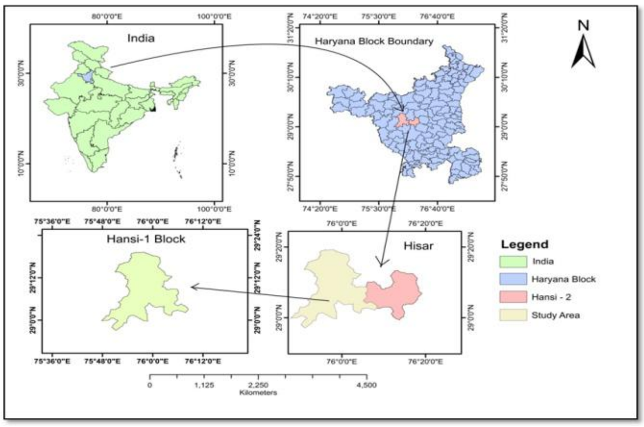

Fig.1: Location map of the study area.

STUDY AREA

Hansi-1 block is situated in Hisar district of Haryana. The block is located between the latitudes 28^o 57' 57"N - 29^o 19' 13"N and longitudes 75^0 47' 50"E - 76^0 8' 89" E and covers 588 sq km. The average annual rainfall is 460 mm and subtropical steppe climate. Geomorphologically the area is part of alluvial plain of Indo-Ganfteic plain.

OBJECTIVE

The main objective was to study the groundwater quality for drinking purpose in the study area.

Table 1: Results of chemical analysis of groundwater samples.

S. No.	Sample Location	pH (mg/l)	TDS (mg/l0)	Mn (mg/l)	Zn (mg/l)	Fe (mg/l)	Cl (mg/l)	TH (mg/l)	K (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Ca (mg/l)	Mg (mg/l)
1	Dhnderi School	7.5	214	0.08	64.82	0.92	4.5	4.1	5.1	0.4	0	2.73	1.37
2	Daple	7.6	118	0.06	62.43	0.89	4	2.8	3.8	0.2	0	1.87	0.93
3	Dhani Qutub	7.05	1165	0.05	60.71	0.71	11.3	7	9.8	0.4	0	4.67	2.33
4	Civil Hospital	7.2	2640	0.05	58.23	0.77	38.2	32.2	18.4	0.4	0	21.47	10.73
5	Lalpura	7.7	1360	0.04	57.09	0.72	24.2	13	14.6	0.4	0	8.67	4.33
6	Sainipura	7.9	171	0.04	55.62	0.72	4.5	2.9	4.4	0.5	0.1	1.93	0.96
7	Bhidfarm	7.5	450	0.03	53.67	0.64	3.8	6.1	10.9	0.4	0.1	4.06	2.03
8	Sisai	7.2	270	0.03	49.53	0.71	30.5	16	4.3	0.4	0.1	10.66	5.33
9	Bhatla	7.5	308	0.15	45.70	0.53	4	6.8	4.3	0.4	0	4.53	2.26
10	Chanak	7.6	175	0.03	38.94	0.33	6.5	3	11.6	0.2	0	2	1
11	Majood Temple	7.1	1525	0.03	35.49	0.36	8	14.5	65	0.37	0	9.66	4.83
12	Masoodpur	7.9	149	0.02	29.27	0.29	3.6	4.9	3.4	0.3	0	3.67	1.63
13	Dhata	7.8	209	0.02	24.68	0.20	4.1	3	6.2	0.2	0	2	1
14	Khanpur	7.5	2295	0.06	20.68	0.14	52.4	12.8	19.3	0.35	0	8.53	4.27
15	Sindhar	8.3	146	0.05	15.81	0.20	4.5	3	2.9	0.5	0	2	1
16	Rajli	7.2	268	0.02	11.74	0.20	2.7	4.6	6.1	0.2	0	3.06	1.53
17	Ghiraye	6.9	1075	0.02	7.84	0.07	2.9	3.7	4.8	0.3	0	2.46	1.23
18	Sulakhni	7.5	153	0.03	4.96	0.07	16.4	6.2	14.1	0.24	0	4.13	2.07

Table 2: BIS 10500:2012 Drinking Water Standards.

Sl. No.	Parameters	Potable		Non potable
		Desirable	Permissible	
1	pH	6.5 to 8.5	No Relaxation	-
2	Total Hardness (mg/l)	< 200	200-600	> 600
3	Iron (mg/l)	< 0.3	No Relaxation	-
4	Chlorine (mg/l)	< 250	250-1000	> 1000
5	Total Dissolved Solid (mg/l)	< 500	500-2000	> 2000
6	Bicarbonates (mg/l)	< 500	-	> 500
7	Calcium (mg/l)	< 75	75-200	> 200
8	Magnesium (mg/l)	< 30	30-100	> 100
9	Manganese (mg/l)	< 0.1	0.1-0.3	> 0.3
10	Sodium (mg/l)	<50 mg/l	50-200 mg/l	>200 mg/l
11	Potassium (mg/l)	<12 mg/l	-	-
12	Zinc (mg/l)	<5	5-15	>15

METHODOLOGY

In the study area 18 groundwater samples were collected in 250 ml plastic bottles from different sample sources like hand pump,dug well and tube well. Groundwater samples were analysed for pH, total dissolved solids (TDS), magnesium (Mg), chloride (Cl), carbonate (CO_3), bicarbonate (HCO_3), potassium (K), calcium (Ca), manganese (Mn), total hardness (TH), iron (Fe) and zinc (Zn) (Table 1). BIS 10500:2012 drinking water standards were used to determine the suitability of groundwater samples for drinking purpose (Table 2). Chemical parameter wise bar graphs were prepared to present the scenario of chemical parameter at different groundwater sample locations.

RESULTS AND DISCUSSION

i.pH

In the study area pH ranges 6.9 to 8.3. As per BIS 10500: 2012 drinking water standards pH 6.5 to 8.5 is desirable. In the study area pH is desirable at all the groundwater samples.

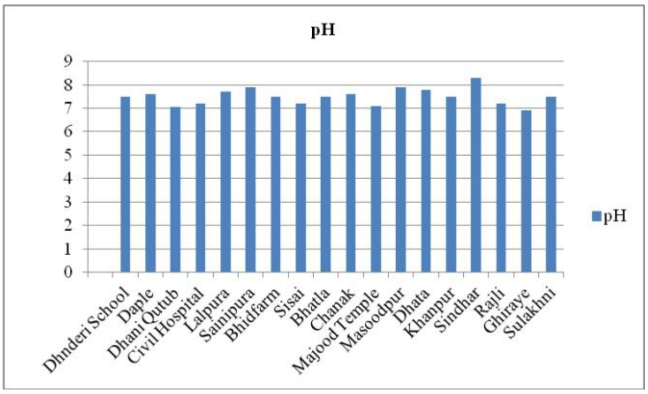

Fig. 2: Sceanrio of pH in groundwater samples in the study area.

ii.Total Dissolved Solids (TDS)

In the study area TDS ranges 118 mg/l to 2640 mg/l. As per BIS 10500:2012 drinking water standards TDS is desirable if less than 500 mg/l, permissible 500 mg/l - 2000 mg/l and non-potable if more than 2000 mg/l. TDS is desirable in groundwater samples -Dhnderi School (214 mg/l), Daple (118 mg/l), Sainipura (171 mg/l), Bhidfarm (450 mg/l), Sisai (270 mg/l), bhatla (308 mg/l), Chanak (175 mg/l), Masoodpur (149 mg/l), Dhata (209 mg/l), Sindhar (146 mg/l), Rajli (268 mg/l), Sulakhni (153 mg/l), permissibe in Dhani Qutub (1165 mg/l), Lalpura (1360 mg/l), Majood Temple (1525 mg/l), Ghiraye (1075 mg/l) and non-potable in Civil Hospital (2640 mg/l), Khanpur (2295 mg/l).

iii.Manganese (Mn)

In the study area manganese ranges 0.02 mg/l to 0.15mg/l. As per BIS 10500:2012 drinking water standards calcium is desirable if less than 0.1 mg/l, permissible 0.1 mg/l- 0.3 mg/l and non-potable if more than 0.3 mg/l. In the study area manganse is desirable in all groundwater samples.\

iv.Zinc (Zn)

In the study area zinc ranges 4.96 mg/l to 64.82 mg/l. As per BIS 10500:2012 drinking water standards zinc is desirable if less than 5 mg/l, permissible between 5 mg/l- 15 mg/l and non-potable if more than 15 mg/l. In the study area zinc is non-potable in groundwater samples at Dhnderi School (64.82 mg/l), Daple (62.43mg/l), Dhani Qutub (60.71 mg/l), Civil Hospital (58.23 mg/l), Lalpura (57.09 mg/l), Sainipura (55.62 mg/l), Bhidfarm (53.67 mg/l), Sisai (49.53 mg/l), Bhatla (45.70 mg/l), Chanak (38.94 mg/l), Majood Temple (35.49 mg/l), Masoodpur (29.27 mg/l), Dhata (24.68 mg/l), Khanpur (20.68 mg/l), Sindhar (15.81 mg/l), permissible in Rajli (11.74 mg/l), Ghiraye (7.84 mg/l) and desirable in Sulakhni (4.96 mg/l) groundwater sample.

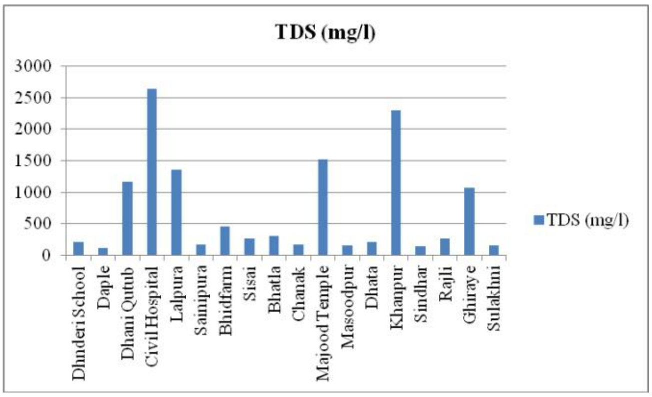

Fig.3: Sceanrio of TDS in groundwater samples in the study area.

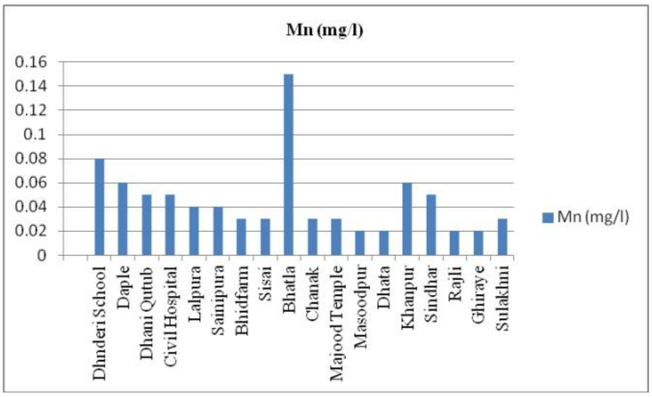

Fig.4: Sceanrio of manganese in groundwater samples in the study area.

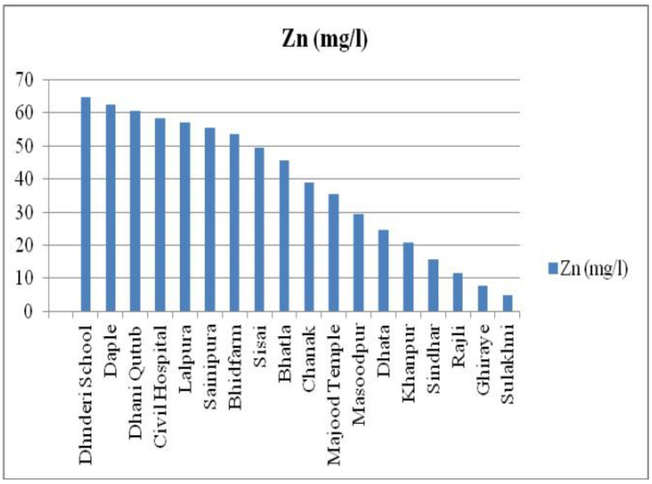

Fig.5: Sceanrio of zinc in groundwater samples in the study area.

v. Iron (Fe)

In the study area iron ranges 0.07 mg/l to 0.92 mg/l. As per BIS 10500:2012 drinking water standards iron is desirable if less than 0.3 mg/l and non-potable if more than 0.3 mg//l. In the study area iron is desirable in groundwater samples in Masoodpur (0.29 mg/l), Dhata (0.20 mg/l), Khanpur (0.14 mg/l), Sindhar (0.20 mg/l), Rajli (0.20 mg/l), Ghiraye (0.07 mg/l), Sulakhni (0.07 mg/l) and non-poyable in groundwater samples in Dhnderi School (0.92 mg/l), Daple (0.89 mg/l), Dhani Qutub (0.71 mg/l), Civil Hospital (0.77 mg/l), Lalpura (0.72 mg/l), Sainipura (0.72 mg/l), Bhidfarm (0.64 mg/l), Sisai (0.71 mg/l), Bhatla (0.53 mg/l), Chanak (0.33 mg/l) and Majood Temple (0.36 mg/l).

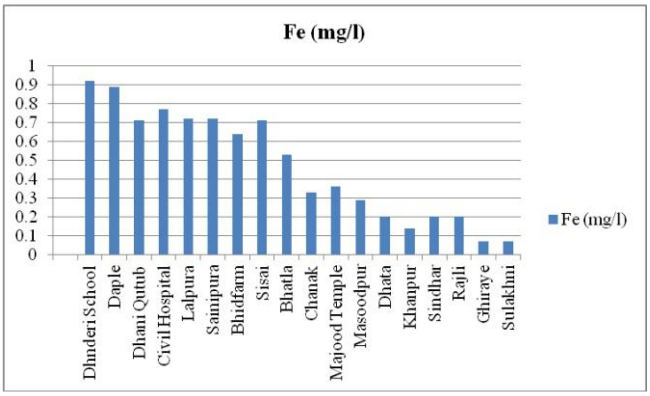

Fig.6: Sceanrio of iron in groundwater samples in the study area.

vi.Chloride (Cl)

In the study area chloride ranges 2.7 mg/l to 38.2 mg/l. As per BIS 10500:2012 drinking water standards chloride is desirable if less than 250 mg/l, permissible 250 mg/l - 1000 mg/l and non-potable if more than 1000 mg/l. in the study area chloride is desirable in all the groundwater samples.

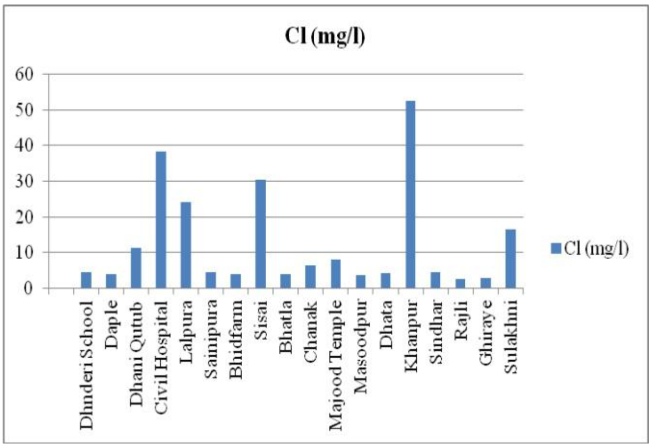

Fig.7:Sceanrio of chloride in groundwater samples in the study area.

vii.Total Hardness (TH)

In the study area total hardness ranges 2.8 mg/l to 32.2 mg/l. As per BIS 10500:2012 drinking water standards total hardness is desirable if less than 200 mg/l, permissible 200 mg/l - 600 mg/l and non-potable if more than 600 mg/l. Thus, in the study area total hardness is desirable in all the groundwater samples.

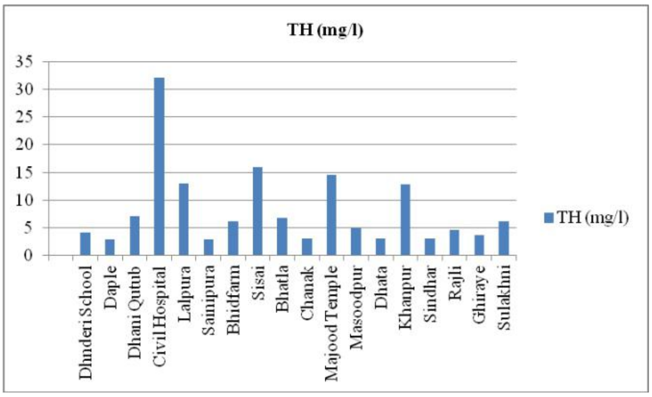

Fig.8: Sceanrio of total hardness in groundwater samples in the study area.

viii.Potassium (K)

In the study area potassium ranges 2.9 to 65 mg/l. As per BIS 10500:2012 drinking water standards total hardness is desirable if less than 12 mg/l and non-potable if more than 12 mg/l. In the study area potassium is desirable in all groundwater samples except Civil Hospital (18.4 mg/l), Lalpura (14.6 mg/l), Majood Temple (65 mg/l), Khanpur (19.3 mg/l), Sulakhni (14.1 mg/l) groundwater samples in which potassium is non-potable.

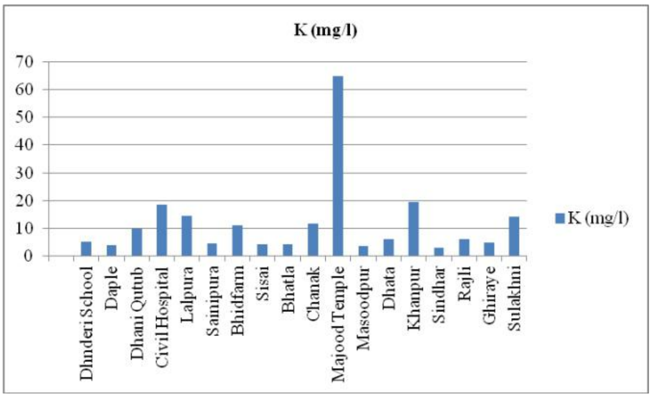

Fig. 9: Sceanrio of total hardness in groundwater samples in the study area.

ix.Bicarbonate (HCO_3)

In the study area bicarbonate ranges 0.2 mg/l to 0.5 mg/l. As per BIS 10500:2012 drinking water standards bicarbonate is desirable if less than 500 mg/l and non-potable if more than 500 mg/l. In the study area bicarbonate is desirable in all the groundwater samples.

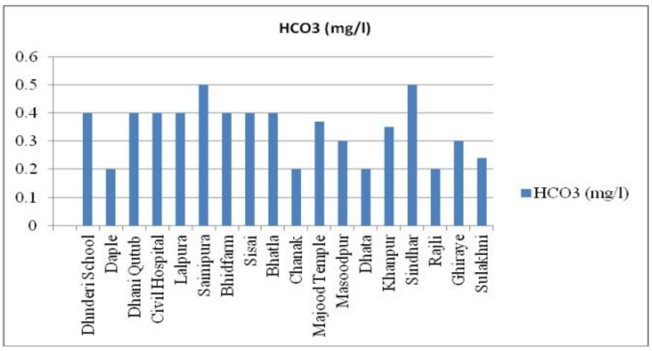

Fig.10: Sceanrio of carbonate in groundwater samples in the sstudy area.

x.Carbonate (CO_3)

In the study area carbonate ranges nil to 0.1 mg/l. In the study area carbonate is desirable in all the groundwater samples.

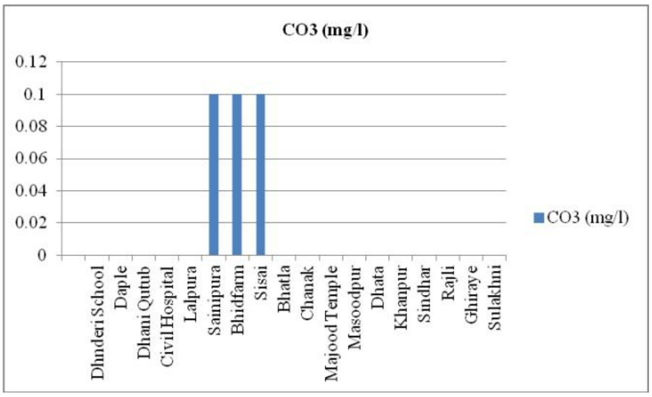

Fig.11:Sceanrio of carbonate in groundwater samples in the sstudy area.

xi.Calcium (Ca)

In the study area calcium ranges 1.87 mg/l to 21.47 mg/l. As per BIS 10500:2012 drinking water standards calcium is desirable if less than 75 mg/l, permissible 75 mg/l - 200 mg/l and non-potable if more than 200 mg/l. Thus, in the study area calcium is desirable in all the groundwater samples.

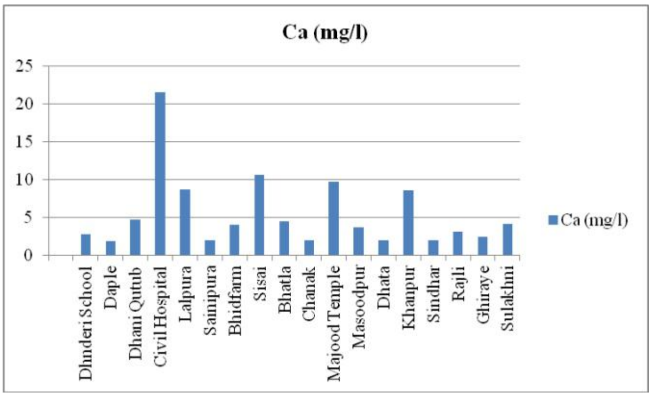

Fig.12:Sceanrio of calcium in groundwater samples in the study area.

xii. Magnesium (Mg)

In the study area magnesium ranges 0.93 mg/l to 10.73 mg/l. As per BIS 10500:2012 drinking water standards magnesium is desirable if less than 30 mg/l, permissible 30 mg/l - 100 mg/l and non-potable if more than 100 mg/l. Thus, in the study area magnesium is desirable in all the groundwater samples.

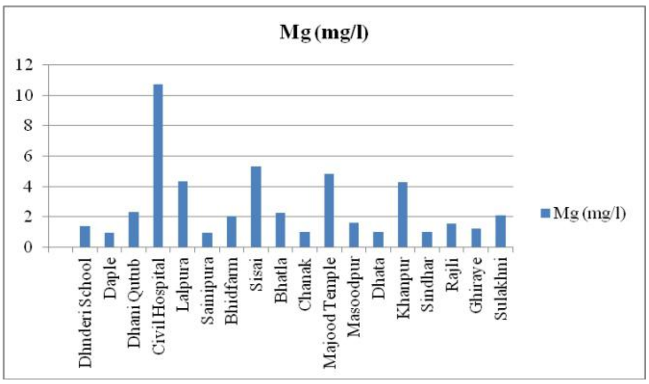

Fig.12:Sceanrio of magnesium in groundwater samples in the sstudy area.

CONCLUSIONS

In the study area pH, manganese, chloride, total hardness, bicarbonate, carbonate, calcium, and magnesium are desirable at all the groundwater samples. TDS is desirable in groundwater samples -Dhnderi School (214 mg/l), Daple (118 mg/l), Sainipura (171 mg/l), Bhidfarm (450 mg/l), Sisai (270 mg/l), bhatla (308 mg/l), Chanak (175 mg/l), Masoodpur (149 mg/l), Dhata (209 mg/l), Sindhar (146 mg/l), Rajli (268 mg/l), Sulakhni (153 mg/l), permissibe in Dhani Qutub (1165 mg/l), Lalpura (1360 mg/l), Majood Temple (1525 mg/l), Ghiraye (1075 mg/l) and non-potable in Civil Hospital (2640 mg/l), Khanpur (2295 mg/l). Zinc is non-potable in groundwater samples at Dhnderi School (64.82 mg/l), Daple (62.43mg/l), Dhani Qutub (60.71 mg/l), Civil Hospital (58.23 mg/l), Lalpura (57.09 mg/l), Sainipura (55.62 mg/l), Bhidfarm (53.67 mg/l), Sisai (49.53 mg/l), Bhatla (45.70 mg/l), Chanak (38.94 mg/l), Majood Temple (35.49 mg/l), Masoodpur (29.27 mg/l), Dhata (24.68 mg/l), Khanpur (20.68 mg/l), Sindhar (15.81 mg/l), permissible in Rajli (11.74 mg/l), Ghiraye (7.84 mg/l) and desirable in Sulakhni (4.96 mg/l) groundwater sample.Iron is desirable in groundwater samples in Masoodpur (0.29 mg/l), Dhata (0.20 mg/l), Khanpur (0.14 mg/l), Sindhar (0.20 mg/l), Rajli (0.20 mg/l), Ghiraye (0.07 mg/l), Sulakhni (0.07 mg/l) and non-poyable in groundwater samples in Dhnderi School (0.92 mg/l), Daple (0.89 mg/l), Dhani Qutub (0.71 mg/l), Civil Hospital (0.77 mg/l), Lalpura (0.72 mg/l), Sainipura (0.72 mg/l), Bhidfarm (0.64 mg/l), Sisai (0.71 mg/l), Bhatla (0.53 mg/l), Chanak (0.33 mg/l) and Majood Temple (0.36 mg/l). Potassium is desirable in all groundwater samples except Civil Hospital (18.4 mg/l), Lalpura (14.6 mg/l), Majood Temple (65 mg/l), Khanpur (19.3 mg/l), Sulakhni (14.1 mg/l) groundwater samples in which potassium is non-potable. The study is highly useful for planning of groundwater quality for drining purpose in the study area.

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STUDY ON HEAVY METAL ACCUMULATION IN THE PLANTS GROWN IN THE SOIL AMENDED WITH CETP SLUDGE IN DIFFERENT COMPOSITIONS

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Abstract
Present study was carried out to demonstrate the utility of sludge generated from a CETP of Delhi as a resource and its use as a soil supplement with special emphasis on heavy metal accumulation in plants. Sludge collected from Wazirpur CETP was analyzed for certain heavy metals. Soil was amended with sludge in 5%, 10%, 20% and 30% to grow experimental plants, in duplicates. The plants were allowed to grow for 45 days and then analyzed for heavy metals using ICP-OES. Results concluded that the addition of sludge in soil do not affects the plant growth in general, but heavy metal content in plant parts increased appreciably after 10% sludge addition. Bioaccumulation Factor (BAF) of more than 1 in case of Cr and Pb in Desi chana and of Cr, Cu, Ni and Pb in Indian mustard indicate that the plants are accumulators of the above-mentioned metals and they may be evaluated for phytoremediation. Sewage sludge contains good amount of nutrients, but due to high concentration of toxic metals, it cannot be applied for land application in considerable amount. However, sewage sludge can still be considered as a beneficial alternative, in order to supplement the organic fertilizers, after suitable chemical characterization and risk assessment.

Keywords: Soil; Sewage sludge; amendment; heavy metals; Bioaccumulation; Phytoremediation.

INTRODUCTION

Priorities in environmental management of wastes are changing with time. In India, the ongoing development of wastewater treatment facilities with improved efficiencies is leading to a notable escalation in the daily generation of sewage sludge, also known as biosolids. It is predicted that around 132 billion liters of wastewater per day would be generated in India by 2050, with a potential to meet 4.5 per cent of the total irrigation water demand [1]. In the upcoming years, overall water management highlights a dual challenge to cope with the surge in wastewater and biosolid production, attributed to the escalating population and industrialization. One of the biggest environmental concerns, worldwide, is about the safe disposal of the sewage sludge [2]. The decision regarding disposal and reclamation of sludge, requires an understanding of the behavior of toxic metals, organic contaminants and other pollutants, specific to local conditions which include climate, mineralogy, geochemistry and topography. Although, landfill disposals of hazardous wastes are still considered to be the main alternative, the escalation in the prices of land and growing population makes it difficult to find new landfill sites. Incineration is another common method to manage sludge but it is costly and difficult to adopt as a regular practice on a large scale or urban set ups. Bioremediation of sludge facilitates in reducing BOD, COD, TSS, Coliform and also reduces odor problem but it is still under nascency.

Use of industrial sewage sludge on agricultural soil seems attractive because of increasing energy requirements and cost associated with alternative disposal methods and benefits gained from recycling of plant nutrients present in these

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wastes. It was also reported that due to green revolution high yield of agriculture production has led to depletion of micronutrients from our croplands. With relation to our recent environmental problems, studies of waste characteristics are the key for the successful, safe and suitable management of our wastes. [3] Utilizing sewage sludge in agriculture emerges as a favorable choice for its secure disposal, presenting an approach to enhance soil physical, chemical and biological attributes, facilitated by the substantial organic matter content in sewage sludge, offering an opportunity to recycle essential plant nutrients such a nitrogen (N), phosphorus (P), potassium (K), secondary nutrients and micronutrients. Contrary to the previously mentioned point, the composition of sewage sludge varies based on its origin, and it frequently harbours elevated levels of potentially toxic heavy metals, prolonged and excessive use of sewage sludge can lead to an increased bioavailability of these metals in the soil, ultimately resulting in contamination of the food chain. [4]

The objective of this work is to study the accumulation of heavy metals in plants grown in different mixtures of soil and Wazirpur CETP sludge. On the basis of calculated Bioaccumulation Factor, the two species may also be classified as excluder and accumulator.

MATERIAL AND METHODS

Study area

The study was conducted using sludge collected from Wazirpur Industrial CETP, located in Delhi. Influent coming to the CETP is heterogenous in nature as it is discharged from different kind of industries, including rolling, pickling, electroplating, textiles, anodizing, soap, rubber plastics, candles, and engineering. As per Delhi State Industrial and Infrastructure Development Corporation Ltd (DSIIDC), out of 1939 industries, 1222 industries are connected to Wazirpur CETP. 3-4 tons of sewage sludge is generated per day and from 2006-2020, 13000 to 15000 tons of sludge was still stored inside the premises during present study. During the monsoon period, many industrial sites experience flooding with acidic wastewater and garbage, reflecting the challenge of managing toxic waste generated by numerous small-scale industries.

Soil and sludge preparation

Soil from the designated area was collected, sealed, and sun-dried. It was ground to a fine consistency using a pestle and mortar and then sieved through a 0.7mm sieve. Sewage sludge, obtained from the Wazirpur CETP, was air-dried, crushed and mixed with soil to create five sludge soil mixtures, representing 0%, 5%, 10%, 20% and 30% of the total mixture.

Selection of Plant material

The seeds of two common plant species, namely, *Brassica juncea* (Black Indian mustard) *and Cicer arietinum* (Desi chana or chick pea) were chosen for the study. Since the species are fast growing and appropriate with the study season, they have been selected.

Pot Experimental Setup

Total 20 experimental pots (10 pots for each plant species), each of inner diameter 6 inches, had been included in the present study. 0%, 5%, 10%, 20% and 30% of sewage sludge was mixed with the soil and each dosage was in duplicate. Each pot was filled with 900g of soil. No sludge was added in the soil of control. No fertilizer or manure was added to the experimental and control pots. All the pots were watered at the same time with appropriate amount of tap water, as required and were kept at a place such that all received uniform sunlight.

Small sprouts were observed in Indian mustard within one week of sowing, while in chickpea, sprouts emerged after 10 days as can be seen in Fig 1(1a & 1b). During initial growth phase, it was observed that the plant growth decreased as the amount of sludge increased in the pots (Figure 2). However, the difference in plant growth disappeared over the next 10-15 days and at the end of growth period (45 days) all plants had same growth (Figure 3). The plants were harvested. Stem and root samples were collected separately, dried in oven and powdered for further analysis (Figure 4).

1a 1b

Figure 1: Appearance of sprouts in Indian mustard (1a) and chickpea (1b) within 7 and 10 days of sowing respectively

Figure 2: Effect of increasing sludge amount on growth pattern in plants of Indian mustard and chickpea from control to 30% mixture
Front row: chick pea (10 pots); Back row: Indian mustard (10 pots)

Figure 2: Effect of increasing sludge amount on growth pattern in plants of Indian mustard and chickpea from control to 30% mixture
Front row: chick pea (10 pots); Back row: Indian mustard (10 pots)

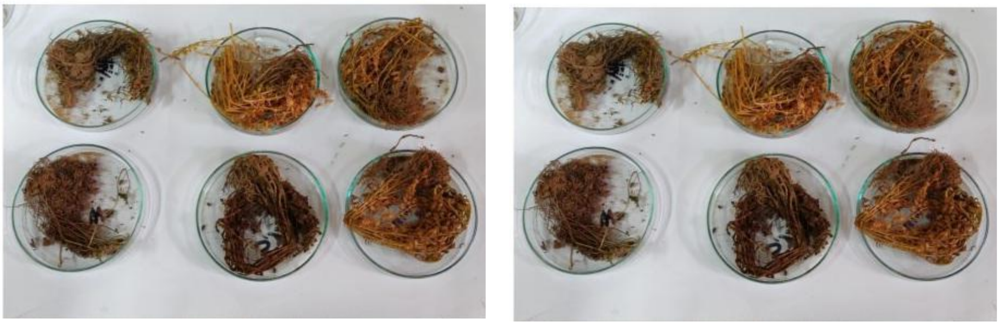

Figure 4: Oven dried stem and roots samples of Indian mustard and Chickpea

Analysis of the soil and plant samples

pH, Electrical conductivity, soluble cations, particle size distribution, bulk density, particle density, porosity and Water Holding Capacity (WHC) have been determined in soil samples using recommended standard methods. Heavy metal analysis of soil, sludge and plant samples has also been performed. 1 gm of soil or sludge samples were digested using 20 ml of aqua regia in microwave digester (Make: CEM Mars one model) [5] [6]. Final volume was 100 ml. 0.5 gm of plant samples were digested with 5 ml of nitric acid and 3 ml of hydrogen peroxide in the microwave digester, with make-up volume of 50 ml. The samples were filtered using Whatman No.4 filter followed by 0.22 micron syringe filter. Prepared samples for heavy metal estimation were ran on

ICP-OES (M/s Teledyne Leeman Labs) with calibration standards ranging from 1-10 ppm for soil and sludge samples. The range of calibration standards for plant samples was 200-1000 ppb. The metal concentration was reported in mg/Kg for all the samples.

RESULTS AND DISCUSSION

Characterization of soil is presented in Table 1. The soil is of sandy-loam texture and slightly alkaline in nature. Table 2 presents the heavy metal (Cd, Cr, Cu, Fe, Ni and Pb) data of soil and sludge. Concentration of heavy metals in sludge is found to be much higher than in the soil. Present heavy metal data has been compared with the limit values prescribed by Council of the European Commission (CEC) on protection of Environment [7], the concentration of Cd, Cr, Cu, Ni and Pb in soil are much below the limit values whereas in sludge only Cd and Zn are found below the limit values. The limit values of heavy metals in sludge prescribed by ECE suggests that the suitability of the sludge to be mixed with agricultural soil.

Table 1: Characteristics of soil.

Parameter	Value
pH	8.4
Electrical conductivity	0.321 mS/cm
Texture	Sandy loam
Soluble cations (meq/L)	Ca^{2}+=122, Mg^{2}+=60, Na^{+}=6.91, K^{+} =31.12
Particle size distribution	sand=74.8%, silt = 6.8%, clay = 8.4%
Bulk density	0.159 g/cc
Particle density	0.318 g/cc
porosity	50%
Water holding capacity	37.34%

Table 2: Composition of heavy metals in soil and sewage sludge

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Soil	1.2	8.3	34	16	17089	315	22	2.8	54
Sludge	6.4	65	11764	1912	104427	7525	1271	2050	105

(All the values are in mg/kg)

Table 3: Limit value for heavy metals in soil and sludge as per Council of European Commission (CEC)

Heavy metal	CEC limits in soil (mg/kg)	CEC limits in Sewage sludge(mg/kg)
Cd	1-3	20
Cr	100-150	1200
Cu	50-140	1200
Ni	30-75	200
Pb	50-300	1200

Metal content in stems of Desi Chana (DC) and Indian Mustard (IM) and their comparison

Table 4 presents the concentration of heavy metals in stems of DC and IM and their comparison. As obvious, concentration of all heavy metals is found to increase as the sludge amount increased in sludge-soil mixtures. Concentration of Cr, Ni and Pb is found to be BDL in both the control samples as well as in all sludge-soil mixture. Cd was also analyzed, but it was found to be BDL in all samples including control, hence not reported in table. On comparison of metal content in the stems of DC and IM, it is found that concentration of Cr, Cu, Fe, Ni and Pb in both the plant species differ significantly. Metal content is found to be higher in the stem of IM than in the DC in all the soil-sludge mixtures and this difference in concentrations is most pronounced in case of Cr and Pb. Their concentration in the stem of IM is found to be more than 100 times than that found in the stem of DC in 10% sludge-soil mixture The difference in the concentration of metals in both type of plants may be attributed to the plant species, the level of the metals in the sludge amended soil, surrounding air, speciation state of heavy metals in soil, their bioavailability, soil parameters like pH, CEC, vegetation period and other factors.

Table 4: Comparison of heavy metal concentration in the stem of Desi Chana and Indian Mustard.

	Cr	Cu	Fe	Ni	Pb
DESI CHANA STEM					
CON DC S	BDL	0.55	786	BDL	BDL
5% DC S	BDL	3	819	BDL	BDL
10% DC S	0.54	3	1323	BDL	0.07
20% DC S	13	3	1366	5	0.67
30% DC S	53	12	2075	9	8.2
INDIAN MUSTARD STEM					
CON IM S	BDL	BDL	2250	BDL	BDL
5% IM S	4	4	1146	BDL	BDL
10% IM S	105	19	3787	8	11
20% IM S	141	42	6124	11	37
30% IM S	252	54	7834	34	45

(CON = Control, DC = Desi Chana, IM = Mustard, S = stem, BDL = Below Detection Limit) (All the values are in mg/kg)

Metal content in roots of Desi Chana (DC) and Indian Mustard (IM) and their comparison

Table 5 presents the concentration of heavy metals in the roots of DC and IM and their comparison. As obvious, concentration of all heavy metals is found to increase as the sludge amount increased in sludge-soil mixtures. There are differences in the concentration of Cr, Cu, Fe, Ni and Pb in the roots of BC and IM but the difference is not so significant as found in their respective stems. On comparison of metal content in the stems of Desi chana and Indian Mustard, it is found that concentration of Cr, Cu, Fe, Ni and Pb in both the plant species differ greatly. Figure 6(a) to 6(e) present the comparison. Metal content is found higher in the roots of Indian mustard than the Desi chana in most soil-sludge mixtures. The difference in the concentration of metals in both type of plants may be attributed to the plant species, the level of the metals in the sludge amended soil, surrounding air, speciation state of heavy metals in soil, their bioavailability, soil parameters like pH, CEC, vegetation period and other factors.

Table 5: Comparison of heavy metal concentration in the roots of Desi Chana and Indian Mustard.

	Cr	Cu	Fe	Ni	Pb
DESI CHANA ROOT					
CON DC R	8	3	4433	BDL	BDL
5% DC R	25	7	2917	BDL	1
10% DC R	196	58	4940	29	55
20% DC R	260	71	5539	37	64
30% DC R	363	76	8235	39	74
INDIAN MUSTARD ROOT					
CON IM R	4	BDL	6115	BDL	BDL
5% IM R	3	7	1469	BDL	3
10% IM R	60	18	6558	9	8
20% IM R	389	77	7376	45	71
30% IM R	1189	239	13412	149	233

(CON = Control, DC = Desi Chana, IM = Mustard, R = Root, BDL = Below Detection Limit) (All the values are in mg/kg)

Bioaccumulation Factor (BAF) of heavy metals

Table 6 presents the BAF for the heavy metals. In case of DC, BF >1 is found only in 30% sludge-soil mixture for Cr and Pb which suggests that DC accumulates metals when they are at very high concentrations in growing media. Cu, Fe and Ni do not accumulate significantly at any sludge-soil amendment in DC.

Table 6: Bioaccumulation Factor for different metals.

	Cr	Cu	Fe	Ni	Pb
DESI CHANA (C shoot / C soil)					
CON DC	-	0.034	0.046	-	-
5% DC	-	0.193	0.047	-	-
10% DC	0.016	0.233	0.077	-	0.024
20% DC	0.38	0.243	0.079	0.208	0.237
30% DC	1.57	0.76	0.121	0.399	2.907
INDIAN MUSTARD (C shoot / C soil)					
CON M	-	-	0.131	-	-
5% M	0.11	0.25	0.067	-	-
10% M	3.09	1.22	0.221	0.507	0.498
20% M	4.16	2.65	0.358	0.345	13.3
30% M	7.43	3.40	0.458	1.5	16.2

(CON = Control, DC = Desi Chana, IM = Indian Mustard)

In case of IM, significant accumulation of Cr, Cu, Ni and Pb is found in the shoot. Cr and Cu showed accumulation in all sludge-soil amendment except 5% whereas Ni showed accumulation only in 30% amendment. Maximum BAF (13.3 and 16.2) is found for Pb in 20% and 30% amendments indicating very high concentration of Pb, contributed by sludge (2050 mg/Kg).

Plants have been classified as excluder and accumulator, depending on BAF. When BAF <1, the plant is classified as excluder and the plant only absorbs the trace metal but does not accumulate. When BAF >1, the plant is an accumulator which means the plant has the ability to accumulate one or more heavy metals in its tissues. This makes plant useful in phytoremediation of metal contaminated soil by accumulating one or more heavy metals. In the present study, BAF of Cr, Cu, Ni and Pb is more than 1 in IM, indicating that IM is an accumulator for them and it can be used for the phytoremediation of soil containing excess of Cr, Cu, Ni and Pb. In case of DC, the plant may be used as an accumulator for Cr and Pb.

CONCLUSION

In the present study, 10% sludge mixture seemed to be appropriate for growing plants, while 20% and 30% sludge mixtures show appreciable accumulation of toxic metals in the plants, which is not favorable for the well-being of plant and its consumers. On the other hand, the study also concludes that *Brassica juncea* (Black Indian mustard) *and Cicer arietinum* (Desi chana or chick pea) are accumulators and they may be used in phytoremediation of the soil contaminated with Cr, Cu, Ni and Pb. Addition of sludge directly in soil for growing plants may be one way of using the CETP sludge without involving any cost for sludge treatment. However, pretreatment of the sludge for removing excess toxic metals before adding into the soil will further enhance the use of sludge in growing plants. This needs an additional study in which sludge nutrient (NPK) profile, presence of organic contaminants, organic matter content etc. must be undertaken. Appropriate dosage of sludge (after necessary characterization) in soil may increase its use in agricultural soil, thus making a judicious use of tons of sludge without any processing.

The application of sewage sludge from the Wazirpur CETP Plant suggests that the sludge may be applied in the soil in appropriate dosage. Growing plants in sludge-soil amendment did not affect the growth of the plants, as evident from the present study, although an alteration in the levels of heavy metals in the soil and plants may occur. Escalating fertilizer costs, coupled with unbalanced and inefficient utilization, pose significant challenges within the agricultural sector. Thus, sewage sludge can be considered as a beneficial alternative in order to supplement the organic fertilizers. However, after risk assessment and proper characterization of the sludge, its use for agricultural purposes should be ecologically evaluated so as to prevent contamination in the soil-plant-animal-continuum.

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HEPATOPROTECTIVE EFFECT OF AN INDIAN MEDICINAL PLANT "*TERMINALIA ARJUNA*"; A REVIEW ON RECENT ADVANCEMENT

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Abstract
This study explores the development and evaluation of hepatoprotective properties of *Terminalia arjuna*, a renowned medicinal plant in traditional medicine. The study investigates the potential of *Terminalia arjuna* in promoting liver health through its pharmacological actions. Various aspects of hepatoprotection, including antioxidant, anti-inflammatory, and detoxification properties, are examined through in vitro and in vivo experiments. The research focuses on elucidating the mechanisms underlying *Terminalia arjuna* hepatoprotective effects, shedding light on its therapeutic potential in treating liver disorders. Additionally, the manuscript discusses the phytochemical composition of *Terminalia arjuna* and its correlation with hepatoprotection, providing insights into the active constituents responsible for its medicinal properties. The findings contribute to a better understanding of the pharmacological profile of *Terminalia arjuna* and its application in liver health management. Overall, this study underscores the significance of *Terminalia arjuna* as a promising candidate for the development of hepatoprotective agents, highlighting its potential as a natural alternative for liver disease management.

Keywords
Terminalia arjuna, hepatoprotective, Pharmacognostic, Evaluation, Traditional uses.

INTRODUCTION

Hepatoprotective activity refers to the ability of certain substances or compounds to safeguard the liver from damage caused by various factors such as toxins, drugs, and infections. The liver plays a crucial role in detoxification and metabolism, making it susceptible to harm from external agents. Hepatoprotective agents are essential in preventing and mitigating liver disorders, promoting overall liver health. It is the ability to protect the liver from damage caused by various factors, such as toxins, drugs, infections, and metabolic disorders. Hepatoprotective agents are substances that can help prevent or mitigate liver damage by promoting the regeneration of liver cells, reducing inflammation, and inhibiting oxidative stress. These agents having natural compounds derived from plants, animals, or minerals, as well as synthetic drugs developed specifically for liver protection (Mangwani et al., 2020; Shakya, 2020; Thilagavathi et al., 2023; Verma, 2018).

Natural compounds such as silymarin (from milk thistle), curcumin (from turmeric), and flavonoids (found in fruits and vegetables) have been studied for

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their hepatoprotective effects. Additionally, synthetic drugs like ursodeoxycholic acid and N-acetylcysteine are used for liver protection in certain medical conditions. Research into hepatoprotective activity is ongoing, with their goal of identifying new compounds and understanding their mechanisms of action. The development of effective hepatoprotective agents is essential for preventing and treating liver diseases, considering the liver's vital role in maintaining overall health. Medicinal plants have been integral to human healthcare since time immemorial, serving as the foundation of traditional medicine systems across diverse cultures worldwide. These plants, endowed with bioactive compounds, possess therapeutic properties that have been harnessed for treating and preventing various ailments. The uses of medicinal plants predate modern pharmaceuticals, and their importance remains undiminished in contemporary medicine (Bhanot et al., 2011; Maya et al., 2013; Srinivasan et al., 2014).

The rich diversity of flora harbors an extensive reservoir of potential remedies, with countless species exhibiting pharmacological significance. From the rainforests to arid deserts, each ecosystem contributes unique plant species with medicinal value. The knowledge surrounding these plants is often passed down through generations within indigenous communities, forming the basis of traditional healing practices. In recent times, scientific exploration has sought to validate and understand the efficacy of these botanical remedies. Researchers can identify their chemical composition of medicinal plants, identifying bioactive compounds responsible for their therapeutic effects. The study of medicinal plants not only holds promise for discovering new drugs but also emphasizes the importance of sustainable practices in harvesting and preserving biodiversity. In the face of emerging health challenges and the pursuit of alternative and complementary therapies, the significance of medicinal plants endures. As humanity continues to explore the intricate relationship between nature and healing, medicinal plants stand as a testament to the profound interconnection between the plant kingdom and the well-being of individuals and communities –(Gaurav, 2022; Gaurav et al., 2023, 2022; Salar et al., 2023).

REVIEW FINDINGS

Characteristic of *Terminalia arjuna*

Terminalia arjuna, a tree native to the Indian subcontinent, has gained recognition for its potential hepatoprotective properties. Traditionally used in Ayurvedic medicine, *Terminalia arjuna* has been revered for its diverse medicinal benefits. The bark of this tree contains bioactive compounds such as tannins, flavonoids, and saponins, which exhibit antioxidant and anti-inflammatory properties. These compounds are believed to contribute to the hepatoprotective effects of Terminalia arjuna. Several studies have explored the hepatoprotective activity of *Terminalia arjuna* in various experimental models. Research suggests that its extracts may help prevent liver damage, enhance liver function, and alleviate oxidative stress. As liver disorders continue to be a global health concern, investigating natural remedies like *Terminalia arjuna* provides valuable insights into potential therapeutic options for maintaining liver health and preventing hepatic ailments. Arjuna consists of the stem bark of *Terminalia arjuna* W.& A. (Family Combretaceae); a large deciduous tree with a spreading crown and drooping branches., commonly found throughout the greater parts of the country. It is very commonly found in Chhota Nagpur area, Baitful in Madhya Pradesh, India and also in Dehradun, usually found growing on river banks or near dry river beds in Bangladesh, Uttar Pradesh, Madhya Pradesh, south and central India. *Terminalia arjuna* is about 20-25 meters tall; usually has a buttressed trunk, and forms a wide canopy at the crown, from which branches drop downwards —(Ali et al., 2013; Dev et al., 2021; Uddin et al., 2021).

It has oblong, conical leaves which are green on the top and brown below; smooth, grey bark; it has pale yellow flowers which appear between March and June; its glabrous, 2.5 to 5 cm fibrous woody fruit, divided into five wings, appears between September and November commonly known as Arjuna or Arjun tree in English and Marudhamaram in Tamil. The tree components are widely used in traditional medicine in several continents in the world for the treatment of numerous diseases including, abdominal disorders, bacterial infections, colds, sore throats, conjunctivitis, diarrhoea, dysentery, fever, gastric ulcers, headaches, heart diseases, hookworm, hypertension, jaundice, leprosy, nosebleed, edema, pneumonia and skin diseases (Bushra et al., 2023; Hossain et al., 2022; Meena et al., 2023; Ramesh and Palaniappan, 2023).

Table 1: Taxonomical classification of *Terminalia arjuna.*

Sr. No	Kingdom	Plantae
1.	Phylum	Angiosperms
2.	Class	Eudicots
3.	Order	Myrtales
4.	Family	Combretaceae
5.	Genus	Terminalia
6.	Species	Terminalia arjuna
7.	Assamese	Arjun
8.	Marathi	Arjun, Anjan, Sadura
9.	Bengali	Arjun, Arjhan
10.	Oriya	Hanjal
11.	English	Arjun, White Marudah
12.	Punjabi	Arjon
13.	Gujarati	Sadada, Salado
14.	Sanskrit	Kakubha, Partha, Indradru, Dhavala
15.	Hindi	Anjan, Anjani, Arjun,
16.	Tamil	Vella marda, Vella maruthu, Vella matti
17.	Kannada	Hole matti, Maddi, Matti
18.	Telugu	Vella marda, Vella matti, Yer maddi, Tella madu

Properties of Terminalia arjuna

Terminalia arjuna, a revered herb in Ayurveda, exhibits unique properties that contribute to its therapeutic effects. Its taste (Rasa) is astringent (Kashaya), which provides drying and tightening effects, beneficial for reducing swelling and controlling excess moisture in the body. The post-digestive taste (Vipaka) is pungent (Katu), which means it has a stimulating and heating effect on digestion, promoting metabolic activity. The herb's potency (Virya) is cool (Shita), indicating its cooling effect that can help in reducing inflammation and calming heat-related conditions in the body. The qualities (Guna) of *Terminalia arjuna* are light (Laghu) and dry (Ruksha), aiding in easy digestion and assimilation while absorbing excess moisture, which is particularly useful in managing conditions associated with high Kapha. In terms of doshic effect, *Terminalia arjuna* pacifies Kapha and Pitta doshas. This means it helps balance excess Kapha by reducing moisture and heaviness, and it calms Pitta by mitigating heat and inflammation, thereby promoting overall bodily harmony and supporting cardiovascular health (Amalraj and Gopi, 2017; Carvalho et al., 2022; Shahid Chatha, 2014; Verma and Jogdand, 2021).

Macroscopic description of Terminalia arjuna

Terminalia arjuna is a large, deciduous tree that can reach heights of up to 25 meters, featuring a wide, spreading crown with horizontal branches. The bark is smooth and greyish-white when young, becoming brown and cracked with age. The leaves are simple, opposite, and elliptical, measuring about 5-12 cm long and 2-5 cm wide. They have a leathery texture and glossy appearance. The flowers are small, greenish-yellow, and borne in dense, spike-like axillary panicles. The fruits are ovoid or oblong drupes, about 2-2.5 cm in length, often with five wings. The outer surface of the bark is smooth and pale greenish-yellow, while the inner surface is finely striated and pinkish. The bark pieces are flat, curved, and recurved in shape. The wood of *Terminalia arjuna* is hard and durable, making it useful for various applications (Cota et al., 2019; Desai and Chanda, 2014; Dhingra et al., 2013).

In microscopic description of *Terminalia arjuna,* it has been characterized by the presence of cork cells in the outer layers. Cork cambium and secondary phloem can be observed in cross-sections. The inner bark contains fibres, parenchyma cells, and vessels. The epidermis of the leaves has stomata, which are more

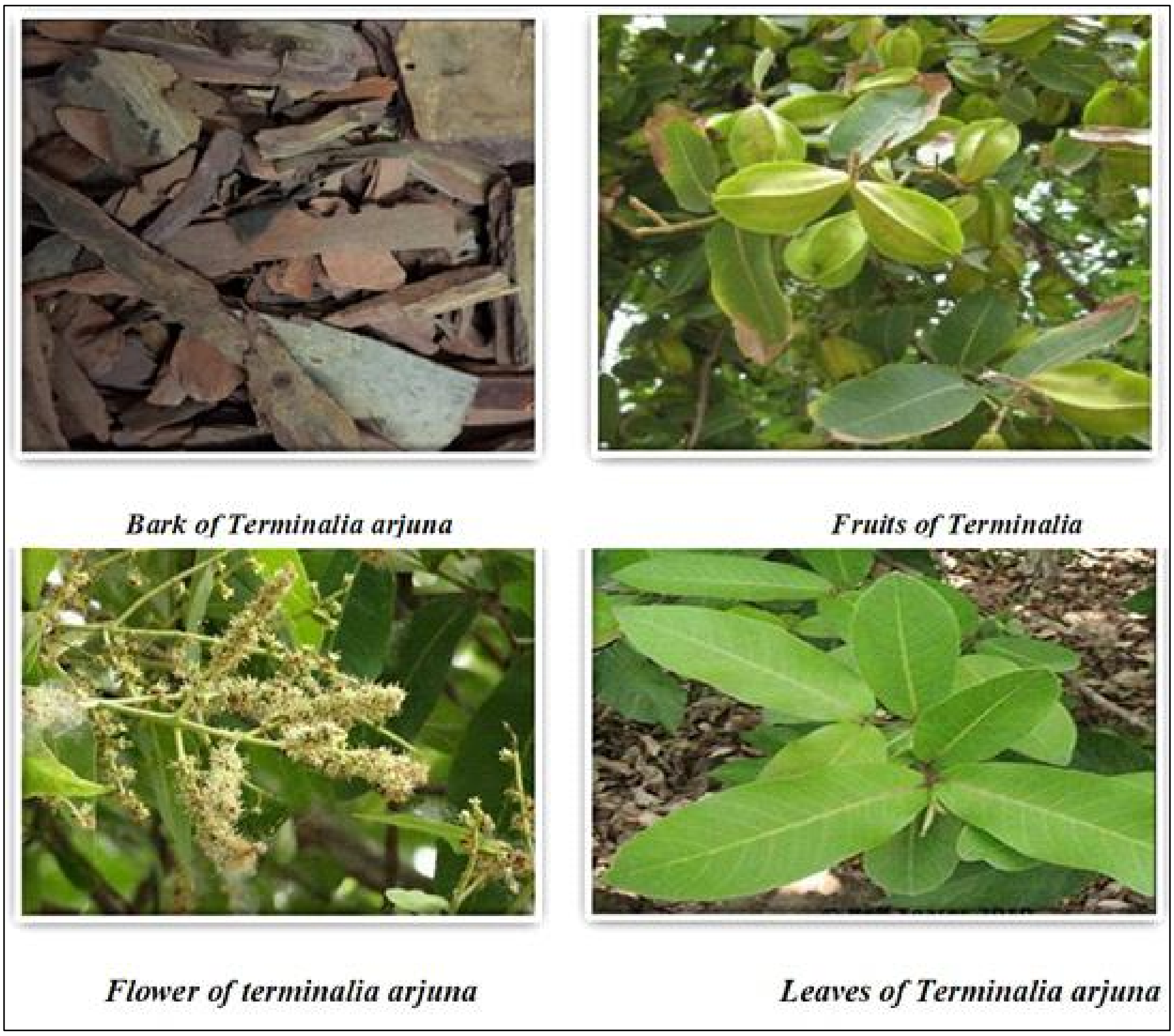

Fig. 1: Morphological appearance of Termonalia arjuna.

abundant on the lower surface. The mesophyll tissue consists of palisade and spongy parenchyma cells. Vascular bundles are collateral and arranged in a continuous ring. The floral anatomy includes typical reproductive structures such as stamens, pistil, and ovary. T.S. (transverse section) of the floral parts reveals the arrangement of tissues and cells involved in reproduction. Cross-sections of the fruit show the arrangement of the seed and the pericarp layers. The seed may have an embryo surrounded by endosperm tissue. The wood exhibits typical characteristics of hardwood, with vessels, fibres, and parenchyma cells (Desai and Chanda, 2014; Dhingra et al., 2013; Sivalokanathan et al., 2006; Yallappa et al., 2013).

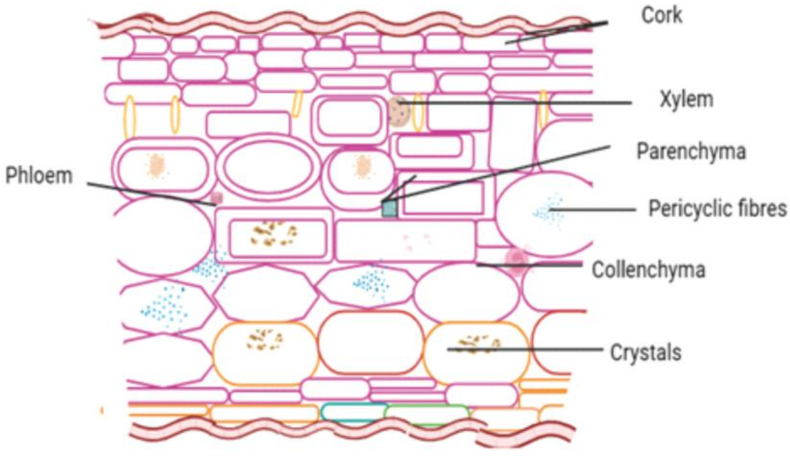

Fig. 2: Microscopy of *Terminalia arjuna.*

Phytochemistry of *Terminalia arjuna*

Terminalia arjuna, a tree widely used in traditional medicine, is rich in a variety of phytochemicals contributing to its therapeutic properties. The main constituents include flavonoids, tannins, triterpenoids, and glycosides. Flavonoids such as arjunone, arjunolone, and arjunolic acid exhibit strong antioxidant properties, helping to reduce oxidative stress and protect against cellular damage. Tannins, which give the bark its astringent quality, aid in wound healing and possess antimicrobial activity. Triterpenoids, including arjunic acid and arjunolic acid, contribute to the cardioprotective effects of the tree, supporting heart health by improving cardiac function and reducing blood pressure. Glycosides, such as arjunetin and arjunosides, have been found to enhance myocardial strength and regulate lipid levels. Additionally, the bark contains minerals like calcium and magnesium, essential for maintaining cardiovascular health. These diverse phytochemicals collectively render *Terminalia arjuna* a potent medicinal plant with applications in treating cardiovascular diseases and promoting overall health (Amalraj and Gopi, 2017; Kapoor et al., 2014; Nerkar et al., 2023; Paarakh, 2010).

Table 2: Major phytoconstituents of various parts of *Terminalia arjuna.*

S. No	Plant Part	Phytochemical Constituents
1.	**Stem bark**	Arjunolic acid, Arjungenin, Arjunetin, Arjunin, Arjunic acid, Arjunanin, Arjunolone, Catechin, Flavonoids, Tannins, β-sitosterol, Ellagic acid, Gallic acid, Gallo tannins, Oleanolic acid, Rutin, Quercetin, Terpenoids, Saponins, Glycosides, Lactone, phenolics, Gallocatechin, Epicatechin, Terminoic acid, Arjunoglucoside IV, V Terminoside A, Terminoglucoside I, II, Ursane triterpenoids 5, 6 Arjunahomosesquiterpenol & Stigmasteryl digalactoside 7 oleaterminaloic acid A, B & C, oleaterminolide and termiarjunoside I
2.	**Leaves**	Arjunolic acid, Arjungenin, Arjunetin, Arjunic acid, Flavonoids, Tannins, β-sitosterol, Ellagic acid, Gallic acid, Gallo tannins, Oleanolic acid, Rutin, Quercetin, Terpenoids, Saponins, Glycosides
3.	**Fruits**	Arjunolic acid, Arjungenin, Arjunetin, Arjunic acid, Flavonoids, Tannins, β-sitosterol, Ellagic acid, Gallic acid, Gallo tannins, Oleanolic acid, Rutin, Quercetin, Terpenoids, Saponins, Glycosides
4.	**Seeds**	Arjunolic acid, Arjungenin, Arjunetin, Arjunic acid, Flavonoids, Tannins, β-sitosterol, Ellagic acid, Gallic acid, Gallo tannins, Oleanolic acid, Rutin, Quercetin, Terpenoids, Saponins, Glycosides
5.	**Heartwood**	Arjunolic acid, Arjungenin, Arjunetin, Arjunic acid, Flavonoids, Tannins, β-sitosterol, Ellagic acid, Gallic acid, Gallo tannins, Oleanolic acid, Rutin, Quercetin, Terpenoids, Saponins, Glycosides

Terminalia arjuna in traditional Ayurvedic herbalism

Terminalia arjuna, commonly known as Arjuna, holds a revered place for its multifaceted uses. Primarily, it is recognized for its cardiovascular benefits, acting as a potent cardiotonic that supports heart function and regulates blood pressure. Arjuna is employed to alleviate conditions such as hypertension, angina, and cardiac palpitations. Additionally, its astringent and anti-inflammatory properties make it valuable for gastrointestinal health, addressing issues like diarrhoea and dysentery. Renowned as a Rasayana (rejuvenating) herb, Arjuna is integral to Ayurvedic formulations, contributing to holistic well-being and promoting longevity.

Pharmacological action of Terminalia arjuna

Terminalia arjuna, a revered plant in Ayurveda, offers a multitude of medicinal benefits, particularly in supporting cardiovascular health. It strengthens cardiac muscles, regulates blood pressure, and improves overall cardiovascular function, owing to its antioxidant properties that combat oxidative stress in the cardiovascular system. Additionally, it aids in managing cholesterol levels, making it beneficial for individuals with high cholesterol and aiding in the

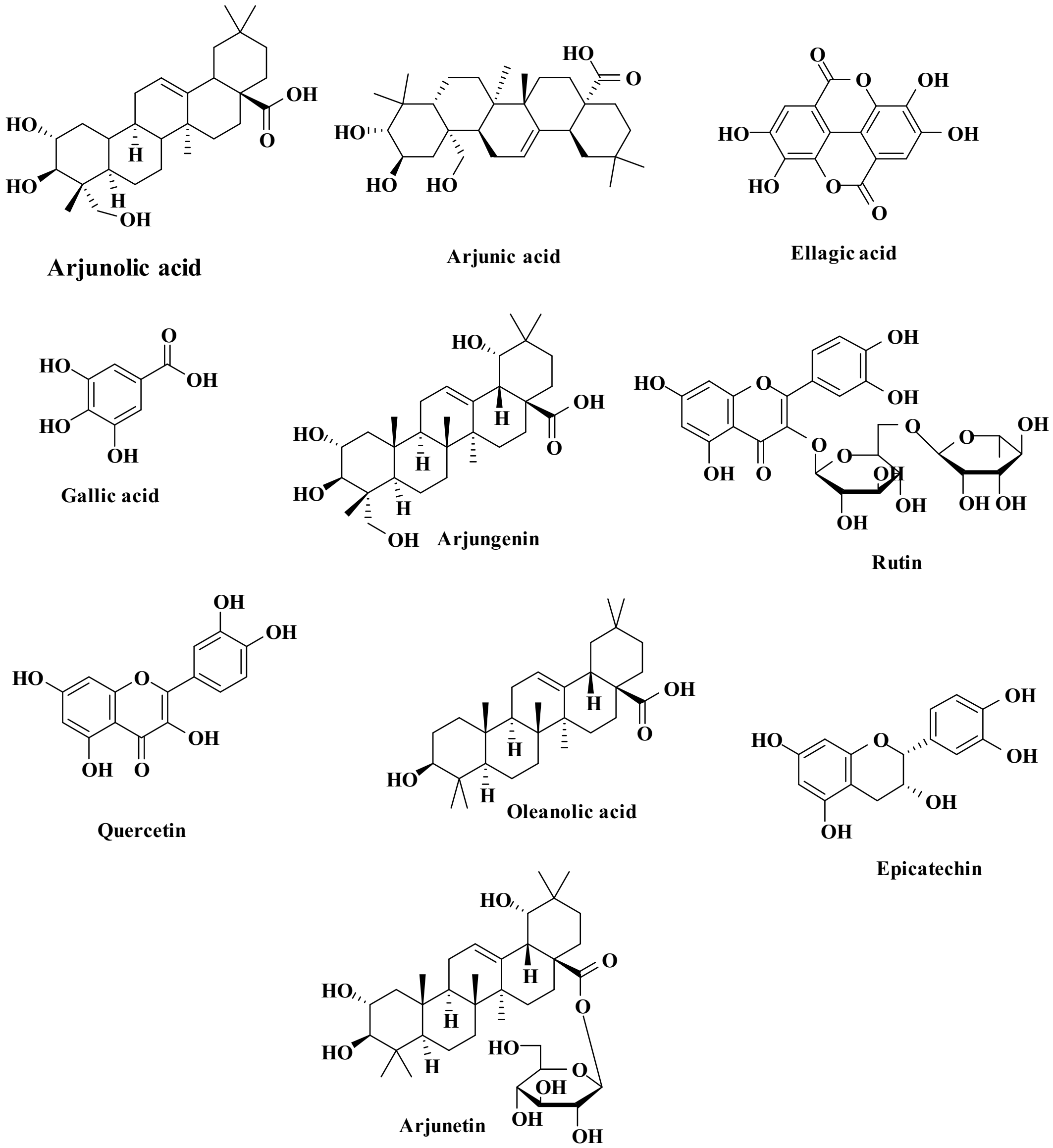

Figure 3: Reported structure of chemical constituents of *Terminalia arjuna.*

prevention of atherosclerosis. The bark of Arjuna also harbors anti-inflammatory compounds, useful in treating arthritis and other inflammatory conditions. Furthermore, it exhibits hepatoprotective effects, promoting liver health and aiding in detoxification. Its astringent properties make it effective in managing digestive issues such as diarrhoea, while its antimicrobial properties facilitate wound healing. Arjuna's benefits extend to respiratory health, with potential relief for asthma and bronchitis symptoms. Its antioxidant activity combats free radicals, potentially reducing the risk of chronic diseases. Moreover, its diuretic and adaptogenic properties contribute to fluid balance, stress management, and overall well-being —(Jawal et al., 2024; Md., 2013; Nerkar et al., 2023; S. et al., 2013).

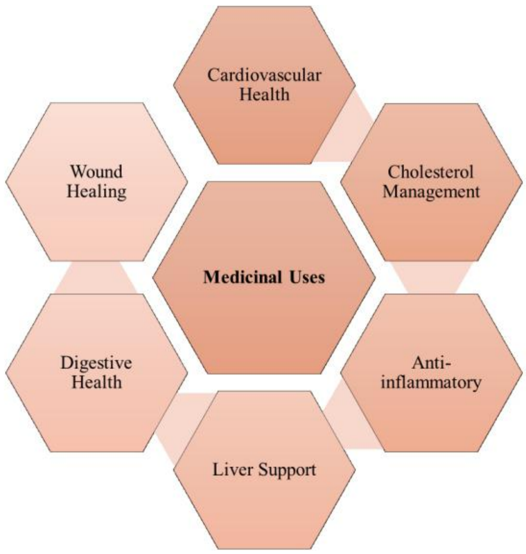

Fig. 4: Pharmacological activities of *Terminalia arjuna.*

Table 3: Diverse medicinal uses of *Terminalia arjuna* and their associated benefits, providing a comprehensive overview of its therapeutic potential in promoting overall health and well-being.

S. No	Medicinal Uses	Benefits
1.	Cardiovascular Health	Strengthens cardiac muscles, regulates blood pressure, improves cardiovascular function, reduces oxidative stress in the cardiovascular system
2.	Cholesterol Management	Helps regulate cholesterol levels, aids in preventing atherosclerosis
3.	Anti-inflammatory	Manages inflammatory conditions such as arthritis and joint disorders
4.	Liver Support	Promotes liver health, aids in detoxification
5.	Digestive Health	Manages digestive issues like diarrhoea, contributes to gastrointestinal health
6.	Wound Healing	Topically promotes wound healing, prevents infections
7.	Respiratory Health	Alleviates symptoms of asthma and bronchitis, thanks to anti-inflammatory and bronchodilator effects
8.	Antioxidant Activity	Neutralizes free radicals, reduces the risk of chronic diseases
9.	Diuretic Properties	Aids in eliminating excess fluids from the body, beneficial for conditions like edema
10.	Adaptogenic Properties	Helps the body adapt to stress, promotes resilience and general well-being

CONCLUSION

Terminalia arjuna stands out as a promising medicinal plant, particularly valued for its hepatoprotective properties. Extensive research supports its efficacy in promoting liver health, making it a valuable natural remedy. As a versatile medicinal plant, *Terminalia arjuna* contributes to traditional and alternative medicine practices, offering potential benefits for various health conditions. The continued exploration of its bioactive compounds and therapeutic mechanisms underscores its significance in the realm of herbal medicine, paving the way for the development of novel treatments and nutritional supplements for liver-related disorders.

Conflict of interest

The authors declare no conflict of interest.

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CHEMICAL STABILITY OF POLYHERBAL FORMULATIONS

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Abstract
Polyherbal formulations, consisting of multiple plant extracts or herbal ingredients, have become increasingly popular in traditional and alternative medicine practices. However, ensuring their chemical stability is essential for maintaining therapeutic efficacy and safety. This chapter provides a systematic and comprehensive examination of the factors influencing the chemical stability of polyherbal formulations. It covers various aspects including degradation pathways, storage conditions, and formulation strategies that impact stability. Understanding the degradation pathways is crucial as it allows for the identification of potential chemical reactions that may occur within the formulation. Factors such as temperature, humidity, light exposure, and oxygen can significantly influence the stability of polyherbal formulations during storage. Additionally, the selection of excipients and formulation techniques play a vital role in maintaining stability. Analytical techniques such as chromatography and spectroscopy are widely employed for assessing the stability of polyherbal formulations. High-performance liquid chromatography (HPLC), gas chromatography (GC), and mass spectrometry (MS) are commonly used methods for analyzing the chemical composition and degradation products of these formulations. Spectroscopic techniques like UV-Vi spectroscopy and infrared (IR) spectroscopy are also valuable tools for monitoring chemical changes. By understanding the chemical stability of polyherbal formulations, manufacturers can ensure product quality and consistency. Furthermore, regulatory authorities can establish guidelines for stability testing and shelf-life determination of these formulations. This comprehensive overview aims to provide valuable insights for researchers, manufacturers, and regulatory agencies involved in the development, production, and regulation of polyherbal products. It emphasizes the importance of systematic studies on chemical stability to enhance the efficacy and safety of polyherbal formulations in healthcare practices.

Keywords
Polyherbal formulations, Chemical stability, Degradation pathways, Storage conditions, Formulation strategies, Analytical techniques, Therapeutic efficacy and Regulatory guidelines.

INTRODUCTION

Polyherbal formulations refer to medicinal products that are composed of a combination of multiple plant extracts or herbal ingredients. These formulations have been widely used in traditional medicine systems, such as Ayurveda, Traditional Chinese Medicine (TCM), and indigenous healing practices across various cultures (Aladejana and Aladejana 2020; Madhusudhan et al. 2021; Sahu et al. 2021).

Polyherbal formulations are believed to harness the synergistic effects of multiple herbs, enhancing therapeutic efficacy and minimizing adverse effects. The popularity of polyherbal formulations stems from their holistic approach to healing, as they target multiple pathways and provide a broader spectrum of bioactive compounds compared to single-herb preparations'(Enioutina et al. 2017; Martin and Ernst 2003; Mukazayire et al. 2011; Zheng et al. 2023).

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Polyherbal formulations often consist of herbs with complementary therapeutic properties. The combination of different herbs can lead to synergistic effects, where the collective action of multiple constituents enhances the overall therapeutic efficacy. Synergy can result from various mechanisms, including enhanced bioavailability, modulation of multiple targets, and improved absorption or metabolism of active compounds. These synergistic effects can potentially increase the therapeutic benefits of the formulation. Many diseases and health conditions involve complex mechanisms and multiple targets. Polyherbal formulations offer a multi-targeted approach by providing a diverse array of bioactive compounds that can act on different pathways simultaneously. This approach may provide a more comprehensive and effective treatment compared to single-herb preparations that target only one aspect of the disease (Maurya and Kumar 2019). The combination of herbs in polyherbal formulations can help mitigate potential adverse effects associated with individual herbs. Certain herbs may contain constituents that counteract or buffer the side effects of others, resulting in a more balanced and harmonious therapeutic response. Additionally, by using lower doses of individual herbs in the formulation, the risk of toxicity or unwanted reactions may be minimized '(Carvalhana et al. 2016; Hammer et al. 2006; Hand Hygiene and Adverse Skin Reactions: COVID-19 Prospect 2020; Inoue 2014).

Polyherbal formulations often draw from traditional knowledge and historical use in various medicinal systems. These formulations have been developed and refined over centuries, based on empirical evidence and observations of their therapeutic effects. By incorporating traditional knowledge into modern healthcare practices, polyherbal formulations contribute to the preservation and utilization of cultural wisdom related to herbal medicine. The popularity of herbal and natural products has been steadily growing worldwide. Polyherbal formulations, with their traditional roots and potential health benefits, have gained significant attention in the global market. They present opportunities for herbal product manufacturers and pharmaceutical companies to develop and market products that cater to the increasing demand for natural and alternative therapies (Albahri et al. 2022).

Analytical techniques play a crucial role in assessing the stability of herbal products, ensuring their safety, efficacy, and quality over time. These techniques allow researchers and manufacturers to monitor changes in the chemical composition, physical properties, and overall stability of herbal products throughout their shelf life. Various analytical methods are employed to evaluate different aspects of stability, including chemical degradation, physical changes, and microbial contamination. Below, we discuss the role of different analytical techniques in the assessment of herbal product stability. HPLC is one of the most widely used analytical techniques for assessing the stability of herbal products. It allows for the separation, identification, and quantification of active compounds and degradation products present in herbal extracts. By monitoring changes in the chromatographic profiles over time, HPLC can detect degradation pathways, identify degradation products, and assess the overall chemical stability of herbal formulations. Gas Chromatography (GC) is employed to analyze volatile compounds and assess the volatile profile of herbal products (Basist et al. 2022; Gaurav et al. 2022; Gautam 2022; Khan et al. 2022, 2024). It is particularly useful for detecting changes in essential oils, terpenes, and other volatile constituents that may be susceptible to degradation or evaporation during storage. GC analysis provides valuable insights into the aroma, flavor, and overall quality of herbal extracts and formulations. Thin-Layer Chromatography (TLC) is a simple and cost-effective technique used for qualitative analysis and fingerprinting of herbal products. It allows for the separation and identification of various compounds present in herbal extracts based on their differential migration on a thin layer of stationary phase. TLC can be employed to monitor changes in the chemical composition and detect the presence of degradation products or adulterants in herbal formulations (Agarwal and Yeluri 2023; Kalyana Sundaram et al. 2018; Ojiako, Chikezie, and Ogbuji 2016a, 2016b).

UV-Visible spectroscopy is utilized to assess the stability of herbal products by monitoring changes in the absorbance of specific wavelengths of light. This technique is particularly useful for quantifying the concentration of active compounds, such as polyphenols, flavonoids, and alkaloids, in herbal extracts. By measuring changes in absorbance over time, UV-Visible spectroscopy can indicate degradation, oxidation, or photodegradation of key constituents in herbal formulations. Fourier Transform Infrared Spectroscopy (FTIR) spectroscopy is employed to analyze the chemical composition and detect structural changes in herbal products. It provides information about functional groups present in herbal extracts and can identify chemical bonds associated with degradation or oxidation processes. FTIR analysis is useful for assessing the stability of herbal formulations and detecting changes in their molecular structure over time. Differential Scanning Calorimetry (DSC) is a thermal analysis technique used to investigate changes in the physical properties of herbal products, such as melting point, crystallization, and phase transitions. It can detect alterations in the thermal behavior of herbal formulations due to chemical degradation, polymorphic transitions, or physical instability. DSC analysis provides valuable insights into the thermal stability and compatibility of herbal extracts with excipients and packaging materials. Microbiological analysis is essential for evaluating the microbial stability and safety of herbal products. It involves assessing the presence of bacteria, fungi, yeasts, and molds in herbal formulations using microbial enumeration and identification techniques. Microbiological analysis helps ensure that herbal products meet microbiological quality standards and are free from microbial contamination that could compromise their safety and efficacy' (Brown and Wright 2020; L. Hu et al. 2023; Huang et al. 2022; Mo et al. 2023).

However, accelerated stability testing involves subjecting herbal products to accelerated aging conditions, such as increased temperature, humidity, and light exposure, to predict their long-term stability. This approach allows researchers to assess the effects of environmental stressors on the stability of herbal formulations and identify potential degradation pathways. Accelerated stability testing is a valuable tool for estimating shelf life and determining appropriate storage conditions for herbal products. Hence, analytical techniques play a critical role in the assessment of stability for herbal products, providing valuable insights into their chemical composition, physical properties, and microbial safety. By employing a combination of chromatographic, spectroscopic, thermal, and microbiological methods, researchers and manufacturers can ensure the quality, safety, and efficacy of herbal formulations throughout their shelf life. These analytical techniques are essential tools for regulatory compliance, quality control, and product development in the herbal industry (Ahmad and Othman 2013; Farizah et al. 2015; Wang and Yang 2019; Zakaria et al. 2019).

REVIEW FINDINGS

Chemical stability of polyherbal formulations

Ensuring the chemical stability of polyherbal formulations poses several challenges due to the complex nature of phytoconstituents. Polyherbal formulations often consist of multiple herbal ingredients, each containing a diverse range of bioactive compounds. The variability in the composition and concentration of these compounds can influence the stability of the formulation. Different herbs may have different degradation pathways and susceptibility to degradation under specific conditions, making it challenging to predict the overall stability of the formulation (More et al. 2022). The combination of herbal ingredients in polyherbal formulations can lead to complex interactions that affect their stability. Some herbs may interact synergistically, enhancing stability, while others may exhibit antagonistic effects, leading to degradation or reduced stability. Incompatibilities among herbs can result in the formation of insoluble precipitates, chemical reactions, or alterations in the pH of the formulation, impacting its stability(Fakher et al. 2020; Frosio et al. 2023; Osorio et al. 2024; Ulvestad et al. 2018).

Polyherbal formulations are prone to various degradation pathways, including hydrolysis, oxidation, and photodegradation. Each herbal ingredient within the formulation may have different degradation mechanisms and rates, complicating the overall stability profile. Factors such as temperature, humidity, and light exposure can accelerate these degradation processes, necessitating careful control of storage conditions. The formulation process itself introduces challenges to maintaining stability. Factors such as the selection of excipients, solvents, and preservatives can impact the stability of polyherbal formulations. The pH of the formulation and the solubility of herbal constituents can influence stability, as some compounds may degrade under acidic or alkaline conditions. Additionally, the presence of certain excipients or preservatives may interact with herbal ingredients, affecting their stability (Enaru et al. 2021; Mohammadi et al. 2023; Nosirov 2023; X. Zhang et al. 2020). Assessing the stability of polyherbal formulations requires the development and validation of analytical methods capable of simultaneously quantifying multiple bioactive compounds. The complexity of polyherbal formulations makes it challenging to analyze individual compounds accurately, especially when they have similar chemical structures or co-elute during analysis. Analytical techniques must be sensitive, selective, and capable of detecting changes in the concentration of active compounds over time. Determining the shelf-life of polyherbal formulations presents a challenge due to the interplay of multiple factor s, including the stability of individual herbal ingredients, formulation complexity, and storage conditions. Conducting long-term stability studies to determine the expiration date of the formulation requires resources and time. Polyherbal formulations often fall under the regulatory purview of various agencies, and demonstrating their chemical stability is a crucial aspect of obtaining regulatory approvals. Compliance with regulatory guidelines and ensuring batch-to-batch consistency in stability is essential for quality control and commercialization(Bhope, Nagore, et al. 2011).

2. FACTORS AFFECTING CHEMICAL STABILITY

2.1. Degradation Pathways

Degradation pathways play a crucial role in the chemical stability of polyherbal formulations. Understanding these pathways is essential for identifying the potential degradation mechanisms and developing strategies to enhance stability. (Bhope, Nagore, et al. 2011) The following are common degradation pathways that can occur in polyherbal formulations. Hydrolysis is a common degradation pathway in which the chemical bonds within the herbal constituents are cleaved by water molecules. Hydrolysis can occur in polyherbal formulations when the formulation contains water or when the herbs themselves contain hydrolytically labile compounds. Factors such as pH, temperature, and the presence of catalysts can influence the rate of hydrolysis. Hydrolytic degradation can lead to the formation of degradation products, loss of potency, and changes in the therapeutic profile of the formulation.

Oxidation is a significant degradation pathway that occurs when herbal constituents are exposed to oxygen or other oxidizing agents. Oxidation can lead to the formation of reactive oxygen species, resulting in the degradation of bioactive compounds. Herbs containing phenolic compounds, terpenes, or other susceptible functional groups are particularly prone to oxidation. Factors such as temperature, light exposure, and the presence of transition metal ions can accelerate oxidation reactions. Antioxidants and packaging materials that minimize oxygen exposure can be employed to mitigate oxidation-related degradation.(Bakr et al. 2019; Sahu et al. 2021)

Photodegradation refers to the degradation of herbal

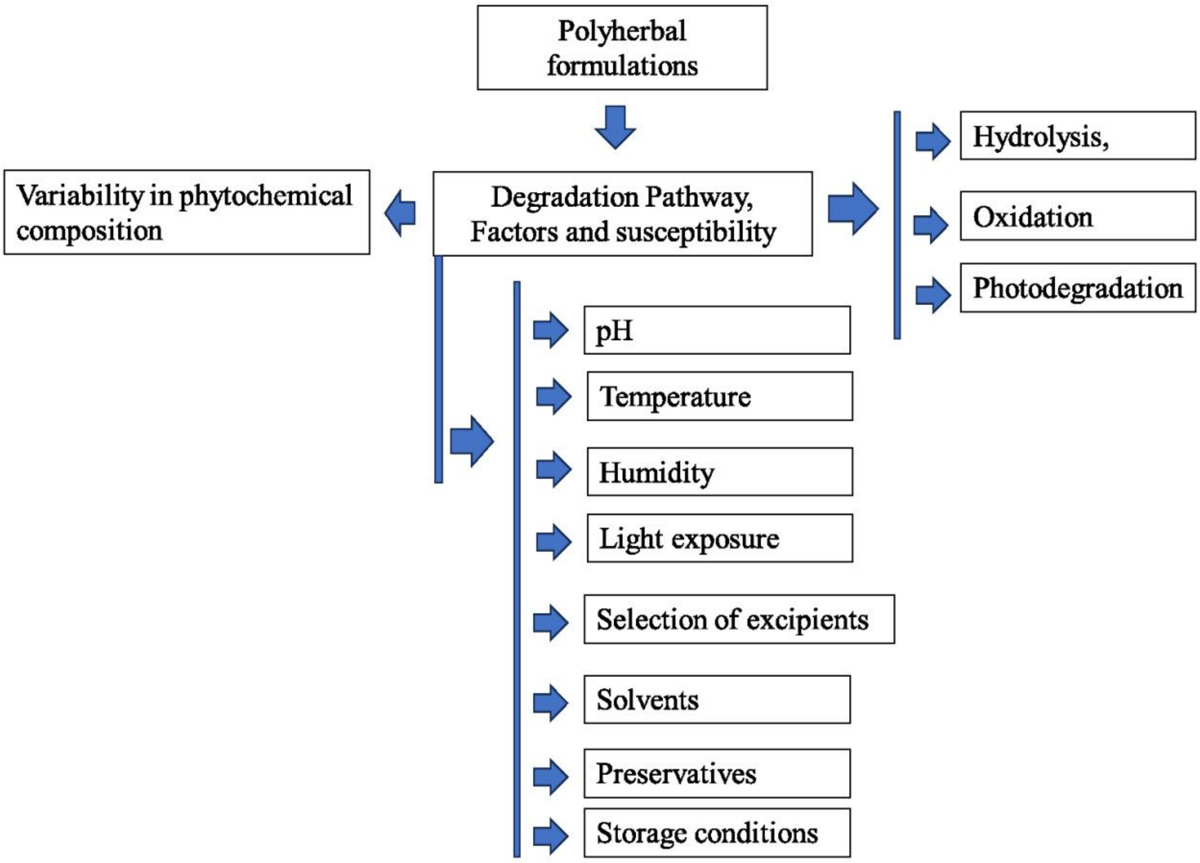

Fig. 1: Degradation pathway, factors affecting pf polyherbal formulation.

constituents induced by light exposure. UV and visible light can trigger photochemical reactions, leading to the formation of free radicals and subsequent degradation. Some herbal compounds, such as flavonoids and photosensitive pigments, are especially vulnerable to photodegradation. The intensity and duration of light exposure, as well as the formulation's packaging and storage conditions, can influence the extent of photodegradation. Light-protective packaging and storage in opaque containers can help reduce photodegradation. Thermal degradation occurs when polyherbal formulations are exposed to elevated temperatures. Heat can promote chemical reactions, including hydrolysis, oxidation, and other degradation pathways. The rate of thermal degradation is dependent on factors such as temperature, time, and the heat sensitivity of the herbal constituents. Storage at controlled temperatures and avoiding exposure to excessive heat during manufacturing, transportation, and storage are critical to minimizing thermal degradation.(Blais, Day, and Wiles 1973)

The excipients and additives used in polyherbal formulations can interact with herbal ingredients, leading to chemical changes and degradation. For example, certain excipients may cause pH shifts, alter solubility, or introduce reactive impurities that can degrade the herbal constituents over time. Incompatibilities between herbal ingredients and excipients can result in precipitation, chemical reactions, or destabilization of the formulation. Careful selection of compatible excipients and additives is necessary to maintain chemical stability. Temperature, humidity, and light exposure are important environmental factors that can significantly affect the chemical stability of polyherbal formulations. These factors can accelerate degradation pathways and lead to changes in the composition and potency of the formulation''(Burton et al. 2017; Lee et al. 2023; Merish and Walter 2019; Widyani 2019).

Higher temperatures can accelerate degradation reactions, such as hydrolysis, oxidation, and thermal degradation, in polyherbal formulations. The rate of chemical reactions typically doubles with every 10°C increase in temperature due to the increased kinetic energy of the molecules. It is crucial to store polyherbal formulations at appropriate temperatures to minimize degradation and maintain their stability, while cold temperatures can slow down degradation reactions, extreme cold conditions can affect the stability of polyherbal formulations. Freezing temperatures can cause physical changes, such as the formation of ice crystals, which can damage the formulation's structure and compromise its stability. Freeze-thaw cycles should be avoided, as they can cause further damage. Polyherbal formulations, particularly those in liquid or semi-solid forms, can absorb moisture from the surrounding environment. Moisture uptake can lead to hydrolysis reactions, especially if the formulation contains hydrolytically labile compounds. Additionally, moisture can promote microbial growth, which can further degrade the formulation. Proper packaging, storage in dry conditions, and the use of desiccants can help prevent moisture-related degradation.

Light exposure, especially in the UV and visible light spectrum, can initiate photochemical reactions that contribute to photodegradation of polyherbal formulations. UV light can generate reactive oxygen species, leading to oxidative degradation. Certain herbal constituents, such as photosensitive pigments and flavonoids, are particularly vulnerable to photodegradation. Transparent or translucent packaging materials allow light penetration, and prolonged exposure to light should be minimized by storing formulations in opaque containers or utilizing light-protective packaging. Temperature, humidity, and light exposure can act synergistically to accelerate degradation processes. For example, elevated temperatures can promote moisture uptake, thereby increasing the likelihood of hydrolysis reactions. Similarly, light exposure can cause temperature elevation within a formulation, amplifying degradation kinetics. Understanding the interplay between these factors is crucial for designing appropriate storage conditions and ensuring chemical stability. (Deepaka, Bhatnagar, and Kumar 2010) To maintain the chemical stability of polyherbal formulations, it is recommended to store them in a cool, dry place, away from direct light exposure. Controlling storage conditions within appropriate ranges (e.g., room temperature, low humidity) helps to minimize the potential for degradation and preserve the formulation's integrity. Stability testing under different temperature and humidity conditions can provide insights into the formulation's stability profile and inform appropriate storage recommendation ' '(Alkhalidi et al. 2022; Mondal, Mukhopadhyay, and Chattopadhyay 2022; Prange and Wright 2023; Vlieland et al. 2018).

2.2. Interactions among Herbal Ingredients:

Interactions among herbal ingredients in polyherbal formulations can significantly impact their chemical stability. The combination of different herbs can lead to complex chemical reactions and interactions, which can influence the stability and potency of the formulation. Various types of interactions that can occur among herbal ingredients and their implications for chemical stability are Chemical reactions can occur between the bioactive compounds present in different herbal ingredients. These reactions can result in the formation of new compounds or degradation products, altering the overall composition and stability of the polyherbal formulation. For example, alkaloids from one herb may react with polyphenols from another herb, leading to the formation of new chemical entities. The pH of the formulation can also influence chemical reactions. Certain herbal constituents may be sensitive to pH changes, leading to chemical transformations or hydrolysis reactions. Incompatibilities between acidic and alkaline compounds can result in pH shifts that impact the stability of the formulation. Synergistic interactions occur when the combined action of multiple herbal ingredients produces a greater therapeutic effect than the sum of their individual effects. While synergistic interactions are desirable for therapeutic efficacy, they can also influence the chemical stability of the formulation. Synergistic interactions can enhance stability by protecting certain herbal constituents from degradation or improving their bioavailability (Di Lorenzo et al. 2021; Manach et al. 2004; Thilakarathna and Vasantha Rupasinghe 2013).

For example, one herb may contain compounds that act as antioxidants, preventing the oxidation of susceptible constituents from other herbs in the formulation. Conversely, synergistic interactions can also lead to chemical reactions that degrade or modify the herbal constituents. For instance, the presence of specific compounds from one herb may catalyze the degradation of sensitive compounds from another herb, affecting the stability of the formulation. Antagonistic interactions occur when the combined action of herbal ingredients inhibits or reduces the individual effects of certain constituents. These interactions can impact the chemical stability of the formulation by altering the activity or availability of specific compounds. Antagonistic interactions may lead to decreased stability by reducing the efficacy of certain compounds that contribute to the stability or shelf-life of the formulation. For example, the presence of one herb may inhibit the antioxidant activity of another herb, leaving susceptible constituents vulnerable to oxidation and degradation.(Delgoda and Westlake 2004).

The solubility of herbal constituents and their interactions can influence the chemical stability of polyherbal formulations. Incompatibilities between herbal ingredients can lead to the formation of insoluble precipitates or complexation, altering the physical and chemical properties of the formulation. Precipitation can result in the loss of active compounds, reduced bioavailability, and changes in the formulation's appearance, texture, and consistency. In some cases, precipitates can also catalyze chemical reactions or act as sites for oxidation, impacting the stability of the formulation (Guo, Shalaev, and Smith 2013; Musakhanian, Rodier, and Dave 2022; Pinto et al. 2021).

2.3. Incompatibilities and complex formation

Interactions among herbal ingredients in polyherbal formulations can give rise to incompatibilities and complex formation, which can impact the chemical stability of the formulation. These interactions can lead to changes in the physical and chemical properties of the formulation, affecting its stability and overall quality. Incompatibilities occur when two or more herbal ingredients in a polyherbal formulation react with each other or with other components, resulting in undesirable effects on stability. Incompatibilities can manifest as changes in color, odor, pH, precipitation, or the formation of insoluble complexes. Incompatibilities can arise due to differences in pH, solubility, or reactivity between herbal ingredients. For example, acidic and alkaline compounds may react with each other, leading to pH shifts that can impact stability. Additionally, certain herbal constituents may be incompatible with specific excipients or preservatives commonly used in formulations. Incompatibilities can result in the degradation of active compounds, loss of therapeutic potency, reduced bioavailability, and compromised stability of the formulation. They can also lead to physical changes, such as changes in appearance, texture, or precipitation, which can affect the overall quality of the product'—(Chaerudin and Syafarudin 2021; Ghodsi and Stehrer 2022; Namjoshi et al. 2020; Suttikun and Meeprom 2021).

Complex formation occurs when two or more herbal ingredients interact and form stable complexes or associations. These complexes can alter the physicochemical properties of the formulation and influence its stability. Complex formation can lead to changes in solubility, bioavailability, or stability of the herbal constituents. The formation of complexes may result in increased or decreased solubility, affecting the dissolution rate and absorption of the bioactive compounds. Complexes can also shield or protect certain constituents from degradation or oxidation, thereby enhancing stability. On the other hand, complex formation may also result in reduced bioavailability or interaction with other formulation components, leading to altered pharmacokinetics or reduced therapeutic efficacy –(García-Bernal et al. 2021; Gubae et al. 2023; Taha et al. 2022).

3. Evaluation of Stability:

Evaluating the stability of a polyherbal formulation involves assessing its physical, chemical, and microbiological properties over time to ensure that it maintains its quality, safety, and efficacy throughout its shelf life. Stability studies are critical for determining the shelf life of the product and guiding proper storage and packaging requirements. The first step is to design a comprehensive stability study protocol. The study should consider factors such as the intended storage conditions (temperature, humidity, light exposure), the proposed shelf life of the product, and the frequency of testing at various time points. Physical stability assessment involves monitoring changes in the appearance, color, odor, and texture of the polyherbal formulation over time. Any signs of physical degradation or alteration may indicate a decrease in product quality. Chemical stability involves analyzing the active compounds and key chemical constituents present in the polyherbal formulation. Techniques like high-performance liquid chromatography (HPLC) or gas chromatography (GC) can help determine the degradation of active ingredients——(Figueiredo et al. 2023; Jin et al. 2022; Piñón-Balderrama et al. 2020; Rajendiran et al. 2021).

The pH of the polyherbal formulation should be monitored as fluctuations may affect the stability of the product. Microbiological stability is essential to ensure that the formulation remains free from microbial contamination throughout its shelf life. Microbiological testing includes evaluating the presence of microorganisms like bacteria, yeast, and mold. These studies expose the polyherbal formulation to elevated temperature and humidity conditions to assess its stability over a shorter period, simulating what would happen over a more extended period under normal storage conditions. These studies involve storing the formulation under recommended storage conditions for the proposed shelf life to observe its stability under actual storage conditions. (Madhusudhan et al. 2021; Maurya and Kumar 2019; More et al. 2022; SHARMA et al. 2022)

It is essential to evaluate whether the polyherbal formulation interacts with its packaging material, potentially affecting its stability. Compatibility studies involve storing the formulation in different packaging materials and analyzing any changes. Analyze the data obtained from stability studies using appropriate statistical methods to determine if the product meets the predefined stability criteria. Based on the stability data, the shelf life of the polyherbal formulation can be determined, which indicates the period during which the product is expected to remain stable under recommended storage conditions– – – (Barajas-Álvarez, González-Ávila, and Espinosa-Andrews 2022; Ge et al. 2014; Zhai et al. 2023).

3.1. Accelerated Stability Studies:

Accelerated stability studies are conducted to predict the stability of a polyherbal formulation over an extended period by subjecting it to elevated temperature and humidity conditions. These studies provide valuable information about the product's stability in a relatively short time, allowing manufacturers to estimate its shelf life more quickly than real-time stability studies. Determine the appropriate elevated temperature and humidity conditions for the accelerated stability study. These conditions should be chosen based on previous experience or knowledge of the product's behavior and its expected storage conditions. For example, higher temperatures (e.g., 40-50°C) and humidity levels (e.g., 75-85% relative humidity) are commonly used for accelerated stability studies. Prepare multiple batches of the polyherbal formulation following the standard manufacturing procedure. Ensure that the samples are representative of the actual product intended for commercialization. Place the samples in appropriate containers (e.g., sealed bottles, blister packs) to prevent any contamination or moisture ingress. Label and store the samples under the predetermined accelerated temperature and humidity conditions' – – —(W. Chen et al. 2022; Manso, Marcelino, and Caldeira 2021; Rybakov et al. 2022).

Plan the sampling time points based on the intended duration of the accelerated study. Typically, samples are tested at various intervals (e.g., 1, 3, 6, and 12 months) to observe changes over time. At each time point, remove the samples from the accelerated storage conditions and conduct stability testing. This testing should include assessments of physical appearance, color, odor, pH, chemical composition (using analytical techniques like HPLC or GC), and microbiological properties. Compare the stability data obtained from accelerated studies with the data from real-time stability studies (if available) and/or historical stability data. Analyze the results to identify any trends or indications of degradation or changes in the polyherbal formulation. Extrapolate the data obtained from accelerated studies to estimate the product's stability under real-time storage conditions. This estimation is usually done using mathematical models that consider the relationship between temperature and stability. Based on the results of the accelerated stability studies and the extrapolation to real-time conditions, determine the expected shelf life of the polyherbal formulation when stored under recommended storage conditions."" (Rani, Rahman, and Younis 2015; To Evaluate Accelerated Stability Study of a Polyherbal Formulation-Turmocin Plus Tablet 2021; Wayal and Gurav 2020)

3.2. Analytical Techniques:

The evaluation of the chemical stability of a polyherbal formulation involves analyzing the composition of the formulation to determine the degradation or changes in its active compounds and key chemical constituents over time. Several analytical techniques are commonly used to assess the chemical stability of polyherbal formulations High-Performance Liquid Chromatography (HPLC): HPLC is one of the most widely used techniques for analyzing the chemical composition of polyherbal formulations. It allows for the separation, identification, and quantification of individual compounds present in the formulation. HPLC can detect and quantify active compounds, markers, and other chemical constituents, making it a valuable tool for stability studies——'(Capelli et al. 2022; Gomez-Rioja et al. 2023; González-González et al. 2022; Kosović, Sýkora, and Kuchař 2021).

Gas Chromatography (GC): GC is employed for the analysis of volatile and semi-volatile compounds in polyherbal formulations. It is particularly useful for determining the stability of essential oils and other volatile components. Thin-Layer Chromatography (TLC): TLC is a simple and cost-effective technique used to separate and identify different components in a polyherbal formulation. It can be employed as a rapid screening tool during stability studies. Spectroscopic Techniques: Techniques like UV-Visible Spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), and Nuclear Magnetic Resonance (NMR) can be utilized to identify and quantify specific compounds or functional groups in the polyherbal formulation. Mass Spectrometry (MS): MS is used in combination with chromatographic techniques to identify and characterize compounds based on their molecular weight and fragmentation patterns. Liquid Chromatography-Mass Spectrometry (LC-MS) and Gas Chromatography-Mass Spectrometry (GC-MS) are commonly used in stability evaluations– (Cho et al. 2018; Hao et al. 2023; Klassen, Tatusch, and Conrad 2023).

Elemental Analysis: Techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS) are employed to determine the levels of trace elements in the polyherbal formulation. Nuclear Magnetic Resonance (NMR): NMR can provide detailed structural information about chemical compounds present in the formulation, aiding in their identification and quantification. Stability-Indicating Methods: These methods are specifically designed to separate and quantify degradation products or impurities that may aris e during the stability testing of the polyherbal formulation. They help distinguish the stability of the active compounds from potential degradation products.(Aslam et al. 2016; Deepaka, Bhatnagar, and Kumar 2010; SHARMA et al. 2022)(Bhope, Kuber, et al. 2011)

4. Stability-Enhancing Strategies:

Stability-enhancing techniques are used to improve the shelf life and preserve the quality of polyherbal formulations. These techniques help prevent degradation, maintain the potency of active compounds, and ensure the formulation remains safe and effective during storage. Careful selection of high-quality raw materials and herbs with well-established stability profiles is crucial. Ensuring the purity and potency of the ingredients can contribute to the overall stability of the formulation. Standardization involves establishing the minimum levels of active compounds or markers in the formulation. By maintaining consistent levels of these compounds, the stability of the formulation can be enhanced. (Manish Kumar Gupta et al. 2020; Pandey et al. 2023).

Incorporating antioxidants into the formulation can help protect sensitive compounds from oxidative degradation. Natural antioxidants like tocopherols (vitamin E), ascorbic acid (vitamin C), and polyphenols can be used to enhance stability. Excipients, such as stabilizers, surfactants, and emulsifiers, can be added to the formulation to improve stability. These excipients can help maintain the homogeneity of the formulation and prevent phase separation. Microencapsulation involves coating the active compounds with a protective layer, which can help protect them from degradation caused by factors like light, oxygen, and moisture. Freeze drying (lyophilization) is a technique that involves removing water from the formulation at low temperatures, preserving the active compounds and preventing microbial growth. Packaging the polyherbal formulation in an environment with controlled gas composition can help extend its shelf life by reducing oxidative degradation and microbial spoilage. Controlling the pH of the formulation within a specific range can enhance stability, as some active compounds may be sensitive to changes in pH. Regular testing and monitoring of the formulation during its shelf life can help identify any changes or degradation, allowing timely intervention if stability issues arise. Ensuring that the packaging material is compatible with the formulation is important. Some materials may interact with the formulation, leading to stability issues. Adhering to GMP guidelines throughout the manufacturing process can help maintain the quality and stability of the formulation. Storing the polyherbal formulation under recommended temperature, humidity, and light conditions is essential for maintaining stability. Proper storage helps prevent degradation and ensures the formulation's longevity. (Calderón-Oliver and Ponce-Alquicira 2022; Choudhury, Meghwal, and Das 2021; Sousa et al. 2022)\

4.1. Formulation Optimization:

Rational selection of ingredients and their proportions in a polyherbal formulation involves a systematic and evidence-based approach to choose the right herbs and determine their appropriate ratios to achieve the desired therapeutic effect. For this clearly define the specific health condition or symptom you intend to address with the polyherbal formulation. Understanding the therapeutic goals will guide the selection of herbs with relevant properties, conduct a thorough review of peer-reviewed scientific literature and clinical studies related to the potential herbs for your formulation. Look for evidence of their medicinal properties, active constituents, and relevant mechanisms of action. Traditional knowledge can offer valuable insights into the safety and efficacy of herbal combinations that have been used for generate Evaluate the individual herbs' efficacy and safety profiles for the targeted health condition. Pay attention to clinical trial results and any reported adverse effects. Synergy occurs when the combined effect of herbs is greater than the sum of their individual effects. Additionally, ensure that the selected herbs have complementary actions to address different aspects of the health condition. Be aware of potential interactions between the herbs and any medications the users might be taking. Avoid combinations that could lead to adverse effects or reduced efficacy of either the herbs or the medications. The dosage should be within safe and effective ranges while avoiding toxic levels. Ensure that the herbal ingredients used in the formulation are of high quality, purity, and authenticity. Work with reputable suppliers and conduct appropriate quality control tests. Consider the bioavailability of active compounds in the selected herbs. Some compounds may have low bioavailability, and strategies may be required to enhance their absorption. Experiment with different proportions of the selected herbs to find the optimal combination. Keep in mind their potency and potential synergistic effects when determining the ratios.(Chopra et al. 2007; Rahim et al. 2018; Tiwari et al. 2020)

Conduct preclinical studies on the formulation to assess its safety and efficacy in animal models. This step provides valuable insights before proceeding to human trials. If possible, conduct well-designed clinical trials to evaluate the safety and efficacy of the polyherbal formulation in humans. Use appropriate controls and endpoints to measure the outcomes accurately. Ensure that the polyherbal formulation complies with the regulations and guidelines for herbal supplements or medicines in the target market. Consider feedback from patients who have used the formulation during the optimization process. Their experiences and outcomes can provide valuable insights for further refinement'—(Loopstra and Rietveld 1969; Oliveira et al. 2022; Ren 2023).

4.2. Use of stabilizers and antioxidants:

Stabilizers and antioxidants play essential roles in maintaining the stability, shelf life, and quality of the product. These additives help prevent deterioration, degradation, and oxidation of the active compounds in the formulation. Stabilizers are added to polyherbal formulations to enhance their physical and chemical stability. They help prevent undesirable changes such as phase separation, precipitation, or degradation of active constituents over time. In polyherbal formulations where different herbs have varying solubilities, emulsifiers and surfactants can help create stable and uniform mixtures. Gelling agents are used to provide a consistent texture and prevent settling in liquid polyherbal formulations. They can help maintain homogeneity and improve ease of administration. In cases where the formulation contains water or is susceptible to microbial growth, preservatives may be added to prevent contamination and maintain the product's integrity. Stabilizing the pH within an optimal range can prevent chemical reactions or precipitation that could lead to reduced efficacy or altered therapeutic properties. In freeze-dried or frozen polyherbal formulations, cryoprotectants are used to safeguard the herbs from damage caused by freezing and thawing. Antioxidants are compounds that protect herbal ingredients from oxidation. Oxidation can lead to the degradation of active compounds and reduce the therapeutic efficacy of the polyherbal formulation. Antioxidants scavenge free radicals and prevent oxidative stress, preserving the integrity and bioactivity of the herbal constituents. By reducing oxidative reactions, antioxidants can extend the shelf life of the polyherbal formulation, ensuring its effectiveness over a more extended period. Antioxidants help maintain the formulation's stability, especially in formulations that are exposed to air, light, or heat. Common antioxidants used in polyherbal formulations include ascorbic acid (vitamin C), tocopherols (vitamin E), beta-carotene, and various plant-derived polyphenols like flavonoids and tannins.(Buacheen et al. 2023; Kirschweng et al. 2017; Shahidi and Zhong 2010).

It's important to note that while stabilizers and antioxidants can improve the formulation's stability and quality, excessive use of these additives might lead to adverse effects or interfere with the herbs' therapeutic actions. Therefore, it's essential to use these additives judiciously and in compliance with regulatory guidelines (Basudkar et al. 2022; Calixto 2000; A. Singh and Narsinghani 2023).

4.3. Packaging and Storage Conditions:

Packaging and storage conditions are critical factors that can significantly impact the stability, efficacy, and shelf life of polyherbal formulations. Proper packaging and storage practices are essential to preserve the integrity of the active constituents and maintain the quality of the product. Guidelines for packaging and storage of polyherbal formulations are: Choose packaging materials that are suitable for the specific formulation. For liquid formulations, dark-colored glass bottles are commonly used to protect the contents from light exposure. For solid formulations, such as powders or capsules, use airtight and moisture-resistant containers. Ensure that the selected packaging materials are inert and do not react with the formulation's ingredients, which could lead to degradation or chemical changes. Polyherbal formulations, especially those containing light-sensitive compounds, should be stored in opaque or dark-colored containers to protect them from light exposure. Light can accelerate the degradation of certain active constituents. Proper moisture control is vital for preserving the stability of polyherbal formulations. Moisture can lead to microbial growth, spoilage, and degradation of the herbal ingredients. Choose moisture-resistant packaging and store the formulations in a cool and dry environment to prevent moisture absorption —(C. Chen et al. 2023; Gudayu et al. 2022; Guloglu and Altan 2020; Xia et al. 2023).

Store the polyherbal formulations at a controlled room temperature unless specified otherwise by the manufacturer or herbal expert. Avoid exposure to extreme heat or cold, as temperature fluctuations can affect the stability and efficacy of the product. Minimize the exposure of the formulation to air, as oxygen can lead to oxidation and degradation of active compounds. For liquid formulations, ensure that the container is tightly sealed after each use. Provide clear and comprehensive labeling on the packaging, including the formulation's name, ingredients, dosage instructions, batch number, expiration date, and any specific storage instructions. Conduct stability studies to determine the formulation's shelf life under various storage conditions. This will help establish an appropriate expiration date and storage recommendations for consumers. For liquid formulations, ensure that the cap or lid provides an airtight s eal to prevent the entry of air and potential contamination. Store the polyherbal formulation in a safe place, out of reach of children and pets, to prevent accidental ingestion or tampering. Regularly monitor the quality of the polyherbal formulation during its shelf life to ensure it remains stable and effective.– (Othman et al. 2021; Sanmartin et al. 2018) Common container materials used for polyherbal formulations include: Amber or dark-colored glass: Offers excellent protection against light exposure. High-density polyethylene (HDPE): Provides good moisture barrier properties and is chemically inert. Aluminum foil pouches: Offers excellent moisture and light barrier, making it suitable for sensitive herbal formulations. Tin or steel containers: Durable and provides protection against light and gas exchange. PET (polyethylene terephthalate) plastic: Suitable for dry formulations and offers a moderate barrier to moisture and gas. Multilayer laminates: Combines different materials to create a package with optimal barrier properties(Boer et al. 2020; D. Hu et al. 2022; Ross et al. 2023).

4.4. Process Validation and Quality Control:

Process validation is the systematic and documented process of confirming that the manufacturing process consistently produces polyherbal formulations meeting predetermined quality standards. The goal is to establish evidence that the process is capable of consistently delivering a product that is safe, effective, and of high quality. The process validation typically involves three stages: Stage1-Process Design: In this stage, the formulation's process is designed and defined based on scientific knowledge and understanding of the herbs' characteristics, interactions, and requirements. Critical process parameters (CPPs) and critical quality attributes (CQAs) are identified. Stage2-Process Qualification: The process is then evaluated to ensure it consistently produces polyherbal formulations that meet the predetermined specifications. This involves performing process qualification batches and analyzing the results to verify process reproducibility—(Pineau et al. 2021; Said et al. 2024; Zhu et al. 2023).

Stage3-Continued Process Verification: After successful process qualification, the process enters routine production. Ongoing monitoring and verification are conducted to ensure that the process remains in a state of control throughout the product's lifecycle. Quality control (QC) involves the systematic and comprehensive testing and evaluation of the polyherbal formulation at various stages of production. The primary objective of QC is to ensure that the final product meets the defined quality standards and is safe for use. Key aspects of quality control for polyherbal formulations include: Raw Material Testing: All herbal ingredients used in the formulation are subjected to rigorous testing to verify their identity, purity, potency, and absence of contaminants or adulterants. In-process Testing: Testing and analysis are performed during the different stages of the manufacturing process to monitor and control critical parameters. This helps ensure that the formulation is being produced as intended''''' (Blay-Roger et al. 2024; COVID-19 (Coronavirus) 2020; Marková and Prajová 2021; Mele and Campana 2022).

Finished Product Testing: The final polyherbal formulation is extensively tested to assess its overall quality, potency, and safety. This includes testing for active compounds, physical characteristics, microbial load, heavy metals, and other relevant parameters. Stability Testing: Stability studies are conducted to determine the shelf life of the formulation under different storage conditions. This helps establish appropriate storage recommendations and expiration dates. Quality Documentation: All testing and quality control activities are documented thoroughly, including the specifications, test methods, results, and any corrective actions taken.– (Choudhary and Sehgal 2021; Husár, Pecha, and Šánek 2021; Karthick and Kathiresan 2022; K. Singh, Tamta, and Mukopadayay 2022)

Both process validation and quality control are crucial components of Good Manufacturing Practices (GMP) in the pharmaceutical and herbal industries. Implementing robust process validation and quality control measures ensures that the polyherbal formulation consistently meets the required quality standards, enhancing patient safety and confidence in the product(Hartini, Kurniawati, and Ihwanudin 2022; Rutz et al. 2019; Y. Zhang, Guan, and Jin 2022).

5. Conclusion

Polyherbal formulations offer a promising avenue for herbal medicine, combining multiple herbs to create synergistic and comprehensive therapeutic effects. As the interest in natural remedies grows, polyherbal formulations have gained significant attention from researchers, healthcare professionals, and consumers alike. The optimization of polyherbal formulations through rational selection of ingredients, appropriate proportions, stabilizers, and antioxidants, along with suitable packaging and storage, is critical for ensuring their efficacy, safety, and shelf life. In conclusion, polyherbal formulations hold significant promise as safe and effective therapeutic options. However, their development, optimization, and stability assessment require a multidisc ciplinary approach, integrating traditional knowledge with modern scientific methods. Addressing the challenges related to stability assessment will be pivotal in realizing the full potential of polyherbal formulations and ensuring their reliable use in healthcare.

Conflict of interest

The authors declare no conflict of interest.

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PESTICIDE PREDICAMENT: EXPLORING ENVIRONMENTAL AND HEALTH IMPACTS, AND POSSIBLE ECO-FRIENDLY SOLUTIONS

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Abstract
Pesticides play a pivotal role in modern agriculture, yet their widespread use has raised significant concerns about their adverse effects on the environment and human health. This study delves into the current status of pesticide impacts, examining their repercussions on ecosystems, water sources, and the broader environment. Additionally, the potential health risks associated with pesticide exposure in humans are explored. In response to these challenges, the abstract highlights the emergence of eco-friendly management strategies, with a particular focus on bioremediation. Bioremediation, as a sustainable and nature-based approach, harnesses the power of microorganisms and plants to detoxify and degrade pesticides. The abstract emphasizes the promise of bioremediation as an effective means of mitigating pesticide pollution and fostering environmental restoration. This study encompasses the multifaceted dimensions of pesticide use, recognizing the urgency of adopting environmentally responsible practices. As society grapples with the repercussions of conventional pesticide use, the exploration of eco-friendly alternatives, especially through bioremediation, offers a ray of hope for a sustainable and harmonious coexistence with nature.

Keywords
Pesticides, Environmental Impact, Human Health, Eco-Friendly Management, Bioremediation, Sustainable Agriculture

INTRODUCTION

The Pesticide Predicament is a complex issue that encompasses environmental and health concerns, as well as the search for eco-friendly alternatives. Pesticides are chemical substances designed to control or eliminate pests that can damage crops, spread diseases, or harm livestock. While pesticides have played a crucial role in enhancing agricultural productivity, they also pose significant challenges and risks (Dayioğlu and Türker, 2021; Prabhukarthikeyan *et al.*, 2022; Soltani-Sarvestani *et al.*, 2020).

In the ever-evolving landscape of agriculture and pest management, the use of pesticides has become a cornerstone in ensuring crop yield and protecting global food supplies. However, the widespread application of these chemical agents has led to a complex and multifaceted predicament, giving rise to environmental and health concerns that demand our immediate attention. This exploration delves into the intricate web of impacts that pesticides have on both our ecosystems and human well-being. From the contamination of soil and water to the potential health risks associated with exposure, the pesticide predicament poses a critical challenge that requires comprehensive understanding and proactive solutions. In this discourse, we navigate the intricate terrain of pesticide usage, investigating its far-reaching consequences while also delving into promising eco-friendly alternatives that hold the promise of a more sustainable and harmonious coexistence with our environment. Join us on this journey as we unravel the layers of the pesticide predicament and seek pathways toward a healthier, more environmentally conscious future (Anderson, 2017; Evans, 2018).

In the ongoing quest for sustainable environmental practices, bioremediation emerges as a powerful and innovative solution to address the challenges of pollution and contamination. The term itself suggests a biological approach

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to remedying the impact of hazardous substances on our ecosystems. Bioremediation harnesses the inherent capabilities of microorganisms, plants, or enzymes to transform, degrade, or neutralize pollutants, offering a promising avenue for restoring balance to ecosystems affected by various forms of environmental degradation. This introduction aims to shed light on the principles, applications, and potential benefits of bioremediation, highlighting its role in mitigating the adverse effects of human activities on our planet and paving the way for a more sustainable and resilient future (Gaurav, 2022; Gaurav *et al*., 2023, 2022; Gautam, 2022; Salar *et al*., 2023)

REVIEW FINDINGS

Disastrous impact of Pesticides

The widespread use of pesticides in agriculture, while instrumental in protecting crops from pests, has also brought forth a myriad of harmful impacts on both the environment and human health. This section will explore the detrimental effects associated with pesticide use, emphasizing the need for a nuanced understanding of the trade-offs involved. From soil contamination and water pollution to the unintended harm inflicted on non-target organisms, pesticides often leave a lasting imprint on ecosystems. Furthermore, the potential health risks to humans, stemming from pesticide residues on food and exposure during application, raise significant concerns. As we unravel the harmful impacts of pesticides, it becomes evident that a balanced and sustainable approach to pest management is imperative to safeguard not only our crops but also the delicate equilibrium of the broader environment. Join us in examining the intricate web of consequences spawned by pesticide usage, prompting a critical reassessment of our agricultural practices for the well-being of both ecosystems and humanity (Tang et al., 2021).

Environmental Impacts

Biodiversity Loss

The escalating use of pesticides in modern agriculture has become a major contributor to the concerning decline in global biodiversity. While these chemical agents are designed to target specific pests, their impact often extends far beyond the intended targets, resulting in collateral damage to non-target organisms and ecosystems. This section sheds light on the profound and often overlooked consequences of pesticides on biodiversity(Saha and Bauddh, 2020).

Pesticides, designed to eliminate pests that threaten crops, can inadvertently harm beneficial insects, birds, and other wildlife in the vicinity. This unintended ecological fallout disrupts the delicate balance within ecosystems, leading to a cascade effect on various species. For example, the decline of pollinators such as bees, crucial for the reproduction of numerous plant species, can have far-reaching consequences for both flora and fauna. Moreover, pesticides can persist in the environment, accumulating in soil and water. This persistence poses a long-term threat to biodiversity as it can affect not only the immediate ecosystem but also impact interconnected habitats. Aquatic organisms, including fish and amphibians, are particularly vulnerable to waterborne pesticides, leading to disruptions in aquatic ecosystems. The loss of biodiversity due to pesticide use has ripple effects throughout the food chain, affecting predators and scavengers as well. As species disappear or decline in numbers, the resilience and adaptability of ecosystems are compromised, making them more susceptible to further environmental stressors –(Erisman et al., 2016; Ollerton et al., 2014; Saha and Bharadwaj, 2023; Van Der Meer et al., 2020)

In recognizing the direct link between pesticide use and biodiversity loss, it becomes imperative to reassess our agricultural practices. Exploring and promoting alternative, more sustainable pest management methods is crucial to mitigate the ongoing impact on biodiversity and preserve the intricate web of life on our planet. This exploration seeks to deepen our understanding of how pesticides contribute to biodiversity decline, urging us to reconsider our approach to agriculture for the sake of a more resilient and balanced natural world. Sparrow bird and honey bees are the good examples to understand the loss of biodiversity with the use of pesticides (Figure 1).

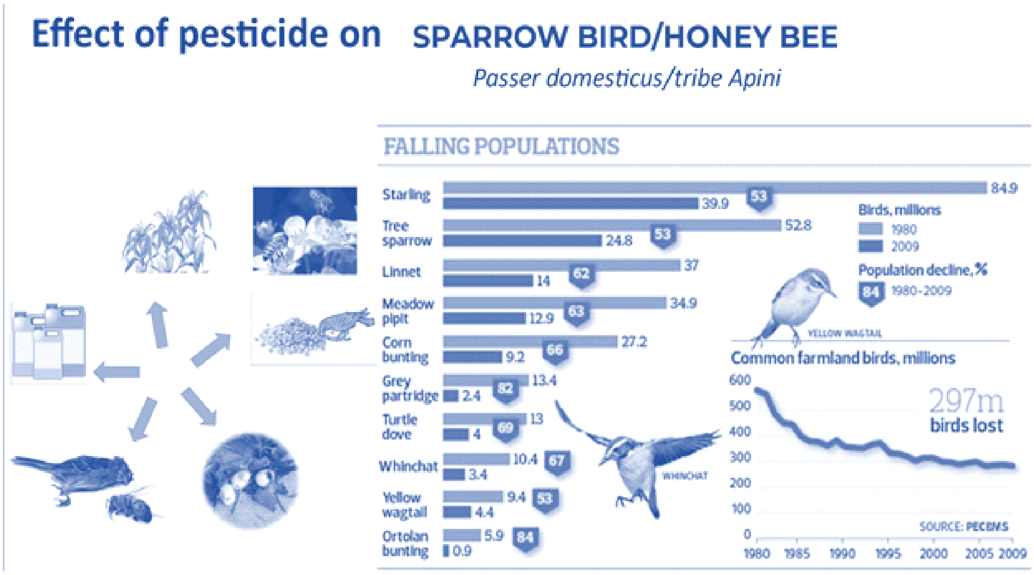

Figure 1: Showing the yearly declined scenario of sparrow bird (Figure credit: https://www.theguardian.com/environment/2012/may/26/eu-farming-policies-bird-population)

A study published on September 2019, in the journal Science, is the first experiment to track the effects of a neonicotinoid pesticide on birds in the wild. The study found that white-crowned sparrows who consumed small doses of an insecticide called imidacloprid suffered weight loss and delays to their migration effects that could severely harm the birds' ability to survive and reproduce. "Our study shows that this is bigger than the bees birds can also be harmed by modern neonicotinoid pesticides, which should worry us all,".

SOIL AND WATER CONTAMINATION

The pervasive use of pesticides in modern agriculture has led to a significant and widespread issue of soil and water contamination. While these chemical agents play a crucial role in protecting crops from pests, their unintended consequences on the environment, particularly on soil and water quality, pose substantial threats. This section examines the intricate ways in which pesticides contribute to contamination in soil and water systems (John and Shaike, 2015; Pretty *et al*., 2000; Sur and Sathiavelu, 2022)

Soil Contamination

Pesticides applied to crops can accumulate in the soil, leading to long-term contamination. The persistent nature of certain pesticides means that they can remain in the soil for extended periods, negatively impacting soil health and fertility. The chemicals may leach into the deeper layers of the soil or bind to organic matter, affecting the composition of the soil microbiota **(Figure 2).**

This contamination can disrupt the balance of soil ecosystems, harming beneficial microorganisms and soil-dwelling organisms crucial for nutrient cycling and overall soil health. The cumulative effect of prolonged pesticide use may result in degraded soil structure, decreased water retention capacity, and increased vulnerability to erosion.

Water Contamination

Pesticides have a propensity to move beyond the targeted crop areas through runoff, reaching nearby water bodies such as rivers, lakes, and groundwater reservoirs. This runoff introduces pesticide residues into aquatic environments, causing water contamination (Figure 2). Waterborne pesticides pose significant risks to aquatic ecosystems and the organisms that inhabit these environments.

Aquatic organisms, including fish and amphibians, can be directly affected by the presence of pesticides. Additionally, the contamination of water sources can have indirect consequences on human health when these contaminated waters are used for drinking or irrigation. The persistent and bio accumulative nature of some pesticides can lead to a gradual buildup in aquatic systems, creating a long-lasting impact on the overall water quality and the health of aquatic ecosystems. As we delve into the consequences of pesticide use on soil and water, it becomes evident that sustainable agricultural practices are crucial for mitigating these environmental impacts. Exploring alternative methods of pest control, promoting precision agriculture, and adopting integrated pest management approaches are essential steps in safeguarding the health of our soil and water systems. This exploration aims to highlight the urgent need for a balanced and environmentally conscious approach to pest management to protect these vital resources for future generations. Pesticides can leach into the soil and contaminate groundwater, posing risks to both terrestrial and aquatic ecosystems. Runoff from agricultural fields can carry pesticides into rivers and lakes, further impacting aquatic life.

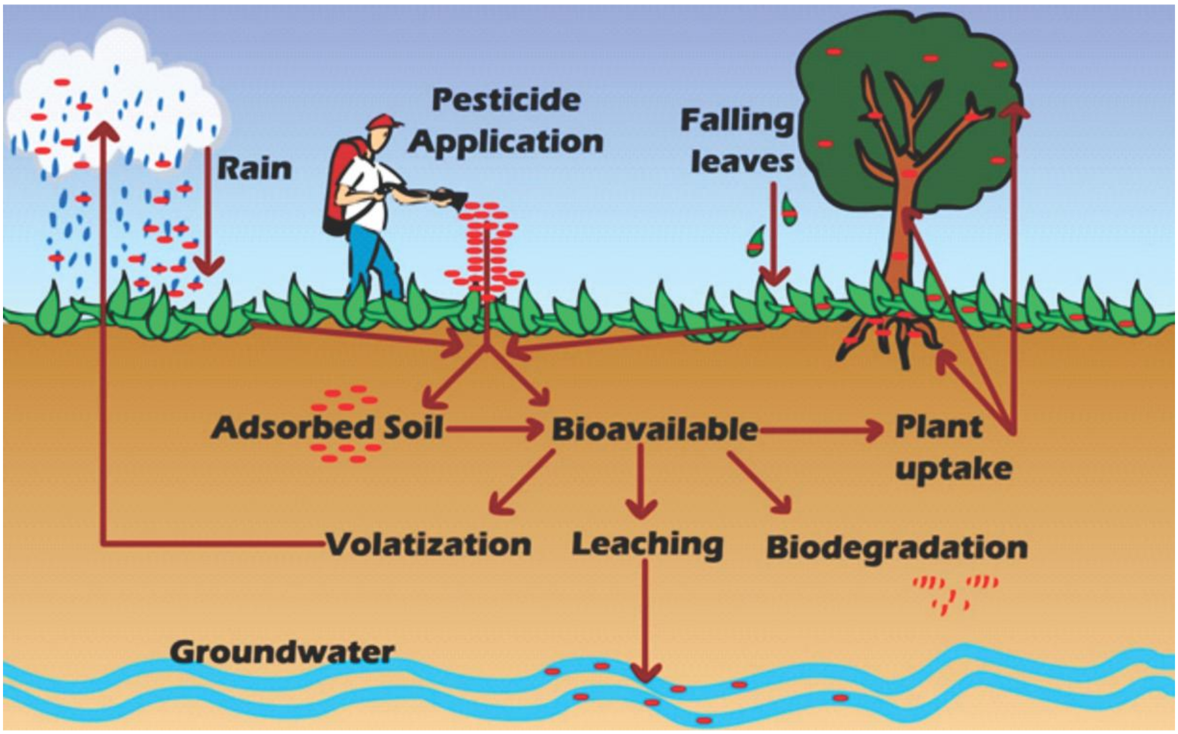

Figure 2: How pesticides polluting soil and groundwater (Langenbach, 2013).

DEVELOPMENT OF RESISTANT PESTS

The development of resistant pests against pesticides is a well-documented phenomenon and a significant challenge in agriculture. Pesticides are chemicals designed to control or eliminate pests that can damage crops and reduce yields. However, over time, some pests can evolve mechanisms to survive exposure to these chemicals, leading to the emergence of pesticide-resistant populations (Figure 3). Here are some key factors contributing to the development of resistant pests (Africa, 1994; Campos *et al*., 2016; Lengai *et al*., 2020; Pola *et al*., 2022).

Overuse of Pesticides

Continuous and widespread use of the same pesticides over an extended period can create strong selection pressures on pest populations. This pressure favors the survival and reproduction of individuals with natural resistance to the pesticide.

Monoculture

Large-scale monoculture, where a single crop is grown over extensive areas, provides a uniform environment for pests. This makes it easier for resistant individuals to survive and reproduce, accelerating the development of resistant populations.

Inadequate Pest Management Practices

Improper use of pesticides, such as applying sublethal doses or not following recommended application practices, can contribute to the development of resistance. Incomplete eradication of pest populations allows resistant individuals to survive and pass on their resistance to the next generation.

Genetic Variation in Pest Populations

Natural genetic variation within pest populations means that some individuals may already have traits that confer resistance to certain pesticides. When exposed to these chemicals, only those individuals with pre-existing resistance will survive and reproduce.

High Reproductive Rates

Pests often have high reproductive rates, allowing for rapid generation turnover. This facilitates the selection and spread of resistance traits within a population in a relatively short period.

Cross-Resistance:

Some pests may develop cross-resistance, where resistance to one pesticide confers resistance to other, similar pesticides. This can happen when the same resistance mechanisms provide protection against multiple chemical compounds.

To address the issue of pesticide resistance, integrated pest management (IPM) practices are recommended. IPM involves a combination of biological, cultural, physical, and chemical control methods to minimize the reliance on pesticides and reduce the selection pressure for resistance. Crop rotation, planting pest-resistant varieties, and using alternative pest control methods are among the strategies employed in IPM to mitigate the development of resistant pests. Additionally, rotating different classes of pesticides with distinct modes of action can help slow down the development of resistance. Regular monitoring of pest populations and adapting control strategies accordingly are crucial components of effective pest management. Over time, pests can develop resistance to pesticides, leading to the need for stronger and more toxic chemicals, exacerbating the environmental impact (Siddiqui et al., 2023).

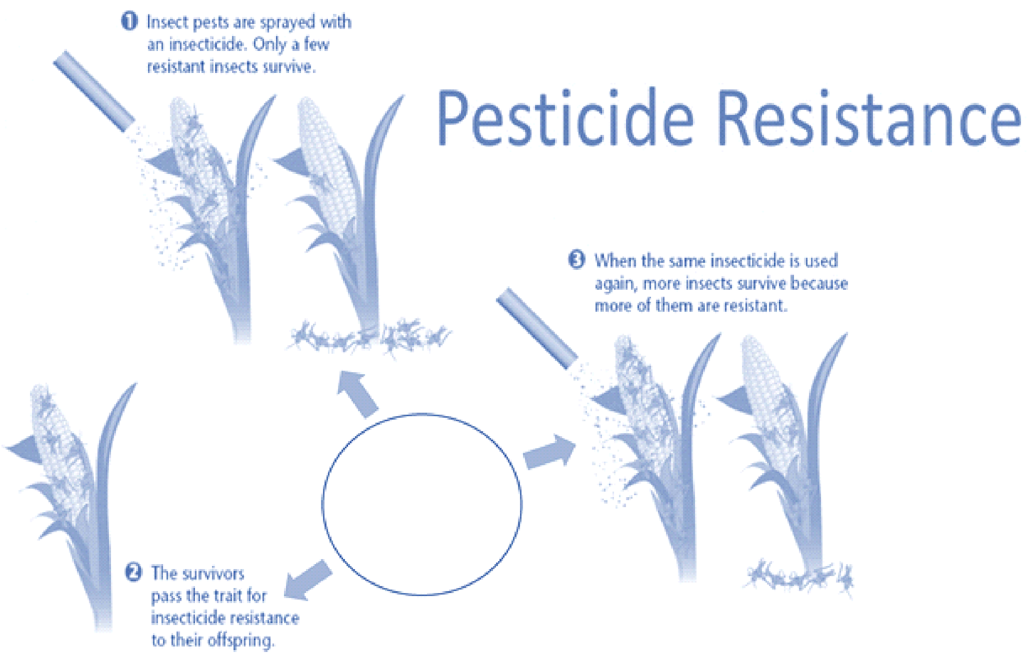

Figure 3: Development of Resistant Pests

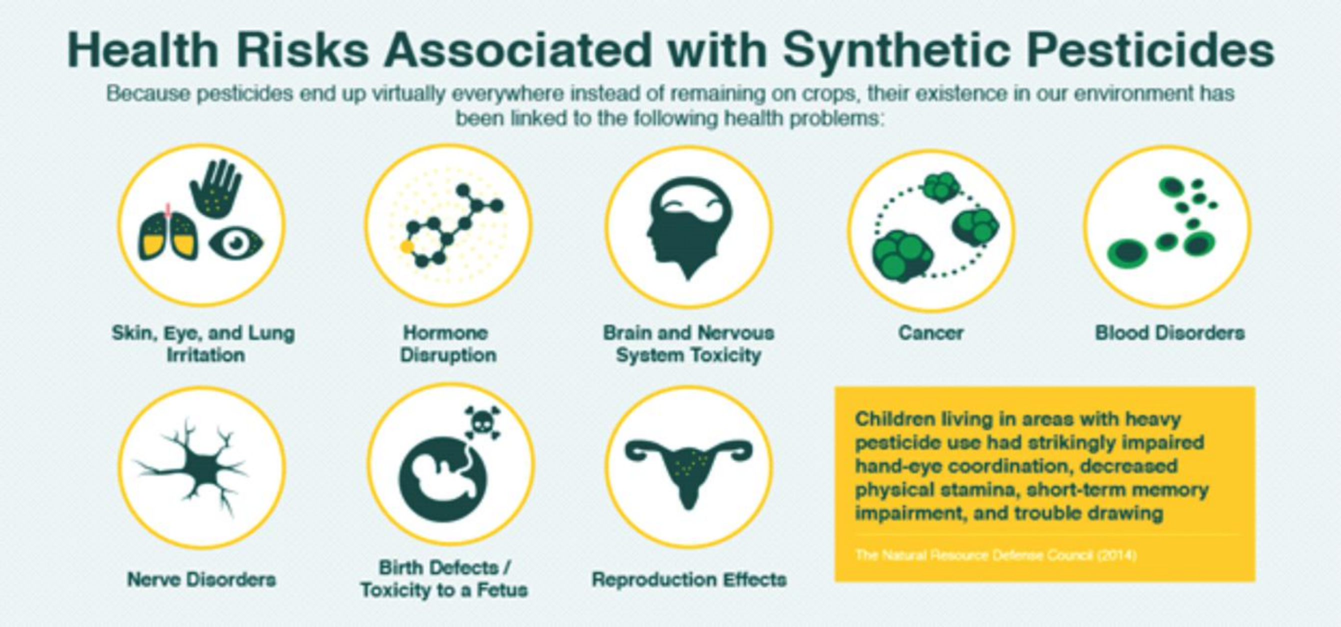

Figure 4: Health impacts associated with the exposure of synthetic pesticides (Health Risks Associated with Pesticides: https://neem.world/health-risks-associated-pesticides/)

Eco-Friendly Solutions of pesticide predicament

Health Impacts:

Agricultural workers and nearby communities may be exposed to pesticides through direct contact, inhalation, or ingestion. Long-term exposure has been linked to various health issues, including respiratory problems, neurological disorders, and certain cancers. Pesticide residues can persist on crops and find their way into the food supply, potentially causing harm to consumers. Chronic exposure to low levels of pesticides through the diet raises concerns about cumulative health effects (**Figure 4**).

Short-term exposure to high levels of pesticides can lead to acute poisoning. Symptoms may include nausea, dizziness, headaches, respiratory problems, and, in severe cases, convulsions or death. Long-term exposure to low levels of pesticides has been linked to chronic health problems. Some pesticides have been associated with the development of chronic conditions such as cancer, neurological disorders, reproductive issues, and endocrine disruption.

Some pesticides are classified as carcinogens, meaning they have the potential to cause cancer. Prolonged exposure to certain pesticides has been linked to various types of cancer, including leukemia, lymphoma, and cancers of the breast, prostate, and lung.

Certain pesticides can affect the nervous system, leading to symptoms such as dizziness, headaches, tremors, and memory loss. Prolonged exposure may contribute to the development of neurodegenerative disorders. Pesticide exposure has been associated with reproductive issues, including fertility problems, birth defects, and developmental delays in children. Pregnant women and young children are often considered more vulnerable to the effects of pesticide exposure. Some pesticides can interfere with the endocrine system, disrupting the normal functioning of hormones. This can lead to a range of health effects, including reproductive abnormalities, metabolic disorders, and developmental issues.

Inhalation of pesticide residues or vapors can cause respiratory problems, including irritation of the nose and throat, coughing, and difficulty breathing. Certain individuals may be allergic to specific pesticides, leading to skin rashes, itching, or respiratory symptoms upon exposure. Farmworkers and individuals involved in the production, application, or handling of pesticides face a higher risk of exposure and associated health effects. Proper protective measures and adherence to safety guidelines are crucial to minimizing these risks. Pesticides can leach into groundwater, posing a risk to drinking water supplies. Prolonged exposure to contaminated water sources can lead to chronic health issues.

To mitigate the harmful health impacts of pesticides, it is important to implement proper safety measures, use protective equipment, follow recommended application practices, and explore alternative pest control methods. Additionally, regulatory agencies play a crucial role in setting and enforcing safety standards for the use of pesticides in agriculture and other industries. Public awareness and education about the potential risks of pesticide exposure are also essential for promoting safer practices and minimizing health risks.

INTEGRATED PEST MANAGEMENT (IPM):

Integrated Pest Management (IPM) is a holistic and sustainable approach to managing pests that aims to minimize economic, environmental, and health risks. IPM combines various strategies to control pests effectively while reducing the reliance on chemical pesticides. The goal is to maintain pest populations at levels below those causing economic or aesthetic damage while promoting natural pest control mechanisms. Here are the key components of Integrated Pest Management (Barzman *et al*., 2015; Chandler *et al*., 2011; Fahad *et al*., 2021; Khan *et al*., 2021; Pretty and Bharucha, 2015).

Biological Control and Cultural Controls

Encouraging natural predators, parasites, and pathogens that feed on or parasitize pests. This can include releasing beneficial organisms like ladybugs, predatory mites, or using pathogens like Bacillus thuringiensis (Bt) for targeted pest control. Modifying agricultural or landscaping practices to make the environment less favorable for pests. This can involve crop rotation, planting resistant varieties, adjusting planting dates, and promoting diverse cropping systems.

Mechanical and Physical Controls

Using physical barriers, traps, or other mechanical methods to prevent pests from reaching crops. Examples include using row covers, sticky traps, and employing cultivation practices to disrupt pest life cycles.

Chemical Controls

Judicious use of pesticides when necessary. In IPM, chemical controls are considered a last resort and are applied selectively and in accordance with a well-defined strategy. It involves choosing pesticides with lower environmental impact, rotating chemical classes, and using them at the right time and in the right amount.

Monitoring, Scouting and Cultural Practices

Regularly assessing pest populations and their impact on crops. This involves monitoring pest levels, identifying beneficial organisms, and using thresholds to determine when control measures are necessary. Implementing practices that promote a healthy and robust crop, making it less susceptible to pest damage. This can include proper irrigation, fertilization, and maintaining optimal plant spacing.

Host Plant Resistance

Developing and using crop varieties that are resistant or tolerant to pests. This can reduce the need for chemical controls and support a more sustainable approach to pest management.

Public Awareness and Education

Educating farmers, landscapers, and the public about the principles of IPM, the importance of biodiversity, and the potential risks associated with excessive pesticide use. This helps foster a broader understanding of sustainable pest management practices.

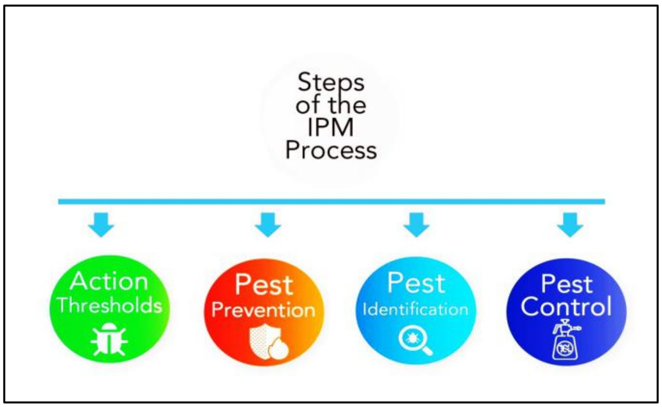

Figure 5: Different steps involved in Integrated Pest Management process.

Economic Thresholds

Establishing economic thresholds to determine when the cost of controlling pests is justified by the potential damage they can cause. This helps in making informed decisions about when and how to implement control measures.

Adaptive Management

Continuously assessing and adjusting pest management strategies based on monitoring and evaluation. This involves learning from experience and adapting practices to changes in pest populations or environmental conditions.

By integrating these various components, IPM provides a comprehensive and environmentally friendly approach to pest management that seeks to balance the need for crop protection with long-term sustainability. It has gained widespread acceptance as an effective and responsible approach in agriculture, horticulture, and landscaping. IPM focuses on a holistic approach to pest control, incorporating biological, cultural, and mechanical methods along with judicious use of pesticides. This approach minimizes the environmental impact and reduces the reliance on chemical treatments.

ORGANIC FARMING PRACTICES

Organic farming is an agricultural approach that emphasizes sustainability, soil health, and the use of natural methods to grow crops and raise livestock. Organic farming practices aim to minimize the use of synthetic inputs, such as chemical fertilizers and pesticides, and promote ecological balance. Here are some key principles and practices associated with organic farming (2023; Atoma *et al*., 2020; Galnaitytė *et al*., 2017; Kanagasabapathi and Sakthivel, 2019; Kavaskar and Govind, 2020; Kumar *et al*., 2022).

Crop Rotation

Organic farmers often use crop rotation to promote soil fertility and reduce the risk of pests and diseases. Rotating different crops on the same land over time helps break pest and disease cycles and enhances soil structure.

Composting

Composting is a common practice in organic farming for recycling organic matter. Compost, which is a mixture of decomposed plant and animal materials, is used to improve soil structure, fertility, and water retention.

Cover Cropping

Growing cover crops, such as legumes, on fallow fields or between cash crops helps prevent soil erosion, suppress weeds, and improve soil fertility by adding organic matter. Cover crops also provide habitat for beneficial insects.

Organic Fertilizers: Organic farmers use natural sources of nutrients, such as compost, manure, and green manure, to fertilize their crops. These materials release nutrients slowly, promoting long-term soil health.

Biological Pest Control: Instead of relying on synthetic pesticides, organic farmers employ biological control methods. This includes introducing or attracting natural predators, using beneficial insects, and implementing other measures to manage pest populations.

Crop Diversity: Growing a variety of crops helps break pest cycles, reduces the risk of diseases, and promotes overall ecosystem health. Crop diversity can also enhance soil fertility and nutrient cycling.

No Synthetic Chemicals: Organic farming prohibits the use of synthetic chemicals, including synthetic pesticides and fertilizers. Instead, farmers rely on natural alternatives and sustainable practices to manage pests and enhance soil fertility.

Livestock Integration: Organic farms often integrate livestock into the farming system. Livestock contribute to nutrient cycling through manure, and their presence can be beneficial for pest control and weed management.

Non-GMO (Genetically Modified Organisms): Organic farming standards typically prohibit the use of genetically modified organisms (GMOs). Organic farmers use traditional breeding methods to develop crop varieties with desirable traits.

Sustainable Water Management: Organic farmers prioritize efficient water use and often employ water conservation practices, such as mulching and drip irrigation, to reduce water consumption.

Minimal Soil Disturbance: Organic farming emphasizes minimal soil disturbance to preserve soil structure and minimize erosion. Practices like no-till or reduced-till farming are common in organic systems.

Certification and Standards: To be recognized as organic, farms must adhere to specific standards and undergo certification processes established by organic certifying bodies. These standards ensure that organic practices are followed, and consumers can trust the organic label.

Organic farming practices aim to create a sustainable and environmentally friendly system that prioritizes soil health, biodiversity, and the well-being of both the environment and consumers. While organic farming has gained popularity, it's important to note that challenges exist, including potential lower yields in certain cases and the need for careful management to control pests and diseases without synthetic inputs. Organic farming avoids synthetic pesticides and promotes the use of natural alternatives, such as neem oil, diatomaceous earth, and beneficial insects. This approach aims to minimize environmental impact and produce healthier, pesticide-free food.

Figure 6: Different aspects of organic farming (https://www.zauca.com/organic-farming-website-design-rs-5900-organic-farm-website-development-company-near-me/).

AGROECOLOGY

Agroecology is an interdisciplinary approach to agriculture that integrates ecological principles into farming systems. It emphasizes the development of sustainable and resilient food production systems while minimizing the use of external inputs like synthetic pesticides and fertilizers. Agroecology seeks to promote ecological balance, enhance biodiversity, and improve the overall health of agricultural ecosystems. Here are key principles and components associated with agroecology (Duff *et al*., 2022; Kerr *et al*., 2022; López-García and de Molina, 2021; van der Ploeg, 2021).

Biodiversity

Agroecology encourages the cultivation of diverse crops and the promotion of on-farm biodiversity. This diversity helps enhance ecosystem resilience, reduce the risk of pests and diseases, and improve overall ecosystem health.

Crop Rotation and Polyculture

Rotating crops and planting multiple crops together (polyculture) are common practices in agroecology. These techniques disrupt pest and disease cycles, improve soil fertility, and contribute to a more balanced ecosystem. Integrating trees and shrubs into agricultural landscapes is a key aspect of agroecology. Agroforestry systems provide multiple benefits, such as improved soil structure, increased biodiversity, carbon sequestration, and additional income sources through the production of fruits, nuts, or timber. Minimizing soil disturbance through practices like no-till or reduced tillage helps maintain soil structure, reduce erosion, and enhance water retention. This is crucial for sustaining soil health and fertility.

Efficient water management practices, such as rainwater harvesting, drip irrigation, and mulching, are emphasized in agroecology. These practices help conserve water resources and reduce the environmental impact of agriculture. Agroecology values traditional knowledge and local farming practices. Indigenous and traditional farming systems often hold valuable insights into sustainable agricultural practices that can be incorporated into modern agroecological approaches. Agroecology emphasizes the use of natural enemies, biological control methods, and other ecological processes to manage pests. This reduces the reliance on synthetic pesticides and promotes a healthier balance between pests and their natural predators ––(Abbona et al., 2007; Bocco et al., 2019; Costa-Pierce et al., 2011; Tully and Ryals, 2017).

Maintaining and improving soil health is a core principle of agroecology. Practices such as cover cropping, composting, and organic matter incorporation contribute to soil fertility, structure, and nutrient cycling. Agroecology takes into account the social and economic dimensions of agriculture. It aims to create equitable and sustainable food systems that benefit local communities, support small-scale farmers, and enhance food security.

Agroecology often involves a participatory and community-based approach, where farmers actively engage in decision-making processes. Local knowledge and community involvement are considered essential for the success of agroecological initiatives. Agroecological practices are designed to build resilience in farming systems against the impacts of climate change. Diverse and resilient ecosystems are better equipped to adapt to changing environmental conditions. Agroecology promotes education and training at various levels, encouraging farmers to understand the ecological principles underlying their practices and fostering a culture of continuous learning.

Agroecology represents a shift toward more sustainable, regenerative, and ecologically conscious agricultural practices. It aligns with the broader goals of sustainable development, emphasizing the interconnectedness of ecological, social, and economic factors in agriculture. Many believe that agroecology can contribute to addressing global challenges such as food insecurity, environmental degradation, and climate change. Agroecological practices focus on sustainable farming systems that enhance biodiversity, soil health, and resilience to pests and diseases (Abbona *et al*., 2007; Tully and Ryals, 2017).

Furthermore, continued research into alternative pest control methods, such as biopesticides and precision agriculture, can contribute to more sustainable and effective solutions. However, addressing the pesticide predicament requires a comprehensive and multi-faceted approach that balances the need for pest control with environmental and health considerations. Transitioning towards eco-friendly alternatives and promoting sustainable agricultural practices are essential steps in mitigating the negative impacts of pesticides on our ecosystems and well-being.

Conclusion

In conclusion, the pesticide predicament poses a multifaceted challenge, intertwining environmental and health impacts that demand urgent attention and innovative solutions. The indiscriminate use of chemical pesticides has undeniably led to severe ecological imbalances, adversely affecting biodiversity, soil health, and water quality. Simultaneously, the detrimental consequences extend to human health, with potential long-term risks linked to pesticide exposure. However, amidst this predicament lies the opportunity for transformative change. The exploration of eco-friendly alternatives emerges as a promising avenue to mitigate the adverse effects of conventional pesticides. Embracing sustainable agricultural practices, integrated pest management, and the development of biopesticides can pave the way towards a harmonious coexistence of agriculture and the environment. Public awareness and education are essential components in fostering a collective commitment to environmentally responsible practices. Governments, researchers, and stakeholders must collaborate to enact and enforce stringent regulations that prioritize the development and adoption of eco-friendly solutions. As we navigate the pesticide predicament, it is imperative to recognize the interconnectedness of environmental and human well-being, striving for a future where agricultural practices coexist harmoniously with nature, ensuring a sustainable and healthier planet for generations to come.

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Conflict of interest

Author declares no conflict of interest

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SAVE THE ENVIRONMENT (STE) was founded and registered on 19th November 1990. In 1992 with the collaboration of WWF (India), the organization started working to combat arsenic poisoning problem of water in the arsenic prone areas of West Bengal. Since then STE has been involved in various projects related to combat arsenic problem in India.

Our Vision

To protect present and future generations from various environmental hazards.

Our Mission

To create awareness and motivation among rural communities & provide cost effective, energy efficient & environment friendly technologies.

Our Activities

Conducting interactive sessions, workshops/ seminars, awareness programs, field operations through projects, science fairs, posters & quiz competitions.

Please join us and become part of our family
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