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Hazardous Waste - Impact on health and Environment for sustainable development in India

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ABSTRACT

Development is the need for any country's progress but not at the cost of livelihood of future generations, says the United Nations World Summit on Sustainable Development. Industries are the bread and butter for our modern evolved country, and surplus hazardous waste that comes out due to it, is continuous and unavoidable. Apart from all the measures for sustainable use of resources, it's the time we must look into better waste management systems since it is potentially harmful to environment and human health if not treated well. Presently India indicates a clear picture of concern over the issue through its strict rules and regulations for the industries. Hazardous waste treatment and disposal requires better strategies to choose the most convenient and green techniques. This paper gives an insight on the various hazardous wastes being generated from industries, nature and characteristics of waste, importance of waste management, churn out various steps to be taken to design and plan the models methods, any changes towards the regulations related to hazardous waste disposal and impact on environment and health,. It also takes a dip into the Indian industrial scenario towards cheap and viable methods of disposal as a step towards sustainable development.

***Keywords*:** Hazardous Wastes, Sustainable Development, Waste Management

1. INTRODUCTION

Urbanization is synonymous to development which meant waste generation in solid, liquid or gas form that finally gets released in the atmosphere [1]. These wastes are hazardous to environment and hinders the livelihood of all living organisms not only due to its nature but

also its quantity. Wastes in the form of air emissions contaminating air quality, leaching surface and ground water, biological waste accumulation and soil degradation [2]. Landfilling of solid hazardous waste pose direct threat to surface and ground water by leaching through soil thus regulating such wastes in a sustainable manner. Water and air emission regulations have been existing since long and government bodies have been responsive enough for its ground implementation [3]. For air and water, almost all comply with the legal requirements laid down by the government but the complexity arises in the case of solid waste management and treatment for the same is mostly not feasible at user site. The complex chemistry of the hazardous solid waste in addition to the toxicity is a major problem [4].

2. MATERIALS & METHOD

Even though municipal and biomedical wastes are a concern, at present industrial hazardous solid waste is taken under consideration here. Waste stream categorization is a very important and first step to waste management on basis of its chemical constituent to prevent any further mixing Table1 and Table 2 give more broad view of the industries and the wastes associated with it.

Table 1. Industries contributing hazardous wastes

Industries	Material Used
Plastic	Organic Chlorine Compounds
Pesticide	Organic Chlorine Compounds, Organic Phosphate Compounds
Medicine	Organic Solvents and residue, heavy metals e.g. Hg, Zn
Paint	Heavy metals, pigments, solvents, organic residues
Petroleum	Oil, phenols and other organic compounds, heavy
Metals	Heavy metals, fluorides, cyanides, acid and alkaline cleaner solvents
Leather	Heavy metals, organic solvent

Table 2. Waste Categorization

Cyanide Waste	Tar wastes from distillation process
Metal finishing waste	Sludge from waste water treatment that contains heavy metals
Asbestos	Phenols
Waste containing mercury, thallium, arsenic and cadmium	Wastes that contain chromium, zinc, nickel, barium, antimony, lead, selenium

Solvents and non halogenated hydrocarbons	Wastes from manufacturing of herbicides, pesticides and such units
Halogenated hydrocarbons	Slurry, alkaline or acidic wastes
Glue, painting, varnish pigments wastes	Discarded and lack of specified wastes
Wastes of dye and its intermediate	Discarded containers with lining of hazardous wastes

2. 1. Categorization of waste

When implementing any waste management plan, segregating them on the basis of its characteristics is very important [5] . Before going any further with any treatment and control of waste, its constituents must be known to lay the strategy. The best way is to identify those manufacturing units that produce hazardous waste and then classify them according to the nature of the waste and the risk they might pose [6].

Table 3. Risk from the hazardous waste can be classified into following:

1	High Risk	It is highly toxic and has the tendency to accumulate in the ecosystem e.g. Cyanide Waste, Chlorinated solvents, Wastes that are dioxin based
2	Intermediate Risk	Wastes containing metal hydroxides that are extremely toxic due its low mobility and insolubility.
3	Low Risk	It is primarily organic wastes that are biodegradable

2. 2. Hazardous Waste Management

As already, mentioned the extreme effects of hazardous wastes thus it requires immediate action and attention. The main focus is to have a safe, cheap and efficient method of collecting, transporting, treating and eventually disposing it. The system must be designed such that it caters the present accumulated state as well future generations. Basic hazardous management plan has been explained in Fig. 1.

2. 2. 1. Details of the effective plan [7]

Characteristics of wastes that includes physical, radioactive, chemical and biodegradability properties, also hazard degree that will enable to choose appropriate disposal method. Criticality in terms of contact to which kind of media (water, air or soil) and potential harm that it can cause to human life and environment if exposed to ecosystem and its assessment. Detailed topography, geology, meteorological and hydrogeology characteristics of disposed sites are collected to determine the extent of service area the disposal facility would work i.e pick waste from local industry and transport it to facility. The suitability of the disposal facility in terms of economic, social and environmental concerns including affect to

nearby water sources, populations, etc. are evaluated. All emergency evacuation plan and equipment for the disposal facility are designed for effective monitoring programs to be provided in the facilities.

2. 2. 2. Detailed plan, design and model of hazardous waste management

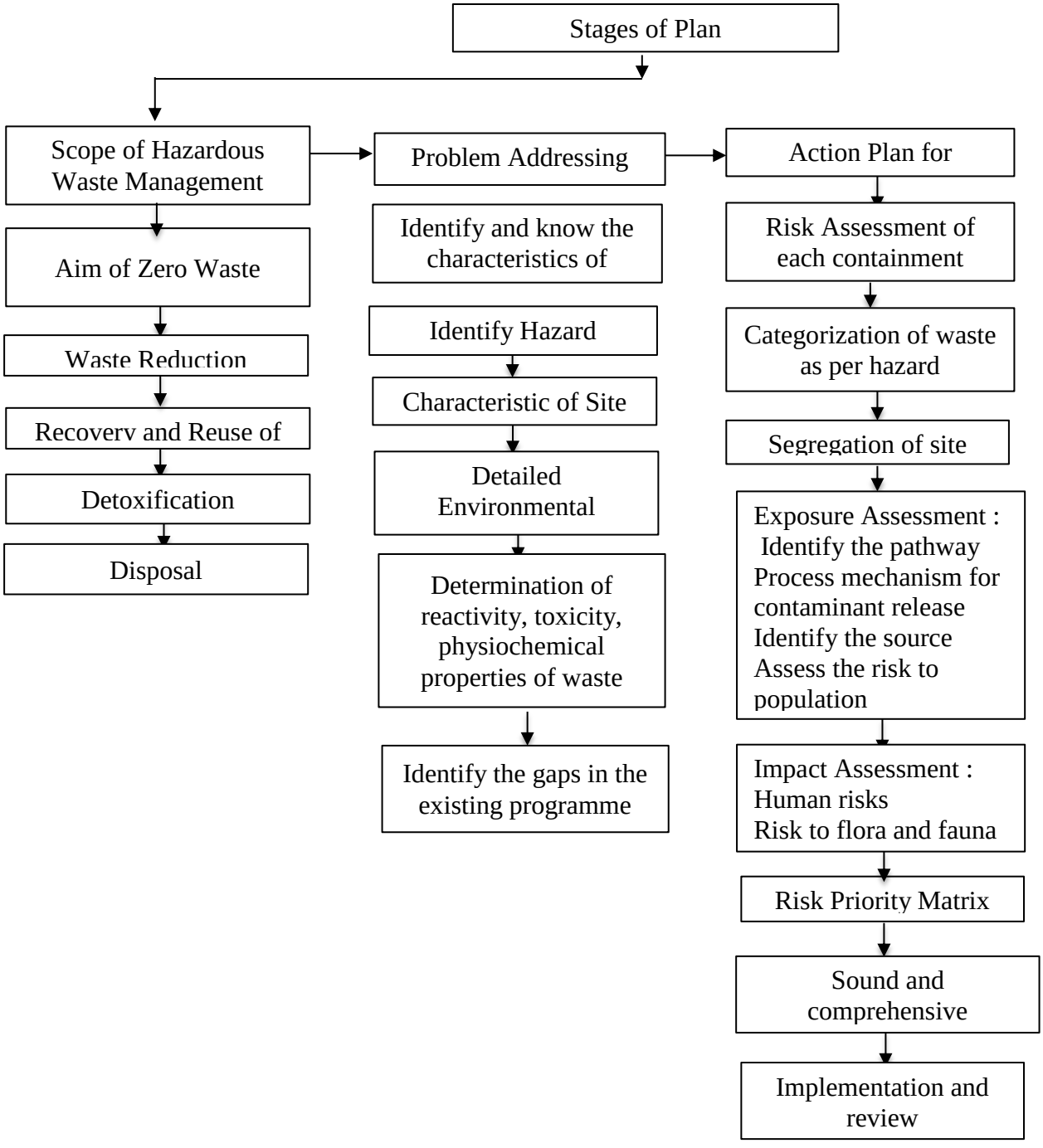

Figure 1. Stages of waste disposal plan

The treatment technology is selected and governed according to the waste properties. Incineration is selected as a treatment method when the facility has small landfill area and produces less residue. A different method is selected where landfill area is more and residue is produced in large amount. It would be a saving for the advanced technology that might have been invested to install in the disposal facility [8].

The design capacity of a disposal facility will remain same with time. But the waste that needs to be landfilled will continue to come and even increase with times to come due to the growing industrialization (only if the unit follows a waste minimizing methods). With stern regulations in place, waste will be sent to landfill sites for disposal while the area available would be constrained. At one point of time, the resources will be consumed and facilities will need to opt for an alternative method or the facility owners would have to relocate the facility.

The exhausted facility needs to be replenished in the due course of time to be reused, this also needs to be included in the planning stage. The risk and cost factor associated with the technology should be evaluated well before going further with the projects [9].

There might be an instance when a particular technology like incineration might not be replaced by a chemical treatment after some years or a certain change in the waste reallocation. With increasing land costs, population surge and expanding urbanization, constructing a new disposal system and acceptance from localities nearby is a difficult task. Similarly, shifting a disposal facility to a new area or region would mean increased risk and cost of transportation and hence an unattractive option [10].

For a proper hazardous waste management system plan, various models are developed keeping in view the characteristics and amount of waste, yearly waste handling capacity, distance covered in transportation, population statistics of the region, functional location of a waste generating industries and the risk associated with the disposal method. Not all models facilitate to serve all the conditions mentioned in detail like it might not be suitable for different waste. There might be wastes generated from the same industry category but the waste characteristic might be different hence it cannot be treated by the same method [11].

If the wastes are not compatible and made to come contact with each other, might lead to a hazard (a fire, toxic gas production, explosion or heat generation). Further, there comes a challenge of designing an efficient management system complying all the legal regulation and compliances, taking care of transport and operational maintenance costs [12].

2. 2. 3. Hazardous Waste Treatment [13]

Table 4. Processes involved under different principles

Physical	Chemical	Biological
Evaporation	Pyrolysis	Waste Stabilization Ponds
Flocculation	Chemical Oxidation	Trickling Filters
Sedimentation	Ion exchange	Aerobic Digestion
Electrostatic Precipitation	Chemical Reduction	Activated Sludge

Absorption	Chemical Precipitation	Spray Irrigation
Thickening	Neutralization	Anaerobic Digestion

The main aim of waste treatment is to improve the physical and chemical attributes of waste so that safe disposal is ensured. Methods like incineration, neutralization, solidification, chemical fixation, etc. can be used before disposing the hazardous wastes. These methods change the waste to a more inert form or weaken the toxic substances or quantity of waste is reduced and governed by the effectiveness of specific waste, quantity of residue generation, risks that pose and the cost. Some methods have been listed in following Table 4.

Overall, the treatment and disposal of waste in any disposal facility depends on the kind of waste received. Having said that, the facility should meet certain requirements of minimum facility to store, treat and dispose. Thus the treatment facility needs to be planned in detail to save its impact on environment and people. Apart from it, there is also need to identify and assess the discarded hazardous waste disposal land and recovery of such facilities to protect from any further impact on human health and quality of environment.

2. 2. 4. Strategic approach towards the system

The end process of the waste facility is the disposal of the wastes hence, it is the focus area of the system. There is some generation of residue irrespective of the method used hence cost effectiveness is difficult to achieve [14]. The hazardous waste produced from any industrial/manufacturing unit can well be estimated from its production process and the chemicals used it in. All the wastes that been listed in table 1 are all very toxic and has certain risks associated with it even if the quantity is very small. The disposal methods include solidification, incineration, land burial, sanitary landfill, deep well disposal and dilution. The method opted for disposal depends on the potential risk to human health and environment and the economics evaluated [15].

2. 2. 5. Treatment methods used in disposal

i. Incineration [16]

It is the combustion process of conversion of solid material capable of burning to non toxic gases that can be releases into atmosphere. It reduces the quantity of wastes, make it less toxic and suitable to be release into atmosphere. The main products from this method are water, carbon dioxide and ash while products which are point of concern are nitrogen, sulfur and halogens. Thus it is said to be a very controlled process, otherwise would result in unwanted releases into atmosphere. Sometimes, even a secondary treatment like scrubbing, burning or filtration is necessary to lower reduce concentrations to safe level before being released into atmosphere. Methods like absorption of gases in water that are produced during incineration which are later neutralized by acid or base for reusing it which further decreases the risk of formation of dioxin. The products from secondary treatment frequently require additional treatment before being disposed. Incineration helps in reducing the sludge volume by turning into ash residue which easy to handle for final disposal simultaneously leading to the toxic soluble oxides of metal formation.

ii Landfill [17]

a. Common Landfill – This method involves waste mixing with soil, infiltration and evaporation or shallow burial. Mostly solid wastes are disposed in landfills but slurries, liquids and sludge also might be buried in landfill. The potential damage by landfill caused on environment depends on quantity and composition of waste. Hazardous wastes that are brought in plastic containers or drums contain arsenic, cyanides and such heavy metal compounds and these are accepted in very less quantity by landfill owners.
b. Approved landfill – Such sites are appropriate for the organic decomposable materials and inert solid disposal. These sites are situated away from water table to avoid any chance of leaching into water sources.
c. Secured Landfill – A securely designed proper landfill site have harmful impact on environment. A site that like this that allows disposal of solid and liquid waste must ensure that in no case it percolates into the surface water or ground water. The main objective is to isolate the landfill site from surrounding environment i.e. water and air quality must be maintained. Some wastes are disposed in open landfills and some in closed landfills, depends upon the waste characteristics.
   Open Landfills – Wastes like glass bottles and metal cans are incorporated in these.
   Control Landfill – Wastes that are potentially harmful or toxic such as sludge from sewage or incinerator ash are buries here.
   Closed Landfills – Wastes that highly toxic that contain mercury compounds or biphenyls where the landfill site is set aloof by a concrete wall, floor and a roof, thus minimizing risk of water percolation into it.
   Secure landfill raises the concern of leaching into ground water and to mitigate such risks, USEPA have put forward the solution of using LCRS (Leachate Collection and Removal system) and Double Liners. Liner material is selected keeping in mind the chemical suitability with gas generated from landfill, hydraulic conductivity, stress-strain attributes, durability, aging, etc. thus Darcy establishing a formula relating flow rate, area and driving force to calculate the infiltration for three different liners:

   - Soil liner, q (in m^3/s) = ¼ $K_s iA$
   - Geo membrane Line, q (in m^3/s) = ¼ $K_s iA$
   - Composite liner, q (in m^3/s) = $0.21n^{0.9}a^{0.1}k_s^{0.74}$, for good contact
     or = $1.15n^{0.9}a^{0.1}k_s^{0.74}$, for poor contact

where:

Ks = hydraulic conductivity of soil (m/s)
A = Area of soil (m^2)
I = hydraulic gradient [(h+d)/d]; h = liquid head (m); d = soil thickness (m)
a = Area of hole (m^2)
C_B = 0.6 (flow coefficient)
N = porosity = volume of voids/total volume.
G = Acceleration due to gravity (m/s^2)

Leachate collection efficiency for landfills is the percentage of sum of liquid collected and that removed in LCRS to total liquid that has been fed to LCRS. Results have shown that efficiency of composite liners are far better mitigating any leaching over the compacted soil.

iii. Disposal in adjacent water bodies

Mostly solid wastes are stored for temporary period of time in lagoons for minimal impact on environment. Neutralization is done and suspended particles are allowed to settle and for rivers, such wastes are attempted to be released during high flood time. Sometimes, it is directly disposed of on ground [18].

iv. Lagoon

It is treated as a temporary as well as permanent storage component even though it leads to potential environmental issues that result from it related to runoff into surface water and leaching into subsurface. Like, during the rains, the lagoon might overflow and thus contaminate the surface [19].

v. Subsurface leaching

In this method, solid waste is reduced in size and mixed with water to form slurry which is then pumped into cavities that are underground. As the slurry passes through different strata of the soil, it gets treated naturally. There are some new systems that include gravelless or chamber system [20].

2. 2. 6. Waste Initialization before disposal

Due to the potential risk of the wastes, it should be segregated and recorded. Sometimes, chemical fixation, neutralization, encapsulation and other methods are required [21]. Due to concentrated hazardous wastes, maximum capacity to withhold such wastes is reached. Leachate treatment method is even more complicated due to variety of types of waste and its constituents [22]. Sometimes, due to volatile nature of the hazardous wastes, it needs to be covered immediately and often need extra sophisticated design and care than normally done to municipal waste [23].

There are ways to pretreat waste before being disposed and these include volume reduction, chemical stabilization, degradation, waste segregation and encapsulation.

i. Volume Reduction: Incineration is the best method to achieve this, upto 60% reduction is volume. Major wastes can be totally destroyed except small amounts [24].
ii. Chemical Stabilization: It involves addition of chemicals to reduce the movement of pollutants that help in stabilization and solidification of hazardous waste. It is a cheap method where chemical are mixed with waste sludge thus resulting mixture is pumped into the land where it takes few weeks to solidify. Some of these methods helps in forming matrix and while some get bounded chemically [20].
iii. Degradation: Some methods are being utilized for chemical degradation of wastes like oxidation, de chlorination, hydrolysis, etc but no single one line method can be effective in this [25]. Hydrolysis proves to be effective method of all degrading carbamate and organophosphorus pesticides. Using strong oxidants is one

approach towards degradation while biological degradation of these in soil is one such method [26].

iv. Waste Segregation: Waste is segregated based on chemical characteristics which is usually followed to avoid any unnecessary reaction in the landfill. Number of issues can arise due to mixing of wastes. Segregation before disposing the wastes allows to understand it compatibility with the available facility such as a major acidic waste can used to neutralize a high pH waste [20].

v. Encapsulation: Some wastes which cannot be detoxified may be confined in a material like molten asphalt, concrete and plastics before being disposed. Wastes containing heavy metals should follow such method to avoid leaching of potential toxic materials into the water. For small inorganic waste quantities like one ton of waste per day, steel drums are a good option. In wet regions, full landfill area is covered by addition of asphalt caps or clay to landfill liners but in case of dry regions, encapsulation is not required [20].

2. 2. 7. Selection criterion for chemical waste landfill [27]

Such landfill sites take benefits of the geological factors in consideration and overcome any disadvantage through its design.

The main considerations include:

- Physical Aspects:
  a. General topography of the place is taken into account
  b. Presence of water table and geological features of the soil
  c. Examine the presence of streams and surface water
  d. Stability of land and seismic activity in the region
  e. Wind flow and its direction in the area

- Ecological Aspects:
  a. Natural habitat of the area
  b. Conservation/Restrictions by State Government

- Land Features:
  a. Transportation feasibility
  b. Land use is commercial/industrial
  c. Any mining activity

- Logistics value:
  a. Availability of transport
  b. Proximity to industrial region
  c. Firefighting and medical facilities availability

- Human Aspects:
  a. Opportunities for employment
  b. Recreational activity
  c. Health Condition and population density
  d. Archaeological and historical importance

Some guidelines for Waste Management Practices:

- Segregation of waste products into hazardous and non-hazardous avoids to further complicated products
- Regular audit to improve continuously on the already established production and operations
- Preventive maintenance to be followed to avoid any unnecessary wastes
- All the hazardous material should be stored in enclosed rooms to avoid any contact with other chemicals and protect workers from its effect
- Label every waste container with details of chemical composition and safety procedures clearly mentioned if exposed
- Only when municipal body and industry operators work in coordination, the impact of waste would be checked
- Ensuring no contact of functioning open dumps with atmosphere
- To any extent feasible, pretreatment of waste before disposal would ensure reduced volume and toxicity.

As far as Indian scenario goes Ministry of Environment, Forests and Climate Change along with the Central Pollution Control Boards and State Pollution Control Boards have acted well in place the Hazardous Wastes (Management and Handling) rules, 1989. Even though regulations were in places, a strict vigilance and lack of proactive approach has led to massive disruption. There are some measures being taken up to implement effective waste management plan:

a. Identification of hazardous waste producers, quantifying and records of inventory to be maintained.

b. Central and State Pollution control boards have been working and inspecting sites to advice industry operators on reduction of waste production

c. Separate hazardous waste management rules aims at addressing the issues and concerns arising from generation to disposal of hazardous waste. It lists all the hazardous waste generators along with industry size on its official website and also lists the chemicals that are banned by it. [28]

Regular and surprise visit to industry ensures sampling which are further tested in nearest zonal laboratories set up by CPCB and also reflects efficient working towards waste management. Main features of hazardous waste (handling and management) rules, 1989 are:

- Separate categories of wastes are listed along with various processes that generate such hazardous waste products
- Every generator must hold an authorization letter to handle hazardous waste which is to be renewed periodically. The authorization can be denied and accepted only after thorough inspections are conducted on sites.
- Records of generation, disposal and storage must be maintained and accordingly file annual return as required.
- Transportation Emergency Card must be provided to the transporter of hazardous wastes
- State Pollution Control Board records the annual returns and prepares the impact assessment to be submitted to CPCB.

Major focus areas are the following:

a. Toxic Substances [29]

The main problem arises from the toxic chemicals being used in the production processes which is leading to secondary formation of furans and dioxins that are major organic pollutants. Working conditions of incinerator is important to avoid the release of secondary contaminant. In India, majority of municipal wastes are burnt while some incinerators that work, doesn't function in the required temperature. Shortage of enough check on incinerators that not only burn MSW but only biomedical, pesticide and petrochemical wastes. Even after sufficient training and awareness of banned pesticides, it is still used and piled up at sites, this increased audits are required.

b. Concerns for achieving sustainable development in waste management [30]

Development meant industrialization, urbanization and increased production but it also meant resource depletion and degradation of ecosystem which are made concern in achieving sustainable development. Disintegrated approach of development and environment lead to imbalance in the ecosystem. But now a single framework is being promoted that merges proper technology like biotechnology and vermicomposting in one space. It has been mandatory to utilize full utilization of fly ash produced in boilers and furnaces by brick manufactures. The most recent has been banning plastic bags and all such plastic packaging and encouraging recycled products.

c. International Agreements [31]

India has signed the Basel convention to control the Trans boundary movement of hazardous waste on March 15th, 1990. To comply with the same agreement, Hazardous Waste (Management and Handling) rules, 1989 was further amended on January 6th, 2000. Our country has even signed the Stockholm convention on POP (Persistent Organic Pollutants) in May, 2002. MOEFCC is also working towards implementing the scheme put forward by UNEP on Exchange of Information on Chemicals in International Trade and Prior Informed Consent**.**

3. SUGGESTIONS AND DISCUSSION:

Human race has been exposed to toxic substances since its existence when it had to inhale the gases vented out of a volcano or when they lived in low ventilated caves and died due to carbon monoxide inhalation. Some contaminations due to industrial hazardous waste has been prominent like the natural river in India and the open landfill sites in Mumbai [32]. There has been serious impact on the slums nearby those sites where health deteriorating diseases have been prevalent even causing birth disorders. Almost same as stated before, incidents in Japan, Europe and other places in Asia were also observed. Lack of a waste management practice can be potentially harming posing extreme risk to the society in whole. If the dumping of the wastes continue without any proper plan, these noxious wastes would enter the ecosystem and cause both long and short term effects [33]. Apart from it, inappropriate storage, treatment and disposal also pose harm to health and environment [34]. Some even interfere with normal functioning of organs depending on the extent of exposure, personal factors (like sex, age) and characteristics of the waste [35].

Factor that depend on varying response of toxic chemical on humans [36]:

a. Extent of exposure
b. Age group
c. Gender of the person affected
d. Body weight
e. Psychological state of a person
f. Immunity mechanism and genetics
g. Environmental Conditions like temperature, pressure, humidity

Health Impact in Population due to hazardous waste exposure [37]:

a. Cancer
b. Genetic Interference
c. Birth disorders
d. Immunity system breakdown
e. Neurological imbalance

Improper waste disposal reduces lifetime of each existing living organism and degrades environment causing several environmental and health issues.

4. CONCLUSIONS

- In India, all the rules and regulations are well structured and enforced but its effective practice to ensure proper waste management plan is the challenge.
- All the technical assistance and technological up gradation required to achieve the same needs to be worked upon.
- The cost incurrence must be compared with the potential harm to ecosystem as whole must be studied to avoid any hesitations with investments.
- Work needs to be taken up from minimizing the waste generation to its safe disposal strengthening the local bodies, administrative bodies and industrial tycoon's coordination and effective environmental legal policies in place.

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