ENVIRONMENTAL FORENSIC INVESTIGATION OF IMPROPER MEDICAL WASTE DISPOSAL: SOURCE ATTRIBUTION, ENVIRONMENTAL DAMAGE ASSESSMENT AND ITS ROLE IN ESTABLISHING LEGAL ACCOUNTABILITY IN INDIA

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ABSTRACT:

Improper disposal of medical wastes poses a considerable danger to environmental quality because the healthcare wastes may be laden with infectious material, drugs, chemicals, and other types of hazardous material. If the wastes are not properly segregated, transported, treated and disposed of, the contaminants end up in soil, water, and air. This paper attempts to look at how the environmental forensic investigation methodology applies to improper medical waste disposal in India, concentrating particularly on source attribution and environmental damage assessment. Some of the investigative methods considered in the paper include site examination, sampling, analysis of physical evidence, chemical and biological analysis, spatial assessment, as well as source-pathway-receptor analysis. The paper further looks into how scientific findings from the environmental forensics can help in proper implementation of regulations, and attribution of blame, especially as per the environmental and biomedical waste laws of India.

Keywords: Environmental Forensics, Medical Waste, Source Attribution, Environmental Damage, Legal Accountability, India.

I. INTRODUCTION

The medical waste is produced at hospitals, clinics, laboratories, blood banks, and other health care institutions. The waste may include infectious waste, waste sharps, pharmaceuticals waste, chemicals and other dangerous materials. In case the waste is not sorted, transported, treated and disposed of appropriately, the contamination of soil, water, air and people and other living beings, as well as of the environment will result.[1]

Bio-Medical Waste Management Rules, 2016 are set to regulate the proper disposal of biomedical waste in India. Nevertheless, the improper disposal of the waste creates problems of determination of the source of pollution and its responsibility for the environmental damage caused.[2]

The environmental forensic investigation can become an efficient solution to the problem, as this process includes the use of scientific techniques of waste identification, determination of the source of the pollution, the way of its appearance in the environment and the damage caused to the environment.

However, the conclusions drawn from the findings of an environmental forensic study may also serve in the process of litigation as the source of the waste, the pathway of its entry into the environment, environmental damage caused, and the entity responsible for it. This aspect becomes extremely important in the context of the implementation of environmental laws and principles, such as the Polluter Pays Principle in India.

II. CONCEPT OF ENVIRONMENTAL FORENSICS

Environmental forensics is the use of scientific and forensic techniques in the detection of environmental pollution and contamination. Environmental forensics is primarily used to detect the origin of pollution, how the pollutant entered the environment and the resulting effects on the environment.[3]

This discipline involves the application of scientific knowledge drawn from various disciplines such as environmental science, forensic science, chemistry, microbiology, toxicology, geology

[1] World Health Organization, *Health-care Waste*, WHO.
[2] Bio-Medical Waste Management Rules, 2016, Ministry of Environment, Forest and Climate Change, Government of India.
[3] R.D. Morrison, *Introduction to Environmental Forensics*, 3rd ed., Academic Press, 2015.

and many others.[4] The scientific approaches provide tools for investigating environmental samples and other evidence in detecting the origin of the contamination.

The primary questions that arise in environmental forensics investigations include:

- What contaminant is involved?
- Where is it coming from?
- How does it get into the environment?
- How does it travel from its point of origin to the contaminated site?
- What damage has been done to the environment?

Environmental forensic investigations are distinct from routine environmental monitoring activities. The latter typically detects and quantifies pollutant compounds, but environmental forensics moves beyond these steps in that it tries to trace pollution to its likely source.[5]

In situations involving improper disposal of medical waste, environmental forensic investigations may be able to analyse disposed medical products, soil, water, and other environmental samples to establish their links with a certain healthcare organization. That makes environmental forensic investigations extremely important for establishing sources and responsibility for the environmental problems.

III. IMPROPER MEDICAL WASTE DISPOSAL AS AN ENVIRONMENTAL FORENSIC PROBLEM

Medical waste is produced from hospitals, clinics, labs, blood banks and other health care institutions. The medical waste contains items that can be either infectious, toxic or hazardous for the environment. The primary forms of medical waste are infectious waste, anatomical waste, sharps, pharmaceutical waste, chemical waste, contaminated plastics, lab waste, blood-

[4] R.D. Morrison, "Definitions and Historical Perspectives in Environmental Forensics," *Microbiology Spectrum*, Vol. 6, 2018.
[5] U.S. Environmental Protection Agency, *National Enforcement Investigations Center (NEIC)*, Environmental Forensics resources.

contaminated material and expired drugs.[6]

The failure to segregate, transport, treat or dispose of the medical waste may lead to their contamination of the soil, water and air. For instance, the improper disposal of pharmaceuticals will cause contamination of water by pharmaceutical substances, whereas improper disposal of sharps will cause physical and biological hazards. Also, the unregulated burning of the medical waste results in contamination of the air.[7]

In addition, improperly disposed medical waste may serve as good forensics as well. The label, barcode, strips of medicines, packages, bottles, and other elements can help to define the potential origin of the waste. Also, the chemical composition of the pharmaceutical or another kind of waste may be analysed and compared with samples taken from healthcare facilities.

Thus, medical waste is not only an ecological issue, but it may also become forensic evidence. Appropriate analysis of the evidence will allow to define the source of the waste and connect it with the pollution of the environment.

IV. ENVIRONMENTAL FORENSIC INVESTIGATION

The investigation of improper medical waste disposal is to include a thorough investigation of the environment where the medical waste is located. Environmental investigation starts with the examination of the environmental incident site. It should be done prior to the moving or disturbance of the waste or other evidence. The location of the site of the incident, time and date of the examination, the kind and estimated amount of the waste, condition of the containers of the waste and the color-coded bags, as well as hospital or laboratory labels, barcodes, identification numbers, or pharmaceutical packaging should be recorded. It also includes recording of the presence of syringes, sharps, medical equipment, burning, drainage channels, water bodies, vegetation, and weather. The potential routes of migration of contaminants from the disposal site should be considered as well. All this should be supported by photographs, videos, GPS locations, drawings and field notes. Proper documentation of the site will help retain the original state of the site and will provide important information about the possible

[6] Ministry of Environment, Forest and Climate Change, Government of India, Bio-Medical Waste Management Rules, 2016, G.S.R. 343(E), 28 March 2016. Bio-Medical Waste Management Rules, 2016

[7] World Health Organization, Health-care Waste, describing the environmental and health risks associated with inappropriate healthcare-waste treatment and disposal. WHO – Health-care Waste

source of the waste and the route of contamination.[8]

V. COLLECTION AND PRESERVATION OF ENVIRONMENTAL EVIDENCE

Proper collection and preservation of samples are very important in environmental forensics. This is because it is necessary to ensure that the samples are collected in such a manner that they are not contaminated or altered in any way before conducting the laboratory tests on them.

A. Medical Waste Samples: Medical waste samples are collected from the suspected site of disposal. This could include syringes, medicine packaging materials, contaminated substances and other forms of medical waste. Analysis of the samples would help determine the nature and source of the medical waste.

B. Soil Samples: Soil samples are collected from the site where the disposal takes place as well as from neighbouring sites. Tests could be conducted to establish whether harmful elements have leached into the soil as a result of the medical waste.

C. Water Samples: Water samples could be obtained from the neighbouring drainage channels, river, lake or ground water. The test could be conducted to ascertain what chemicals, medicines or microorganisms are present in the water.

D. Sediment Samples: The sediment samples are collected from the bottom of the water bodies and drainage systems.

E. Ash and Air Samples: In case burning has been done on medical wastes, ash and air samples can be taken. Analysis of these samples can give information about pollutants that might have been released through the burning process.

F. Biological Samples: In case there has been pollution affecting living things, plants or aquatic organisms can be used as biological samples. The samples can help determine the effect that the pollution has had on the environment.

G. Labelling and Chain of Custody: All samples should be properly labelled, sealed and accounted for. Information like where the sample was collected, the date and time of collection

[8] U.S. Environmental Protection Agency, *Environmental Investigation*, explaining the importance of systematic environmental site investigation, documentation, sampling and evaluation of potential sources and pathways. U.S. EPA – Environmental Investigation Resources

should be kept. The chain of custody should be maintained from collection to analysis in the laboratory.[9]

VI. SOURCE ATTRIBUTION

Source attribution is a critical component in conducting environmental forensic investigation. Source attribution involves identifying the probable source of the waste and contamination present in the environment. Regarding cases involving improper medical waste disposal, the investigator seeks to identify whether the found medical waste is related to any hospital, laboratory, clinic or any other healthcare facility.

In most cases, source attribution cannot rely only on one type of evidence. Various physical, chemical, biological and geographic evidence can be considered when drawing conclusions.[10]

A. Physical Source Attribution

When attempting to identify the probable source of medical waste, physical evidence can act as the starting point. Some of the pieces of physical evidence which may be considered by the investigators include **hospital names, logos, labels, barcodes, batch numbers, prescription labels, pharmaceutical packaging, waste containers, colour-coded bags and medical equipment** at the disposal site.

For example, medicine strips or containers with the name of a certain hospital or laboratory will offer vital evidence in tracing the origin of the waste. Similarly, labels and barcodes can be helpful in the identification of the generators of the waste.

However, the physical evidence does not always prove the real source. Medical waste can be carried, transferred or handled by different individuals before being brought to the disposal site. It is therefore important for the physical evidence to be supplemented with other forms of evidence, such as **chemical testing and environmental samples**.[11]

B. Chemical Source Attribution

Chemical source attribution refers to the process that involves the identification of the possible source of contamination based on the chemical composition of the medical waste and

[9] Central Pollution Control Board, *Guidelines for Handling, Treatment and Disposal of Biomedical Wastes*, Government of India.
[10] R.D. Morrison, *Introduction to Environmental Forensics*, 3rd ed., Academic Press, 2015.
[11] R.D. Morrison, *Environmental Forensics: Principles and Applications*, CRC Press, 2000.

environmental samples. Laboratory tests involving different methods may be carried out to identify chemicals, medicines, and metals. These may then be compared to samples from suspected sources. Chemical similarities alone will not be enough to confirm the source; other possible sources should also be considered.[12]

- **Gas Chromatography-Mass Spectrometry (GC-MS):** This technique is used to separate chemicals from the mixture. GC-MS is helpful for volatile and semi-volatile materials. This technique may be useful in determining organic chemicals present in medical waste and contaminated environmental samples.[13]

- **Liquid Chromatography-Mass Spectrometry (LC-MS):** This test is helpful in the identification of substances which are difficult to analyze through GC-MS. LC-MS is useful in identifying drug residue present in water, soil and medical waste.[14]

- **High-Performance Liquid Chromatography (HPLC):** This method separates and measures chemicals present in a sample. It is helpful for identifying and quantifying medicine and pharmaceuticals present in the medical waste and contaminated water.[15]

- **Atomic Absorption Spectroscopy (AAS):** This is used for identification and quantification of certain metals within the samples. It may be used in analysing soil, water and medical-waste samples for metal contamination.[16]

- **Inductively Coupled Plasma Mass Spectrometry (ICP-MS):** This is an analytical method that detects very low amounts of metals and other elements. It helps analyse soil, water and waste samples, thus comparing their elemental composition.[17]

- **Fourier Transform Infrared Spectroscopy (FTIR):** This is the process of using molecular properties in identifying materials. It helps to determine plastics, polymers and certain chemicals contained in the medical waste.[18]

[12] Ibid.
[13] U.S. Environmental Protection Agency, *SW-846 Test Methods for Evaluating Solid Waste*, EPA.
[14] World Health Organization, *Pharmaceuticals in Drinking-water*, WHO, 2012.
[15] Ibid.
[16] U.S. Environmental Protection Agency, *SW-846 Test Methods for Evaluating Solid Waste*, Method 7000 Series.
[17] U.S. Environmental Protection Agency, *SW-846 Test Methods for Evaluating Solid Waste*, Method 6020B.
[18] National Institute of Standards and Technology, *Infrared Spectroscopy*.

- **X-Ray Fluorescence (XRF):** This is used in identification of elemental composition of solid materials. This technique may be applied in analysis of soil, sediment, ash and certain wastes.[19]

C. Pharmaceutical Residues as Forensic Markers

The use of pharmaceutical residues is useful in forensics as the medicines which have expired or disposed of wrongly could end up in **soil, surface water and groundwater**. Chemicals like antibiotics, analgesics, antiseptics, hormones and cytotoxins could be identified by laboratory testing. The detection of a certain pharmaceutical residue would give an indication of the type of waste and the possible source. Laboratory tests can be correlated with documentary evidence like **hospital inventory list, purchase receipts, pharmacy list, waste-generating list and disposal list**. This would allow investigators to tie in the contaminated site to the alleged healthcare institution.[20]

D. Biological and Microbiological Source Attribution

Medical waste may be contaminated with **pathogenic microorganisms** as well as other biologically harmful substances. Consequently, environmental forensic study can involve microbiological examination of microorganisms that may be found in the waste, soil or water samples. These methods include **microbiological culture, detection of indicator microorganisms, molecular identification** as well as **microbiological community analysis**. The occurrence of antimicrobial-resistant microorganisms can be helpful in some cases. However, this information needs careful interpretation since there are a lot of microorganisms naturally present in the environment. Therefore, microbiological data should be complemented by **physical, chemical, spatial and documentary evidence**.[21]

VII. ENVIRONMENTAL DAMAGE ASSESSMENT

The process of determining and assessing the damage to the environment caused by the incorrect disposal of medical waste is environmental damage assessment. After the contamination is detected and the source of the problem identified, the type, scale and

[19] U.S. Environmental Protection Agency, *SW-846 Test Methods for Evaluating Solid Waste*.
[20] World Health Organization, *Pharmaceuticals in Drinking-water*, WHO, 2012.
[21] World Health Organization, *Safe Management of Wastes from Health-Care Activities*, 2nd ed., WHO, 2014.

consequences of the damage are assessed.

A. Physical Damage

Inappropriate medical waste disposal leads to physical changes in the environment. Medical waste can change the quality of the land, soil, vegetation, as well as clog drainage facilities. Medical waste in water bodies also causes changes in the physical state of the aquatic environment.[22]

B. Chemical Contamination

Medical waste can contaminate the environment by releasing heavy metals, pharmaceutical compounds, toxic and other hazardous substances. Testing of soil, water, and sediment samples helps detect these contaminants and find out their quantity and distribution.[23]

C. Biological Contamination

Medical waste may pose a risk of introducing pathogenic microorganisms and biological contamination of soils and water bodies. Pathogenic microorganisms and antibiotic-resistant microorganisms may pose a threat to people, animals and the environment. The microbiological testing method will help determine whether there is any kind of contamination.[24]

D. Ecological Consequences

The improper disposal of medical waste may cause ecological problems. Such contamination may pose a threat to plants, aquatic organisms, soil microorganisms and other living organisms. The contamination may accumulate in organisms and move along the food chain. That is why the ecological impact assessment should include both immediate and possible long-term consequences of contamination.[25]

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[22] Ibid.
[23] World Health Organization, Health-care Waste, WHO. WHO – Health-care Waste
[24] Ibid.
[25] United Nations Environment Programme, *Compendium of Technologies for Treatment/Destruction of Healthcare Waste*, UNEP.

VIII. SOURCE – PATHWAY – RECEPTOR RELATIONSHIP

The Source – Pathway – Receptor model is an appropriate strategy in environmental forensic investigations. This model helps the investigator understand the movement of a contaminant from its source to the affected part of the environment. **Source** refers to the origin of pollution; this could be a hospital or any other medical facility. **Pathway** refers to the medium used in the transport of the contamination, which could be drainage system, surface runoff, soil or water. The **receptor** is the part of the environment that receives the contamination, which could be rivers, soil, plants, animals or human beings.[26]

In the medical waste disposal case, the source-pathway-receptor relationship may be represented as:

Hospital → Improper disposal → Drainage channel → River → Aquatic ecosystem

In this case, **hospital is the source**, **drainage channel is the pathway**, and **river/aquatic ecosystem is the receptor**. Environmental forensic investigation uses evidence in all the above stages to establish whether there is any reliable link between the source and environmental damage. The presence of medical waste near a contaminated area alone cannot establish that medical waste causes pollution; therefore, physical, chemical, biological and geographical evidence must be considered together.[27]

IX. ROLE OF ENVIRONMENTAL FORENSICS IN LEGAL ACCOUNTABILITY

Environmental forensics can be used to determine the legal accountability in cases of improper disposal of medical waste. It is used to investigate scientifically the case and try to trace the source of the waste and the reasons for the environmental contamination. Through the investigation process, the following key questions may be answered: **Who generated or handled the waste? What kind of waste was disposed? Where was the waste generated and collected? How did the waste get to the environment? What kind of environmental damages were caused by that?**[28]

By analysing the results of physical examination, laboratory analysis, environmental sampling

[26] R.D. Morrison, *Introduction to Environmental Forensics*, 3rd ed., Academic Press, 2015.
[27] U.S. Environmental Protection Agency, *Risk Assessment Guidance for Superfund*, describing the source–pathway–receptor approach to environmental contamination. U.S. EPA – Risk Assessment Guidance
[28] R.D. Morrison, *Introduction to Environmental Forensics*, 3rd ed., Academic Press, 2015.

and source-pathway-receptor analysis, a scientific link between the waste and the responsible party may be established. This will help in determining the regulatory or judicial actions that should be taken against the party.[29]

The basic forensic connection may be illustrated as follows:

Source → Waste → Disposal → Pathway → Contamination → Environmental Damage → Responsibility

Hence, environmental forensics is a **connecting link between scientific data and legal accountability**. It can help in tracing responsible parties, determining the environmental damage and compensation.

X. INDIAN LEGAL FRAMEWORK

India has several laws and rules that regulate environmental protection and the management of biomedical waste. These laws are important in cases of improper medical waste disposal because they provide the legal basis for preventing pollution, regulating waste management and taking action against responsible persons or establishments.

A. Environmental (Protection) Act, 1986

The Environmental (Protection) Act, 1986 is one of the main environmental laws in India. It provides a broad framework for protecting and improving environmental quality and for preventing and controlling pollution. Section 7 prohibits the discharge or emission of environmental pollutants beyond the prescribed standards. The Act also gives powers to the Central Government to take necessary measures and issue directions for environmental protection.[30] The **Bio-Medical Waste Management Rules, 2016** were also made under this Act. Therefore, where improper medical waste disposal causes environmental pollution, the Act provides an important legal framework for regulatory action.

B. Bio-Medical Waste Management Rules, 2016

The Bio-Medical Waste Management Rules, 2016 specifically regulate the management of

[29] *National Green Tribunal Act, 2010*, ss. 14, 15 and 20. Section 20 requires the Tribunal to apply the principles of sustainable development, precautionary principle and polluter pays principle.
[30] Environment (Protection) Act, 1986, ss. 3, 5 and 7.

biomedical waste in India. They provide requirements for the segregation, collection, storage, transportation, treatment and disposal of biomedical waste. Healthcare facilities are required to handle biomedical waste according to the prescribed requirements so that it does not cause harm to human health or the environment.[31] Environmental forensic investigation can assist authorities in determining whether these requirements have been violated by examining the waste, identifying its possible source and assessing the environmental contamination caused by improper disposal.

C. Water (Prevention and Control of Pollution) Act, 1974

The Water (Prevention and Control of Pollution) Act, 1974 aims to prevent and control water pollution and to maintain or restore the quality of water.[32] It becomes relevant when improperly disposed medical waste enters rivers, lakes, drainage systems, groundwater or other water sources. Environmental forensic techniques such as water sampling and laboratory analysis can help identify pollutants and determine their distribution. Comparison of samples from different locations can also assist in investigating the possible source of water contamination.

D. Air (Prevention and Control of Pollution) Act, 1981

The Air (Prevention and Control of Pollution) Act, 1981 provides a legal framework for the prevention, control and reduction of air pollution.[33] It is relevant where medical waste is improperly burned or incinerated and produces harmful emissions. Environmental forensic investigation can examine ash, particulate matter and other relevant samples to identify pollutants associated with the burning of medical waste. Such scientific findings can support the assessment of environmental harm and regulatory action.

XI. ROLE OF THE NATIONAL GREEN TRIBUNAL

The National Green Tribunal (NGT) was constituted under the **National Green Tribunal Act, 2010** to provide fast and efficient means for dealing with cases concerning the issues of environmental protection and conservation. The Tribunal can consider environmental disputes, compensation for environmental harm and restoration of environmental damage and restitution

[31] Ministry of Environment, Forest and Climate Change, Government of India, *Bio-Medical Waste Management Rules, 2016*, G.S.R. 343(E), 28 March 2016. Bio-Medical Waste Management Rules, 2016 – CPCB
[32] Water (Prevention and Control of Pollution) Act, 1974.
[33] Air (Prevention and Control of Pollution) Act, 1981.

of property damaged.[34] The Tribunal is also involved in the application of environmental principles including sustainable development, precautionary principle and polluter pays principle. As stated in section 20 of the Act, the application of these principles is required when resolving a case by the Tribunal.[35] In case of improper disposal of medical wastes, environmental forensics can be helpful in the process of dealing with such cases because it will help to determine the source of contamination, pathways of pollution and magnitude of environmental harm. Therefore, environmental forensics will be useful for the Tribunal to find out the party responsible for environmental harm and determine necessary measures to be taken.

XII. POLLUTER PAYS PRINCIPLE AND SOURCE ATTRIBUTION

Polluter Pays Principle is a principle of environmental law that mandates the party or the entity causing pollution to pay the cost associated with prevention and remedy of the resultant environmental damage. In the case of illegal disposal of medical waste, the principle can be applied by ascertaining the source of the waste as well as linking the source to the resultant environmental damage. In such a case, environmental forensic examination can be helpful in identifying the source of the waste as well as the extent of contamination. The results of the forensic examination will help in establishing a scientific link between the polluting activity, source of the pollution, environmental contamination and resultant damage. This can help the relevant authorities as well as judicial bodies to take necessary action for the cleanup, restoration of the environment as well as compensation, in line with the relevant laws. Thus, source attribution through environmental forensics can be helpful in ensuring the practical application of the Polluter Pays Principle.

XIII. CHALLENGES IN INDIA

Though environmental forensics can be very useful in establishing cases of improper handling of medical waste, its practical application in India comes with several difficulties that need to be addressed. Such difficulties can pose obstacles to identification of the source of pollution and allocation of responsibility for that.

[34] National Green Tribunal Act, 2010, ss. 14–15.
[35] Ibid., s. 20.

a. Contamination with Municipal and Other Types of Waste

Sometimes biomedical waste gets contaminated with municipal and other kinds of waste. After this happens, it becomes hard to find out the source of the pollution since the material becomes impossible to differentiate.[36]

b. Different Possible Sources

Sometimes there may be more than one source of some contaminant – different hospitals, industries, households or some other activity. Thus, it is necessary to analyse all the available evidence to find out which exact source is responsible for the pollution.

c. Environmental Degradation of the Pollutants

Environmental factors like rain, sunlight, temperature, microorganisms, chemical reactions can cause changes in the characteristics of pollutants. This makes it harder to determine the original composition and the source of pollution.

d. Absence of Baseline Environmental Data

The baseline or background data is very useful in deciding whether the contamination level at the particular spot is abnormal. In the absence of appropriate background data or historical environmental data, it would be quite difficult to determine the contribution of the particular activity towards contamination.

e. Inadequate Documentation

Correct documentation regarding the generation, transportation, treatment and disposal of biomedical waste become very essential in tracing its path. Incomplete and poor documentation may hinder the process of tracking the path of waste and identifying its source.

f. Chain of Custody Issues

To be admissible as evidence in the court of law, environmental evidence needs proper collection, labelling, sealing, transportation and storage. Any lapse in the chain of custody may

[36] Ministry of Environment, Forest and Climate Change, Government of India, *Bio-Medical Waste Management Rules, 2016*. Bio-Medical Waste Management Rules, 2016 – CPCB

have an adverse effect on the authenticity of the evidence.

g. Specialised Infrastructure Constraints

For conducting environmental forensics investigation, specialised laboratories, equipment and professional expertise are required. For that matter, collaboration amongst forensic experts, environmental scientists, chemists, microbiologists, geologists, GIS experts and pollution control authorities become essential. Lack of such specialised resources and collaboration in India would certainly hinder environmental forensics investigations.

XIV. PROPOSED ENVIRONMENTAL FORENSIC FRAMEWORK FOR INDIA

A structured environmental forensic framework can help authorities investigate cases of improper medical waste disposal in a systematic manner. The proposed framework connects scientific investigation, environmental assessment and legal action.

Step 1 – Identification of Suspected Disposal

The investigation begins when improperly disposed medical waste is reported or discovered. The location and basic nature of the incident are recorded.

Step 2 – Site Examination and Documentation

The site is carefully examined and documented through photographs, videos, location details and field observations. Possible sources and pathways of contamination are also identified.

Step 3 – Identification and Classification of Medical Waste

The waste is examined and classified according to its type, such as infectious waste, sharps, pharmaceutical waste, chemical waste or contaminated materials.

Step 4 – Collection and Preservation of Samples

Medical waste and relevant environmental samples such as soil, water, sediment, air or biological samples are collected. Samples are properly labelled, sealed and preserved.

Step 5 – Laboratory Analysis

The collected samples are examined using appropriate physical, chemical and biological methods. The analysis helps identify the contaminants and their characteristics.

Step 6 – Source Characterisation

The characteristics of the waste and contaminants are studied to develop a profile of the possible source.

Step 7 – Comparison with Suspected Sources

The results obtained from the environmental samples are compared with samples and records from possible sources, such as hospitals, laboratories or waste-treatment facilities.

Step 8 – Source–Pathway–Receptor Analysis

Investigators determine the relationship between the source of the waste, the pathway through which contamination travelled and the environmental receptor that was affected.

Step 9 – Environmental Damage Assessment

The extent and nature of contamination are assessed by examining its effects on soil, water, air, plants, animals and ecosystems.

Step 10 – Attribution of Responsibility

Based on the combined physical, chemical, biological, spatial and documentary evidence, the probable responsible person or organisation is identified.

Step 11 – Regulatory and Legal Action

The findings are provided to the appropriate authorities for taking action under the applicable environmental and biomedical waste laws.

Step 12 – Remediation and Environmental Restoration

Finally, appropriate measures are taken to remove the contamination, restore the affected environment and recover applicable environmental costs or compensation.

Thus, the proposed framework creates a systematic chain:

Waste Identification → Evidence Collection → Laboratory Analysis → Source Attribution → Damage Assessment → Legal Accountability → Remediation

This framework integrates forensic science, environmental science and environmental law and can help strengthen the investigation and enforcement of improper medical waste disposal in India.[37]

XV. SUGGESTIONS

To enhance the application of environmental forensics in medical waste disposal cases in India, the following recommendations could be taken into consideration:

Development of Standard Forensic Protocols: It is recommended to develop standard procedures for investigating the crime scene and for collecting, preserving, analysing and reporting the results obtained on environmental evidence.

Strengthening the Chain of Custody: There must be followed certain procedures concerning the labelling, sealing, transport and storage of environmental samples to protect the integrity of the evidence in court.

Enhancing Traceability of Biomedical Waste: Bar codes, documentation and electronic tracking can be enhanced to trace back biomedical waste to the generator and further to its final disposal.

Strengthening the Laboratory Facilities: Specialized labs can be supplied with appropriate equipment and specialists who will conduct chemical, biological and toxicological analysis.

Development of Environmental Baseline Data: It is important for the authorities to keep up-to-date data concerning soil, water and other environmental factors because this information will be useful for identifying the contamination caused by a certain disposal event.

Increased Application of GIS and Spatial Analysis: Geographical Information System (GIS) technology must be applied in mapping sites of medical waste disposal, health facilities,

[37] Ibid.

drainage systems, bodies of water, and polluted areas. GIS can be helpful in determining potential routes of contamination.

Multidisciplinary Investigation: Investigation of environmental forensic evidence needs collaborative efforts by forensic experts, environmental scientists, chemists, microbiologists, GIS technicians, pollution control agencies, and lawyers. A multidisciplinary approach will give an insight into the event.

Scientific and Legal Documentation: Findings made through the scientific investigation should be properly documented and presented together with the available documentation on medical wastes, observations of the site and other relevant environmental data. This can enable the regulatory and judicial authorities to understand the cause of pollution, its effects and the right measures to be taken in terms of accountability, compensation and restoration of the environment.

Generally, these strategies will be helpful in linking scientific investigation and environmental laws and thus enforcing the laws of medical waste disposal in India.

XVI. CONCLUSION

Improper medical waste disposal is a serious environmental issue because it can contaminate soil, water and air and create risks to human health and ecosystems. The major challenge is not only to identify the presence of pollution but also to determine where the waste came from, how the contamination occurred and who is responsible for it.

Environmental forensic investigation provides a scientific approach to address these questions. Site examination, proper sample collection, physical and chemical analysis, pharmaceutical-residue analysis, microbiological examination and GIS-based assessment can help identify the source and movement of contamination. The Source–Pathway–Receptor approach further helps establish the connection between the waste, the route of contamination and the affected environment.

Environmental damage assessment is equally important because it helps determine the extent of physical, chemical, biological and ecological damage caused by improper disposal. When forensic findings are combined with waste-management records and other documentary evidence, they can provide stronger support for determining responsibility.

In India, laws such as the Environment (Protection) Act, 1986, Bio-Medical Waste Management Rules, 2016, Water (Prevention and Control of Pollution) Act, 1974, Air (Prevention and Control of Pollution) Act, 1981 and National Green Tribunal Act, 2010 provide the legal framework for addressing environmental harm.

Thus, environmental forensics can create a clear connection:

Improper Medical Waste → Source Identification → Contamination Pathway → Environmental Damage → Responsibility → Legal Action → Remediation

Therefore, greater use of environmental forensic methods can strengthen environmental protection, source attribution, legal accountability, compensation and environmental restoration in India.

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