Decision Support System for Nuclear Emergency Management

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Abstract: - Emergency planning and management is the last level of the defense in depth approach for nuclear safety. Coordinated efforts are essential to ensure effective response thereby ensuring safety of public and environment. With the rapid growth and development in mapping technology, the role of Geographic Information System (GIS) is gaining more importance in the response and recovery of a disaster. The capability of GIS to integrate spatial information along with site specific information strengthens the emergency planning. This paper demonstrates a GIS based decision support system combining spatial data and atmospheric dispersion modelling to provide a real time support for nuclear emergency management.

Key-words: - GIS, Emergency management, Decision Support System, Atmospheric Dispersion model, nuclear power plant.

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1 Introduction

International safety standards and stringent regulatory control exist throughout the lifetime of a nuclear facility starting from the stage of siting, design, construction, operation and decommissioning [1, 2, 13, 14]. Three tier safety objectives and defense in depth principles are followed to protect individuals, society and environment against nuclear and radiological hazard. However, natural hazards like earthquake, tsunami, floods, cyclones, etc. or human errors have the potential to cause a huge loss of life and property. During such exigencies, one of the safety measures adopted is nuclear emergency management which is a highly difficult task [15, 17]. It involves a number of technical measures with well-ordered planning and involvement of a host of agencies to reduce the risk of radioactivity [23, 24, 26]. The primary objective of emergency management is to minimize the potential risk by providing early warning systems, safe evacuation of public, if needed and to restore normalcy as early as possible. A decision support system (DSS) is a tool that helps in decision-making during an actual emergency. Geographic information system (GIS) provides the ability to integrate satellite imagery with other site-specific data to provide useful graphical information for the DSS [3, 4, 5, 6, 8, 10, 19, 26, 27, 30, 33]. This paper demonstrates the application of GIS for development of a DSS for nuclear emergency management. The graphical user interface (GUI) based DSS contains satellite imagery and various databases related to emergency planning such as road network, emergency zones and sectors, land use-land cover, population distribution, rallying posts, medical facilities, transport details etc. for immediate query-based data retrieval that will aid decision making during an emergency situation [28, 29]. A module incorporating atmospheric dispersion model is also included to provide information on the radioactive plume dispersion and its spread, for quick remedial action. The DSS is expected to assist nuclear emergency management teams to plan effective and efficient evacuation strategies [11, 18, 22, 25, 34]. A case study of two NPP sites is provided in the paper. The paper is arranged as follows: Section 2 describes the materials and methods with a brief description of the study area. Various databases used in the study are given in Section 3. Section 4 explains the model used for the DSS and Section 5 discusses the results. Finally, section 6 summarizes the study and explains the advantages of the DSS for emergency management.

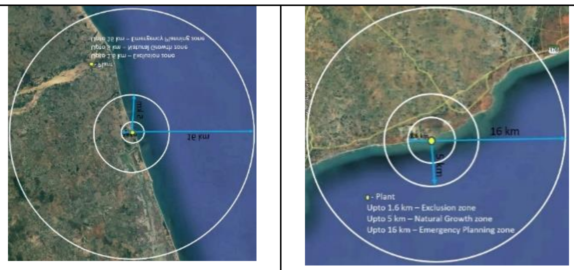
2 Materials and methods

Satellite imagery of the study area is integrated with the database obtained from various sources. GIS software and Visual Basic application are used for the development of the DSS. Site specific information for the zones, rallying posts, transport, hospitals, etc. are obtained from the respective plant emergency manual. The details on the study area and the datasets used are described in the following sections.

2.1 Description of study area

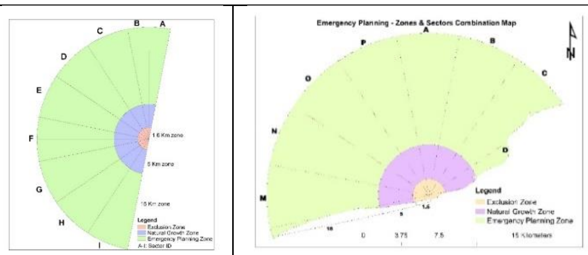
Two study areas are identified, viz., Emergency Planning Zone (EPZ) of two NPP sites (Fig. 1a &

1b). Generally, a distance of 16km radius around the nuclear plant is considered in preparation of the emergency plan. This includes three zones depending on the degree of contamination in case of an accident viz. exclusion zone, natural growth zone and emergency planning zone. (Fig. 2a & 2b).



(a) (b)

Fig. 1.Study area of 16 km radial zone around the plant sites



(a) (b)

Fig. 2.Different zones with Sectors identified for emergency planning

Exclusion zone: This covers a distance of 1.6 km around a nuclear power plant (NPP) site within which no habitation is permitted. This zone is physically isolated by a wall and fencing and is under the control of plant authorities.

Natural Growth zone: This covers a distance of 5 km around a NPP site. Human activities are regulated here so as to check undue increase in population within this zone by administrative control.

Emergency Planning zone: A 16 km radius around a NPP is considered in preparation of the emergency plan to provide a basic geographic framework to help in implementing counter measures as part of a graded response in the event of an emergency. (Fig. 2).

2.1.1 Site characteristics

The NPP site in Fig.1a is located in the coastal area and is characterized by flat sandy beach with sparse vegetation cover. This is followed by plain area. The major land use/ land cover type are agricultural lands, plantations, reserve forest, water body, scrub forest, mud flats, back water and sandy beach. The NPP site in Fig.1b is also a coastal site but has no major surface water bodies such as rivers, lakes, reservoirs, dams, tanks and ponds existing within 16 km radius zone around the site except small rain fed tanks. The 2011 census survey reveals that the density of population is 458 persons per square kilometer.

3 Data used

To develop the decision support system using GIS, necessary data from various accredited agencies are collected and thematic libraries containing spatial and descriptive data are built to form the layers. The data employed in the study are given in the Table-1.

Table 1 Data used in this study

Data	Source
Digital Village maps	TWAD Board, Govt. of Tamil Nadu
Census data (year 2011)	Census of India, Ministry of Home Affairs
Data on Emergency Planning zone ➢ List of villages ➢ List of Rallying Posts ➢ List of Hospitals/ Primary Health Centers	Manual on Emergency Preparedness from NPP's
Digital Elevation Model	USGS SRTM 90m (3-arc seconds)
Land use/ land cover	IRS satellite data

3.1 Land use and Land Cover

The land use / land cover map has been prepared in three domain areas for atmospheric dispersion simulation i.e. 2 km, 4 km and 100 km area. However, for emergency preparedness and response, 16 km area has been considered. IRS-1D and Resourcesat-2 satellite imagery are employed in the preparation of maps. First, unsupervised classification is performed by using image processing software to know the general pattern of the land use / land cover in the study area, then in second step manual classification by following visual interpretation techniques is performed to identify the land use / land cover pattern. The land use / land cover types present in study area are Evergreen forest, Scrub forest, Forest Plantation, Crop land, Agricultural Plantation, Coastal Plantation, Build up area and Water body. This data is useful in the third stage of the study for calculating the environmental impact due to any accidental release and fall out. (Fig. 3)

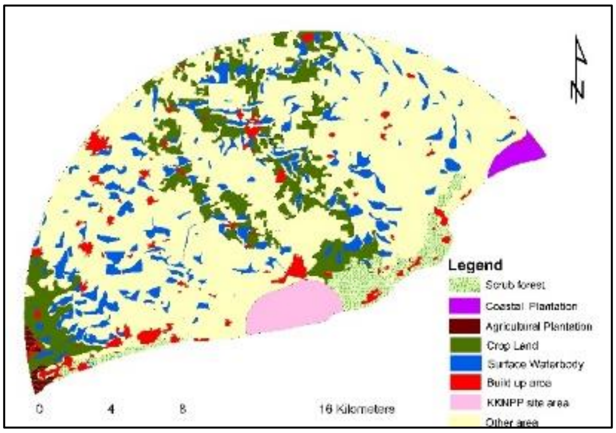


Fig. 3.Land use Land cover pattern around the NPP sites

3.2 Digital Elevation Map

Digital Elevation Model of both sites has been prepared from the Shuttle Radar Topography Mission (SRTM) data (Fig.4). It has the 90m spatial accuracy and 1m vertical accuracy. By employing image processing software a raster based DEM is created from the source data. This data is used as one of the inputs in atmospheric dispersion calculation.

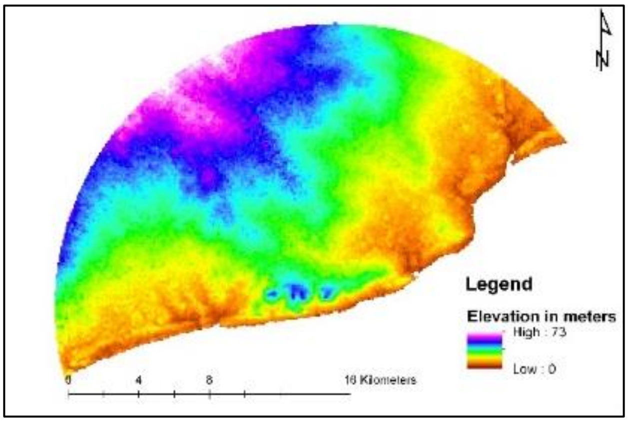
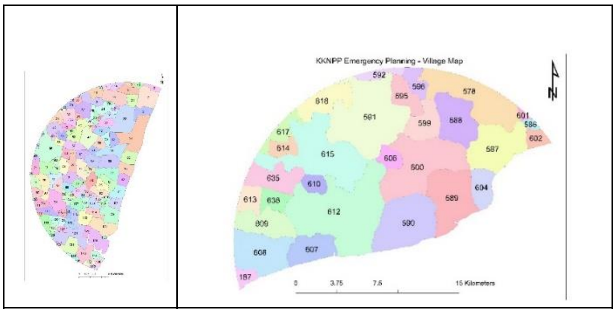


Fig. 4.Digital Elevation map of NPP sites

3.3 Village Map

The village map for an extent of 16 km radial distance around the NPP site is generated from the data published by state Government of Tamil Nadu (Fig.5a & 5b). The map contains basic information such as village name, area, population distribution (male and female), etc. This map serves as a primary source for the nuclear emergency management information system



(a) (b)

Fig. 5.Village maps

3.4 Rallying Posts

Rallying posts are defined as identified public buildings where the evacuated personnel can be sheltered temporarily during off-site emergency (Fig.6). For each sector rallying posts are identified. Each rallying post contains information on type of building, capacity, availability of electricity, drinking water, sanitary facility.

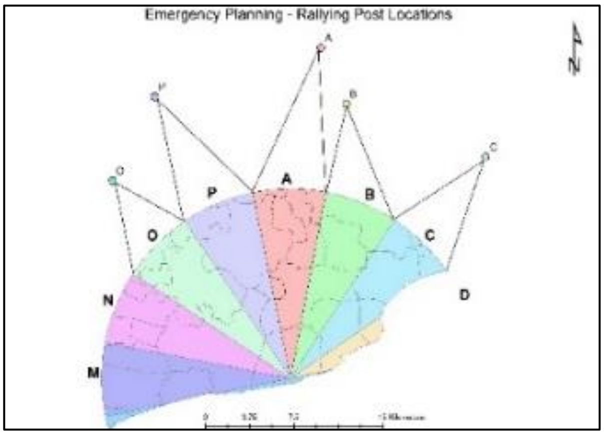


Fig. 6.Rallying posts identified around the sites

3.5 Transport

In transport information, distance of parking yard, distance between rallying posts and the village to be evacuated, running time and the numbers of vehicles required for evacuation in case of emergency, the identified best route etc. are given. (Fig. 7)

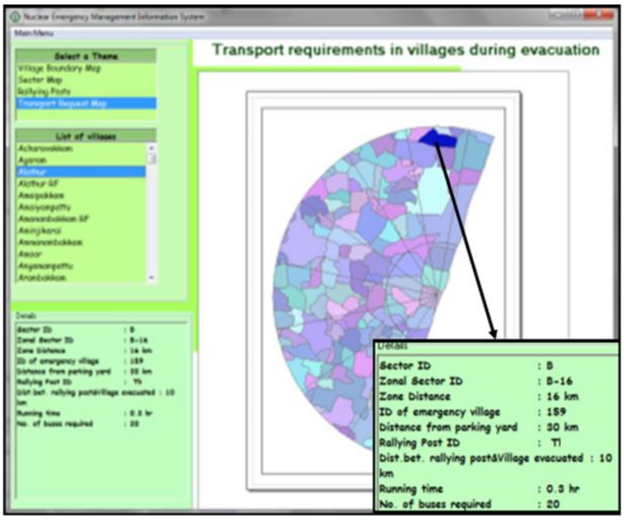


Fig. 7.Transport request information at a site

3.6 Hospitals

A list of hospitals and primary health centers (PHC) are identified in the EPZ for each sector to provide medical facility in the impacted area (Fig. 8). The responsibility of the identified hospitals is to implement protective and relief measures during emergency. The database contains information on facilities available in each hospital such as number of doctors, supporting staffs, beds, stock of Iodine tablets, etc.

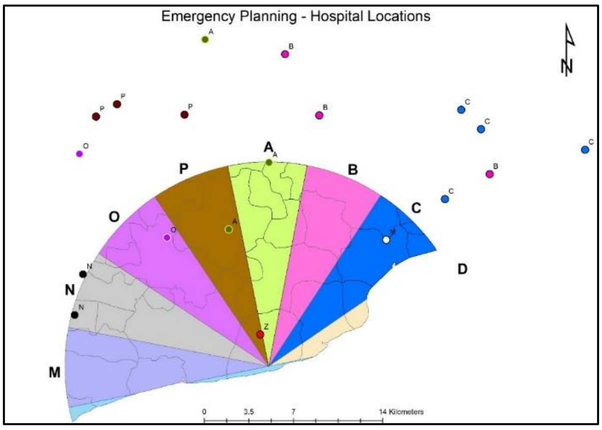


Fig.8.Hospital information at a site

4 Model

In developing the GIS based DSS for nuclear emergency preparedness, the focus has been on the integration of three components: site characteristics, atmospheric dispersion and the inclusion of end-user preferences [7, 9, 12, 16, 20, 21]. The DSS named as Nuclear Emergency Management Information System (NEMIS) is a GUI based customization using Visual Basic code system integrated with GIS software. Figure 9 gives the different dataset layers collected for a site and included in database. Figure 10 gives the schematic of atmospheric dispersion calculation and Figure 11 provides the schematic of the user interface provided for the DSS.

The GIS interface comprises of three phases viz. Phase I – Village Information, Phase II – Plume Information and Phase III – Emergency Planning.

The phase I interface allows the user to select one of the four thematic layers: village wise information, sector wise information, rallying post information or transport information. Once the theme is selected, the corresponding information based on selection: list of villages or sector details or rallying posts is displayed. On further selection, text information of the selected village / sector along with a graphical display of different shape files and raster layers corresponding to the selected village / sector. Interactive tools such as zoom, refresh, etc. are provided.

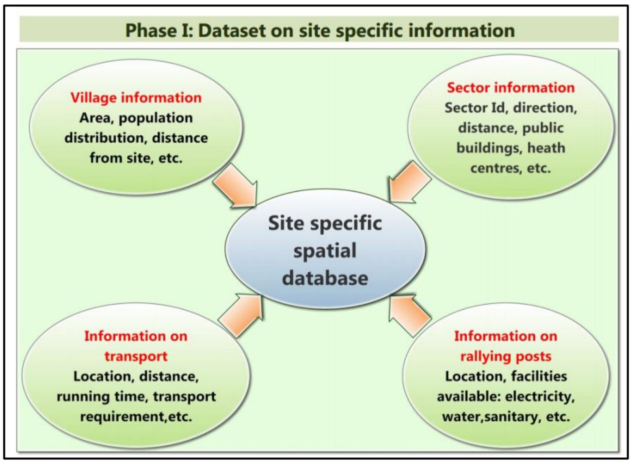


Fig. 9.Dataset layers integrated based on site specific information from different agencies

The phase II interface allows the user to select either a dynamic online simulation of plume dispersion by user defined input parameters or use an already generated output from a validated atmospheric dispersion modelling tool. For online simulation, a simple Gaussian plume model is used. Graphical display of different shape files and raster layers for the site and overlay of the plume output generated from the input parameters are subsequently displayed. This phase provides the emergency management team a realistic scenario of the accidental condition and the details of the radioactive plume released from the site. This will help in initiating appropriate safety actions at the right time.

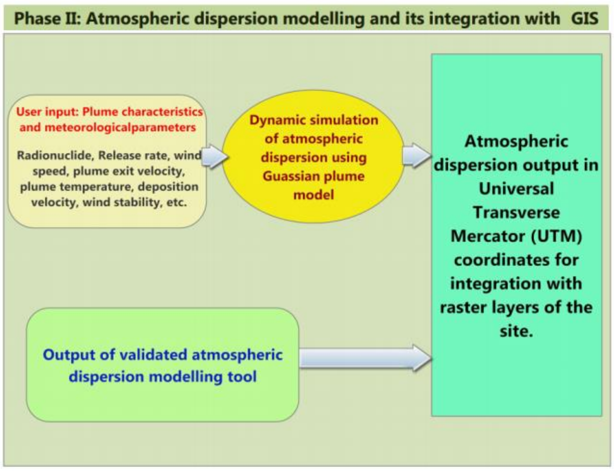


Fig. 10.Schematic of atmospheric dispersion calculation

The phase III interface list the villages of the selected site and allows the user to select a village for which text display of the details on rallying post, medical facilities available, population to be evacuated, transport requirement and the shortest possible evacuation routes and a graphical display of different shape files and raster layers for the site, overlay of the plume output along with the possible evacuation routes, distance between any two locations are shown. Further to phase II results, phase III provides the evacuation strategy of the affected population.

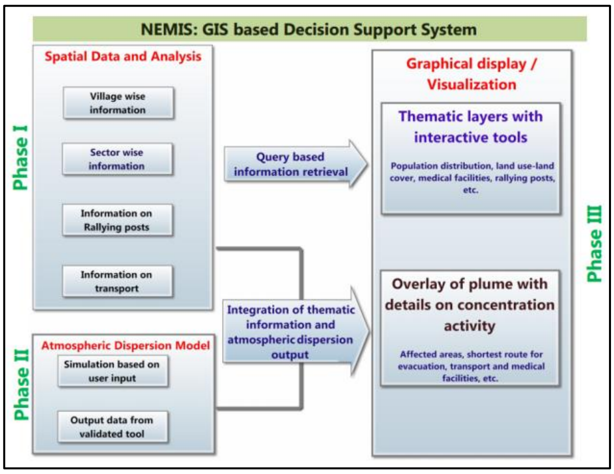


Fig. 11.Schematic of graphical user interface of GIS based DSS

5 Results and discussion

The main purpose of this paper is to show how the GIS based DSS may increase the effectiveness in implementation of emergency plans in NPPs. This is done by exploiting the inherent GIS capabilities of spatial data manipulation. The most important feature is the user interface provided with the provision to visually compare and jointly analyze several different layers of information. The analysis is effective as it is capable of using site specific information. The front-end programming in Visual Basic makes the system a powerful data analysis tool to retrieve query-based information. (Fig. 12)

5.1 Emergency management

This user friendly DSS is capable of providing vital information during a real emergency by way of identifying the plume direction and distribution of plume radionuclide concentration graphically on real time basis. This vital information can be combined with spatial GIS data to identify the evacuation route, shelters, facilities available, rallying posts, transport requirements, etc. Further, the system can also be used for emergency drill for training purposes (Fig. 12). The only limitation of DSS will be the completeness of the data fed into the system. A periodic update of the system will help in maintaining the system up to date.

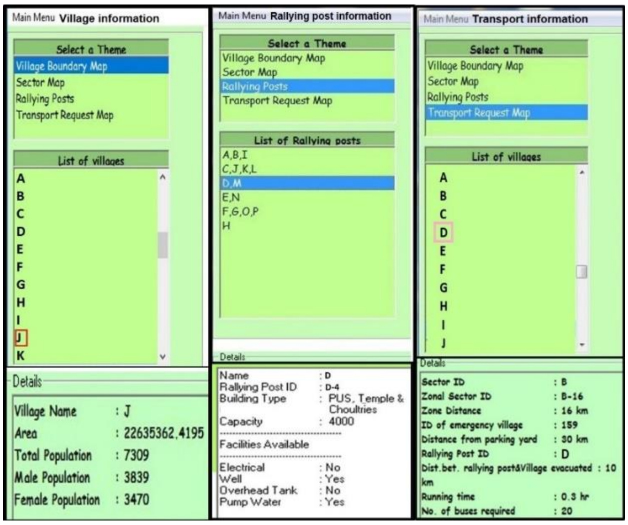


Fig. 12.Drop down menu for various emergency planning information

5.1.1 Plume dispersion

A separate module for atmospheric dispersion is provided in the system. The module consists of two options. First option is to perform the dispersion calculation using a simple Gaussian model based on user defined inputs and generate the output (Fig. 13). Input parameters such as radioactive material involved, release category: continuous or discrete puff release, height and radius of stack, plume temperature, plume exit velocity, rainfall rate, deposition velocity, etc., and atmospheric parameters such as wind speed, wind direction, ambient temperature, stability class, etc. are obtained from the user. This option provides a quick assessment to aid in decision-making during actual emergency conditions. The second option is to use the output data generated from a detailed calculation using a validated numerical weather prediction model such as Weather Research and Forecasting (WRF) coupled with Lagrangian particle model, FLEXPART [31, 32]. The output data from either of the option is converted to UTM coordinates for overlay of the plume on the raster layers of the study area. Figure 13 is the output from option 1 using a simple Gaussian model where the left pane shows the user input on release characteristics. Figure 14 is the output from option 2 using a WRF and FLEXPART for a postulated accident scenario.

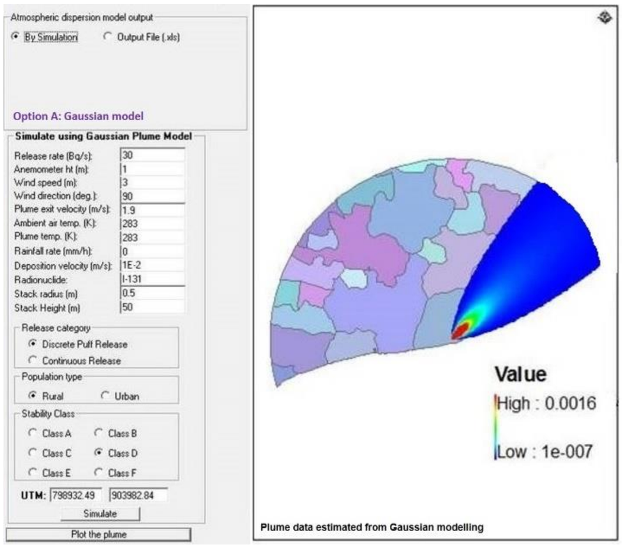


Fig. 13.Simulation of atmospheric dispersion model - Gaussian plume – for a given condition

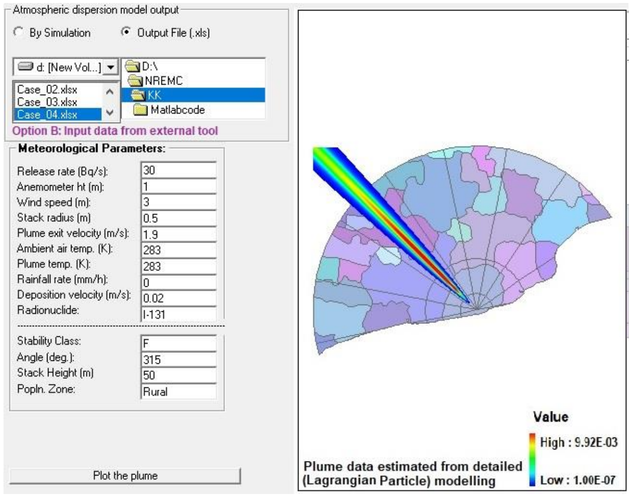


Fig. 14. Simulation of atmospheric dispersion model -using a WRF and FLEXPART - for a postulated accident scenario

5.1.2 Evacuation routes

The DSS helps to identify the shortest path to evacuate the affected public by employing network analysis option in GIS and by integrating rallying post information, road network map. To get the best route, user has to give the place of origin and place of evacuation by considering the opposite direction of prevailing plume movement at that time. Depending on the information provided into the database, the route can also indicate alternate paths, barriers present, if any, etc. and display the shortest path to reach the rallying posts.

6 Conclusion

A GIS based user friendly DSS for off-site emergency management during nuclear accidents has been developed to assist in decision making. The modelling approach based on GIS is capable of handling data from different agencies to form the basis for the interactive system. The atmospheric dispersion modelling integrated with the analysis provide a realistic scenario of the condition to assist regulators and emergency management personnel to understand and communicate different options available during a real emergency situation and for effective planning of remedial actions. Currently, the DSS is implemented with data integrated for all Indian NPP sites. This decision support system also has further scope for improvement to include ground fall out, identifying the possible pathway of intake and calculation of radiation intake by a general public.

The DSS is expected to be useful for performing drills / trial runs to improve emergency measures available and also to assist and help in reducing the impact of a real emergency situation and protect public and environment.

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