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A GIS based approach for Radiation Risk Assessment around a thermal power plant towards adopting remedial measures

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Abstract

Coal combustion in thermal power plants releases ash. Ash is reported to cause different adverse health hazards in humans and other organisms. Owing to the presence of radionuclides, it is also considered as a potential radiation hazard. In this study, based on the surface radiation measurements and relevant ancillary data, expected radiation risk zones were identified with regard to the human population residing near the Thermal Power Plant. With population density as the risk determining criteria, about 20% of the study area was at 'High' risk and another 20% of the study area was at 'Low' risk zone. The remaining 60% was under medium risk zone. Based on the findings remedial measures which may be adopted have been suggested.

Keywords

Radiation risk analysis, GIS based model, thermal power plant, surface radiation, remedial measures

1. Introduction

Coal based Thermal Power Plants (TPP) release different chemical substances in the environment in form of flue gas and ash. Most of these substances, beyond a certain limit, are known to have the potential to adversely affect the environment as well as different other organisms including human beings. As a result, the continuous release of the coal-ash, is expected to have a cumulative impact and hence, considered as a potential threat to the ambient environment including the human population in the long run. The finer fraction of ash, released from the stacks, may be directly taken up by the local population whereas, the bottom ash, stored in the ash ponds may contaminate the local soil and water resources, both surficial and underground. In absence of proper monitoring and management, the contamination may become hazardous for the ambient environment and expose its components to risk of being adversely affected.

The elemental concentration of the ash is highly variable and is mainly dependent on the coal type. The environmentally significant component of ash is the inorganic fraction, inherited from coal, like the primordial radionuclides (238U, 232Th and 40K), different trace elements (TEs) and rare earth elements (REEs).The partitioning behaviour of these elements play a major role in deciding the environmental impact of the ash (especially for concentration of radon, thoron and associated radiation doses) [1–3]. Several studies regarding the partitioning of the radionuclides in the ash particles has reported that elements like 238U (as compared to 232Th) and most of the TEs are found to be enriched in the fine fly ash particles leading to greater mobility of the species[3–5]. Presence of toxic elements like radionuclides, along with high mobility and long residence time [6]of fine ash particles, make the fine ash more hazardous than bottom ash. The small particle size significantly increases the probability of these particles to be wind borne resulting in wide area of impact due the deposition of the ash upto a considerable distance from the thermal power plant. In addition, the bottom ash particles, rich in other elements, from the open ash mounds are also windblown and deposited in the vicinity. The major pathways for exposure to the contaminants for human beings are -i) direct inhalation of the ash from the moving plume, ii) external exposure (on skin, hairs) and iii) inhalation and ingestion from the deposition on soil[7]. Another possible way of exposure to these elements can be through groundwater. Hence, it becomes essential to asses subsequent risk to the population residing in the environment near a TPP periodically, due to the ash particles. After Varnes's (1984)[8]definition of natural hazards, i.e. the probability of occurrence within a specified period within a given area of potentially damaging phenomenon, in the present study, the continuous release and deposition of ash and from a TPP is designated as the 'potentially damaging phenomenon' or the 'hazard'. Although there can be different hazards due to ash deposition, in this study any potential adverse impact on population arising from radiation is referred to as radiation hazard for risk assessment.

The different toxic elements, if ignored for a long span of time, may cause undesirable impact on environment owing to the continuous built up of these elements. The exercise of risk assessment in such area is essential because: *"Risks may be encountered long before they are recognized. Once they are recognized and quantified with some certainty, it may be too late to control or limit them. The question of whether to wait for irrefutable evidence about an adverse effect or to take what may be a costly course of action is a policy question that cannot be answered by the analyst. Yet it is necessary to know what the likely risks and benefits are, even though there is considerable "fuzziness" about the causes and effects of many health risks."*[9]

In the present study a TPP in eastern India is considered. A few studies in the area suggested the occurrence of certain adverse impact on the environment as well as human population, especially on children[10,11]. Although, plants and animals (aquatic and terrestrial) are equally vulnerable to the effects of the radioactive and elemental contamination resulting from the ash1[10–14],the present study is limited to the effects on humans due to ash, in terms of radiation dose. The surface radiation owing to the primordial radionuclides was considered to identify the probable zones with potential risk for affecting human health. Theimpacts on exposure to radionuclides occur mostly due to inhalation of the ash particles for a long time. This prolonged exposure to the high radiation dose (due to the radionuclides) results in a cumulative effect on the biota[15,16]as well as human population[3]. The objectives of the study are a) to identify potential risk zones on the basis of human exposure to ash and b) to recommend some remedial as well as precautionary measures.

2. Study area

Geographically, the area lies 60 km WSW of Kolkata, on the right bank of the river Rupnarayan. Geologically, the area is made up of quaternary alluvial deposition[17]. The terrain is almost flat with a gentle slope towards east-southeast (average elevation being 5 - 7 meters above the mean sea level). The soil is mainly alluvial with about 60% clay content[17]. Apart from Rupnarayan River, the other two major water bodies in the study area are Denan – Dehati canal and Medinipur canal. The Medinipur canal, an artificial canal, is used to pump water from the Rupnarayan River and supply to the KTPP for its operation. The localities in the area are situated as close as within a radius of a few meters from the TPP as well as the ash ponds.

3. Methodology

3.1. Data collection

Surface radiation over an area of ~ 25 Km^2, with the TPP in the center, was recorded using a portable low level gamma survey meter – the microR-Surveymeter (R for Roentgen).

(model UR-709, manufactured by Nucleonix Systems Private Limited, Hyderabad, India).The survey meter provides its output in dose rate and is known as MicroR–survey meter Surface radiation measurements were conducted at 95 locations spanning across the study area. In each location three readings were recorded for 100 seconds each. The sample spacing was of 400 m on an average in an almost grid pattern. The GPS locations at each site were collected. The measurements were made in micro-Roentgen per hour ($\mu R\ h^{-1}$) and were converted tonano-gray per hour ($nGy\ h^{-1}$) (dose) by applying suitable conversion factor.

A schematic overview of the methodology is given in Figure 1.

3.2 Preparation of Maps

The base map and landuse map for the study area were prepared using pan-sharpened LISS IV image through on-screen visual interpretation technique (Figure 1) in GIS platform at scale 1: 22,000 and in WGS 84 datum. The land-use map was verified through intensive field visits. The major land-use classes interpreted in the area were settlement with homestead orchards, agricultural lands, industrial lands, open space, river and canals, surface water bodies, road and railways. The settlement wise population density was calculated using the settlement area of respective mouzas, computed from the land-use map, and the population of each mouza, as retrieved from the census data (Census, 2011)[18]. The hazard, vulnerability and risk analysis were performed using GIS.

3.2.1 Radiation Hazard zonation

The zonation of the study area on the basis of surface radiation measurements was done following the recommendation of the population-weighted average absorbed dose rate (in air outdoors from terrestrial gamma hazard) of 60 $nGy\ h^{-1}$ by United Nations Scientific Committee on Environmental and Atomic Radiation[19]. The surface radiation data collected

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for the study area were interpolated. Empirical Bayesian Kriging (EBK) method was used to obtain a kriged layer of interpolated dose over the entire area followed by the reclassification of the newly generated surface based on the population-weighted average absorbed dose rate of 60 nGy h^{-1} as the threshold value. EBK is a geostatistical interpolation technique based on the Empirical Bayes estimation method[20]. Traditional kriging methods ignore the error introduced due to estimating the semivariogram from the known data points, assuming that it is the true semivariogram. However, EBK by virtue of its properties estimates the error in the semivariogram as well. This results in a better estimation of the error in the prediction[21] and hence was attempted in the present study. Two zones were created: low hazard zone with values ≤60 nGy $h^{-1}$and high hazard zone with values >60 nGy h^{-1}.

3.2.2 Vulnerability analysis

Vulnerability is a relative term and different fields have its own conceptual description of vulnerability as well as risk[22]. In this study, vulnerability is referred to as the extent to which the human populations residing in the neighborhood of a TPP are expected to experience the adverse impact due to radiation. The vulnerability analysis traditionally involves ranking of different 'elements at risk' followed by assignment of score to each element on the basis of ranks. In the present study, Analytical Hierarchical Process (AHP) was used to calculate the vulnerability scores for the determining criteria - high population density, medium population density, low population density, agriculture, waterbodies and open space.

AHP is an internationally accepted robust and flexible multicriteria decision making tool[23].The basic concept of AHP is to decompose a complex decision problem into a hierarchical structure of goal, criteria, sub-criteria and alternatives followed by the pairwise comparison of the elements in terms of a ratio scale based on both qualitative and quantitative information about the elements. The ratio scale generally ranges from 1 to 9 where 1 indicates equal importance of both the elements and 9 indicates an extremely strong significance of one element over the other[24]. The ratios are used to construct a comparison matrix (say A). This matrix A must be transitive i.e. if *i*, *j* and *k* are the alternatives and if $i > j$ and $j > k$ then $i > k$ for all *i, j* and *k;* and reciprocal $a_{ij} = 1/a_{ji}$. Each column of the comparison matrix is normalized using its principal eigenvector (or positive multiple of the vector) and λ_{max} is the principal eigenvalue of the matrix (Equation 1)[24–28].

$$Aw = \lambda_{max} w \qquad \text{Eq. 1}$$

In this study,the weightage for each criteria was generated as per Saaty's 'The fundamental 9-point scale for comparative judgements'[20]. The weightage for population density was generated considering the fact that radiation risk in terms of collective dose increases with higher population density and vice versa[3]. The weightage for rivers, waterbodies and agricultural lands were generated considering the reports of adverse effect of ash on them[10,11]. Since, the local population generally consumes the local produce of fishes and crops in the study area, some adverse effects are expected on their intake.

3.2.3 Risk analysis

Risk was calculated as function of radiation score and vulnerability score. Based on the risk score obtained, the final risk map was generated. In the present study, three risk zones were created based on the risk score. Jenks natural break method was followed to classify the area into different zones. The areas with risk score < 40 was designated as low risk zone, medium risk comprised of areas with score 40 to 60 and areas with risk score > 60 was designated as high risk zones.

4. Results and discussion

The landuse map of the study area is given in Figure 2. The percentage of area covered by the major landuse types are as follows: settlements with homestead orchards (36%), agriculture (36%), surface water bodies (including the canals) (7.9%), industrial area (6.2%) and ash ponds (2.7%). The radiation zones are shown in Figure 3. About ~ 37% of the total area is found to be 'Low hazard' zone, receiving dose rate below or equal to 60 nGy h^{-1}. The remaining 63% area comes under the 'High hazard' zone receiving average ambient dose rate > 60 nGy h^{-1}. The 'High hazard' zone is present towards the north and the 'Low radiation' zone is present towards south and southeast of the study area. The high zone, primarily, coincides with the ash ponds and the TPPs.

The ash ponds and the industrial areas were at very low vulnerability area. This is due to the fact that, the population density in these areas is almost negligible. The rivers, waterbodies and agricultural lands were in medium vulnerability zone. In these areas also, the population density is comparatively low.

The radiation risk zones are shown in Figure 4. The risk map shows that, although a large area (63%) is estimated to be under 'High hazard' zone, the area under 'High' risk zone is less. About 20% of the area is found to come under 'High' risk. The 'Low' risk zone also covered 20% of the study area and the rest of the area is under medium risk. Such distribution of risk is due to the fact that, most of the 'High radiation' zones are devoid of any human settlement. Since, the study mainly focussed on the adverse impact of the radiation dose to the human population, the areas with no population was found to be less vulnerable.

5. Remediation

The present study thus highlights the necessity to adopt appropriate remedial measure(s). A feasible remediation option, in this study may be the creation of the 'Greenbelt'. The alluvial soil found in the study area can be used as a resource for planting of trees along the ash ponds. This can significantly reduce the risk due to the windblown ash. A schematic given below shows the pattern of plantation that may be adopted to serve the purpose of minimizing the exposure to ash. Based on the landuse and riskmap of the study area two tier of plantation can be done. The first tier may be around the ash ponds following the scheme in Figure 5. The second tier may be close to the human settlements. Both these plantation tier is expected to significantly reduce the exposure of the local population to the ash from the ash ponds as well as from stack emission.

6. Conclusion

The hazard map shows the distribution of the hazard in the study area due to the surface radiation. About 63% of the total area has dose rate above 60 nGy h^{-1} and the rest of the area have dose rate below 60 nGy h^{-1}. The radiation risk zonation map of the study area also shows that, since hazard and risk are not synonymous, mere identification of hazard zones can overestimate or underestimate the gravity of the situation. Hence, apart from measuring and estimating the concentration of the contaminants in the environment, it is necessary to estimate the resultant risk as well.

The radiation zone map, vulnerability map and the risk map generated can be used for future planning in the study area as well. The radiation hazard zone map can be used to determine areas where, in future, new settlements can be constructed or are to be averted. For example, the high hazard zone areas may be strictly avoided for allowing human occupancy in any form. In addition, these areas may be avoided for creating ash ponds in future, in case any such necessity arises. The highly vulnerable areas should be monitored regularly and should preferably be avoided for any further increase of hazardous activity like, creation of ash ponds and ash handling. The risk maps generated based on the radiation and vulnerability maps shows the distribution of radiation-induced risk in the study area. This map may play a key role in both identifying the areas demanding immediate intervention, as well as deciding upon the type of remedial measure that can be adopted. Greenbelt creation was found to be a feasible option for this study area. The risk map may be used to identify the areas for planting trees.

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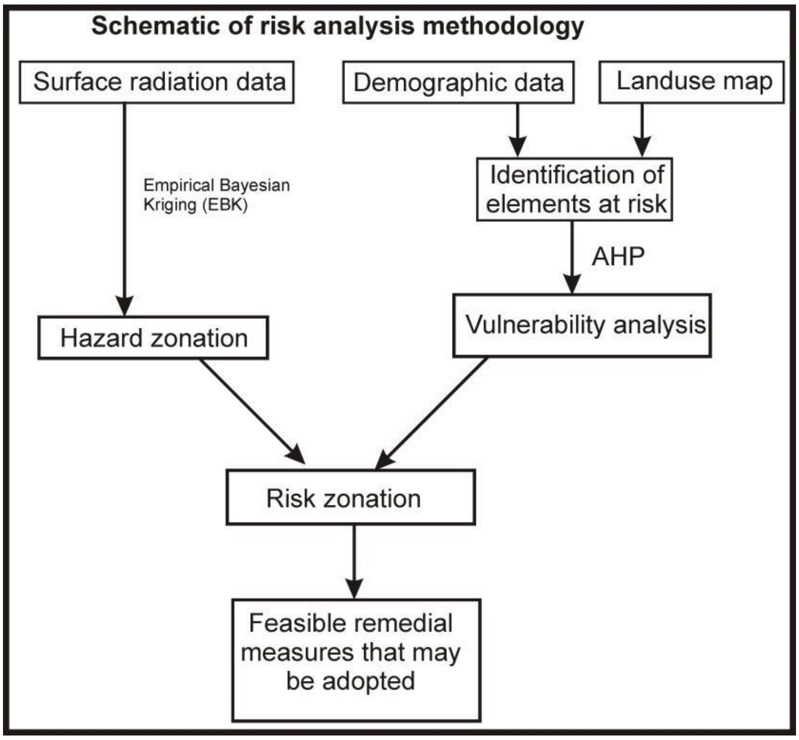

Figure 1: Schematic overview of methodology

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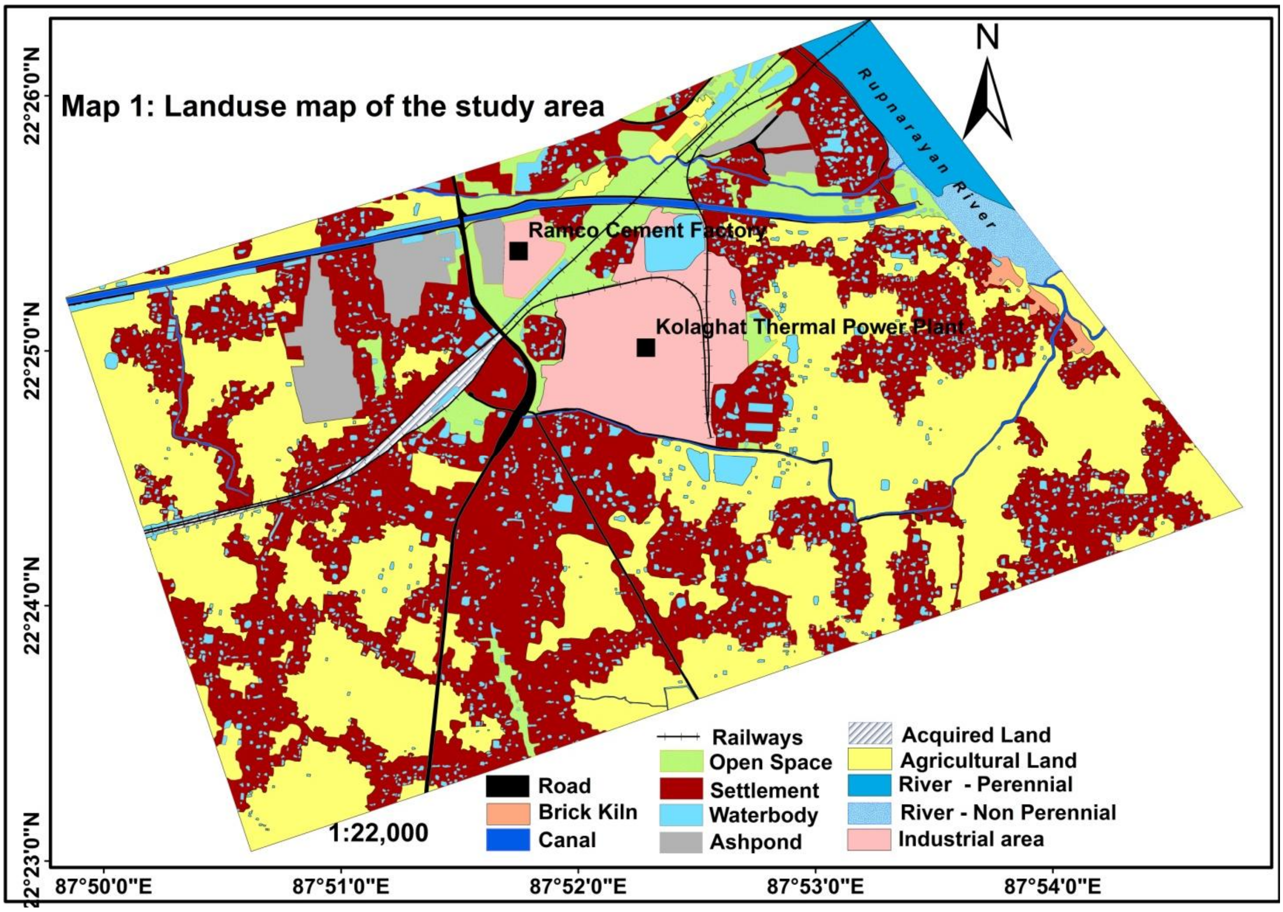

Figure 2: Landuse Map of the study area

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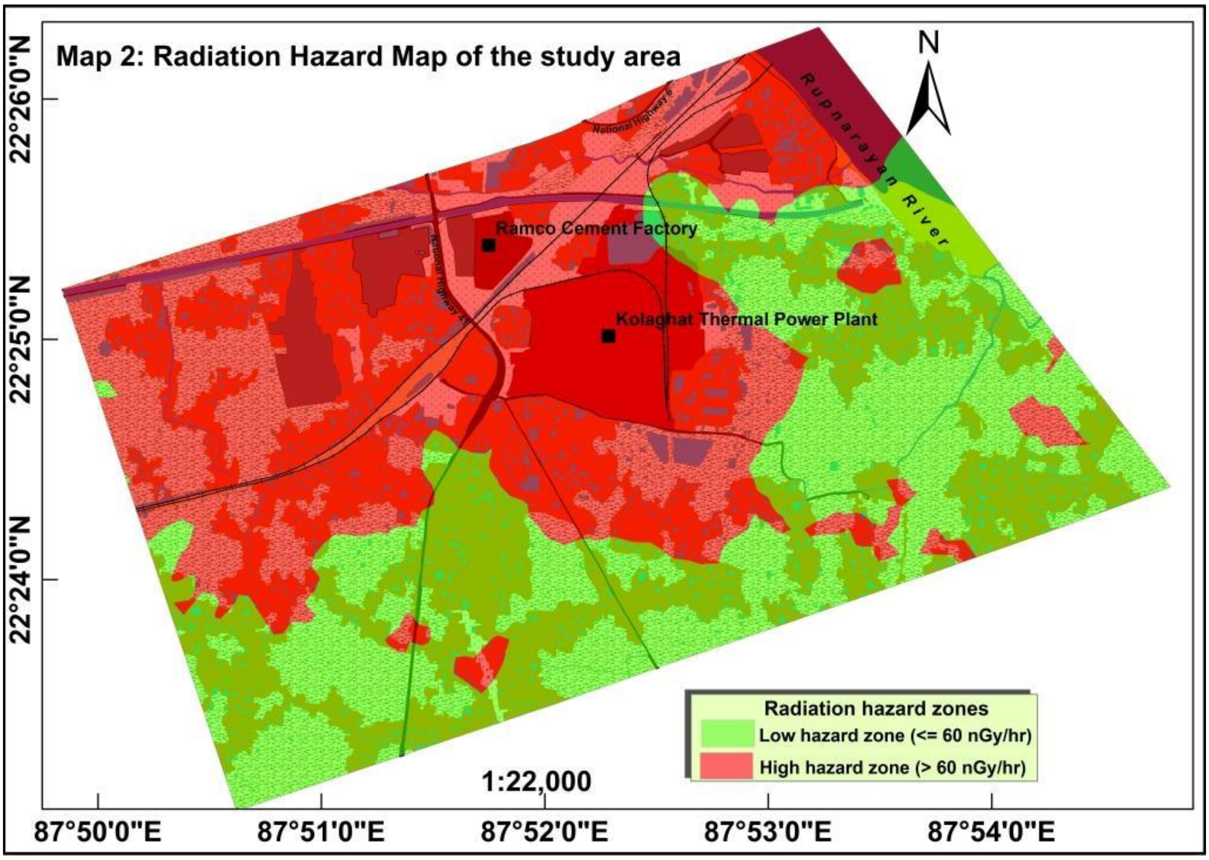

Figure 3 Radiation Zone Map of the study area

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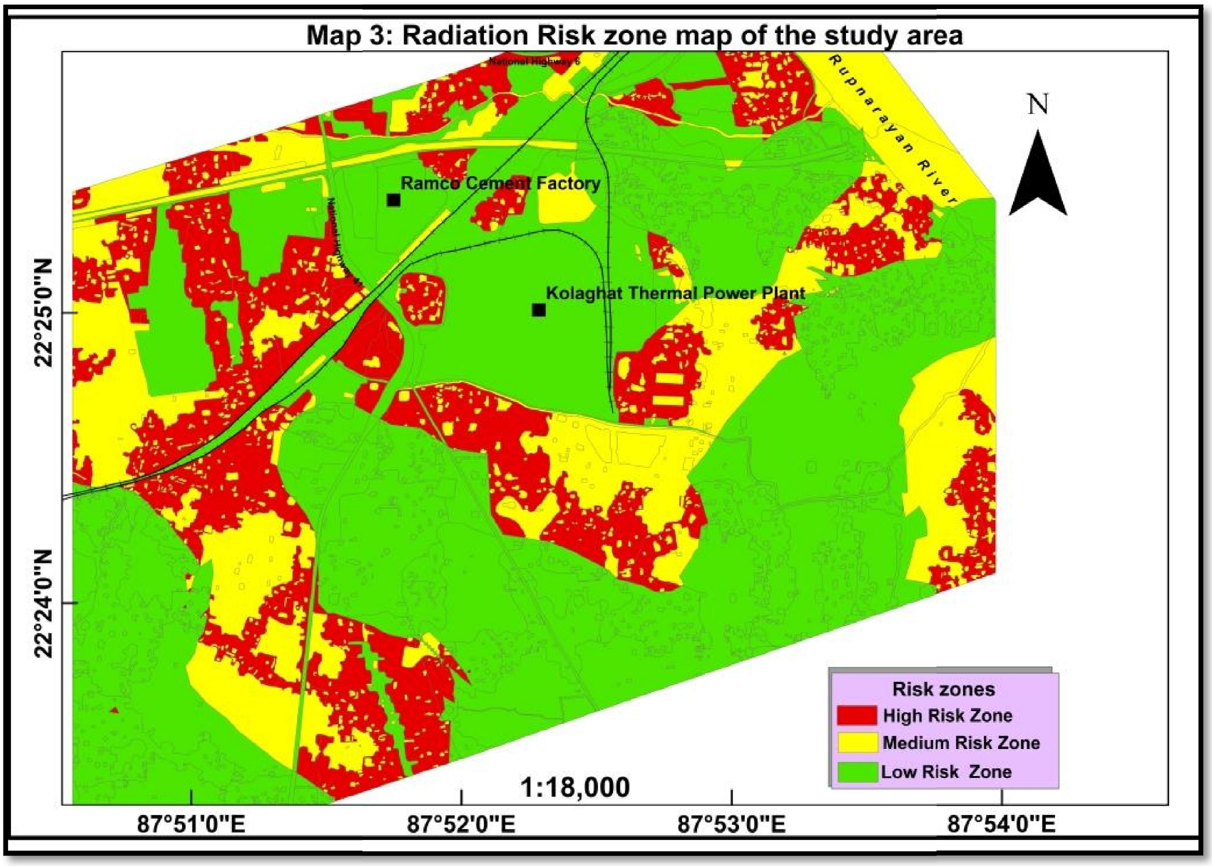

Figure 4 Radiation Risk Map of the study area

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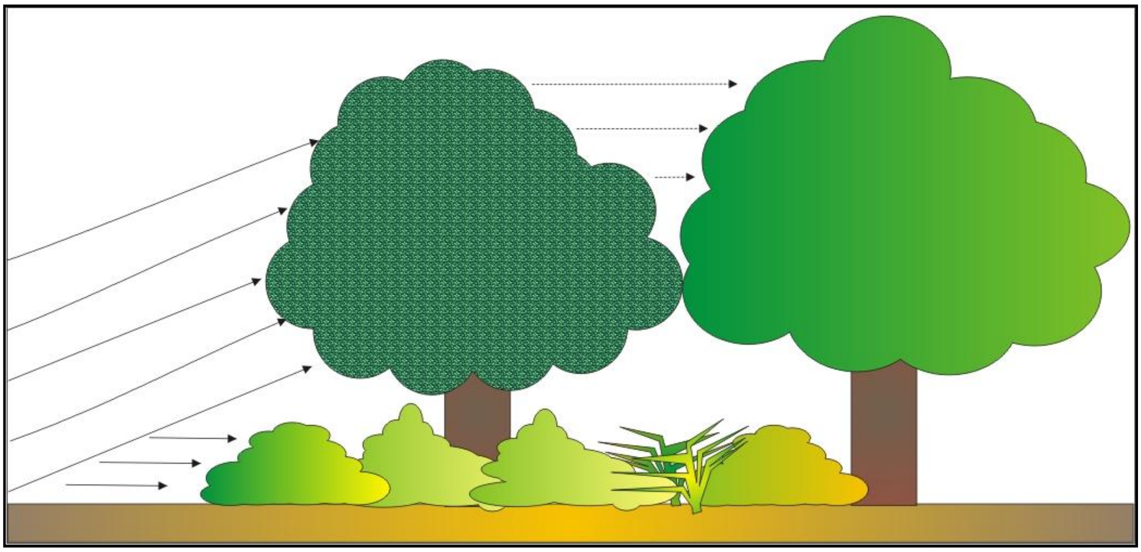

Figure 5 Schematic diagram of Greenbelt plantation pattern around KTPP ash ponds