Studies on radon in soil, its concentration in the atmosphere and gamma exposure rate around Mysore city, India

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Concentrations of radon in soil, rate of its exhalation from the ground surface and its concentration in the atmospheric air have been studied in and around Mysore city (12°N and 76°E). Variation of radon concentration in the soil-gas under dry and wet conditions at different depths was also studied. Radon in soil-gas was found to increase with depth and decrease with increase in moisture content of the soil. Radon in soil varies from 0.11 to 11.85 kBq m^{-3} with a median of 1.92 kBq m^{-3}. The annual average values of radon and its progeny concentrations in the atmosphere vary from 15.33 to 47.81 Bq m^{-3} with a median value of 24.36 Bq m^{-3} and 0.08 to 3.54 mWL with a median value of 0.33 mWL respectively. Good correlations were observed between radon in soil, radon exhalation rate from the ground surface and radon concentration in the atmosphere in these locations. ^{226}Ra in soil at these locations was also estimated using the HPGe detector. The activity of ^{226}Ra varies from 11.3 to 74.2 Bq kg^{-1}. Radon concentration in soil-gas shows good correlation with the activity of ^{226}Ra in soil. The correlation coefficient was 0.76.

Keywords: Gamma exposure rate, radiation dose, radon, soil-gas.

RADON is one of the naturally occurring radioactive elements in the environment produced from the radioactive decay of radium isotopes, which are the decay products of ^{238}U, ^{232}Th and ^{235}U. Hence the concentrations of uranium and thorium in the bedrock and soil materials determine the amount of radon produced in the soil. The radon produced in the soil migrates through the mechanism of diffusion and convection through pore spaces in the soil, fractures in the rocks and along with weak zones such as shear, faults, thrust, etc. For some geological situations, radon migrates long distances from its place of origin and can be detected by alpha-particle recorders at the earth's surface[1,2]. Concentration of radon in an area is governed by the radium content in the minerals, radon emanating power in the materials, permeability of the soil and the underlying rock, and moisture content of the soil[3]. Moisture content in the soil can increase radon emanation to some extent, but if the soil pores become saturated emission is inhibited[4].

Radon and its progeny are responsible for about 45% of radiation exposure received by the world population from natural sources[5]. Radon (^{222}Rn) and thoron (^{220}Rn) are usually produced in approximately equal amounts, but the latter is often ignored because its contribution to the overall dose of radiation is relatively small. Estimation of radon in the soil-gas and the atmosphere has been suggested as a tool for many investigations, such as exploration for uranium, earthquake prediction, groundwater transport and assessment of geothermal resources[6].

The existence of radon within dwellings is the significant risk of lung cancer[5,7]. Soil-gas studies have been applied successfully to a number of fields from hydrocarbon to uranium exploration, and from geothermal processing to volcanic and seismic forecasting[8]. Our objective was to determine the relationship between emanation of radon in soil-gas, rate of radon exhalation rate and its concentration in outdoor atmosphere.

The study was carried out in Mysore city, Karnataka, India. It lies between 12°15″–12°25″N lat. and 76°35″–76°45″E long., at an altitude of about 767 m amsl. The study area was about 140 sq. km. A large water reservoir, namely Krishna Raja Sagar (KRS), situated at the north-western part and Chamundi Hills (1048 m amsl) located on the southeastern part of the city are prominent features of the region.

Meta-sedimentary rocks like biotite, schist, mica schist and hornblende schist belonging to Dharwar group are seen in the form of patches. Younger intrusions like felsite, pegmatite and granite of 800 m.y. age are found in the study area. These intrusions are known for rich concentrations of radioactive minerals.

Solid State Nuclear Track Detectors (SSNTDs) have been extensively used to perform integrated measurements of radon in the soil[8–13]. The present experimental set-up is shown in Figure 1. For measurement of radon in the soil, a twin-cup dosimeter designed and fabricated by Mayya and his group at Bhabha Atomic Research Centre (BARC), Mumbai has been used here[14]. The twin-cup dosimeter has two chambers, and each chamber has a length of 4.1 cm and radius of 3.1 cm. The SSNTD film placed in one compartment measures radon alone that diffuses into it from the ambient air through a semi-permeable membrane (cellulose nitrate) of 25 μm thickness. These films having diffusion coefficient in the range 10^{-8}–10^{-7} sq. cm per s, allow more than 95% of the radon gas to diffuse[13] and suppress thoron gas to less than 1%. In our measurement we have used only one chamber covered with a semi-permeable membrane. Using the same dimensions of the dosimeter cup, Eappen and Mayya[15] have reported a calibration factor of 0.021 tracks cm^{-2} d^{-1} per Bq m^{-3} for radon concentration. We have made use of the same cup designed and characterized by Mayya and group[14,15], with the same dimensions and other conditions.

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We have used the same calibration factor for our computation. The cup was inserted into a 1 m long PVC pipe closed at the top. The PVC pipe was inserted through bore holes of 7 cm diameter drilled to 80 cm depth in the ground. Measurements were repeated for depths of 50 and 100 cm.

For measurement of ^{222}Rn concentrations at a height of 2 m from the ground surface, the detector was mounted inside an inverted plastic cylinder for protection against direct sunlight and a nylon stocking covered the entire assembly to protect the dust filter from insects.

After an exposure time of 30 days, the detectors were removed and etched in 2.5 N NaOH solution at 60°C in a constant temperature bath for 1 h. The tracks were counted using spark counter and radon concentration in the soil-gas was calculated using the sensitivity factor of 0.021 tracks cm^{-2} d^{-1} per Bq m^{-3}. This exposure cycle has been extended in time-integrated four quarterly cycles to cover all the four seasons of a calendar year to evaluate the annual radon and its progeny levels.

The soil-gas radon concentration, C_R, is calculated using the following relation[14].

$$C_R\,(\text{Bq m}^{-3}) = \frac{T}{DS}, \tag{1}$$

where T is the track density of the film (tracks cm^{-2}), D, the period of exposure (days) and S the sensitivity factor (0.021 tracks cm^{-2} d^{-1} per Bq m^{-3}).

The concentration of radon in the atmospheric air was measured using Low Level Radon Detection System (LLRDS) following a well-established procedure[16]. The advantage of this system is that no pump is required for sampling. The evacuated chamber can be taken to the site of sampling and a grab sample taken by opening the stopcock, after which it is sealed automatically. Measurement is done later at a centralized place. The minimum detectable level for radon in LLRDS is as low as 1.7–8.8 Bq m^{-3}, depending on the relative humidity conditions. The positively charged ^{218}Po (RaA) atoms created in the chamber get collected on the metallic plate maintained at an optimum negative potential. The efficiency of collection of RaA atoms (F) on the metallic disc, is empirically related to humidity H by $F = 0.9 \times (1 - \exp(0.039H - 4.188))$. The collection was carried out for an optimized period of 90 min and thereafter the collection plate was removed from the chamber for alpha-counting. The concentration of radon R_{atm} (Bq m^{-3}) was calculated using the expression[16]:

$$R_{atm} = \frac{1000C}{EFVZ}, \tag{2}$$

where C is the total number of counts observed during the counting period, E the efficiency of the alpha counting system (26%), F the efficiency of collection of RaA atoms on the metallic disc, V the volume of the LLRDS chamber (l) and Z the correction factor for build-up and decay of radon daughter atoms on the metallic disc during the exposure and counting period. The value of Z worked out for 5000 s is 3000.

Rate of exhalation of ^{222}Rn was estimated by employing the accumulation chamber method. The accumulation chamber used in the present study is a cylindrical metallic container of diameter 420 mm and height 270 mm, with its open end buried to a depth of 150 mm at the selected location. Radon exhaled from the soil gets collected in the chamber. On the top of the chamber two openings are provided, one for connecting a hard rubber bulb used for mixing the air uniformly in the collection chamber, and the other for transferring air from the collection chamber to the LLRDS. The procedure for the measurement of ^{222}Rn exhalation rate consists of the following steps.

1. Collection of the ^{222}Rn exhaled from a known area (L) of the indoor floor for a given time in a collection chamber.
2. Transfer of a specific fraction of the air from the collection chamber to LLRDS.
3. Estimation of ^{222}Rn concentration in LLRDS.
4. Calculation of ^{222}Rn exhalation from the measured ^{222}Rn concentration.

Radon exhaled from the soil gets collected in the chamber. The time of collection of radon in the accumulation chamber has been standardized for 1 h by repeating the collection for different time intervals. The collection period of 1 h has been found to be adequate for the estimation of radon exhalation rate using this method. Radon concentration can then be estimated using LLRDS. Radon exha-

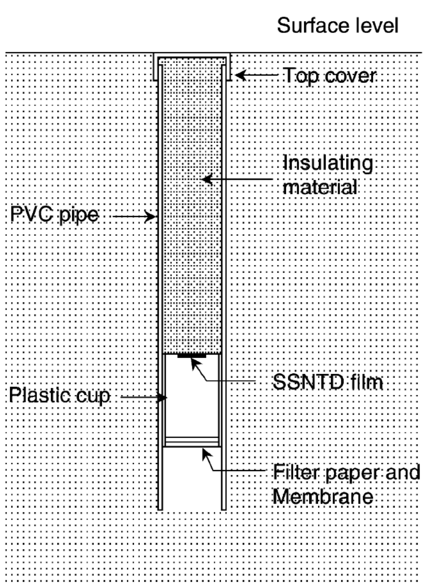

Figure 1. Experimental set-up for soil-gas measurements.

lation rate J (Bq m^{-2} s^{-1}) from the soil was calculated from the estimated radon concentration using the formula[17]:

$$J = \frac{C_R \lambda (V_1 + V_2)}{A(1 - e^{-\lambda t})}, \qquad (3)$$

where C_R is the concentration of radon in LLRDS (Bq per cubic), V_1 the volume of accumulation (cubic m), V_2 the volume of the LLRDS chamber (cubic m), λ the decay constant of radon (per s), A the exhalation area (sq. m) and t the duration of accumulation of radon gas in the collection chamber (s).

The ambient gamma radiation levels were measured using a scintillometer. Measurements were carried out in the outdoor during the installation and retrieval of the radon dosimeter at all locations. All measurements were made 1 m above ground level. The arithmetic mean of about 100 readings was taken as the representative figure for each location.

Gamma ray spectrometry method was employed to estimate the activity of ^{226}Ra, ^{232}Th and ^{40}K in the soil and building materials. Soil samples were collected at several locations near houses with different types of construction in Mysore city. Locations, which were free from surface run-off during heavy rain, were carefully selected. An area of about 0.5 m^2 was marked and cleared of vegetation and roots. The marked spot was dug up to a depth of 15 cm and about 2 kg of soil was collected at each spot. Finally the samples were mixed thoroughly and extraneous materials like plants, debris, pieces of stones and pebbles were removed[18]. Composite samples of about 2 kg were taken and sealed in a polythene bag. The samples were transferred to a porcelain dish and oven-dried overnight at 110°C. The samples were powdered and sieved through 150 mesh sieve, weighed and sealed in a 300 ml plastic container, and kept for a month before counting by gamma spectrometry, in order to ensure that radioactive equilibrium was reached between ^{226}Ra, ^{222}Rn and its progeny.

The spectrometer consisted of n-type HPGe coaxial detector (EG&G ORTEC, USA) of 17% efficiency having a resolution of 1.75 keV at 1.33 MeV and 641 eV at 5.9 keV, and coupled to a 4096 channel MCA. The detector was shielded with lead to reduce the background. The gamma peak of energy 609.51 keV (emitted by ^{214}Bi, a decay product of ^{222}Rn) with intensity 46.1% was used as proxy for the quantitative determination of ^{226}Ra (ref. 19).

$$\text{Activity (Bq kg}^{-1}) = \frac{(S \pm \sigma) \times 100 \times 1000 \times 100}{E \times W \times A}, \qquad (4)$$

where S is the net counts/s under the photo peak of interest, σ the standard deviation of S, E the counting efficiency (%), A the gamma abundance (%) of the radionuclide and W the mass of the sample (g).

The moisture content of the soil was determined by drying the soil core sample at 110°C for 48 h in an oven. Moisture content is the ratio of the mass of the water W_w in the soil sample to the dry weight of the solid mass W_d. $W_w = (w_1 - w_2)$, where w_1 is the mass of the soil before drying and w_2 is the mass of the soil after drying.

$$\text{Moisture content } W = \frac{W_w}{W_d} \times 100.$$

Experiments for the estimation of radon in the soil, its exhalation rate and its concentration in outdoor atmosphere were performed at several selected locations around Mysore city. The soil type in the University campus is red sandy, developed over Archean peninsular gneiss. Variation of ^{226}Ra in both measured locations was small and therefore its effect on the radon measurements is considered negligible. Exhalation of ^{222}Rn is influenced by the soil characteristics, its porosity, moisture content, temperature of the ground and atmospheric pressure[4,20]. The radon flux density is directly proportional to radium concentration in the soil, and it is the central part of the exhalation rate[21].

Table 1 gives the results of variation of radon concentration with depth for dry and wet soil. In dry soil, the concentration of radon increases with increasing depth. This may be due to increase in pressure and moisture content with depth. Soil moisture, in the form of a thin film of water surrounding soil grains, directly affects radon emanation by capturing the radon recoils from the solid matrix. These captures increase the likelihood that radon

Table 1. Variation of radon in soil with depth for different moisture conditions

	Wet condition		Dry condition	
Depth (m)	Radon concentration in soil-gas (kBq m^{-3})	Moisture (%)	Radon concentration in soil-gas (kBq m^{-3})	Moisture (%)
0.3	0.47 ± 0.01	22.8 ± 0.1	0.81 ± 0.01	3.2 ± 0.1
0.6	0.66 ± 0.01	23.4 ± 0.1	1.26 ± 0.01	4.6 ± 0.1
0.9	1.53 ± 0.01	24.1 ± 0.1	3.89 ± 0.03	4.8 ± 0.1
1.2	2.35 ± 0.02	25.2 ± 0.1	5.15 ± 0.04	5.3 ± 0.1
1.5	2.17 ± 0.02	27.1 ± 0.1	6.24 ± 0.05	7.4 ± 0.1

Table 2. Variation of ^{222}Rn in soil-gas, concentration of ^{222}Rn and its progeny in the atmosphere and inhalation dose in different locations around Mysore city

Location	^{222}Rn in soil-gas (kBq m^{-3}) Winter 0.5 m depth	Winter 1 m depth	Summer 0.5 m depth	Summer 1 m depth	Rainy 0.5 m depth	Rainy 1 m depth	Autumn 0.5 m depth	Autumn 1 m depth	^{222}Rn in atmosphere (Bq m^{-3})	^{222}Rn progeny in atmosphere (mWL)	Inhalation dose (mSv per year)
Manasagangotri	3.33	4.27	0.24	0.40	3.20	3.78	2.11	3.35	15.33	2.67	0.15
Baburayana Koppalu	3.96	4.42	0.23	0.46	3.02	4.18	0.81	2.07	32.25	0.11	0.31
Naguvana Halli	1.14	0.90	0.11	0.30	0.85	1.04	0.44	0.35	47.81	0.29	0.47
Vijaya Nagara	2.53	3.11	0.35	0.32	1.34	2.54	1.38	2.31	18.36	0.37	0.18
Chamundi Hills	3.28	4.50	0.72	1.26	9.40	11.85	1.86	3.81	24.33	2.81	0.23
Karigatta	1.98	2.94	0.32	0.97	4.26	8.96	1.24	6.36	40.85	3.54	0.39
Yelwala	2.22	2.48	0.48	1.57	3.63	5.44	1.39	2.06	22.84	0.08	0.22
Thuruganur	0.99	1.54	0.54	0.29	2.06	2.37	0.91	0.91	24.38	0.09	0.23
Median	2.38	3.03	0.34	0.43	3.11	3.98	1.31	2.19	24.36	0.33	0.23
Standard deviation	1.06	1.35	0.20	0.50	2.66	3.66	0.55	1.88	11.22	1.48	0.11

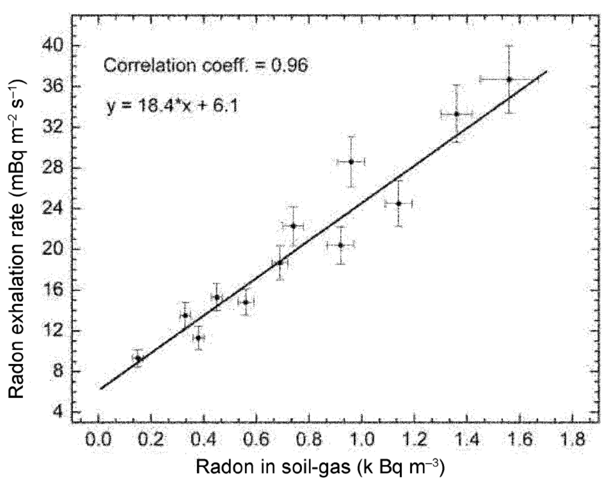

Figure 2. Variation of radon exhalation rate with radon in soil-gas.

atoms will remain in the pore space instead of crossing the pores and imbedding themselves in adjacent soil grains[4]. In wet soil, the concentration increases with depth and reaches a maximum and then decreases slightly. The decrease in radon in the soil at higher depth may be due to high moisture content in the soil pores. As the soil hydrates its permeability decreases and hence emanation of radon decreases[22]. This behaviour agrees with the results reported by Vohra *et al.*[23].

The variation of ^{222}Rn concentration in soil-gas, concentration of ^{222}Rn and its progeny in the atmosphere and inhalation dose in different locations around Mysore city are shown in Table 2. Radon in soil-gas and the atmosphere was measured using SSNTDs for one year, covering all seasons. Radon in soil varies from 0.11 to 11.85 kBq m^{-3}, with a median of 1.92 kBq m^{-3}. Higher radon concentration in soil-gas was observed at Chamundi Hills and Karigatta village, with an average value of 5.36 and 4.81 kBq m^{-3} respectively, at 1.0 m depth from the ground surface. Whereas lower radon concentration in soil-gas was observed at Naguvana Halli, with an average value of 0.65 kBq m^{-3} at 1.0 m depth from the ground surface. The higher values in Chamundi Hills and Karigatta village may be due to higher ^{226}Ra concentration in the soil at these places (Table 3). ^{226}Ra concentration at Chamundi Hills and Karigatta was 70.3 and 51.1 Bq per kg and at Naguvana Halli it was 13.0 Bq kg^{-1}. Radon concentration in soil-gas shows good correlation with the activity of ^{226}Ra in the soil, with a correlation coefficient of 0.76. Concentrations of radon and its progeny vary at these locations from 15.33 to 47.81 Bq m^{-3}, with a median of 24.36 Bq m^{-3} and 0.08 to 3.54 mWL, with a median of 0.33 mWL.

The absorbed dose rate in air measured and calculated using dose coefficients[4] of 0.462, 0.604, 0.0417 for ^{226}Ra, ^{232}Th and ^{40}K radionuclides respectively, is given in Table 3. The average absorbed dose rate in air referred from concentrations of radionuclides in the soil varies from 43 to 174 nGy per h and the measured gamma-exposure level varies from 85 to 160 nGy per h. Absorbed dose rate in air referred from concentrations of radionuclides in the soil shows good correlation with the direct gamma measurements. The correlation coefficient was 0.89.

Figure 2 is a scatter-plot of average radon exhalation rate with average concentration of radon in the soil at twelve locations in the University campus, measured during March–October 2006. Good correlation between radon in the soil and radon exhalation rate was observed, with a correlation coefficient of 0.96. Radon in the soil varies from 0.15 to 1.56 kBq m^{-3}, with a median of 0.72 kBq m^{-3}. Whereas radon exhalation rate varies from 9.3 to 36.7 mBq m^{-2} s^{-1}, with an average value of 20.7 mBq $m^{-2}s^{-1}$. Figure 3 shows the variation of radon concentration in the atmosphere measured using LLRDS with radon exhalation rate from the ground surface. Ra-

Table 3. Variation of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples and absorbed dose rate in different locations around Mysore city

Location	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Absorbed dose rate in air (nGy h^{-1})	
				From soil concentrations	From direct measurements
Manasagangotri	20.3	60.4	343.0	60	90
Baburayana Koppalu	11.9	50.2	492.3	56	94
Naguvana Halli	13.0	36.3	359.8	43	99
Vijaya Nagara	48.2	68.7	391.9	80	85
Chamundi Hills	70.3	156.2	1138.1	174	160
Karigatta	51.1	67.6	51.1	66	88
Yelwala	74.2	134.5	401.6	132	111
Thuruganur	11.3	32.0	1225.6	76	110
Median	34.3	64.0	396.8	71	97
Standard deviation	26.6	45.4	410.7	44	24

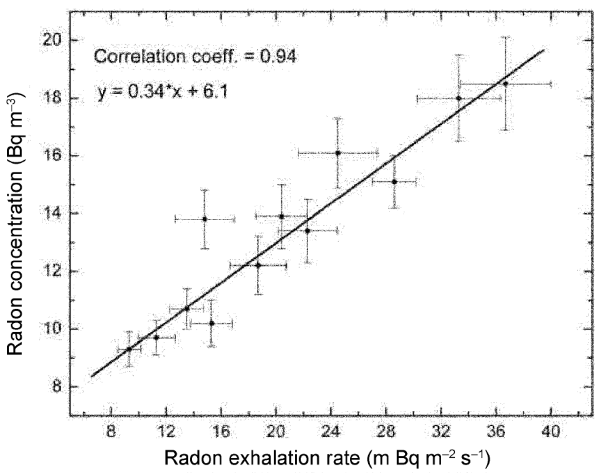

Figure 3. Variation of radon concentration with its exhalation rate.

don concentration varies from 9.3 to 18.5 Bq m^{-3} with an average value of 13.3 Bq m^{-3}. Radon concentration in the atmosphere shows good correlation with radon exhalation rate measured at the same location. The correlation coefficient was 0.94.

Radon concentration from different parts of the world are available in the literature. Choubey *et al.*[11] have reported soil-gas in Doon Valley, India, which varies from 1.00 to 19.68 kBq m^{-3}. Vaupotic *et al.*[24] have reported soil-gas in Ljubljna, Slovenia, varying from 2 to 14 kBq m^{-3}. Pena *et al.*[10] have reported radon in the soil-gas in coastal regions in Mexico city in the range 0.1–12.0 kBq m^{-3}. Shweikani and Hushari[25] have observed correlations between radon in soil-gas and its exhalation rate and concentration in the air in the southern part of Syria. In western Turkey, Erees *et al.*[8] have observed radon concentration is soil-gas and gamma dose rate varying from 0.21 to 7.39 kBq m^{-3}, with an average of 1.13 kBq m^{-3} and from 4 to 21 μRh^{-1}, with an average of 9.8 μRh^{-1} respectively. Concentrations of radon in the soil from Mysore city are lower compared to those in other parts of the world.

The activity of ^{226}Ra in the soil, radon in soil-gas and radon concentrations in the atmosphere were studied around Mysore city. Radon in the soil varies from 0.11 to 11.85 kBq m^{-3}, with a median of 1.92 kBq m^{-3}. Radon in the soil-gas was found to be higher at a depth of 1 m compared to a depth of 0.5 m from the ground surface. Higher radon concentration in the soil was observed near Chamundi hills and Karigatta village, with average values of 5.36 and 4.81 kBq m^{-3} respectively, at 1 m depth from the ground surface. The activity of ^{226}Ra varies from 11.3 to 74.2 Bq per kg. Good correlation was observed between radium content in the soil, radon in soil-gas, radon exhalation rate from the ground surface and radon concentration in the atmosphere at these locations.

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Identifying biomass burned patches of agriculture residue using satellite remote sensing data

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The combine harvesting technology which has become common in the rice–wheat system in India leaves behind large quantities of straw in the field for open residue burning, and Punjab is one such region where this is regularly happening. This becomes a source for the emission of trace gases, resulting in perturbations to regional atmospheric chemistry. The study attempts to estimate district-wise burned area from agriculture residue burning. The feasibility of using low resolution (MODIS) and moderate resolution (AWiFS) satellite data for estimation of burned areas is shown. It utilizes thermal channels of MODIS and knowledge-based approach for AWiFS data for burned area estimation. A hybrid contextual test-fire detection and tentative-fire detection algorithm for satellite thermal images has been followed to identify the fire pixels over the region. The algorithm essentially treats fire pixels as anomalies in images and can be considered a special case of the more general clutter or background suppression problem. It utilizes the local background around a potential fire pixel, and discriminates fire pixels and avoids the false alarm. It incorporates the statistical properties of individual bands and requires the manual setting of multiple thresholds. Also, a decision-tree classification based on See5 algorithm is applied to AWiFS data. When combined with image classification using a machine learning decision tree (See5) classification, it gives high accuracy. The study compares the estimated burned area over the region using the two algorithms.

Keywords: Burned patches, decision-tree classifier, knowledge-based classification, thermal band.

BIOMASS burning is a major source of many atmospheric particulates and trace gases, which have a major impact on climate; it also affects human health causing respiratory problems. It is recognized as a significant global source of emissions, contributing as much as 40% of gross carbon dioxide and 38% of tropospheric ozone[1]. It has significant impact on the atmospheric chemistry and biogeochemical cycles[2], radiative energy balance and climate[3,4]. Smoke particles from biomass burning have direct radiative impact by scattering and absorbing shortwave

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