The influence of geology on terrestrial gamma radiation dose rate in Pahang state, Malaysia

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Terrestrial gamma radiation dose (TGRD) rate measurements have been made in Pahang state, Malaysia. Significant variations were found between TGRD measurements and the underlying geological formations. In some cases revealing significant elevations of TGRD. The acid-intrusive geological formation has the highest mean TGRD measurement of 367 nGy h⁻¹. This is more than six times the average value of 59 nGy h⁻¹, while the quaternary geological formation has the lowest mean gamma radiation dose rate of 99 nGy h⁻¹. The annual effective dose equivalent outdoor to the population was 0.216 mSv. The lifetime equivalent dose and relative lifetime cancer risks for an individual living in Pahang state were 81 mSv and 4.7 × 10⁻³ respectively. These values are more than two times the world average of 34 mSv and 1.95 × 10⁻³ respectively.

Keywords: Annual effective dose, cancer risk, geological formations, terrestrial gamma radiation dose.

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions of the area. The presence of naturally occurring radionuclides in the environment may result in an external and internal dose received by a population exposed to them directly and via ingestion or inhalation pathways. The assessment of radiological impact on a population as a result of radiation emitted by natural radionuclides is important, since it contributes to the collective dose on the population. Exposure to ionizing radiation from natural sources is a continuous and unavoidable feature of life on earth. An assessment of the gamma radiation dose rate from natural source is of particular importance because natural radiation is the largest contributor of the external dose to the world population. The worldwide average annual effective dose equivalent due to terrestrial gamma radiation is 0.48 mSv (ref. 1). This study therefore aimed at determining the influence of geology on terrestrial gamma radiation dose (TGRD) rate in Pahang state, Malaysia. It also aimed at extending and combining with a data from previous study to explore the distribution of TGRD over all the geological formations in the region. The lifetime effective dose rate and lifetime cancer risk for persons living in the state were also estimated.

Pahang is the largest state in the Malaysian peninsula. It covers an area of 36,137 sq. km with a population of 1,500,817 (ref. 3) and is located between lat. 2°29′ and 4°46′N and long. 101°20′ and 103°37′E. The state has the long Pahang River. The bordering states include Kelantan to the north, Perak, Selangor, Negeri Sembilan, to the west, Terengganu state to the east and Johor to the south. Kuantan is the capital and the royal house is at Pekan. Jerantut, Kuala Lipis and Raub are the other major towns in the state. Pahang state has 11 districts with 15 underlying geological formations (Figure 1). These formations are described in Table 1.

The data collection method was based on the geological formations in the area of survey. A geological map of the area (Figure 1) was used to mark the points of measurements for TGRD; coordinates of the points located were recorded and traced in the field using a GPS. Where the location was found to be inaccessible, a nearby accessible location on the same geological formation was used for measurements. TGRD was measured by holding the survey meter 1 m above level ground at the location. Measurements were made at 640 locations (Figure 2) in the area using Survey Meter model 19, micro R Meter (Ludlum Measurement, USA)². It has linear energy response to gamma radiation between 0.08 and 1.2 MeV (ref. 6), which is considered to be acceptable for covering the majority of gamma ray emissions from major sources of natural gamma radiation. The instrument uses a 2.54 cm × 2.54 cm sodium iodide (NaI) crystal doped with thallium (Tl). The survey meter was calibrated at the Malaysian Nuclear Agency, which is recognized by the IAEA as a Secondary Standards Dosimetry Laboratory. The meter display was in micro rontgen per hour (µR h⁻¹). Global positioning system receiver Garmin (GPSmap 76CSx) with an accuracy of ±10 m recorded the latitude and longitude of each measurement location.

The terrestrial gamma dose rates ranged from 26 to 750 nGy h⁻¹, with a mean value of 176 ± 5 nGy h⁻¹ (ref. 7). Also, 68% of dose rates values ranged between 50 and 200 nGy h⁻¹, which indicated that the mean value in the study area should be within this range. This value is three times the world and two times the Malaysian average of 59 and 92 nGy h⁻¹ respectively⁵. The readings were then transformed using natural logarithm to fit a normal distribution. The skewness (symmetry) and kurtosis (pointiness) in natural logarithm had a good fit to normal distribution (bell shape), as shown in Figure 3. This shows that the measured gamma dose rate data are normally distributed and can be used to draw reliable conclusions. It also indicates that the distribution of gamma dose rates measurements satisfied the null hypothesis of

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Table 1. Geological formations of Pahang state

<table>
<thead>
<tr>
<th>Geological formations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary 1</td>
<td>Continental and marine deposits with unconsolidated sand</td>
</tr>
<tr>
<td>Quaternary 2</td>
<td>Continental and marine deposits with unconsolidated silt and clay</td>
</tr>
<tr>
<td>Quaternary 3</td>
<td>Continental and marine deposits with unconsolidated humic clay, peat and silt</td>
</tr>
<tr>
<td>Quaternary 4</td>
<td>Continental and marine deposits with unconsolidated clay, sand, silt and gravel — undifferentiated</td>
</tr>
<tr>
<td>Cretaceous–Jurassic 9</td>
<td>Continental deposits of thick, cross-beded shale/mudstone. Volcanic products are present</td>
</tr>
<tr>
<td>Cretaceous–Jurassic 10</td>
<td>Cretaceous–Jurassic 9 with metamorphic and sedimentary rocks of sandstone/metastone</td>
</tr>
<tr>
<td>Triassic 14</td>
<td>Interblended sandstone, siltstone and shale; widespread volcanic products, mainly tuff of rhyolite dacitic composition in the central Peninsula</td>
</tr>
<tr>
<td>Triassic 15</td>
<td>Triassic 14 with acid to intermediate volcanic extrusive rocks</td>
</tr>
<tr>
<td>Permian 20</td>
<td>Shale, slate and phyllite with subordinate schist and sandstone. Prominent development of limestone through the succession. Volcanic media, rhyolitic to andesitic in composition, widespread</td>
</tr>
<tr>
<td>Permian 21</td>
<td>Permian 20 with extrusive rocks deposits of intermediate to basic volcanic rocks</td>
</tr>
<tr>
<td>Carboniferous 25</td>
<td>Phyllite, slate and sandstone; argillaceous rock are commonly carbonaceous</td>
</tr>
<tr>
<td>Devonian 30</td>
<td>Phyllite, schist and slate; limestone and sandstone locally prominent</td>
</tr>
<tr>
<td>Silurian–Ordovician 35</td>
<td>Schist, phyllite, slate and limestone. Minor intercalations of sandstone and volcanic rocks</td>
</tr>
<tr>
<td>Acid intrusive 38</td>
<td>Basalt and rhyolite undifferentiated</td>
</tr>
<tr>
<td>Acid intrusive 39</td>
<td>Igneous rocks with intermediate intrusives, undifferentiated</td>
</tr>
</tbody>
</table>

Figure 1. Geological formations of Pahang state, Malaysia.

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normality and therefore, the measured data are reliable to a great extent.

The mean values of dose rate at 95% confidence interval for each district in Pahang state are shown in Table 2.

The distribution of gamma radiation dose rate through various districts has been reported. The district of Cameron Highlands appears to have the highest mean gamma radiation dose rates values of $285 \pm 13$ nGy h$^{-1}$, which is approximately five times the world average. The district of Maran has the lowest gamma dose rate of $102 \pm 9$ nGy h$^{-1}$, which is approximately two times the world average. Jerantut district, which covers total land area of 21% of the state, has a mean gamma radiation dose rates of $158 \pm 9$ nGy h$^{-1}$.

The standard deviation is used to estimate the variability of gamma radiation dose rates for each group of geological formations, whereas standard error is used to estimate the uncertainty of dose rates since the population size of each group of geological formation was not the same. The 95% confidence interval was used to test the significant difference between the gamma radiation dose rates for each group of the geological formation.

Table 3 shows the mean values of TGRD and 95% confidence interval for each geological formation. Triassic 14, which is the most abundant geological formation in
the state, has a mean gamma radiation dose rate of 158 ± 7 nGy h⁻¹. Geological formations 38 and 39, which consists of acid and intermediate intrusive, have the highest mean gamma radiation dose rate of 367 ± 43 nGy h⁻¹ and 258 ± 12 nGy h⁻¹ respectively. These areas are acidic and extensively intruded by granitic rocks. The granite is relatively rich in radioactive minerals. The lowest mean gamma radiation dose rate of 99 ± 8 nGy h⁻¹ was recorded in the Quaternary 3 geological formation, which comprises of continental and marine deposits with unconsolidated humic clay, peat and silt.

The annual effective dose (AED) outdoors and indoors was obtained using the conversion coefficient (0.7 Sv Gy⁻¹) from the absorbed dose in air. The outdoor and indoor occupancy factor was 0.2 and 0.8 respectively. AED was calculated using eqs (1) and (2) as follows

AEDₘₐₓ (mSv) = D (nGy h⁻¹) × 8760 h × 0.2 × 0.7 (Sv Gy⁻¹),

AEDₙₐₗₜ (mSv) = 176 × 8760 × 0.2 × 0.7,

AEDₜₒᵤₜₜ (mSv) = 0.216 mSv. (1)

The mean outdoor and indoor gamma radiation dose rate in Malaysia are approximately the same, 92 and 94 nGy h⁻¹ respectively. Therefore, the indoor gamma radiation dose rate in Pahang state should also be approximately 176 nGy h⁻¹

AEDₙₐₗₜ (mSv) = 176 × 8760 × 0.2 × 0.7,

AEDₜₒᵤₜₜ (mSv) = 0.863 mSv. (2)

The value of annual effective dose rate outdoors and indoors in the study area was found to be 0.216 and

<table>
<thead>
<tr>
<th>Geological formation</th>
<th>Mean</th>
<th>Standard error</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Lower bound</th>
<th>Upper bound</th>
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<td>45</td>
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<td>57</td>
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<td>89</td>
<td>57</td>
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<td>75</td>
<td>59</td>
<td>339</td>
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<td>207</td>
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<td>Permian 21</td>
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<td>7</td>
<td>61</td>
<td>35</td>
<td>315</td>
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<td>146</td>
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<td>Carboniferous 25</td>
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<td>80</td>
<td>39</td>
<td>348</td>
<td>114</td>
<td>193</td>
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<td>Devonian 30</td>
<td>180</td>
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<td>116</td>
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<td>587</td>
<td>137</td>
<td>224</td>
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<td>Acid intrusive 38</td>
<td>258</td>
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<td>125</td>
<td>36</td>
<td>631</td>
<td>234</td>
<td>281</td>
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<td>Acid intrusive 39</td>
<td>367</td>
<td>43</td>
<td>194</td>
<td>99</td>
<td>750</td>
<td>276</td>
<td>457</td>
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<table>
<thead>
<tr>
<th>District</th>
<th>N</th>
<th>Mean</th>
<th>Standard error</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>95% confidence interval for mean</th>
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<td>Cameron Highlands</td>
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<td>285</td>
<td>13</td>
<td>42</td>
<td>222</td>
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<td>257 to 313</td>
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<td>Raub</td>
<td>85</td>
<td>235</td>
<td>17</td>
<td>158</td>
<td>26</td>
<td>750</td>
<td>201 to 269</td>
</tr>
<tr>
<td>Lipis</td>
<td>65</td>
<td>135</td>
<td>8</td>
<td>68</td>
<td>46</td>
<td>302</td>
<td>118 to 152</td>
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<tr>
<td>Temerloh</td>
<td>62</td>
<td>192</td>
<td>14</td>
<td>111</td>
<td>44</td>
<td>511</td>
<td>164 to 220</td>
</tr>
<tr>
<td>Jerantut</td>
<td>90</td>
<td>158</td>
<td>9</td>
<td>81</td>
<td>35</td>
<td>435</td>
<td>141 to 175</td>
</tr>
<tr>
<td>Bentong</td>
<td>62</td>
<td>248</td>
<td>19</td>
<td>146</td>
<td>78</td>
<td>631</td>
<td>211 to 286</td>
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<tr>
<td>Bera</td>
<td>84</td>
<td>139</td>
<td>10</td>
<td>89</td>
<td>39</td>
<td>522</td>
<td>119 to 158</td>
</tr>
<tr>
<td>Rompin</td>
<td>93</td>
<td>169</td>
<td>11</td>
<td>110</td>
<td>35</td>
<td>620</td>
<td>146 to 192</td>
</tr>
<tr>
<td>Pekan</td>
<td>32</td>
<td>154</td>
<td>14</td>
<td>78</td>
<td>39</td>
<td>348</td>
<td>126 to 182</td>
</tr>
<tr>
<td>Maran</td>
<td>29</td>
<td>102</td>
<td>9</td>
<td>51</td>
<td>39</td>
<td>216</td>
<td>82 to 121</td>
</tr>
<tr>
<td>Kuantan</td>
<td>27</td>
<td>149</td>
<td>13</td>
<td>68</td>
<td>59</td>
<td>349</td>
<td>122 to 176</td>
</tr>
</tbody>
</table>

| Mean                  | 640  | 176  | 5              | 115                | 26      | 750     | 167 to 185                     |

Table 2. Statistical distribution of gamma radiation dose rates in Pahang state, Malaysia

Table 3. Mean of gamma radiation dose rate for each geological formation of Pahang state
0.863 mSv respectively. These values are three and two times the world average value of 0.07 and 0.41 mSv respectively. The total annual effective dose rate is therefore given by

$$A_{\text{ED, tot}} = A_{\text{ED, out}} + A_{\text{ED, in}},$$

$$A_{\text{ED, out}} = 0.216 + 0.863 = 1.079 \, \text{mSv.} \quad (3)$$

This is more than two times the world average value of 0.48 mSv. The collective effective dose (SC) was estimated using eq. (4)

$$SC = A_{\text{ED, tot}} \times N(P),$$

where $N(P)$ is the inhabitant population in the state, which is 1,500,817 (ref. 3)

$$SC = 1.079 \times 1500817 = 1.62 \times 10^6 \, \text{mSv.}$$

The average lifetime dose rate (ALED) and cancer risk ($R$) for an individual living in Pahang state were estimated using eqs (5) and (6) (ref. 8)

$$A_{\text{LED}} (\text{mSv}) = A_{\text{ED, tot}} (\text{mSv}) \times A_{\text{L}} (y), \quad (5)$$

where $A_{\text{L}}$ is the average life expectancy of 75 years in Pahang state (ref. 9)

$$A_{\text{LED}} (\text{mSv}) = 1.079 \times 75 = 80.93 \, \text{mSv.}$$

The cancer risk

$$R = A_{\text{ED, tot}} \times RF, \quad (6)$$

where RF is the risk factor which is $5.82 \times 10^{-2} \, \text{Sv}^{-1}$ (ref. 10). Therefore

$$R = 1.079 \times 10^{-3} \times 5.82 \times 10^{-2} = 6.28 \times 10^{-5}.$$

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Figure 4. Isodose map of gamma dose rates in Pahang state.
The lifetime cancer risk $R_L$ is given by

$$R_L = A_{L_L} \times R,$$

$$= 75 \times 6.28 \times 10^{-4} = 4.7 \times 10^{-3}.$$

(7)

The computed lifetime effective dose, cancer risk and lifetime cancer risk for an individual living in Pahang state were 81 mSv, $6.28 \times 10^{-5}$ and $4.7 \times 10^{-3}$ respectively.

The results for gamma radiation dose rates at each measurement point were plotted using the ArcGIS software. Figure 4 shows a plot of the computer-generated Isodose map of gamma radiation dose rates in Pahang state.

A few areas of enhanced activity ranging between 500 and 750 nGy h$^{-1}$ were noted. These areas are predominantly underlaid by acidic granite intrusives rock formations. Lowest gamma radiation dose rate between 20 and 50 nGy h$^{-1}$ was found mostly in the southeastern coast in Pekan district, which is underlaid by Quaternary geological formation covered by peat soil. Table 4 provides a summary of annual effective gamma radiation dose rate, mean lifetime dose rate and cancer risk in different areas in Malaysia. The United Nations Scientific Committee on the Effect of Atomic Radiation reported that the natural radiation dose rate outdoors in Malaysia is 92 nGy h$^{-1}$. Pahang state has recorded approximately twice the average value of Malaysia.

Thus, this study presents the distribution of gamma radiation dose rates over different underlying geological formations for Pahang state. The data supports a strong link between gamma radiation dose rates and underlying geological formations. Acid and intermediate intrusive igneous rock terrain (undifferentiated) in Pehang state gave the highest mean TGRD of 367 nGy h$^{-1}$, whereas Quaternary geological formations formed from continental and marine deposits with unconsolidated humic clay, peat and silt yielded the lowest mean TGRD of 99 nGy h$^{-1}$. From the distribution of gamma radiation dose rate in Pahang state, the mean gamma radiation dose rate was found to be 176 nGy h$^{-1}$. This gives the annual outdoor effective dose equivalent to the population of 0.216 mSv. The lifetime equivalent dose and relative life time cancer risk for an individual living in Pahang state are 81 mSv and $4.7 \times 10^{-3}$ respectively. These values are more than two times the world average of 34 mSv and 1.95 $\times 10^{-3}$ respectively. However, this does not translate into significant cancer risk in the area. The data could be used as a baseline for future radiological studies in the area as well as other areas with similar geological formations.


### Table 4: Summary of radiological indices in different areas of Malaysia and the world

<table>
<thead>
<tr>
<th>State/district</th>
<th>Mean dose rates (outdoor) (nGy h$^{-1}$)</th>
<th>AED$_{m}$ (µSv)</th>
<th>Mean lifetime dose (mSv)</th>
<th>Cancer risk</th>
<th>Lifetime cancer risk</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pahang state</td>
<td>176</td>
<td>216</td>
<td>81</td>
<td>6.28 $\times 10^{-5}$</td>
<td>4.7 $\times 10^{-3}$</td>
<td>Present study</td>
</tr>
<tr>
<td>Negeri Sembilan</td>
<td>330</td>
<td>405</td>
<td>30</td>
<td>2.36 $\times 10^{-5}$</td>
<td>1.8 $\times 10^{-3}$</td>
<td>11</td>
</tr>
<tr>
<td>Jhelum valley, Pakistan</td>
<td>116</td>
<td>654</td>
<td>43</td>
<td>3.29 $\times 10^{-5}$</td>
<td>2.17 $\times 10^{-3}$</td>
<td>12</td>
</tr>
<tr>
<td>Terengganu state</td>
<td>150</td>
<td>184</td>
<td>69</td>
<td>5.35 $\times 10^{-5}$</td>
<td>4.0 $\times 10^{-3}$</td>
<td>13</td>
</tr>
<tr>
<td>Mersing district, Johor</td>
<td>140</td>
<td>172</td>
<td>13</td>
<td>1.00 $\times 10^{-5}$</td>
<td>0.8 $\times 10^{-3}$</td>
<td>14</td>
</tr>
<tr>
<td>Kerala, India</td>
<td>414</td>
<td>508</td>
<td>36</td>
<td>2.43 $\times 10^{-5}$</td>
<td>1.7 $\times 10^{-3}$</td>
<td>15</td>
</tr>
<tr>
<td>W. Mazandaran, Iran</td>
<td>612</td>
<td>750</td>
<td>53</td>
<td>3.71 $\times 10^{-5}$</td>
<td>2.6 $\times 10^{-3}$</td>
<td>16</td>
</tr>
<tr>
<td>Kg. Sg. Durian, Perak</td>
<td>458</td>
<td>562</td>
<td>42</td>
<td>3.27 $\times 10^{-5}$</td>
<td>2.5 $\times 10^{-3}$</td>
<td>17</td>
</tr>
<tr>
<td>Kirkareli, Turkey</td>
<td>118</td>
<td>144</td>
<td>10</td>
<td>0.71 $\times 10^{-5}$</td>
<td>0.51 $\times 10^{-3}$</td>
<td>18</td>
</tr>
<tr>
<td>Palong, Johor</td>
<td>500</td>
<td>613</td>
<td>46</td>
<td>3.56 $\times 10^{-5}$</td>
<td>2.7 $\times 10^{-3}$</td>
<td>19</td>
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<tr>
<td>Malaysia</td>
<td>92</td>
<td>113</td>
<td>43</td>
<td>3.34 $\times 10^{-5}$</td>
<td>2.5 $\times 10^{-3}$</td>
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<td>World</td>
<td>59</td>
<td>72</td>
<td>34</td>
<td>2.79 $\times 10^{-5}$</td>
<td>1.95 $\times 10^{-3}$</td>
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</table>
to anticipate and reduce their negative effect on native ecosystems. The potential distribution can be predicted using invasive species distribution models (iSDMs). Thus far, few studies have investigated the human influence on the distribution of alien species when modelling their potential distribution. In the present study, we predict the potential distribution of *Acacia farnesiana* in the Himalayan hotspot using a popular iSDM. The effect of human influence was studied by comparing the potential distribution predicted using only bioclimatic variables and that using both bioclimatic and human footprint variables. We found that using both bioclimatic and human footprint variables, the potential distribution of target species could be 55.38% larger than that of using only bioclimatic variables. This proves the positive effect of human activities on distribution of invasive species. Among the six considered bioclimatic variables, the mean temperature of the coldest quarter, the precipitation of the coldest quarter, and temperature seasonality are the most influential factors in determining the potential distribution of *A. farnesiana*.

**Keywords:** *Acacia farnesiana*, alien species, human footprint, potential distribution.

The spread of alien species that have been deliberately or unwittingly introduced into new habitats has resulted in inevitable consequences to various native ecosystems\(^1\)–\(^2\). The ecological consequence of alien species is a major one. For example, in South Africa, cattle grazing over the past six centuries has enabled invasive scrub and small trees to displace much of the original grassland, resulting in a massive reduction in forage for native bovid and other grazers\(^3\). Since the introduction of rabbits to Australia from Europe, these animals have become the most significant factors contributing to native species loss and have been identified to be responsible for serious erosion problems because they consume surface plants and leave the topsoil exposed and vulnerable to sheet, gully and wind erosion\(^4\). The invasion of alien species can also adversely affect the following: natural ecosystems\(^5\)–\(^6\), agriculture and forestry production\(^1\), recreation activities such as fishing, hiking and hunting\(^2\), human health\(^7\)–\(^10\) and genetic pollution\(^11\).

The negative effects of invasive species on various ecosystems can be reduced if detailed information related to the actual distribution of these species is obtained. These negative effects can also be anticipated if the potential distribution of the species is delineated. Although the actual distribution of invasive species cannot be reliably obtained because of the expensive investigation cost, the potential distribution can be modelled using invasive species distribution models (iSDMs). The iSDMs have been used to project the potential distribution of invasive species, investigate the relationship between invasive species and environmental conditions, and provide useful information for conservation planning.