Izvirni znanstveni članek / Original scientific article

THE INFLUENCE OF LAND USE ON THE SPATIAL DISTRIBUTION AND INTENSITY OF HEAT ISLANDS IN SLOVENIA

VPLIV RABE TAL NA PROSTORSKO RAZPOREDITEV IN INTENZIVNOST TOPLOTNIH OTOKOV V SLOVENIJI

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ABSTRACT

Heat islands (HI) are a common anthropogenic phenomenon and are defined as artificial surfaces (urban areas) that have a higher average temperature than their surroundings (rural areas). The aim of this work was to determine the influence of land use on the spatial distribution and intensity (HI_i) of HI in Slovenia. The MODIS Land Surface Temperature (LST) and Corine Land Cover (CLC) databases were used to perform the analysis. Within the identified HI, two HI levels were determined based on temperature difference. The results revealed a statistically significant negative correlation between HI_i and both forest cover and forest fragmentation (forest edge density and ratio of mean forest patch size to HI size). Artificial surface was positively correlated with HI_i. The results contribute to the understanding of the spatial distribution of HI and HI_i and provide information for spatial planning and policy-making to reduce the negative impact of HI.

Ključne besede: heat island (HI), forest cover, artificial surface, forest fragmentation

IZVLEČEK

Toplotni otoki (HI) so pogost antropogeni pojav, ki ponazarjajo temperaturno razliko med umetnimi površinami (urbana območja) in okolico (ruralna območja). Namen prispevka je ugotoviti vpliv rabe tal na prostorsko razporeditev in intenziteto HI (HI_i) v Sloveniji. Uporabili smo karto temperature površja MODIS LST in podatke rabe tal Corine Land Cover (CLC). Na podlagi temperaturnih razlik smo določili dve ravni HI. Rezultati so pokazali statistično značilno negativno korelacijo med HI_i in gozdnatostjo in/ali fragmentiranostjo gozdov (gostota gozdnega roba in razmerje povprečna velikost gozdne zaplate - velikost HI). Umetne površine vplivajo na povečanje HI_i. Rezultati prispevajo k razumevanju prostorske razporeditve HI in HI_i ter dajejo informacije za prostorsko načrtovanje in oblikovanje politik za zmanjšanje negativnega vpliva HI.

Key words: toplotni otok (HI), gozdnatost, umetne površine, fragmentiranost gozda

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1 INTRODUCTION

1 UVOD

It is expected that 66 % of the world's population will live in cities by 2050 (Gunawardena et al., 2017). With the rapid expansion of cities, urban sprawl is encroaching into green spaces, leading to their fragmentation into heterogeneous forms with irregular boundaries or even total loss (Kong, 2014a). Urbanisation increases the frequency and severity of extreme weather events, such as heat islands (hereafter HI) (Komac et al., 2017; Zalar et al., 2017).

HI are defined as urban areas with significantly higher temperatures compared to their rural surroundings (Schwarz et al., 2011). The main cause of urban HI is the absorption and radiation of solar energy by urban structures and other anthropogenic heat sources (Rizwan et al., 2008). Due to heat stress, HI affect urban ecosystems, energy demand, air quality and consequently public health and well-being (Luo et al., 2007; Rizwan et al., 2008).

In addition to urbanisation, activities such as agriculture, grazing, forestry and irrigation can directly alter heat flow at the land surface and indirectly alter atmospheric circulation. Consequently, local temperature increases occur (Jusuf et al., 2007), leading to the formation of HI. The potential to reduce HI is associated with urban geometry and urban greening. Street trees and urban park design are some of the most important elements that determine the incidence of sunlight and wind speed in urban greening design (Jamei et al., 2016). Effective techniques to reduce HI include changes in land use and land cover, as well as urban land use patterns (i.e. urban geometry), the use of low albedo objects and building materials, and the use of different types of (building) greening. The relationship between land use and climate has increasingly drawn the attention of urban planners and policy makers to the identification, formulation and implementation of urban development strategies to improve the well-being of the population (Meerow and Newell, 2017).

Most studies have identified urban green spaces as one of the most efficient and simple nature-based solutions to reduce urban HI (e.g. Norton et al., 2015), especially due to their cooling and shading effects and absorption of short-wave radiation (Kong et al., 2014b). Studies examining the effects of forests and other green spaces on average temperature variability have shown that temperatures are lower in forests than in other areas (Dugord et al., 2014; Kong et al., 2014b; Nastran et al., 2019). Due to their thermal benefits, urban forests play an important role in reducing HI intensity (hereafter HI_i) and improving the quality of life in cities. On the other hand, the amount of artificial land is a crucial factor affecting the size of urban HI and HI_i (Lin et al., 2016). Moreover, some studies (e.g. Dugord at al., 2014; Kong et al., 2014b; Nastran et al., 2019) show that urban HI depend not only on the proportion of a particular land use, but also on its spatial configuration.

Urban planners should prevent deforestation of green areas for construction purposes and ensure the even distribution of green areas in cities. Trees and vegetation reduce surface and air temperature through shading and evapotranspiration. Vegetation in urban environments can reduce energy consumption, improve air quality, reduce greenhouse gasses, manage stormwater, improve water quality and reduce noise. It also enhances the aesthetic value of an area and is a popular recreational area during heat waves, when temperatures outside forests threaten human health. The dynamic cooling effects of green and forest areas are therefore becoming increasingly important (Oliveira et al., 2011; Aram et al., 2019).

The main objective of this study was to analyse how land use influences the spatial distribution and intensity of HI in Slovenia. The correlation between the selected land use cover and HI_i is shown with forest fragmentation indices (forest edge density and ratio of mean forest patch size to HI size). The three hypotheses underlying this study are as follows:

- The effect of forest cover on HI_i is statistically significant and negative.
- The effect of artificial surface on HI_i is statistically significant and positive.
- The effect of forest fragmentation on HI_i is statistically significant and negative.

2 DATA AND METHODS

2 PODATKI IN METODE

2.1 Study area

2.1 Območje raziskave

The study area covered the entire territory of Slovenia, a Central European country with traditionally scattered and relatively small urban areas. Slovenia has a continental climate with hot summers and cold winters in the plateaus and valleys to the east and north, and a Mediterranean climate near the coast. The Slovenian littoral refers to the short coastline and southeast strip of predominantly karstic topography. The towns are predominately located on flat terrain, while smaller villages are located on steep terrain.

According to Corine Land Cover (hereafter CLC) data, there were 34 land cover categories in Slovenia in 2012, out of the 44 defined by the CLC methodology. The proportion of different types of land cover in Slovenia is as follows: forests and other semi-natural land (58 %), agricultural land (35 %), artificial surfaces (3 %), wetlands (2 %) and water bodies (2 %) (EEA, 2016).

2.2 Source of data

2.2 Viri podatkov

2.2.1 Land use map (Corine Land Cover - CLC)

2.2.1 Karta rabe tal (Corine Land Cover - CLC)

We used the 2012 CLC map for the whole Slovenian territory (EEA, 2016). The original methodology for the Slovenian CLC used in this analysis is based on visual photo interpretation of Landsat satellite imagery at a scale of 1:100,000. The classification is hierarchical at three levels. The first level comprises five CLC classes: 1) artificial surfaces, 2) agricultural land, 3) forest and semi-natural land, 4) wetlands and 5) water bodies. The second level comprises 15 land use categories and the third includes 44 land use categories.

In this analysis, we used the following categories of land uses:

- artificial surfaces (CLC code: 112 - discontinuous, urban fabric, 121 - industrial or commercial units, 122 - road and rail networks and associated land, 124 - airports, 131 - mineral extraction sites and 133 - construction sites)
- green urban areas (CLC code: 141 - green urban areas and 142 - sport and leisure facilities)
- agricultural areas (CLC code: 211 - non-irrigated ara-

ble land, 221 - vineyards, 222 - fruit trees and berry plantations, 231 - pastures, 242 - complex cultivation patterns and 243 - land principally occupied by agriculture, with significant areas of natural vegetation)
- forests (CLC code: 311 - broad-leaved forest, 312 - coniferous forest, 313 - mixed forest, 321 - natural grasslands and 324 - transitional woodland-shrub)
- wetlands (CLC code: 411 - inland marshes, 511 - water courses and 512 - water bodies)

Other land uses were not present in the HI in Slovenia.

2.2.2 Map of the land surface temperature of Europe (LST)
2.2.2 Karta temperature površja Evrope (LST)

The MODIS Land Surface Temperature (LST) map of Europe with a spatial resolution of 250 × 250 m was used for the determination of HI and measurement of HI_i. The dataset per each pixel included four temporal records per day. The LST map is based on the analysis of records reconstructed from MODIS satellite data from 2001 to 2011 (Metz et al., 2014) and includes night-time and daily temperatures. Ten-year average temperature data eliminates abnormalities in the occurrence of HI. The LST dataset is available online for download and direct usage in GIS programs on the GFOSS Blog webpage (Metz et al., 2014).

Since the correlation of HI_i and HI with urban green infrastructure is highest in summer (Chang et al., 2007; Hamada and Ohta, 2010; Imhoff et al., 2010; Li et al., 2011), we used the average temperature of the warmest quarter of the year, i.e. June, July and August. HI smaller than 50 ha were eliminated from the study, so every HI polygon could be represented with at least 8 image cells (temperature values).

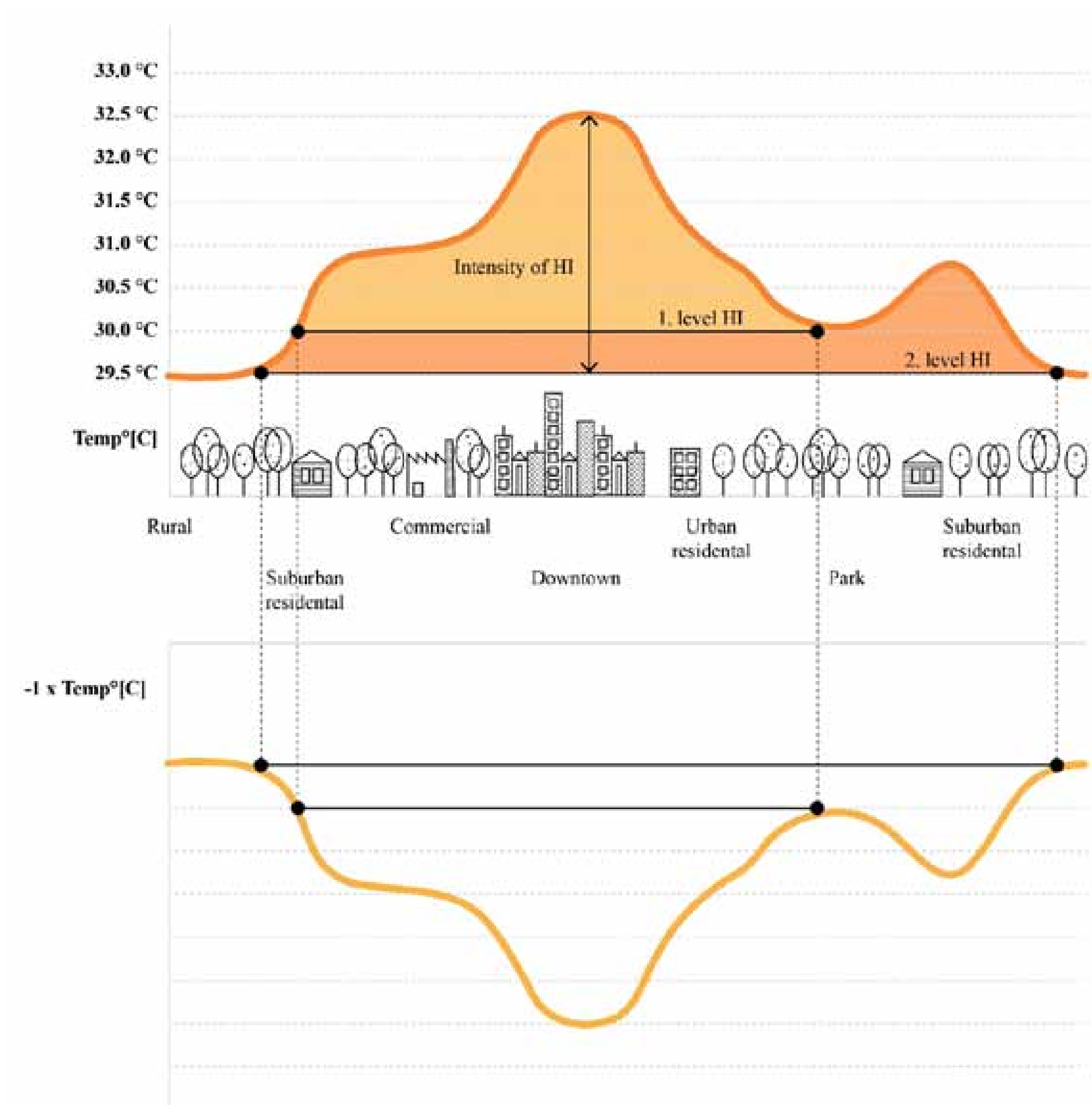

Fig. 1: Example of elimination of higher level HI (adapted by: Obu and Podobnikar, 2013; Kralj, 2017)

Slika 1: Primer omejevanja kotanj višjega reda (prirejeno po: Obu and Podobnikar, 2013; Kralj, 2017)

2.3 Determination of HI
2.3 Določanje HI

The determination of HI was based on a GIS algorithm used for watershed delineation in hydrological analyses, where delineation was based on the simulation of waterflow over the surface raster map. We replaced the surface raster map with the temperature raster map and multiplied by the constant value of -1 to create a map of inverse temperature where the local minimum value (sink) represented the highest value of temperature and vice versa (Fig. 1). The further procedure was the same as described by Doctor and Young (2013), Obu and Podobnikar (2013) and Kobal et al. (2015) and is based on water flow simulations on a surface raster map (inverse temperature) and incorporated three steps: (i) watershed delineation (increasing temperature along the gradient from rural to urban area), (ii) confining sinkholes (HI) and (iii) confining higher rank sinkholes (higher level of HI).

The spatial distribution of HI was defined in ArcMap 10.5.1. (ESRI, 2017) using the tools from the "Hydrology" toolbox implemented in Model Builder. The flow direction for each raster cell was identified, and each raster cell received a value representing the total number of raster cells that drained into it. In the second step, effluent levels confined the sinkholes (HI), and the raster cells below the effluent level were designated as part of the sinkhole (HI). The input data in this step included a layer containing delineated watersheds and a layer containing inverse temperature information. For each delineated watershed, the raster cell with the lowest inverse temperature value among the watershed boundary raster cells was defined as the effluent level. The output consisted of a list of watersheds with elevation information for the effluent raster cells, and the raster cells below the effluent level were assigned as forming an HI. In the third step, sinkholes (HI) were ranked according to their locations and sizes with respect to surrounding sinkholes (HI). The 1st level of sinkholes (HI) are the smallest and are located within larger sinkholes (HI) of a higher rank. Figure 1 contains a graphical presentation of sinkholes (HI) of different ranks. When a smaller sinkhole (HI) was located within a larger sinkhole (HI), the effluent level was first determined for the smaller sinkhole (HI). HI intensity (HI_i) was defined here as the range of temperature inside the above described methodology for the delineation of HI.

Based on the LST map, the size and spatial distribution of HI were determined by extracting polygons with an area greater than 50 ha, where the temperature difference was more than 0.1 °C compared to the neighbouring area.

2.4 Variables considered and statistical analyses
2.4 Obravnavane spremenljivke in statistična analiza

To determine the two HI levels, we evaluated the effects of various variables on HI_i. For this study we

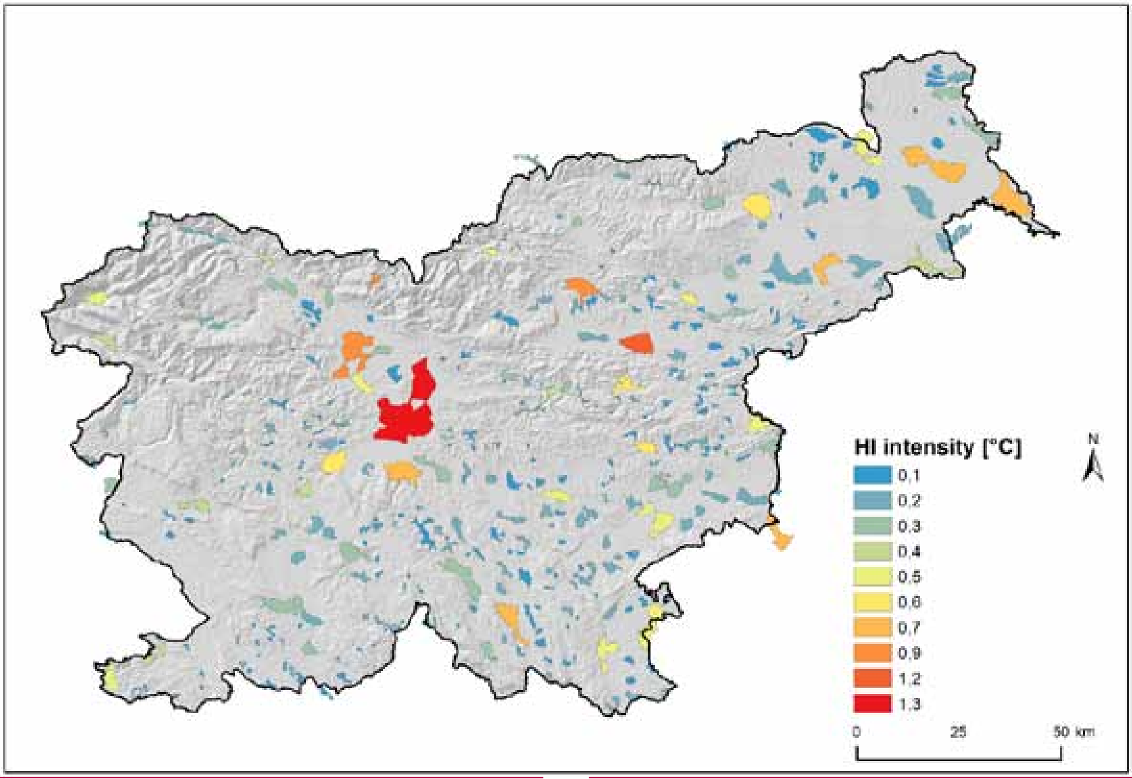

Fig. 2: Spatial distribution of HI and HI_i in Slovenia - 1st level

Slika 2: Prostorska porazdelitev HI in HI_i v Sloveniji - raven 1 chose forest area because it is the most common land cover in Slovenia, and artificial surface area because it has been proven that HI are most intense in built up areas. We considered two variables as a forest fragmentation indicator: i) forest edge density and ii) ratio of mean forest patch size to HI size.

Simple linear regression with log transformation of variables was used to relate HI_i to corresponding attributes at the single HI level. All statistical analyses were done in Python3 using the *numpy* and *statsmodels* packages.

3 RESULTS
3 REZULTATI
3.1 Spatial distribution and intensity of HI in Slovenia
3.1 Prostorska razporeditev in intenziteta HI v Sloveniji

We identified 392 and 60 HI at the 1st and 2nd level of HI, respectively (Fig. 2 and Fig. 3). HI size ranges from 0.5 to 551.8 km^2. The mean size of HI is 5.40 km^2 (1st level) and 60.00 km^2 (2nd level). HI of the 1st level occur in large cities and their surroundings (e.g. Ljubljana, Kranj, Celje, Velenje, Murska Sobota, Lendava, Koper and Nova Gorica), while HI of the 2nd level occur in larger cities and form "HI agglomerations" (e.g. Ljubljana - Kranj, Celje - Velenje, Maribor - Ptuj, Murska Sobota - Lendava, Krško - Zagreb, Novo mesto, Carinthia region - Austria). HI_i ranges from 0.1 to 1.8 °C, with a mean value of 0.19 °C (1st level) and 0.58 °C (2nd level).

Forest cover within HI ranges from 0 to 100.0 % (Table 1). Mean forest cover within HI with the lowest HI_i is 53.2 % and 9.8 % with HI_i = 1.3 °C (1st level). Mean forest cover within HI with the lowest HI_i is 60.7 % and 18.8 % with HI_i = 1.8 °C (2nd level).

The artificial surface within HI ranges from 0 to 73.0 % (Table 1). The lowest value of HI_i is observed in the area without artificial surfaces (both levels of HI). The highest value of HI_i is observed in HI with 47 % of artificial surface (1st level) and 30 % of artificial surface (2nd level). At the 2nd level of HI, with the highest share of artificial surfaces (41.3 %), HI_i increases by 1.1 °C compared to the surroundings.

Forest edge density ranges from 0.0 to 59.7 m/ha and is on average lower at the 2nd level of HI (17.00 m/ha). The HI with the highest value of HI_i has 5.31 m/ha of forest edge (1st level). The forest edge density of the lowest value of HI_i at the 2nd level of HI level range from 15.9 m/ha to 36.97 m/ha, while the HI with the highest value of HI_i vary from 9.29 m/ha to 15.05 m/ha of forest edge (Table 2).

The ratio between the mean forest patch size and size of HI ranges from 0.01 (smaller forest patches, forests are more fragmented) to 0.99 (larger forest patches, forests are less fragmented) (Table 1). HI at the 1st level have a higher value of HI_i with a higher ratio of the mean forest patch size to HI size, while HI at the 2nd level have a lower value of HI_i up to 1. The largest forest patch size is 7.12 km^2 with an intensity of 0.3 °C.

3.2 The influence of land use on the intensity of HI in Slovenia
3.2 Vpliv rabe tal na intenziteto HI v Sloveniji
3.2.1 The influence of forest cover on HI_i
3.2.1 Vpliv gozdnatosti na HI_i

The results of the statistical analysis confirm a statistically significant negative effect ($p < 0.05$) of forest cover on HI_i (Fig. 4). The effect of forest at the first level

Table 1: Characteristics of HI for both levels

Preglednica 1: Značilnosti HI na obeh ravneh

HI *HI*		1st level *Raven 1*	2nd level *Raven 2*
	Number / *Število*	392	60
	Size range / *Razpon velikosti*	0.5–151.1 km^2	0.6–551.8 km^2
	Mean size / *Povprečna velikost*	5.40 ± 1.05 km^2	60.00 ± 24.76 km^2
	Total area / *Skupna površina*	2115.56 km^2	3600.06 km^2
HI_i *HI_i*	Range / *Razpon*	0.1–1.3 °C	0.1–1.8 °C
	Mean / *Povprečje*	0.19 ± 0.02 °C	0.58 ± 0.11 °C
Forest cover *Gozdnatost*	Range / *Razpon*	0.0–100.0 %	6.1–100.0 %
	Mean / *Povprečje*	46.38 ± 3.15 %	38.23 ± 6.66 %
Artificial surface *Delež umetnih površin*	Range / *Razpon*	0.0–73.0 %	0.0–41.3 %
	Mean / *Povprečje*	5.76 ± 1.19 %	7.81 ± 2.50 %
Forest edge density *Gostota gozdnega roba*	Range / *Razpon*	0.0–59.7 m/ha	0.0–38.3 m/ha
	Mean / *Povprečje*	18.2 ± 1.29 m/ha	17.00 ± 2.15 m/ha
Mean forest patch size / HI size *Povprečna velikost zaplate gozda / velikost HI*	Range / *Razpon*	0.01–0.99	0.01–0.99
	Mean / *Povprečje*	0.36 ± 0.03	0.19 ± 0.07

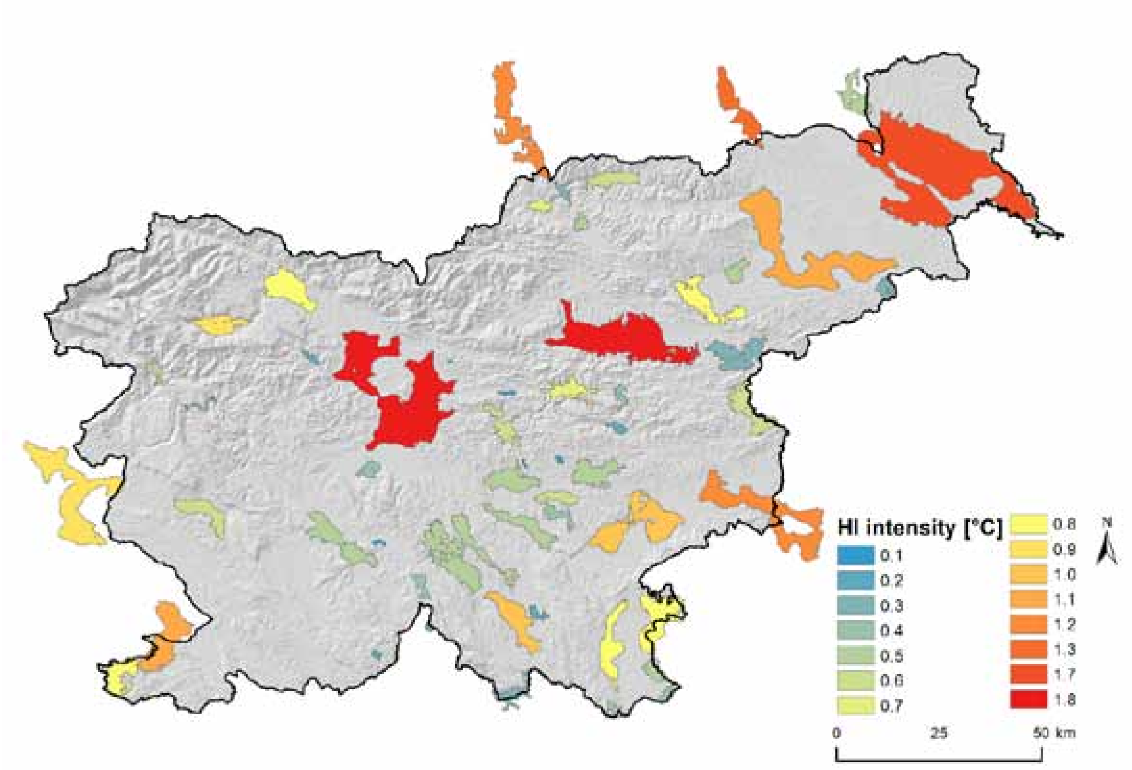

Fig. 3: Spatial distribution of HI and HI_i in Slovenia - 2nd level

Slika 3: Prostorska porazdelitev HI in HI_i v Sloveniji - raven 2

is smaller (for a 10 percentage point increase in forest cover, HI_i decreases by 4.7 %) than that at the second level (for a 10 percentage point increase in forest cover, HI_i decreases by 18.4 %).

3.2.2 The influence of artificial surface on HI_i
3.2.2 Vpliv deleža umetnih površin na HI_i

The results of the statistical analysis confirm a statically significant positive ($p < 0.05$) effect of artificial surfaces on HI_i at both levels (Fig. 5). The effect of artificial surfaces at the 1st level is lower (for a 10 percentage point increase in artificial surface cover, HI_i increases by 21.6 %) than for the 2nd level (for a 10 percentage point increase in artificial surfaces cover, HI_i increases by 48.5 %).

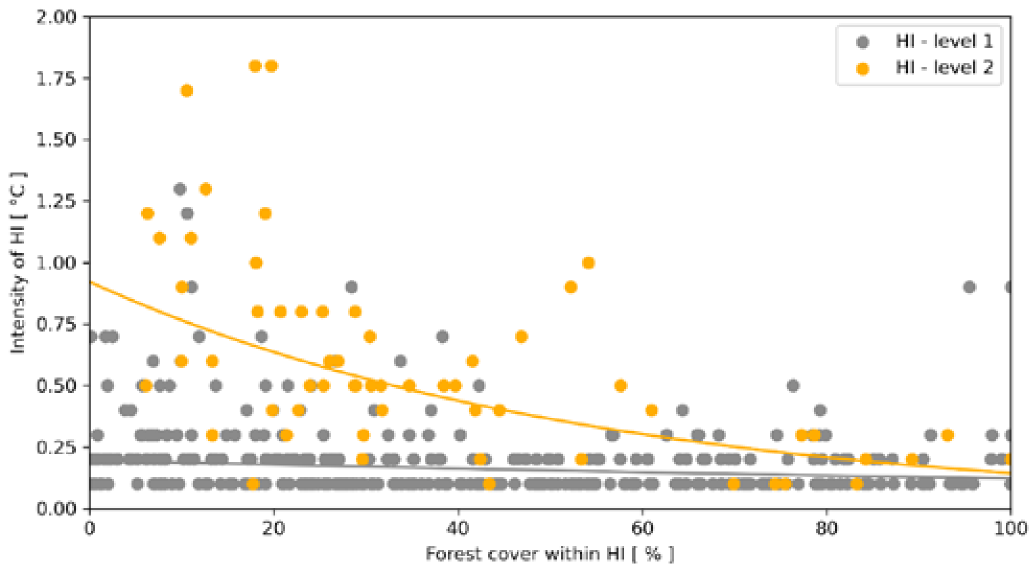

Fig. 4: The influence of forest cover on HI_i for both levels of HI in Slovenia

Slika 4: Vpliv gozdnatosti na HI_i za obe ravni HI v Sloveniji

Table 2: Linear model equations, level of statistical significance (p), and coefficient of determination (R^2) for the dependence of HI intensity (HI_i) on forest cover (COV_f) for both levels of HI

Preglednica 2: Enačbe linearnega modela, statistična značilnost (p) in koeficient determinacije (R^2) za odvisnost intenzivnosti HI (HI_i) od deleža gozdov (COV_f) znotraj HI za obe ravni

HI	Equation	*p*	R^2
1st level *1. raven*	$\log(HI_i) = -1.629 - 0.005 \times COV_f$	< 0.001	0.07
2nd level *2. raven*	$\log(HI_i) = -0.081 - 0.017 \times COV_f$	< 0.001	0.39

Table 3: Linear model equations, level of statistical significance (p), and coefficient of determination (R^2) for the dependence of HI intensity (HI_i) on artificial surfaces (COV_a) for both levels of HI

Preglednica 3: Enačbe linearnega modela, statistična značilnost (p) in koeficient determinacije (R^2) za odvisnost intenzivnosti HI (HI_i) od deleža umetnih površin (COV_a) znotraj HI obeh ravni

HI	Equation	*p*	R^2
1st level *1. raven*	$\log(HI_i) = -1.973 + 0.021 \times COV_a$	< 0.001	0.20
2nd level *2. raven*	$\log(HI_i) = -1.161 + 0.047 \times COV_a$	< 0.001	0.36

3.3 The influence of forest fragmentation on the intensity of HI in Slovenia

3.3 Vpliv fragmentiranosti gozda na intenziteto HI v Sloveniji

3.3.1 The effect of forest edge density on HI_i

3.3.1 Vpliv gostote gozdnega roba na HI_i

The results also confirm a significant negative ($p < 0.05$) relationship between HI_i and forest edge density for the 1st level of HI and the 2nd level of HI (Fig. 6). The influence of forests on the HI of the 1st level is lower (for a 10 m/ha increase in forest edge density, HI_i decreases by 11.0 %) than that at the 2nd level (for a 10 m/ha increase in forest edge density, HI_i decreases by 39.0 %).

3.3.2 The influence of the ratio of mean forest patch size to HI size on HI_i

3.3.2 Vpliv razmerja povprečne velikosti gozdne zaplate - velikost HI na HI_i

The correlation between the ratio of mean forest patch size to HI size and HI_i is statistically significantly negative ($p < 0.05$) (Fig. 7). The influence of the ratio of mean forest patch size to HI size on HI_i at the 1st level is significantly lower (for a 10 % increase in the ratio of mean forest patch size to HI size, HI_i decreases by 1.1 %) than that at the 2nd level (for a 10 % increase in the ratio of mean forest patch size to HI size, HI_i decreases by 3.1 %).

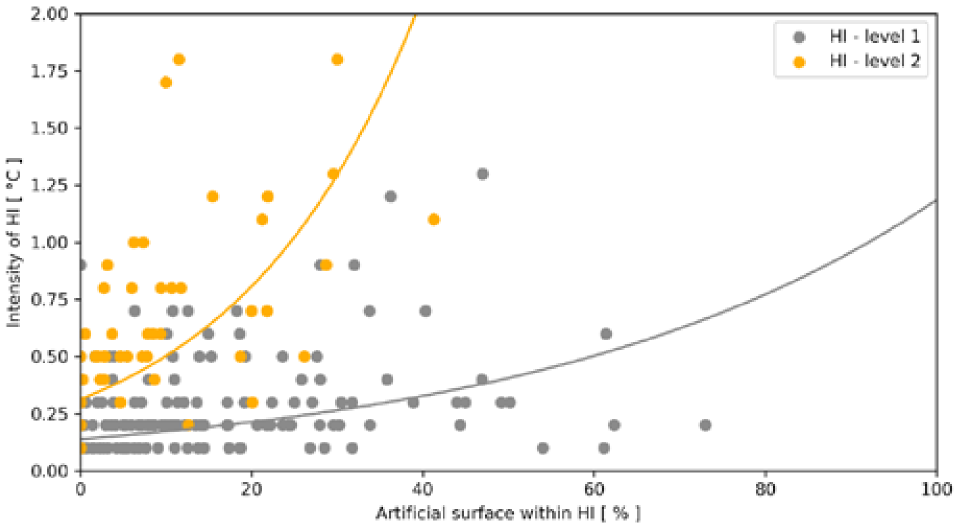

Fig. 5: The influence of artificial surface on HIi for both levels of HI in Slovenia

Slika 5: Vpliv deleža umetnih površin na HIi za obe ravni HI

Table 4: Linear model equations, level of statistical significance (p), and coefficient of determination (R^2) for the dependence of HI intensity (HI_i) on forest edge density (FED) for both levels of HI

Preglednica 4: Enačbe linearnega modela, statistična značilnost (p) in koeficient determinacije (R^2) za odvisnost intenzivnosti HI (HI_i) od gostote gozdnega roba (FED) znotraj HI za obe ravni

HI	Equation	p	R^2
1st level *1. raven*	$\log(HI_i) = -1.649 - 0.011 \times FED$	< 0.001	0.06
2nd level *2. raven*	$\log(HI_i) = -0.116 - 0.040 \times FED$	< 0.001	0.19

4 DISCUSSION AND CONCLUSION
4 RAZPRAVA IN ZAKLJUČEK
4.1 The impact of artificial surfaces on the intensity of HI
4.1 Vpliv deleža umetnih površin na intenziteto HI

Numerous studies have shown that artificial surfaces have a warming effect in urbanized areas, while vegetation has a cooling effect (Oliveira et al., 2011; Aram et al., 2019). Our study shows that the share of artificial areas has a statistically significant influence on HI_i (Fig. 5). Our results showed that the highest HI temperature increase (1.3 °C) is in areas with 47 % artificial areas, while the lowest temperature increase (0.1 °C) is in areas without artificial areas for the 1st level of HI. These findings are consistent with those of other studies. For example, Kong et al. (2014b) showed that the average surface temperature in Nanjing, China is typically higher on artificial surfaces and lower in green spaces. Yang et al. (2013) analysed the occurrence of urban HI in Beijing (China), where air temperatures increased linearly with increasing area of artificial surfaces.

4.2 The impact of forest cover on the intensity of HI
4.2 Vpliv gozdnatosti na intenziteto HI

Our study revealed that forest cover has a statistically significant negative effect on HI_i. The highest value of HI_i (1.8 °C) was observed for HI from the second level, in areas with 20.7 % artificial surfaces, and the smallest increase (0.1 °C) was observed in areas without artificial surfaces. The highest temperature increase (1.3 °C) for HI from the 1st level was observed in areas with 9.8 % forest cover, while the lowest increase (0.1 °C) was observed at the 2nd level in areas with 53.2 % forest cover (Fig. 4). Similarly, in Hanoi (Vietnam) researchers found that the warmest districts are located along the main roads and industrial zones, while colder areas are closer to green spaces and water bodies (Tran et al., 2017). Dugord et al. (2014) claim that the function of forests and other green spaces is reduced when HI_i is moderated. The cooling effect of forests was studied in Nanjing, China, where it was found that the daily mean temperature in the forest was 1.9 °C lower compared to the temperature of the surrounding

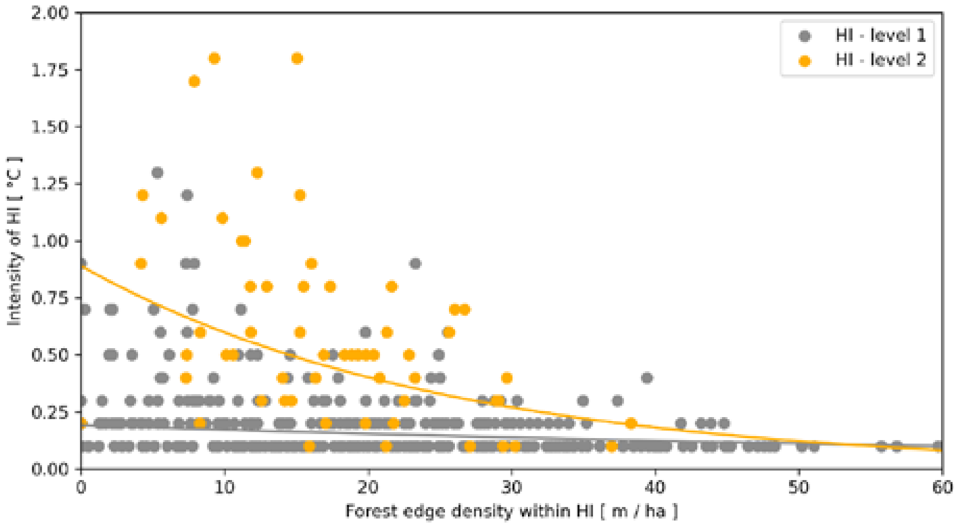

Fig. 6: The length of the forest edge calculated for the surface of forests within HI

Slika 6: Dolžina gozdnega roba glede na površino HI

Table 5: Linear model equations, level of statistical significance (p), and coefficient of determination (R^2) for the dependence of HI intensity (HI_i) on the mean forest patch size (MFPS) for both levels of HI

Preglednica 5: Enačbe linearnega modela, statistična značilnost (p) in koeficient determinacije (R^2) za odvisnost intenzivnosti HI (HI_i) od povprečne velikosti zaplate gozda (MFPS) znotraj HI za obe ravni

HI	Equation	*p*	R^2
1st level *1. raven*	$\log(HI_i) = -2.071 - 0.117 \times MFPS$	< 0.001	0.12
2nd level *2. raven*	$\log(HI_i) = -1.701 - 0.306 \times MFPS$	< 0.001	0.50

concrete surface, while the maximum daily temperature was up to 3.2 °C lower than that of the surrounding concrete surface (Kong et al., 2016). Furthermore, Kong et al. (2014b) in Nanjing, China found that a 10 % increase in forest cover reduced air temperature by 0.83 °C. These studies concluded that a sufficient amount of green space with small, fragmented forest areas would effectively ensure the cooling of the area.

4.3 The impact of forest edge density on the intensity of HI

4.3 Vpliv gostote gozdnega roba na intenziteto HI

Various fragmentation variables observed in other studies prevent a direct comparison of the results; nevertheless, some common patterns can be identified. We found that HI with higher intensity have less forest edge, and HI with lower intensity have more forest edge (Fig. 6). Li et al. (2016) pointed out that the spatial distribution and fragmentation of green space has a significant influence on surface temperature, sometimes even greater than the land use itself. In our study, the fragmentation of the forest edge had a statistically significant effect.

Our findings are in agreement with the results of other research (Chang et al., 2007; Jusuf et al., 2007) showing that the fragmentation, type, size, and shape of green spaces have a positive effect on temperature reduction. The proximity, location and size of green spaces were statistically significant factors for the reduction in air temperature (Chang et al., 2007; Jusuf et al., 2007), although how the fragmentation of green spaces contributes to the reduction of surface temperature was not considered. By understanding how vegetation cools the environment in an urban area, it may be possible to maximize the cooling potential of green spaces and to incorporate these features in urban planning for the express purpose of reducing the HI effect.

4.4 The impact of the ratio of the mean forest patch size to HI size on the intensity of HI

4.4 Vpliv povprečne velikosti gozdne zaplate na intenziteto HI

The ratio of the mean forest patch size to HI size in our study ranges from 0 (smaller forest areas, more

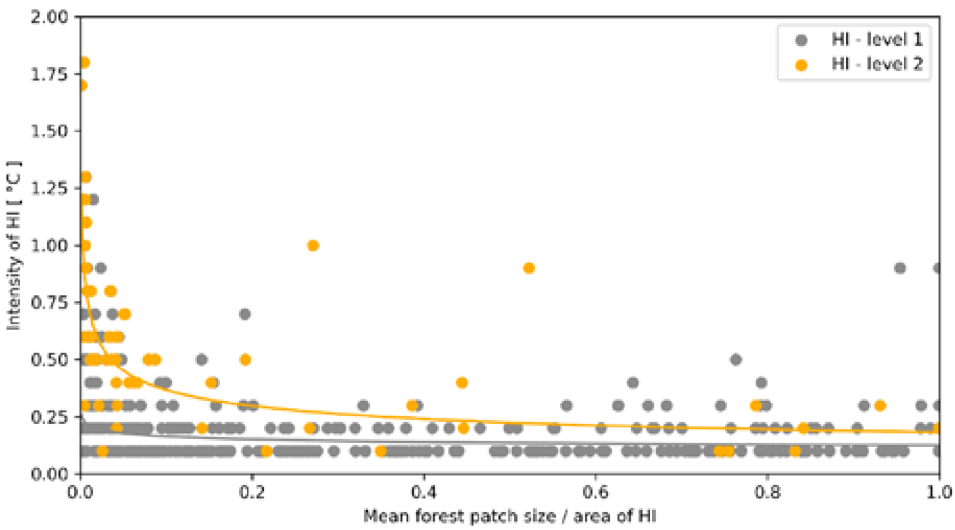

Fig. 7: The correlation between the mean forest patch size and the size of HI

Slika 7: Razmerje med povprečno velikostjo gozdne površine in površino HI fragmented) to 1 (larger forest areas, less fragmented). We confirmed that temperatures are lower in HI with larger, less fragmented forest patches and are higher in those with smaller, more fragmented forest patches (Fig. 7). We cannot compare our results with many other works because Nastran et al. (2019) found that the effects of forest configuration on urban HI_i in Europe are not the same for all climatic regions. In principle, larger and more fragmented forest areas are associated with lower urban HI_i, except in Central and Mediterranean Europe. Dugord et al. (2014) reported similar results in Berlin, Germany. They found that (although scattered vegetation is important to regulate urban temperatures) large and/or spatially aggregated green spaces are more important for temperature reduction. On the other hand, dense and interconnected traffic areas tend to increase temperatures. However, the potential cooling effect of green spaces depends strongly on the degree of tree cover (Dugord et al., 2014).

Slovenia is near Central and Mediterranean Europe, so our results coincide with the aforementioned works. Other studies have shown opposite results. Park et al. (2017) found a positive effect of small green spaces on urban HI reduction in Seoul, Korea, where the temperature dropped by 1.66 °C due to the presence of small green spaces. Kim et al. (2016) showed the influence of the shape of green spaces on surface temperatures in Austin, Texas. The number of surfaces was presented as one influencing factor. Many surfaces have a positive influence on LST reduction. Li et al. (2016) pointed out that the shape of the surface has a greater influence on temperature than the land use itself; it is better to distribute them evenly over the face rather than to concentrate them in one place.

While most research only provides a qualitative description of cooling effects, quantifiable effects and statistically significant correlations are missing. Kong et al. (2014a), Durgod et al. (2014) and Li et al. (2011, 2016) provide statistical analyses of the size, shape and fragmentation of green spaces. Kong et al. (2014a) emphasise that fragmented green spaces are also effective for cooling purposes when the forest cover is solid. Furthermore, a correlation analysis between mean patch size, patch density and an aggregation index of forest with temperature showed that for a fixed share of forest vegetation, fragmented green space also has an effective cooling effect (Kong et al., 2014a).

The results provide urban planners, architects and natural resource managers with important theoretical and practical information on urban green space planning and management that they can use to adapt to and mitigate the effects of HI that will evolve with climate change. These lessons should be taken into account in the formulation of planning strategies at higher levels and incorporated into lower-level planning guidelines. More variables need to be introduced and calculated to better understand which variable corelates most strongly with HI intensity, which would be helpful information for urban decision makers.

5 SUMMARY

5 POVZETEK

Pričujoča študija prikazuje kvantitativno raziskavo vpliva rabe tal na prostorsko razporeditev in intenzivnost pojavljanja toplotnih otokov v Sloveniji. Toplotni otoki (HI) so rezultat antropogenega delovanja v urbanih območjih in ponazarjajo temperaturno razliko med urbano in ruralno krajino. Toplotni otoki so bili v raziskavi določeni za tista območja, znotraj katerih je temperatura površja najtoplejše četrtine leta (junij, julij, avgust) presegala več kot 0,1 °C v primerjavi s temperaturo okolice. V Sloveniji se pojavljajo tako v urbanih kot ruralnih predelih države.

Raziskava preučuje vpliv gozdnih in umetnih površin na razporeditev HI, vpliv gostote gozdnega roba ter razmerje povprečna površina gozdne zaplate - velikost HI na pojavljanje HI. Podatki o rabi tal so bili povzeti po evropski karti rabe tal Corine Land Cover (EEA, 2016), podatki o povprečni temperaturi najtoplejše četrtine leta pa so bili pridobljeni na spletni strani GFOSS Blog (Metz et al., 2014). Območje raziskave je zajemalo celotno območje Slovenije ter tista območja sosednjih držav, do koder segajo vplivi HI. Analiza je podrobneje raziskala vpliv različnih rab tal (umetne površine, zelene mestne površine, kmetijske površine, gozdne površine in močvirnate površine).

Vpliv rabe tal na prostorsko razporeditev HI in intenziteto HI (HI_i) je bil obravnavan na dveh ravneh. Znotraj posameznih HI smo izračunali delež posamezne rabe tal, gostoto gozdnega roba ter povprečno velikost gozdne zaplate glede na velikost toplotnega otoka. Pri tem so bile posamezne kategorije rabe tal združene v 5 kategorij: umetne površine, kmetijske površine, gozdne in deloma ohranjene naravne površine, močvirnate površine in vodne površine. Analiza je bila opravljena v programu ArcMap 10.5.1 (ESRI, 2017). Za prostorsko določitev in razmejitev HI so bila uporabljena orodja iz paketa ArcGIS ''Hydrology''. V prvem koraku smo z orodjem ArcGIS ''Sink'' določili najnižje vrednosti rastrskih celic. V drugem koraku smo z orodjem ''Flow Direction'' določili smer padcev temperature (obrnjene vrednosti) in z uporabo ''Watershed'' določili rastrske celice z najnižjimi vrednostmi (obrnjene vrednosti). Nato smo določili najvišje vrednosti

za vsako rastrsko celico in jih združili v posamezne HI. Območje HI smo določili z dvigom povprečne temperature za 0,1 °C v primerjavi z okolico. Zaradi prostorske ločljivosti temperaturne karte so bili iz raziskave izločeni vsi otoki, manjši od 50 ha, tako da je bilo vsako območje HI predstavljeno z vsaj 8 slikovnimi celicami.

Korelacija med deležem gozda in HI_i je je statistično značilno negativna na obeh ravneh HI. Analiza vpliva gozda (slika 4) na pojavljanje HI (1. raven) kaže, da je najvišja HI_i (1,3 °C) pri 9,81 % gozdnatosti. Najnižjo HI_i (0,1 °C) pa so imeli tisti HI, ki so imeli v povprečju 53,15 % gozdnih površin. Statistično značilno negativen vpliv na HI_i ima tudi gostota gozdnega roba (slika 6). Najvišjo HI_i (1,3 °C) smo zabeležili pri 5,30 m/ha dolžine gozdnega roba. Najnižjo HI_i (0,1 °C) pa je imel HI z 59,7 m/ha gozdnega roba. Delež umetnih površin ima statistično značilen pozitiven vpliv na HI_i na obeh ravneh (slika 5).

Navedeni izsledki lahko prostorskim planerjem pomagajo pri izbiri najustreznejših ukrepov za blaženje učinkov HI, ki so lahko škodljivi tako za okolje kot zdravje ljudi.

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