Assessing Ecological Risks of Urban Air and Water Environment to Analyse the Scenarios for Mainstreaming Nature-Based Solutions: A Case Study of Bengaluru City, India

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Abstract

Urban ecological risks are intricately linked to several environmental and anthropogenic factors which need closer attention to these relationships at local scales. Among factors enhancing the impacts of urbanisation, land use changes and land management frameworks, the management of the urban air quality as well as the availability of blue-green infrastructure to alleviate these risks are not well connected with each other despite their synergistic effects over the environmental and public health of urban centres as reported by several studies. Hence, quantification of the ecological risks as well as derivation of nature-based solutions as effective strategies facilitating the urban sustainability needs to be examined in detail at different spatio-temporal scales to derive the appropriate strategies and policy formulations to decrease the risks. The present study takes the case of Bengaluru city to assess and quantify the ward-wise and overall ecological risks associated with the reduction in green cover, conversion of permeable land into concreted surface as well as the increase in particulate matter in the air. Differential scenarios with respect to the combination of three factors, ratios of the extents of green-to-blue areas, percentage impervious surface area and air quality index, were studied to identify those causing summative reduction in the ecological risks for the city. The use of nature-based solutions in managing the risks is examined from the perspective of mainstreaming them in land management practices for urban areas such as the Bengaluru urban area.

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8.1   Introduction

Human activities have significant impact on ecosystem health all around the world and contribute to the ecological risks, due to the intricate links with different socioeconomic practices of a given region. Predominantly, anthropogenic activities contribute to ecological risks in urban ecosystems, including the risks posed to the biological, air, water and land environments over different scales of the impacts to the biotic and abiotic components (Tang et al. 2018) as well as the biodiversity. Urban biodiversity, as urban units, refers to the diversity of life which includes ecosystem, animals and their genes. While these 'green spaces' play vital role in cooling the cities and provide space for physical activities, for social interaction and also for recreation purpose, their roles as nature-based solutions (NbS) in the reduction of pollution and ecological risks are noteworthy. For example, trees produce oxygen and help to filter out harmful air pollutants including airborne particulates. Biodiversity of flora and fauna is viewed from standpoint of its under-lying asset, regardless of their direct or indirect benefits to mankind (Swartjes et al. 2011), and has also been explored as agents alleviating urban ecological risks due to their presence in the buffer regions of the cities. Most often, complicated resource usage scenarios and decrease in the carrying capacities of the natural environments in the urban areas lead to drastic amplification of the ecological risks over the short term as well as the long-terms. Notably, structural and functional changes to the ecological units, such as parks, fields, natural meadows and wetlands, due to the accelerated pace of urbanisation can drastically reduce their ecosystem services while inducing risks (Pickett et al. 1989; Jax 2006). However, identification, assessment and management of the urban ecological risks have a lot of scope for improvement (e.g. Tang et al. 2018) owing to the local-specific definitions of the nature and the manifestations of the changes (e.g. Zhao et al. 2000; Power and McCarty 2002; Wu et al. 2004; Deng et al. 2011, etc.).

For example, ecological risks posed by urban floods to developing urban centres vary from those posed for the developed ones (Balica et al. 2009). Further, cities may be flooded predominantly due to natural changes such as acute or chronic changes to the precipitation levels and patterns or due to anthropogenically induced land use changes to areas covered by flood plains (Jha et al. 2012). This also results in land degradation due to soil erosion, further decreasing the yield capacity of the soil. However, the risks posed vary based on the land use and management policies prevailing at the respective urban centres (De et al. 2013). Such changes impact both the land and the water ecosystems of the urban centres to a large extent. Similarly, the occurrence of spontaneous fire in urban areas may be attributed to different reasons—natural disasters or anthropogenic activities such as waste fires from landfill and recycling centres (e.g. Ibrahim 2020). Large amount of heat flux and

heatwaves can cause serious fires over the buildings and/or green cover region of the city (e.g. Davao City; Villa and Ceballos 2021), alongside the accelerated increase in the land surface temperatures in response to reduction in the soil permeability and moisture (Ahmed et al. 2013). These events, if single or in series over a temporal scale, can compound the ecological risks over the urban areas. The ecological risks are connected with severe pollution levels which are reflected on the public health problems, resulting in respiratory illness, bronchitis, asthma, cancer and other serious health issues. These connections are often ignored in urban policymaking leading to huge economic and social losses (e.g. Corburn 2004). In the present times and warming world, there is a growing need to find innovative solutions to solve the urban challenges because of rampant urbanisation and climate change (Sarabi et al. 2020). Nature-based solutions (NbS) have the much required potential to offer support for sustainability and resilience building for advancing the urban planning approach and finding solutions to complex and emerging global urban challenges (Frantzeskaki et al. 2019). NbS can conserve, sustainably manage as well as help in restoring the natural as well as man-made ecosystems (Oral et al. 2020). NbS requires multidisciplinary-integrated approach to solve societal and environmental challenges especially disaster risk reduction and climate change adaptations (Cohen-Shacham et al. 2019). While solving societal and environmental issues, NbS are sure sort approach to secure human well-being and provide many additional co-benefits, viz. improving water quality, conservation of biodiversity, social co-benefits, thermal stability and cooling by improving microclimate that helps in reduction of energy consumption (Dhyani et al. 2018, 2019, 2020, 2021). There are evidences that urban planning can be relevant area to support mainstreaming of NbS and address trade-offs. NbS has been clearly observed being mainstreamed in circular cities to make them self-regenerative and more resourceful (Oral et al. 2020). NbS inclusive urban planning can also help in conflict resolution and addressing the need of environmental and social justice (Bush and Doyon 2019). Despite being increasingly at the centre of discussion for mitigating urban heatwaves and flooding, there has been really slow, inconsistent as well as very limited implementation and mainstreaming of NbS in urban planning and disaster risk reduction approaches (Croeser et al. 2021). There is a growing need and international consensus on that urban planners, policymakers, practitioners and scientists to understand, acknowledge and recognise the synergies as well as trade-offs that are linked with NbS and to enable NbS for its larger benefits (Seddon et al. 2021). It is crucial that NbS to be implemented in urban areas is guided by customised or place-specific solutions and are evidence based to facilitate replication and upscaling of NbS, and the integration of NbS efforts follows the principles of social and environmental justice and transdisciplinarity (Albert et al. 2021).

The above discussion illustrates the need to integrate the ecological risks due to land use modification, air quality degradation and loss of green and blue spaces and derive the optimal strategies to adopt NbS in the long term to provide impetus for urban sustainable development. The present study is an attempt in this direction and provides a basis for a more formal discussion of quantification of the place-specific

risks as well as to plan the appropriate place-specific and customised NbS strategies using the case study of Bengaluru, India.

8.2   Study Area

The Bengaluru Urban district occupies about 2196 km^2 and is located between 12° 50′ 0″ N to 13° 20′ 0″ N and 77° 10′ 0″ E to 77° 50′ 0″ E (Fig. 8.1). In the past, Bengaluru was popularly known as 'Pensioner's paradise' because of quaint cottages and pretty bungalows surrounded by lovely gardens, which attest to its long association with nature-based living. It has also known with many other names such as 'Gandu Bhoomi (i.e. Land of Heroes)' and 'Bendakaaluru (i.e. Land of boiled beans)' which popularly indicate, recognise and celebrate local scale practices that gave rise to the multi-cultural city with affinity for environmentalism. Historical documents have referred to the construction of a large number of lakes by its rulers, thus giving Bengaluru the name 'Land of Lakes', and during the same period, a large number of parks were created like Lalbagh, Cubbon Park, etc., thus getting the name as 'Garden City'. However, Bengaluru has experienced the sudden urbanisation from the past few decades due to unprecedented scales of development activities focussed more on the economic development in the area, leading to the pressures on the air and water environments.
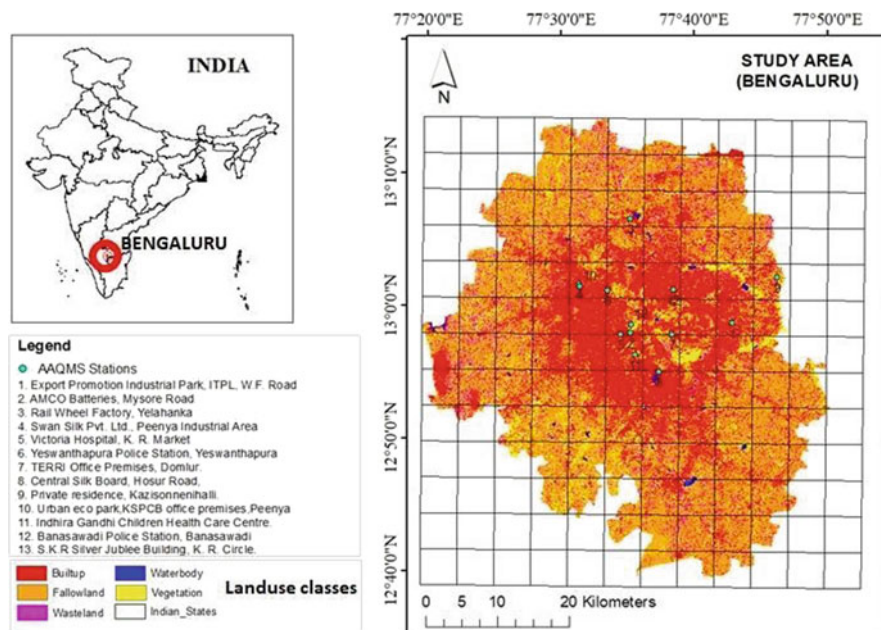

Fig. 8.1 Study area, the Bengaluru urban region showing the locations of sites where air quality is monitored and the various land use categories in existence

With increase in the developmental activities, there are some factors which affect the ecology of the city. Bengaluru city ranks the sixth among the ten cities globally in terms of the traffic congestion and volume contributing to pollution (The Times of India Report, January 2020) which led to increase in impervious layers throughout the cities. This is due to rapid urbanisation and migration of people from rural to urban areas leading to urban sprawl. Due to increase migration, the city faces major problems like decrease in the green spaces, depletion in ground water level, increase in energy consumption and increase in traffic congestion and pollution levels. The population has also increased about 154.5% in past two decades. Increase in livelihoods of urban people with better life standards, good educational opportunities and business prospects has spurred large-scale migration from the sub-urban and rural areas into the city. However, a shift from agricultural to residential and commercial land uses has been detrimental (Verma et al. 2017). These factors have led to the drastic increase in the concentrated population leading to the pressure on infrastructure development and natural resources, thus causing serious challenges such as climatic change; ecological change; traffic congestion; lack of amenities such as electricity, water and sanitation; and increase in greenhouse gas emission. This has contributed to the increase in the ecological risks for urban Bengaluru, compounded by air pollution.

As per the 2019 reports, Bengaluru is the most traffic congested city in India where drivers spend around 71% extra time on roads which is equivalent to wasting 10 days and 3 h on road every year creating more vehicular pollution (Zhou et al. 2014). The city is also experiencing different levels of pollution with areas having high level of pollutants. A study by IISc in 2016 shows Bangalore holds second position in emission of nitrogen oxides after Chennai. Agriculture, ammonium-based fertiliser application and animal husbandry are the sources of emission of ammonia to the air by chemical transformations. These gaseous pollutants also influence in formation of particulate matter and degradation in visibility. Hence predominantly the anthropogenic factors related to urbanisation such as changes in land use as well as the traffic sources for air pollutants indicate the significant contributions to ecological risks, which have not been investigated for their synergistic contributions.

The present investigation provides analyses of the ward-wise contributions to the total ecological risks for the city as well as the spatio-temporal variations between the years 2001, 2010 and 2019. The study combines the reported levels of emissions from limited air quality monitoring stations for the entire city with the changes to the land use using new indices proposed in the current study to determine the effects of the spatial variability of the impacts of land use on the differences in the risks at different parts of the city using geospatial analyses (e.g. by spatial interpolation techniques like inverse distance weighting, IDW; Chinnaswamy et al. 2016). These procedures are detailed in the subsequent sections.

8.3   Methodology

8.3.1   Derivation of LULC and NDVI

The land use changes were derived using satellite images of Landsat 4–5 TM for the years 2001 and 2010. Using the pixels of the satellite data to obtain the digital number values, the latter were converted into reflectance using the given formula:

$$\text{Reflectance} = (M\rho * Q_{\text{cal}} + A\rho)/\sin \gamma\text{SE} \qquad (8.1)$$

where

$M\rho = \text{REFLECTANCE\_MULT\_BAND}$
$Q_{\text{cal}} = \text{Quantised and calibrated pixel values}$
$A\rho = \text{REFLECTANCE\_ADD\_BAND}$
$\gamma_{\text{SE}} = \text{SUN\_ELEVATION}$

All these are obtained from Metadata file.

For the year 2019, data from the satellite Sentinel was considered which required no conversion. Later the layer stacking of the image was performed. LULC analysis refers to the categorisation of natural environment along with human activities on the land surface of a particular time frame based on statistical and scientific methods of analysis. Here the supervised classification using maximum likelihood parameter was carried out. Five land use land cover classes were considered, and accordingly the spectral signatures were created. Normalised Difference Vegetation Index (NDVI) analysis was performed to measure the state of health of plant based on how the plants reflect the light at a certain frequency. The value of NDVI lies between −1 and 1. The formula used to calculate NDVI is provided in Eq. (8.2).

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \qquad (8.2)$$
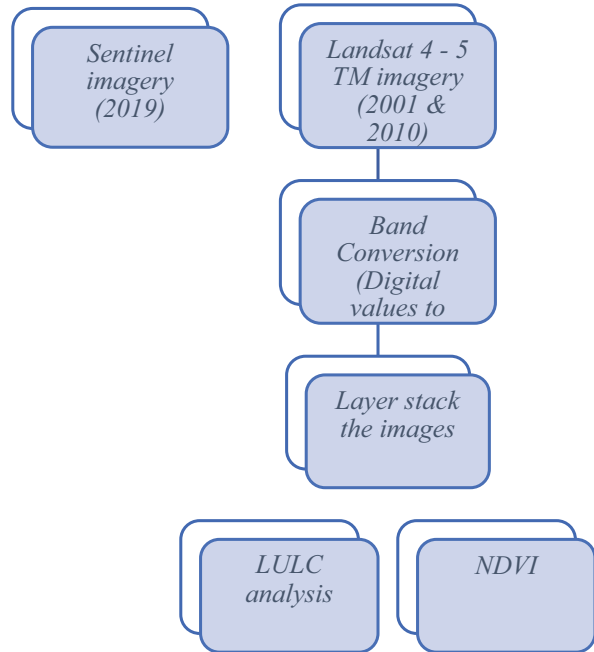
where

NIR is reflection in near-infrared spectrum.
Red is reflection in red spectrum.

For Landsat 4–5 TM satellite, data band 4 corresponding to the NIR band and band 3 corresponding to Red band were used for the analyses. In the case of Landsat 8 OLI satellite data, band 5 corresponding to NIR band and band 4 of Red band were used. In the case of Sentinel 2A satellite data, band 8 which is the NIR band and band 4 corresponding to the Red band were used for the purpose of mapping. The steps followed for analyses of LULC and NDVI are illustrated in Fig. 8.2.

Fig. 8.2 Methodology followed for LULC and NDVI analyses

Sentinel imagery (2019)

Landsat 4 - 5 TM imagery (2001 & 2010)

Band Conversion (Digital values to

Layer stack the images

LULC analysis

NDVI

8.3.2 Derivation of Urban Expansion Index, ERI, GBR, BBA and ISA

Using the fishnet tool, the grid size of 5 × 5 km is created for the Bengaluru urban district. The lat-long values are obtained from the attribute table and are exported to the MS Excel. By using split tool, split each grids and overlay on LULC created and clip it. Then the area of each class of the grid is calculated. Once all the areas are calculated, urban expansion index, ecological risk index, green-to-blue ratio, blue by built-up area and impervious surface area are calculated for each grid. The centroid point of each grid is calculated, and inverse distance weighting interpolation is carried out for the study area. Finally, mapping is done for the same.

8.3.2.1 Urban Expansion Index

The urban expansion index represents the rate of growth of urban area. High value of the index represents the rapid growth of urban area, whereas low rate represents the slow growth of the urban area. This can be calculated using the formula provided in Eq. (8.3).

$$I_{\text{ve}} = \frac{\Delta U * 100}{\text{TLA} * \Delta t} \qquad (8.3)$$

where

I_{ve} is urban expansion index.

ΔU is urban expansion during certain period.

TLA is total research area.

Δt is time span of certain period considered.

8.3.2.2 Ecological Risk Index

The ecological risk index is used to understand the comprehensive spatial difference in ecological risk on a particular land type. This can be obtained by the formula shown in Eq. (8.4):

$$\text{ERI} = \sum_{i=1}^{N} \left(\frac{A_i}{A} * w_i \right)$$ (8.4)

where

ERI is ecological risk index.

i is the land type considered.

A_i is area of land type i.

A is total area of research.

w_i is weightage assigned to each land type is calculated using AHP method.

For built-up land, weightage assigned was 0.472. In the case of vegetation and water bodies, the weightages assigned were 0.033 and 0.063, respectively. In the case of barren land and fallow up land, the weightage assigned was 0.216.

8.3.2.3 Green-to-Blue Ratio

The green-to-blue ratio is a qualitative estimate of vegetation cover over the waterbodies. The estimation can be done using the formula as shown in Eq. (8.5):

$$\text{GBR} = \sum \frac{G}{B}$$ (8.5)

where

GBR is green-to-blue ratio.

G is sum of areas of the vegetation cover.

B is sum of areas of the waterbodies.

8.3.2.4 Blue to Built-up Area

The blue to built-up area is the ratio of waterbodies to built-up. This is calculated using the Eq. (8.6) as follows:

$$\text{BBA} = \sum \frac{B}{C}$$ (8.6)

where

BBA is blue to built-up area.
B is sum of areas of the waterbodies.
C is sum of areas of the built-up.

8.3.2.5 Percentage Impervious Surface Area

Impervious surface area is the percentage of impervious spaces in the area. It is estimated using Eq. ($_{8.7}$) as follows:

$$\text{ISA} = \frac{\Sigma C}{\sum (G + C)} * 100 \tag{8.7}$$

where

ISA is percentage of impervious surface area.
C is sum of areas of the built-up.
G is sum of areas of the vegetation cover.

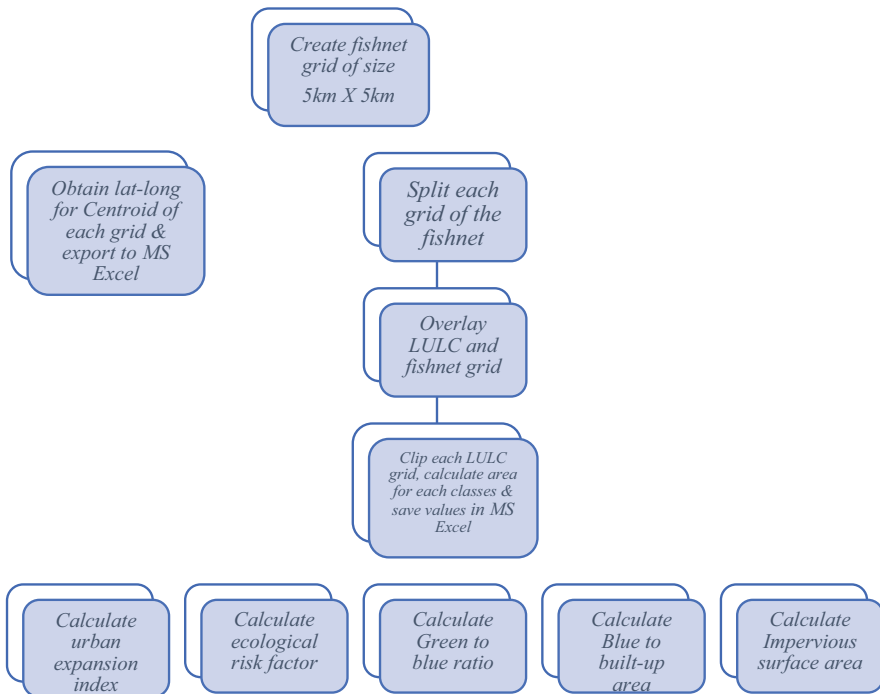The overall procedure followed is summarised in Fig. 8.3.

Fig. 8.3 Methodology followed for derivation of urban expansion index, ecological risk index, green-to-blue ratio, blue to built-up ratio and percentage impervious surface area

8.3.2.6 Methodology for Generating Air Pollution Maps Using Ground-Based Data

For studying the changes in the cumulative Air Quality Index (AQI), 2019 data were considered. The methodology followed for generating air pollution maps using ground-based data is shown in Fig. 8.4.

Interpolation using inverse distance weighting (Eq. 8.8) was carried out to create new data points within a distinct set of known data points to estimate unknown values by providing search distance, nearest points, power settings and barriers within a GIS environment.

$$Z_P = \frac{\sum_{i=1}^{n}\left(\frac{Z_i}{d_i}\right)}{\sum_{i=1}^{n}(1\ d_i\ )} \tag{8.8}$$

where

Z_p is value of unknown point.
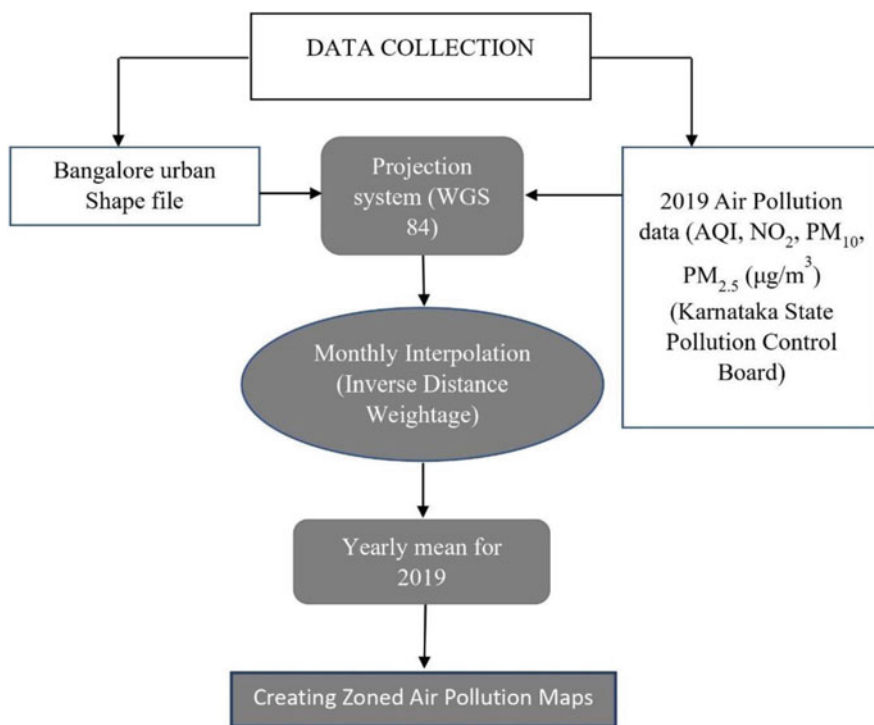Z_i is value of known point.

Fig. 8.4 Methodology for 3 years air pollution trend analysis using Karnataka State Pollution Control Board Data

d_i is distance of known point.

n is user picked exponent.

Overlay analyses by overlaying individual air pollutants such as nitrogen dioxide (NO_2) over Air Quality Index (AQI) and particulate matters ($PM_{2.5}$ as well as PM_{10}) over Air Quality Index (AQI) were performed as shown in Eqs. 8.9, 8.10, 8.11 and 8.12 by the addition of interpolated digital numbers (DN) of NO_2, $PM_{2.5}$, PM_{10} and ERI with and AQI in raster calculator.

$$NO_2 \text{ over AQI} = DN \text{ values of } NO_2 + DN \text{ values of AQI} \tag{8.9}$$

$$PM_{2.5} \text{ over AQI} = DN \text{ values of } PM_{2.5} + DN \text{ values of AQI} \tag{8.10}$$

$$PM_{10} \text{ over AQI} = DN \text{ values of } PM_{10} + DN \text{ values of AQI} \tag{8.11}$$

$$ERI \text{ over AQI} = DN \text{ values of ERI} + DN \text{ values of AQI} \tag{8.12}$$

8.3.3 Derivation of NbS Scenarios

Based on the values of the AQI, ERI, BBA, GBR and ISA reported in the earlier sections, the scenarios of low and high ERI and AQI based on the changes to ground-based indices were performed. Using the assessment of AQI, ERI, BBA, GBR and ISA in 5×5 km grid analysis over the Bangalore city, the above-mentioned four major criteria have been identified to represent the NbS scenarios of the city. The values of the indices, i.e. the centroid mean values from spatial interpolation for each of the 5×5 km grids derived, were normalised to a value between 0 and 5 and classified into six major classes: negligible (n), very low (l), low (l), moderate (m), high (h) and very high (vh). Scores ranging between 0 and 5 (n = 0; vl = 1, l = 2, m = 3, h = 4, vh = 5) were allotted based on the ranges of the values obtained as per the classes to the ERI as well as AQI, BBA, GBR and ISA as shown in the following Table 8.1.

Summation of the scores of the yielded final scores based on four NbS scenarios which are as follows with respect to different combinations for each of the 5×5 km grids:

1. Scenarios causing major decrease in final score.
2. Scenarios causing major increase in final score.
3. Scenarios causing moderate decrease in final score.
4. Scenarios causing moderate increase in final score.

The scenarios were further analysed for suggesting appropriate NbS methods to be adopted.

Table 8.1 Grid-wise classification and scoring for derivation of NbS scenarios

Grid ID (5 × 5 km) linked to geodatabase	Values of the indices computed					Classification for scoring				
	AQI	ERI	BBA	GBR	ISA	AQI	ERI	BBA	GBR	ISA
7	80.51	0.18	0.27	58.36	56.33	m	m	vl	vl	m
8	79.98	0.17	0.02	242.18	71.91	m	m	n	vl	h
18	82.43	0.13	0.05	71.96	36.61	m	l	n	vl	vl
19	81.62	0.19	0.06	62.41	37.41	m	m	n	vl	l
20	80.52	0.22	0.04	115.12	49.17	m	m	n	vl	l
21	79.70	0.21	0.02	363.46	51.53	m	m	n	vl	m
29	83.06	0.18	0.03	1529.85	36.12	m	m	n	l	vl
30	83.99	0.21	0.02	597.37	53.58	m	m	n	vl	m
31	84.28	0.22	0.01	346.10	47.26	h	m	n	vl	l
32	82.57	0.25	0.02	44.42	56.62	m	h	n	vl	m
33	80.29	0.22	0.08	27.52	46.10	m	m	n	vl	l
34	79.06	0.22	0.05	179.46	45.59	m	m	n	vl	l
35	78.75	0.18	0.01	756.01	48.91	m	m	n	vl	l
40	82.04	0.10	0.01	6097.57	32.86	m	l	n	vh	vl
41	82.64	0.17	0.03	4060.34	32.52	m	m	n	m	vl
42	83.57	0.22	0.06	1203.02	45.39	m	m	n	vl	l
43	85.80	0.25	0.01	8154.70	59.65	h	h	n	vh	m
44	88.91	0.31	0.02	360.04	76.45	h	h	n	vl	h
45	83.97	0.34	0.02	38.50	79.77	m	vh	n	vl	vh
46	78.96	0.31	0.03	23.56	73.26	m	h	n	vl	h
47	77.70	0.26	0.02	59.19	58.03	m	h	n	vl	m
48	78.00	0.19	0.05	114.95	34.52	m	m	n	vl	vl
49	78.47	0.16	0.06	145.99	30.14	m	m	n	vl	vl
50	78.82	0.15	0.07	100.19	33.58	m	l	n	vl	vl

53	81.41	0.12	0.00	6404.57	45.22	m	l	n	vh	l
54	82.81	0.21	0.00	5179.61	42.48	m	m	n	h	l
55	83.69	0.23	0.01	3685.83	46.61	m	m	n	m	l
56	85.23	0.28	0.01	549.64	65.08	h	h	n	vl	h
57	92.35	0.33	0.01	290.57	73.22	vh	vh	n	vl	h
58	80.25	0.34	0.05	36.37	86.98	m	vh	n	vl	vh
59	73.81	0.37	0.14	207.07	80.93	l	vh	vl	vl	vh
60	75.63	0.32	0.01	62.94	70.45	l	vh	n	vl	h
61	77.49	0.23	0.04	47.41	46.31	m	m	n	vl	l
62	78.40	0.18	0.12	73.23	29.33	m	m	vl	vl	vl
63	78.84	0.18	0.10	96.44	33.41	m	m	n	vl	vl
67	82.51	0.21	0.00	30351.92	50.37	m	m	n	vh	l
68	85.30	0.26	0.01	1809.23	59.28	h	h	n	l	m
69	82.60	0.31	0.01	66.70	70.53	m	h	n	vl	h
70	78.92	0.34	0.02	181.62	74.93	m	vh	n	vl	h
71	69.41	0.34	0.01	507.96	74.01	vl	vh	n	vl	h
72	66.23	0.38	0.02	769.54	82.10	vl	vh	n	vl	vh
73	76.29	0.37	0.01	372.27	79.73	l	vh	n	vl	vh
74	78.49	0.30	0.02	55.37	67.73	m	h	n	vl	h
75	78.77	0.21	0.03	121.82	39.92	m	m	n	vl	l
77	79.06	0.13	0.01	622.98	40.30	m	l	n	vl	l
80	81.50	0.21	0.01	1779.21	64.04	m	m	n	l	h
81	82.21	0.26	0.02	789.37	63.00	m	h	n	vl	m
82	78.97	0.30	0.04	24.06	73.65	m	h	n	vl	h
83	72.72	0.36	0.02	280.63	82.02	l	vh	n	vl	vh
84	76.78	0.35	0.02	1103.24	76.32	l	vh	n	vl	h
85	81.30	0.34	0.01	10681.25	73.99	m	vh	n	vh	h

(continued)

Table 8.1 (continued)

Grid ID (5 × 5 km) linked to geodatabase	Values of the indices computed					Classification for scoring				
	AQI	ERI	BBA	GBR	ISA	AQI	ERI	BBA	GBR	ISA
86	88.52	0.37	0.04	530.66	83.07	h	vh	n	vl	vh
87	80.87	0.31	0.04	14.25	75.03	m	h	n	vl	h
88	79.65	0.24	0.10	29.13	52.28	m	m	vl	vl	m
89	79.36	0.24	0.03	73.70	58.77	m	h	n	vl	m
90	79.29	0.18	0.03	105.71	40.02	m	m	n	vl	l
93	80.23	0.19	0.02	1921.04	59.70	m	m	n	l	m
94	79.71	0.24	0.03	69.41	60.52	m	m	n	vl	m
95	77.95	0.26	0.02	31.72	62.70	m	m	n	vl	m
96	75.88	0.32	0.03	18.04	72.61	l	h	n	vl	h
97	80.11	0.34	0.02	588.03	73.76	m	vh	n	vl	h
98	81.97	0.30	0.06	708.92	66.88	m	h	n	vl	h
99	82.88	0.32	0.03	591.84	72.79	m	h	n	vl	h
100	81.18	0.31	0.04	207.36	76.46	m	h	n	vl	h
101	80.14	0.29	0.05	31.19	70.46	m	h	n	vl	h
102	79.71	0.24	0.16	50.29	56.46	m	m	vl	vl	m
103	79.53	0.20	0.01	204.90	42.34	m	m	n	vl	l
106	79.71	0.15	0.01	1630.19	53.85	m	l	n	l	m
107	79.52	0.19	0.02	117.61	48.29	m	m	n	vl	l
108	79.83	0.23	0.03	40.52	52.46	m	m	n	vl	m
109	81.16	0.27	0.07	18.37	62.02	m	h	n	vl	m
110	88.76	0.33	0.02	197.77	76.15	h	vh	n	vl	h
111	83.95	0.30	0.02	938.25	70.21	m	h	n	vl	h
112	81.73	0.26	0.01	4448.81	62.19	m	h	n	m	m
113	80.89	0.25	0.05	665.52	57.56	m	h	n	vl	m

114	80.29	0.25	0.08	218.96	59.41	m	h	n	vl	m
115	79.91	0.24	0.01	314.77	59.08	m	m	n	vl	m
116	79.70	0.22	0.01	435.59	51.73	m	m	n	vl	m
122	81.06	0.22	0.02	55.53	60.21	m	m	n	vl	m
123	82.82	0.23	0.02	271.22	59.29	m	m	n	vl	m
124	82.48	0.20	0.05	996.32	53.54	m	m	n	vl	m
125	81.49	0.22	0.01	4937.19	51.81	m	m	n	h	m
126	80.79	0.23	0.01	5657.56	57.13	m	m	n	h	m
127	80.33	0.22	0.01	552.87	54.18	m	m	n	vl	m
128	80.02	0.22	0.01	519.46	60.77	m	m	n	vl	m
129	79.82	0.14	0.01	769.18	41.03	m	l	n	vl	–
138	80.67	0.17	0.00	1352.26	43.13	m	m	n	vl	–

8.4 Results and Discussion

8.4.1 LULC Analysis

The land use/land cover maps are obtained by the supervised classification (Level 1; Patra et al. 2018) as per Space-Based Information Support for Decentralised Planning at Panchayat level (SIS DP). The spatio-temporal distribution of these classes for the area of Bengaluru urban district is obtained for the years 2001, 2010 and 2019. The images are shown in Fig. 8.5a–c, and the trend in changes of land use land cover classes is shown in Fig. 8.5d.

The LULC analysis maps and the graph show that the urban area has been increasing continuously from 2001 to 2019. It is found that about 15.3% (i.e. 334.61 km^2) of urban area increased from 2001 to 2010 and subsequently 8.3% (i.e. 180.44 km^2) of urban area increased from 2010 to 2019, whereas the barren land has been decreasing continuously from 2001 to 2019. It is found that about 12.1% (i.e. 265.63 km^2) of barren land decreased from 2001 to 2019, and further from 2010 to 2019, 17% (i.e. 373.24 km^2) of the barren land has decreased. Thus, it is observed that that city is experiencing large amount of urbanisation and the spread of urban area is taking place from the core of the city towards the Bengaluru north, south and east part to a major extent. And towards Anekal region, the less extent of urban expansion has taken place.

The overall accuracy of the LULC map for 2001, 2010 and 2019 is 88.24%, 80.00% and 80.00%, respectively. It is calculated by using the class values of created random points and then assigning the values to the reference using Google Earth (substitute of ground truthing).

8.4.2 NDVI Analysis

The NDVI images are obtained by processing the satellite data using ERDAS IMAGINE 2014. The spatial distribution of plant growth and its health are studied here. For the same, the NDVI images are obtained for the year 2001, 2010 and 2019 and are shown in Fig. 8.6a–c, while the changes in trends of NDVI are represented in Fig. 8.6d.

In the NDVI maps, higher value represents the good quality of vegetation, and other lower values represent the barren land and other built-up area. From the graph it is observed that the NDVI value has decreased from 2001 to 2010, whereas it has increased from 2010 to 2019. This trend in NDVI can also be justified from LULC maps where vegetation has decreased from 2001 to 2010 and increased from 2010 to 2019.

The reasons for this change in trend could be as follows:

- The decrease in NDVI values from 2001 to 2010 may be due to urbanisation and cutting of trees and utilisation of other agricultural/barren land.
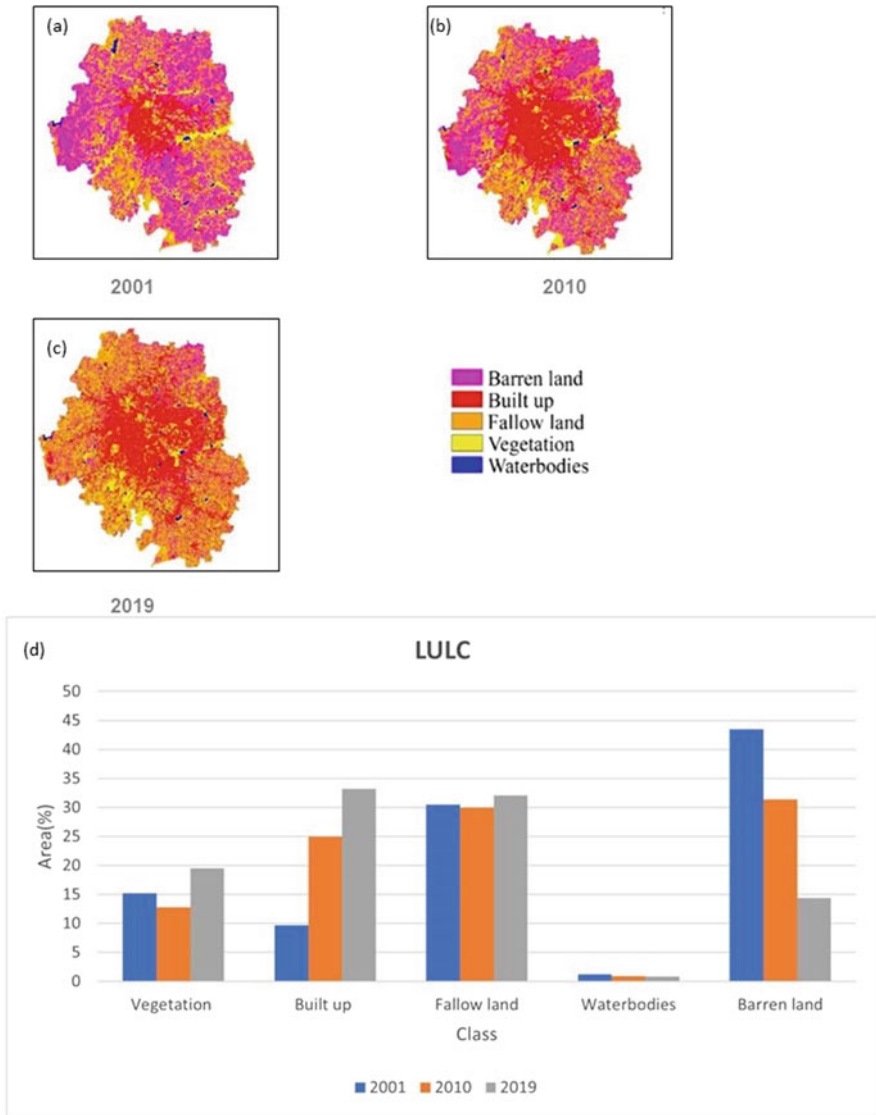
Fig. 8.5 Land-Use Land-Cover (LULC) classification for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 for different parts of Bengaluru city and (**d**) illustration of the percentages of the LULC classes

- The increase in NDVI values from 2010 to 2019 may be attributed to the growth of vegetation and subsequent greenery in the layouts/IT parks.
- Nowadays the awareness about the importance of greenery among the people is improving. So, there are social campaigns, and NGOs are coming forwards to save the greenery.
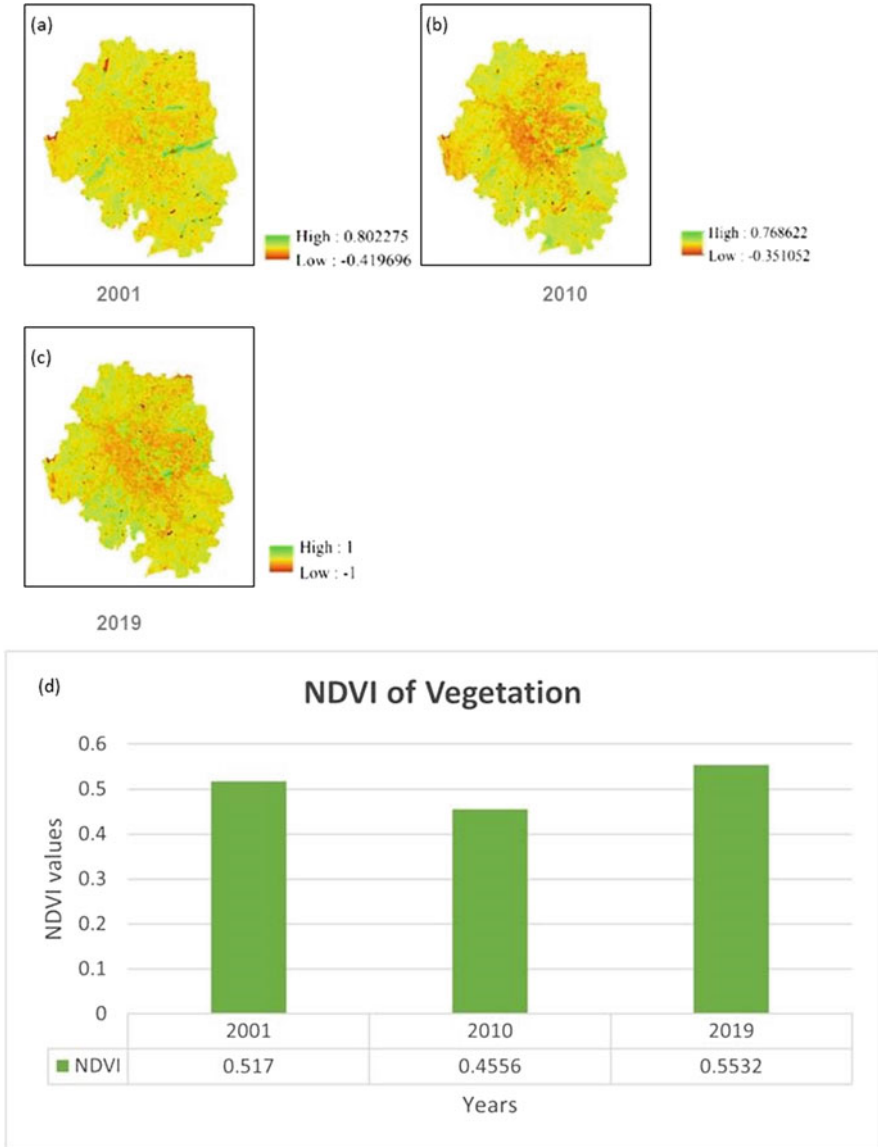
Fig. 8.6 Normalised Difference Vegetation Index (NDVI) changes for vegetation for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 and (**d**) illustrates the graph of NDVI for different parts of Bengaluru city

8.4.3 Urbanisation Expansion Index

The rate of growth of urban area can be quantified using the urban expansion index. To understand this, the urban expansion index for each grid considered is shown in
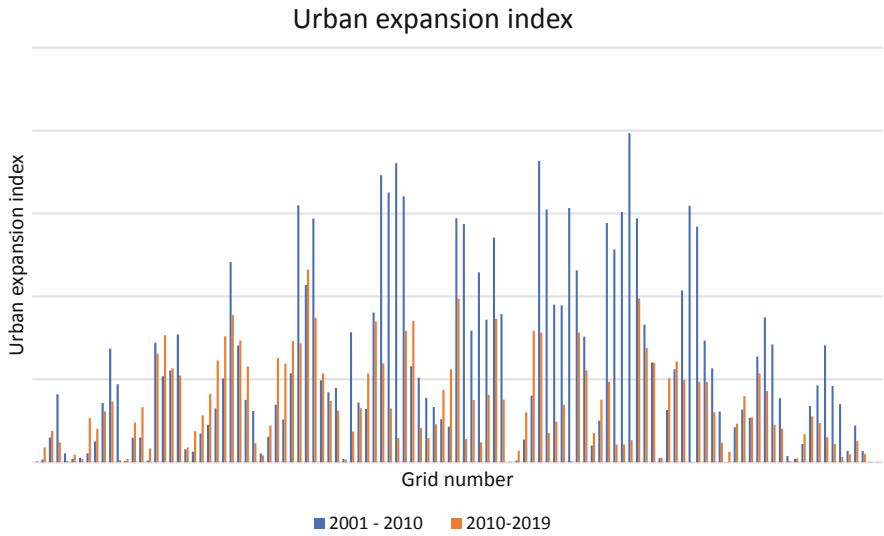
Fig. 8.7 The urban expansion rate for 2001–2010 and 2010–2019
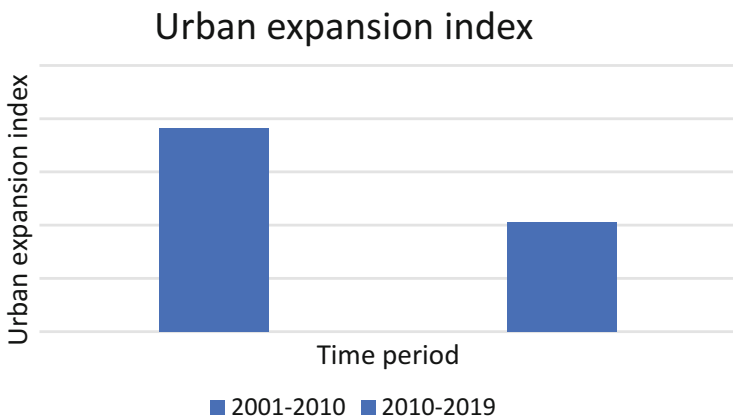
Fig. 8.8 Urban expansion index

Table 8.2 Urban expansion index

Different period	Extension area in km^2	Annual expansion area (km^2/year)	Urbanisation expansion index
2001–2010	334.61	33.461	1.526130904
2010–2019	180.44	18.044	0.822973194

Fig. 8.7. For the same considered grids, the urban expansion index is calculated and plotted as shown in Fig. 8.8. The overall urban expansion index is then calculated as shown in Table 8.2.

The rapid expansion of urban area has taken place from the year 2001 to 2010 as compared to 2010 to 2019. The reason for the sudden development of the city may be due to the development in IT sectors, transportation, job opportunities or resources.

8.4.4   GBR, BBA Ratios and ISA

The blue to built-up area and green-to-blue ratio area are calculated for each grid and then interpolated using IDW technique as shown in Fig. 8.9.

The blue to built-up areas have constantly decreased from 2000 to 2019. The change in pattern of blue to built-up areas shows that the built-up have increased drastically over the period of 2001 to 2019. The green-to-blue ratio areas have decreased a bit from 2001 to 2010 and then had a large increase from 2010 to 2019. This shows that green areas have decreased from 2000 to 2010 and then increased from 2010 to 2019. The LULC and NDVI analyses justify the trend of green-to-blue ratio areas. The impervious surface area and ecological risk index are calculated for each grid, and interpolation is done using IDW. They are shown in Fig. 8.10a. The overlay of blue to built-up area, green-to-blue ratio and impervious surface area on ecological risk index is shown in Fig. 8.10b, c.
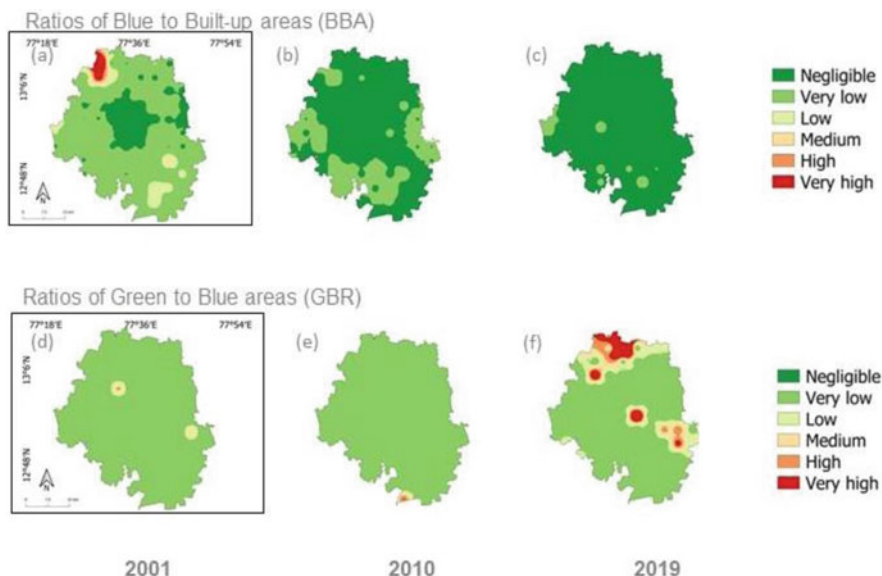
Fig. 8.9 1 Ratios of blue to built-up area (BBA) ratios for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 and, green-to-blue ratio areas (GBR) for Bengaluru during (**d**) 2001, (**e**) 2010 and (**f**) 2019

Percentage of Impervious Surface Areas (ISA)
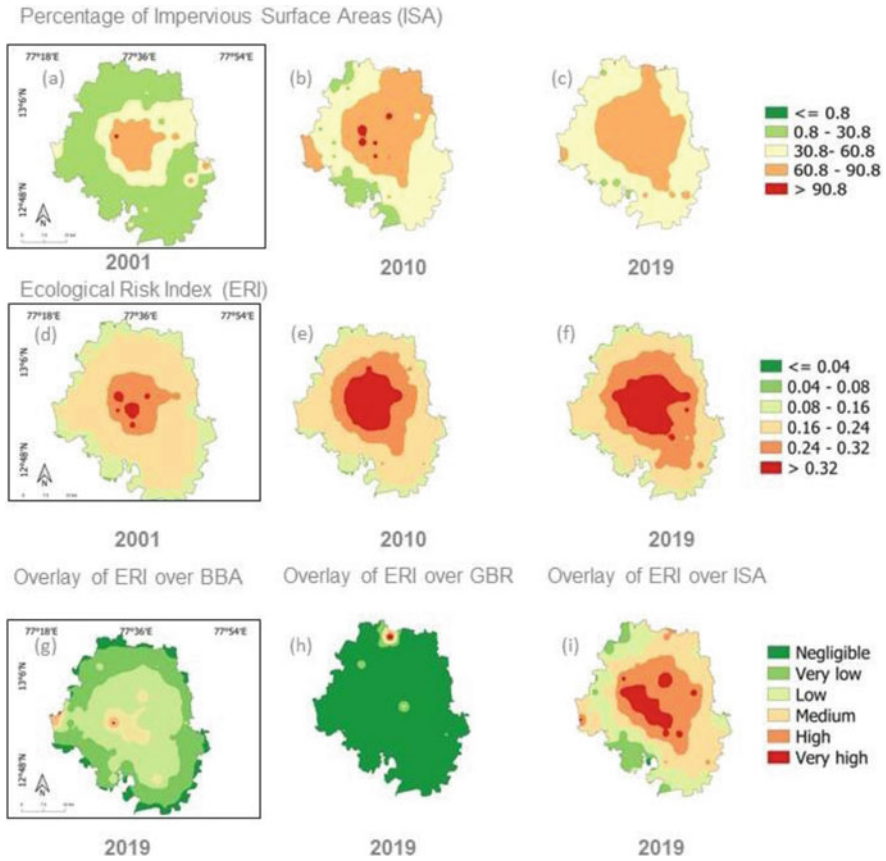
Fig. 8.10 Impervious Surface Areas (ISA) for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 and, Ecological Risk Index (ERI) for Bengaluru during (**d**) 2001, (**e**) 2010 and (**f**) 2019. Overlay analyses are represented as (**g**) ERI over BBA, (**h**) ERI over GBR and (**i**) ERI over ISA

The percentage impervious surface area has increased from the core of the city towards the periphery over the period of 2001 to 2019. The dominating impervious areas represent the urban built-up. The ecological risk index is shown in the part of urban area, and it has increased as the urban area expansion has taken place. The overlay of blue to built-up area on ecological risk index for the year 2019 shows very high and high value in the core representing the built-up area with high ecological risk involved. The overlay of green-to-blue ratio on ecological risk index for the year 2019 shows negligible to very low value. This means that in high ecological risk area, the value of green-to-blue ratio area is less which implies that the green cover is very low in that area. The overlay of impervious surface area on ecological risk index for the year 2019 shows very high to high value in the core. It can be inferred that the core of the city which has high ecological risk index will have high impervious surface area due to built-up.

8.4.5   Air Quality Index and Its Parameters

Highest emission of nitrogen dioxide is observed in and around areas of Peenya and Peenya Industrial Area which are around 28 μg/m^3, while the spread is observed quite lower in ITPL, Silk Board and Domlur regions (Fig. 8.11). Lowest values are observed over central part of Bengaluru region over surroundings of KR Circle, KR Market and Banaswadi areas where values range between 22 and 24 μg/m^3. The concentrations of particulate matter less than 2.5 micrometre ($PM_{2.5}$) show highest concentration in Silk Board region which is more than 38 μg/m^3. Concentration levels are reasonably low compared to concentration levels in Silk Board in area like Peenya, Peenya Industrial area, ITPL and Yeshwanthpur regions. Values are relatively lower in central regions like Khaji Sonnenahalli, KR Circle, KR Market, AMCO Batteries and some parts of Yelahanka with concentration levels around 27 μg/m^3 (Fig. 8.11).

Particulate matter having size less than 10 micrometre and more than 2.5 micrometre (PM_{10}) exhibit indistinguishable spatial patterns as $PM_{2.5}$ except areas like Yelahanka. The overall Air Quality Index (AQI) for Bengaluru urban region shows highest accumulation in areas like White Field, Silk Board, Peenya Industrial Region and Yelahanka. This is largely due to higher level of emission from vehicles as well as emission from industries. The value of AQI ranges from 61 to 92 which is almost near to National Ambient Air Quality Standards (Fig. 8.12).

Overlay analysis of NO_2 and PM_{10} over Air Quality Index exhibits similar pattern showing higher values around Peenya, Peenya Industrial Area, Silk Board and Yelahanka and lower values in central region, while the only difference of $PM_{2.5}$
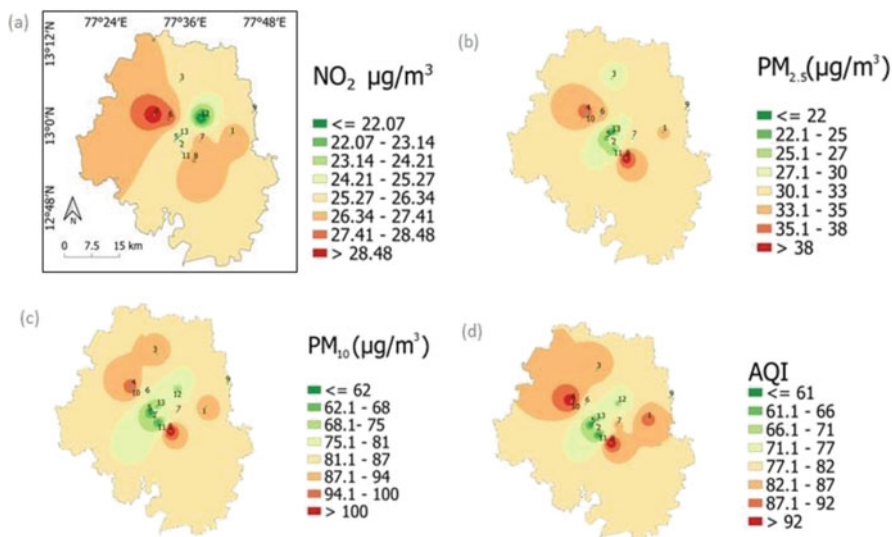

Fig. 8.11 Spatial distribution of air pollutants nitrogen dioxide and particulate matter as well as Air Quality Index (AQI) for Bengaluru city in 2019
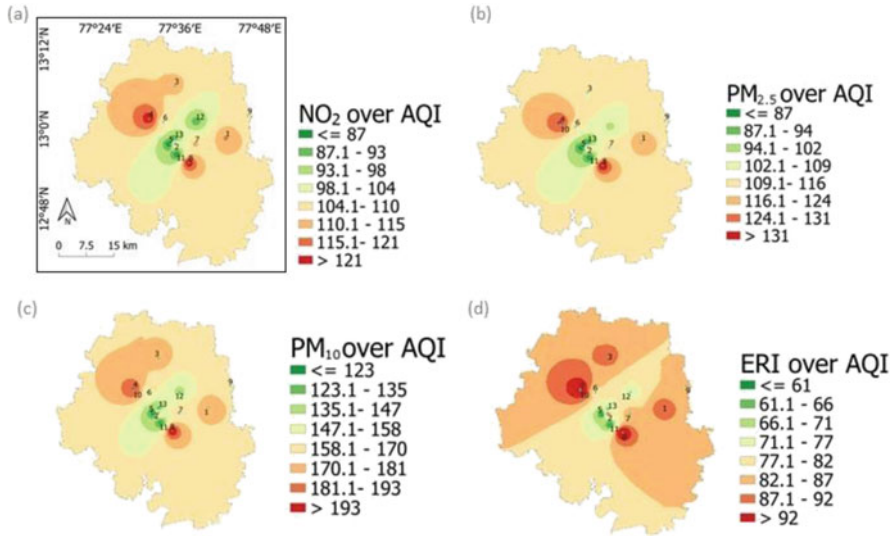
Fig. 8.12 Overlay analyses of air pollutants over Air Quality Index (AQI) to determine their relative contributions to the overall AQI for Bengaluru city, illustrating the overlay of (**a**) NO$_2$ over AQI, (**b**) PM$_{2.5}$ over AQI, (**c**) PM$_{10}$ over AQI and (**d**) ERI over AQI

over AQI is that the values are lower around Yelahanka. Ecological risk index over AQI shows higher values in north-west and south-east region of Bengaluru, while it shows lower values in central regions of the city.

8.4.6   Derivation of NbS Scenarios Based on the AQI, ERI, BBA, GBR and ISA (Under Preparation)

The results of the NbS analyses are shown in Fig. 8.13. It has emerged from the study that the combination of the indices causing major decrease in score is associated with very low values of GBR and ISA suggesting that the presence of very less impervious surface area influenced the increase in the ERI observed here. Hence, the appropriate NbS options would be the increase in the GBR which corresponds to an increase in the green and blue areas in the respective area corresponding to this scenario (e.g. Dhyani et al. 2021). Further, a combination of high and medium AQI with high ISA caused major increase in score, suggesting that both high AQI and high ISA caused a high ERI. The combined increase in air pollution indicated by high AQI as well as the increase in the impervious surface had increased the ecological risks associated with the combined influences on the environmental quality, possibly due to longer resuspension of the particulate matter in the air in selected regions of the city. The appropriate NbS for dealing with the above scenario should hence be targeted towards both a decrease in the AQI and the ISA. Although the increasing presence of the green areas seem more effective, other NbS measures
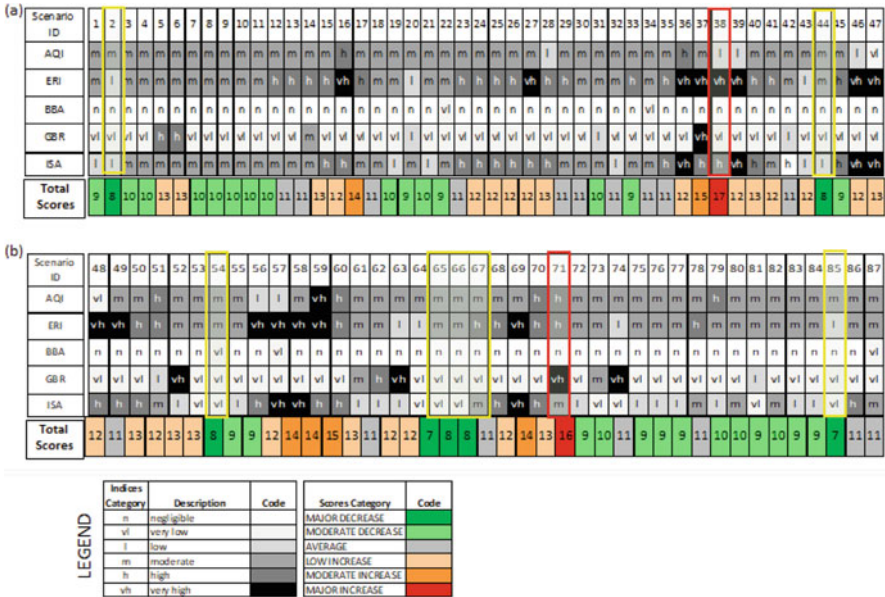
Fig. 8.13 Various NbS scenarios evolved with respect to AQI (Air Quality Index), ERI (ecological risk index), GBR (green-to-blue ratio), BBA (blue built-up ratio) and ISA (percentage impervious surface area) for Bengaluru city with the corresponding legends

such as particulate settlement strategies (considering the local scale meteorology) as well as the prevention of overland flooding by using permeable pavement networks (e.g. Santhanam and Majumdar 2020) seem effective. Designing planting configuration in urban areas can be more practical than selection of tree species (following air pollution tolerance index or APTI) for attenuation of the ambient PM concentrations (Chen et al. 2016). Hence it is observed that two different scenarios of NbS have emerged from the present investigation, which requires the mainstreaming of unique NbS strategies. It is interesting to note that major decrease and increase of ERI scores were observed only in selected areas of the city where there may be the new construction of built-up area could have overlain the water bodies previously located at the same place as observed using the LULC. It is observed that a moderate decrease in score is mostly related to the low to moderate ISA, while high to very high ISA and moderate to very high AQI caused a moderate increase in the score.

Further activity-based assessments of the existing scenarios revealed interesting results detailed as follows. As evident from the observations detailed above, the combined effects of ISA and AQI are found to be critical in increasing or decreasing the overall scores for Bengaluru city. For example, the NbS scenarios corresponding to numbers 37 and 71 (Fig. 8.13) illustrate a major increase in scores due to the high AQI and high ISA, respectively. Therefore, it can be said that the grids (representing the respective wards) associated with 37 are highly impacted by the increase in the

AQI indicating higher incidence of air pollution. On the other hand, grids corresponding to scenario 71 are associated with few pervious areas and/or disappearance of water bodies due to the increase in the built-up areas here. Similarly, the present study illustrated major decreases in the overall scores for scenarios 2, 43, 53, 64, 65, 66 and 85 mainly attributed to the presence of very low ISA in the respective grids.

The present analyses also showed that the combination of low ISA (i.e. low built-up area) as well as presence of more blue regions, i.e. water bodies, lakes, etc., can be used as effective land cover planning strategies only in few areas within the Bangalore city due to the limitations in space as well as the absence of conducive geomorphology for creation of moderately sized basins as unique NbS options. It is interesting to note that the scale of the decrease or increase in the overall scores (high to moderate or low) could be an important factor to be considered for the duration of selection of the appropriate NbS strategies for lowering the respective ERI. For example, NbS such as creation of street tree networks can be achieved on short-term planning basis for areas where the overall scores are low to moderate. The areas having less space for plantation of trees in the city should focus on having mandatory installation of more vertical green walls (like flyover and metro pillars), green roofs (offices and industrial setups) and green buildings (well ventilated, with indoor vegetation) to reduce air pollution, heat island effects and less energy-intensive future city plan. Whereas, to reduce the risks associated with flash floods, polluted lakes and wetlands in the city NbS is growing choice for mainstreaming can be bioswales, biopores, constructed wetlands and sponge gardens by involving citizen based efforts and initiatives (For details please refer Chap. 1). NbS implementation framework by Albert et al. (2020) will be relevant to be referred for urban area-specific planning that clearly works on three important criteria that follow six planning steps, viz. co-defining the urban context and settings, understanding the specific local challenges, developing better planning for better future scenarios, evaluating the potential impacts of NbS that are to be implemented, development of NbS strategies and implementation following active monitoring of NbS. However, it is also important to mention here that the strongest barriers are in the form of political, institutional and knowledge-related barriers crucial for NbS mainstreaming hence, urban planners should prioritize NbS for managing their actions (Sarabi et al., 2020). It is pertinent that NbS should not be having isolated discussions within scientific communities and experts; it should be further introduced, and capacity building should happen for urban planners, bureaucrats, politicians, civil engineers and architects. To understand the severity of the urban risks and hazards in the warming world for Bangalore as also comprehensively elaborated in the results of NDVI, concretisation of the city, LULC changes and increasing air pollution especially PM, there is a need for proactive planning to ensure which ward requires specific blue-green infrastructure as an important NbS to address the place-specific context with active community participation (Fig. 8.13).

The costs associated with such NbS is also quite less, requiring low investment and maintenance. Still, there is dearth of sufficient economical support available for the implementation of NbS in urban areas. To provide sufficient funding support to

realise implementation of diverse place-specific NbS convergence of policies, public-private partnership mode (PPP) and inner municipal cooperation, creating financial incentives for communities can help achieve the targets for mainstreaming NbS (Droste et al. 2017). However, the long-term effects of such NbS strategy may not be immediately evident. On the other hand, NbS such as creation and/or maintenance of lake-beds or blue spaces may require to be implemented across high to moderate spatio-temporal scales, involve huge investments and sustained community participation as well as stewardship. It is also important to consider and understand that with exponential rise in population and increasing influx to urban areas, every year more cities are expanding and becoming tier II and tier I cities. This is especially true for India where every census in decade adds more small towns graduating to tier III and tier III to tier I cities, while there is less scope for integrating NbS and BGI in fully expanded tier I cities in India because of the over concretisation, infrastructure build-up and shortage of space. Still NbS that cover less space and can give larger benefits should be integrated in urban planning along with proactive restoration of degraded green and blue spaces. The study provides some significant research-based evidence to support efficient NbS planning and implementation in Bangalore. However, there is still a lot of scope for the effective use of NbS in the design of urban infrastructures of small towns, tier II and tier III cities that are expanding where restrictions to control air and water pollution should be applied. Efforts should also undertaken to make them disaster proof, resilient and sustainable by enforcing NbS as a mandatory compliance followed by regulated expansion.

8.5   Conclusions

The present investigation thus provides a suitable quantification of the effects of the LULC, air quality statuses and the prevalence of ecological risks at high spatio-temporal resolutions at a city level, associated with different areas of a city as Bengaluru. The ecological risks can be attributed to the following:

1. The increase in the built-up regions of the different portions of the city causes the high incidence of increase in the ecological risks as indicated by the increase in the values of the indices.
2. The rise in air pollution proves be the co-factor enhancing the ecological risks for the city of Bengaluru.
3. Simulation of various NbS scenarios reflects that the decrease in the built-up to green area, as well as the AQI, corresponding to an increase in the GBR can provide optimal scenarios for reduction of the overall ecological risks across all the wards of Bengaluru city.

The study further provides the scope to select the appropriate NbS options for implementation based on the availability of monetary and labour investments, public participatory approaches as well as planning on varied spatio-temporal scales. The

NbS scenarios associated with major decrease in score can be investigated to derive appropriate city-level plans/framework for effective mainstreaming of NbS and to meet the targets of SDG 11.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Ahmed B, Kamruzzaman MD, Zhu X, Rahman M, Choi K (2013) Simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. Remote Sens 5(11): 5969–5998. https://doi.org/10.3390/rs5115969

Albert C, Brillinger M, Guerrero P, Gottwald S, Henze J, Schmidt S, Ott E, Schröter B (2021) Planning nature-based solutions: principles, steps, and insights. Ambio 50(8):1446–1461

Albert C, Fürst C, Ring I, Sandström C (2020) Research note: spatial planning in Europe and Central Asia–Enhancing the consideration of biodiversity and ecosystem services. Landsc Urban Plan 196:103741

Balica SF, Douben N, Wright NG (2009) Flood vulnerability indices at varying spatial scales. Water Sci Technol 60(10):2571–2580. https://doi.org/10.2166/wst.2009.183

Bush J, Doyon A (2019) Building urban resilience with nature-based solutions: how can urban planning contribute? Cities 95:102483

Chen H, Burnett RT, Copes R, Kwong JC, Villeneuve PJ, Goldberg MS, Brook RD, Van Donkelaar A, Jerrett M, Martin RV, Brook JR (2016) Ambient fine particulate matter and mortality among survivors of myocardial infarction: population-based cohort study. Environ Health Perspect 124 (9):1421–1428

Chinnaswamy AK, Galvez MCD, Balisane H, Nguyen QT, Naguib RN, Trodd N, Marshall IM, Yaacob N, Santos GNC, Vallar EA, Shaker M (2016) Air pollution in Bangalore, India: an eight-year trend analysis. Int J Environ Technol Manag 19(3–4):177–197. https://doi.org/10.1504/IJETM.2016.10003102

Cohen-Shacham E, Andrade A, Dalton J, Dudley N, Jones M, Kumar C, Maginnis S, Maynard S, Nelson CR, Renaud FG, Welling R (2019) Core principles for successfully implementing and upscaling nature-based solutions. Environ Sci Pol 98:20–29

Corburn J (2004) Confronting the challenges in reconnecting urban planning and public health. Am J Public Health 94(4):541–546. https://doi.org/10.2105/ajph.94.4.541

Croeser T, Garrard GE, Thomas FM, Tran TD, Mell I, Clement S, Sánchez R, Bekessy S (2021) Diagnosing delivery capabilities on a large international nature-based solutions project. Urban Sustainability 1(1):1–9

De US, Singh GP, Rase DM (2013) Urban flooding in recent decades in four mega cities of India. J Indian Geophys Union 17(2):153–165

Deng F, Yu YJ, Quan ZZ (2011) Research progresses of regional ecological risk assessment. Environ Sci Technol 34(6G):141–147

Dhyani S, Karki M, Gupta AK (2020) Opportunities and advances to mainstream nature-based solutions in disaster risk management and climate strategy. In: Nature-based solutions for resilient ecosystems and societies. Springer, Singapore, pp 1–26

Dhyani S, Lahoti S, Khare S, Pujari P, Verma P (2018) Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. International journal of disaster risk reduction 32:95–105

Dhyani S, Maikhuri RK, Dhyani D (2019) Impact of anthropogenic interferences on species composition, regeneration and stand quality in moist temperate forests of Central Himalaya. Trop Ecol 60(4):539–551

Dhyani S, Majumdar R, Santhanam H (2021) Scaling-up nature-based solutions for mainstreaming resilience in Indian cities. In: Mukherjee M, Shaw R (eds) Ecosystem-based disaster and climate resilience, Disaster and risk research: GADRI book series. Springer, Singapore. https://doi.org/10.1007/978-981-16-4815-1_12

Droste N, Schröter-Schlaack C, Hansjürgens B, Zimmermann H (2017) Implementing nature-based solutions in urban areas: financing and governance aspects. In nature-based solutions to climate change adaptation in urban areas. Springer, Cham, pp 307–321

Frantzeskaki N (2019) Seven lessons for planning nature-based solutions in cities. Environ Sci Pol 93:101–111

Ibrahim MA (2020) Risk of spontaneous and anthropogenic fires in waste management chain and hazards of secondary fires. Resour Conserv Recycl 159:104852. https://doi.org/10.1016/j.resconrec.2020.104852

Jax K (2006) Ecological units: definitions and application. Q Rev Biol 81(3):237–258. https://doi.org/10.1086/506237

Jha, A.K., Bloch, R. and Lamond, J., 2012. Cities and flooding: a guide to integrated urban flood risk management for the 21st century. World Bank Publications.

Oral HV, Carvalho P, Gajewska M, Ursino N, Masi F, Hullebusch EDV, Kazak JK, Exposito A, Cipolletta G, Andersen TR, Finger DC (2020) A review of nature-based solutions for urban water management in European circular cities: a critical assessment based on case studies and literature. Blue-Green Systems 2(1):112–136

Patra S, Sahoo S, Mishra P, Mahapatra SC (2018) Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level. J Urban Manag 7(2):70–84. https://doi.org/10.1016/j.jum.2018.04.006

Pickett STA, Kolasa J, Armesto JJ, Collins SL (1989) The ecological concept of disturbance and its expression at various hierarchical levels. Oikos 54:129–136. https://doi.org/10.2307/3565258

Power M, McCarty LS (2002) Trends in the development of ecological risk assessment and management frameworks. Hum Ecol Risk Assess 8(1):7–18. https://doi.org/10.1080/20028091056683

Santhanam H, Majumdar R (2020) Permeable pavements as sustainable nature-based solutions for the management of Urban Lake Ecosystems. In: Dhyani S, Gupta A, Karki M (eds) Nature-based solutions for resilient ecosystems and societies, Disaster Resilience and Green Growth. Springer, Singapore. https://doi.org/10.1007/978-981-15-4712-6_19

Sarabi S, Han Q, Romme AGL, de Vries B, Valkenburg R, den Ouden E (2020) Uptake and implementation of nature-based solutions: an analysis of barriers using interpretive structural modeling. J Environ Manag 270:110749

Seddon N, Smith A, Smith P, Key I, Chausson A, Girardin C, House J, Srivastava S, Turner B (2021) Getting the message right on nature-based solutions to climate change. Glob Chang Biol 27(8):1518–1546

Swartjes FA, Breure AM, Beaulieu M (2011) Introduction to ecological risk assessment. In dealing with contaminated sites. Springer, Dordrecht, pp 573–624

Tang L, Wang L, Li Q, Zhao J (2018) A framework designation for the assessment of urban ecological risks. Int J Sustain Dev World Ecol 25(5):387–395. https://doi.org/10.1080/13504509.2018.1434570

The Times of India Report (2020, January 30) Bengaluru has world's worst traffic congestion, Mumbai at number 4. https://timesofindia.indiatimes.com/india/bengaluru-has-worlds-worst-traffic-congestion-mumbai-at-number-4/articleshow/73747725.cms

Verma S, Chatterjee A, Mandal NR (2017) Analysing urban sprawl and shifting of urban growth Centre of Bengaluru City, India using Shannon's entropy method. J Settlements Spatial Planning 8(2):89–98. https://doi.org/10.24193/JSSP.2017.2.02

Villa M, Ceballos RF (2021) Analysis and forecasting of fire incidence in Davao City. Recoletos Multidiscip Res J 8(2):35–50. https://arxiv.org/ftp/arxiv/papers/2101/2101.00356.pdf

Wu XQ, Hong SQ, Wu XC, Cai SQ (2004) The principle, way and technique of environmental policy risk assessment-also discussing the policy environment risk assessment. Safe Environ Eng 11(3):34–36

Zhao J, Xiao H, Wu G (2000) Comparison analysis on physical and value assessment methods for ecosystems services. J Appl Ecol 11(2):290–292. PMID: 11767617

Zhou D, Shi P, Wu X, Ma J, Yu J (2014) Effects of urbanization expansion on landscape pattern and region ecological risk in Chinese coastal city: a case study of Yantai city. Sci World J:821781. https://doi.org/10.1155/2014/821781

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