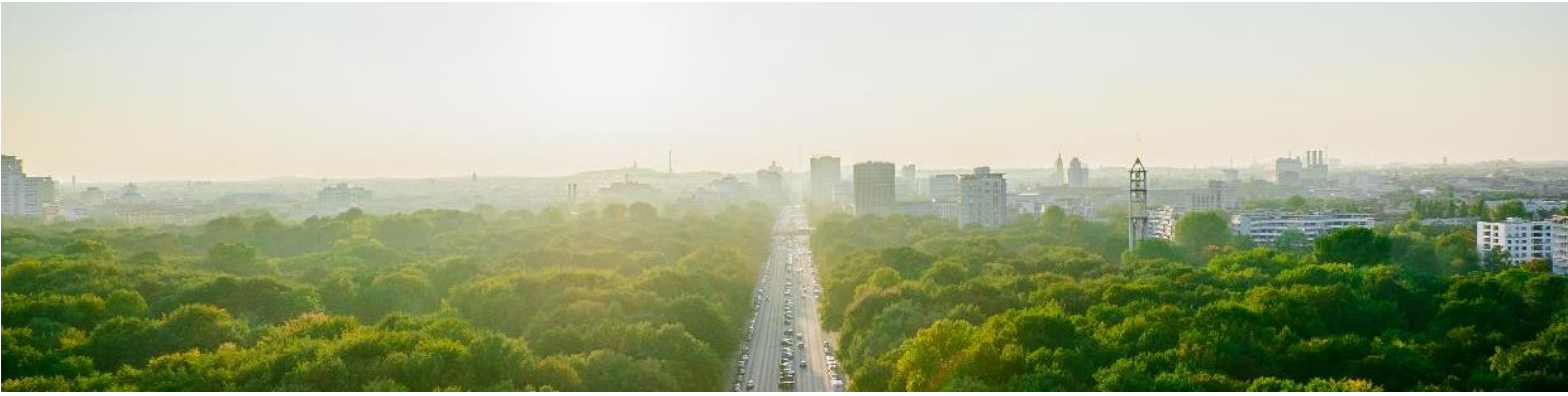
CHARISMA Decision Support System
Manual for use on Virtual Machines



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Authored by:
Raf Theunissen

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Contents

1. Background

Global warming

Earth's changing climate has become an undeniable fact. Since the pre-industrial era, the global temperature has risen by approximately 1.2°C and will, according to the predictions in the 6th IPCC assessment report, continue to rise, even in the scenario of a substantial cut in emissions (Figure 1). Without emissions cuts, global warming is predicted to reach highs of 4°C towards the end of the century. Considering the devasting impact of climate change humanity is experiencing today, at 1.2°C, it goes without saying that preparation for worsening conditions is required.

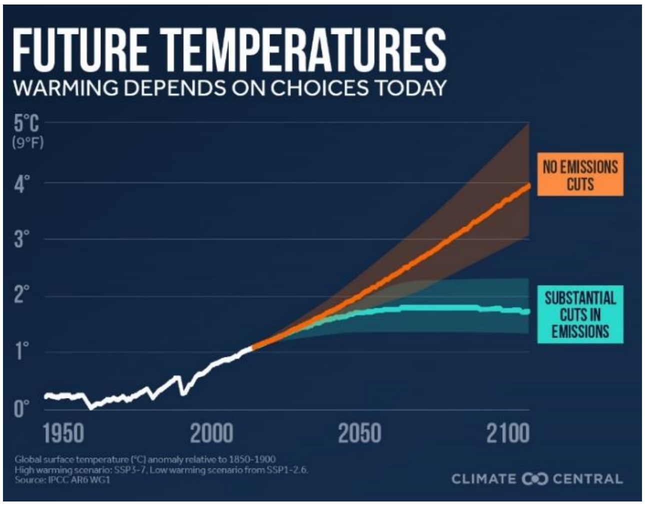


Figure 1: Evolution in global warming according to the 6th IPCC report[1]

Urbanization

Global urban population has rapidly grown from approximately 1 billion in 1950 to 4.4 billion in 2021[2]. By 2050 the world's urban population is expected to reach 6.7 billion, which constitutes almost 70% of the total population (Figure 3a). 90% of the increase in urban population will occur in Africa and Asia. According to a report of the World Urbanization Prospects by UN DESA's Population Division in 2018, India alone is projected to add 404 million people to the urban areas with a continuously growing share (Figure 3b).

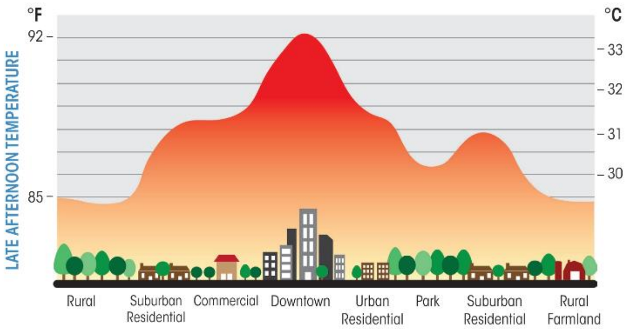
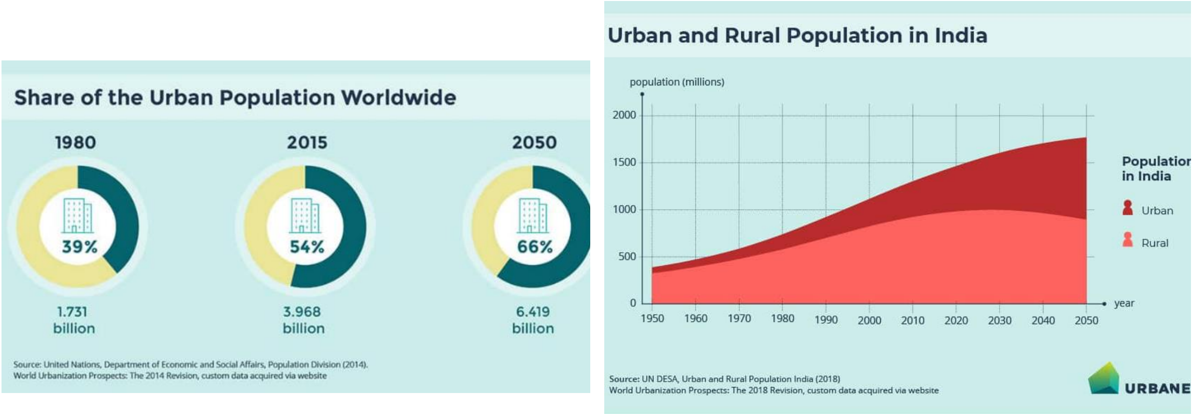


Figure 2: Illustration of the urban heat island effect (Taken from https://eco-intelligent.com/2017/04/13/the-urban-heat-island-effect/).

[1] https://www.climatecentral.org/climate-matters/ipcc-6th-assessment-report-the-physical-science-basis
[2] https://statisticstimes.com/demographics/world-urban-population.php

While global temperatures rise, cities can experience even higher temperature increases because of the urban heat-island effect (Figure 2). Adaptation planning for cities therefore requires both urban expansion and climate change to be incorporated.



(a) *(b)*

Figure 3: (a) Growth in worldwide urban population[3]. (b) Growth in urban and rural population in India[4].

Fatal heat waves

Due to climate change, 160 million to 200 million people in India could be exposed to heat waves exceeding survival thresholds over the next 10 years[5], with urban areas in India expected to be one of the first places in the world to experience fatal heat waves. In addition to the direct effects on health, climate change will reduce the effective number of hours that can be worked outdoors, potentially threatening 2.5% to 4.5% of GNP already by 2030.

Vector borne diseases

Climate change also has a direct effect on vector-borne diseases, such as Malaria and Dengue, as the development period of the insects' life cycle and the subsequent development of parasites in their bodies are influenced by climatic conditions. Climate change has thus emerged as a new threat and challenge to ongoing efforts to reduce vector-borne diseases. For example, recent studies have shown that, as a result of climate change, the transmission windows of malaria in the north-eastern states are likely to be temporarily extended by 2-3 months.

Climate-health risk management in India project

The Flemish Institute for Technological Research (VITO - coordinator), AVIA-GIS and the Public Health Foundation India-Centre for Environmental Health (PHFI-CEH) have partnered up in the project "*Climate-health risk management in India*" (CHARISMA), which is funded through International Climate Financing by the Department of Environment (Government of Flanders, Belgium). In a collaborative effort with local stakeholders and authorities, a web-based information platform has been developed during this three-year project, with the aim of supporting Indian authorities in

[3] https://www.urbanet.info/world-urban-population/
[4] https://www.urbanet.info/urbanisation-in-india-infographics/
[5] https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/will%20india%20get%20too%20hot%20to%20work/will-india-get%20too-hot-to-work-vf.pdf

drawing up measures to adapt and cope with climate and health impacts caused by climate change. This manual guides the user through the dashboard and illustrates how it can be used in planning climate adaptation measures.

Information platform

The information platform allows decision-makers and urban planners to evaluate the urban expansion up to 2070, with or without masterplans (if made available), distinguishing 11 different land use classes, at 100 meter resolution. The platform is unique in that it provides data layers regarding future climate impact in which urban evolution is coupled with future climate model output. The user thus has information for the present and future at hand, enabling quantitative assessment of the severity of upcoming changes in terms of heat stress, identification of urban areas of concern in terms of vector borne diseases and the design of localized robust adaptation strategies. Essentially the data contained within the dashboard thus addresses the majority of recommendations with respect to developing effective Heat Action Plans[6];

1. The dashboard provides climatic data, both for the period 2011-2020 and 2040-2050. This enables authorities to design solutions which are not merely suited for the present climatic conditions, but also for future conditions (cf. Figure 1). The allows for no-regret solutions and thus promotes cost efficiency.
2. For several cities, urban growth has been taken into account when evaluation climatic change within the urban area. For some cities Masterplans have also been considered, allowing the evaluation of the plans in terms of robustness with respect to heat stress. In turn, this can be used to steer urban planning.
3. For the demonstration cities (Lucknow and Guwahati), spatially explicit 2011 census data has been incorporated. Such census data has been taken into account in the ward-wise assessment of heat vulnerability, thus providing authorities with a clear view which wards to prioritize.
4. Besides standard climatic indicators such as air temperature, the dashboard contains specific heat-stress related indicators, such as number of heat wave days, heat wave severity, number of hot days and tropical nights, etc. The dashboard also contains land use statistics such as green area per inhabitant. Data is furthermore at high resolution (from 100m down to 1m) thus providing a rich and unique database to assess and tailor climate change adaptation and mitigation plans to localised conditions.

[6] https://cprindia.org/briefsreports/how-is-india-adapting-to-heatwaves-an-assessment-of-heat-action-plans-with-insights-for-transformative-climate-action/

2. Technical requirements

The information platform, which is a decision support system, is a web-based platform. By providing it in the form of a Virtual Machine, all necessary libraries are automatically incorporated in the package and independent of the operating system. The IT hardware on which the dashboard is run should have however sufficient performance to reduce data loading time.

3. Home page

Landing

After starting the Virtual Machine (please see the related manual "READ_ME_FIRST_CHARISMA_Virtual_Startup.pdf"), the user user will arrive at the overview page where the different cities across India, considered in the CHARISMA project are indicated (Figure 4). The dashboard contains climate-related data, sourced from publicly available databases, for almost 60 Indian cities (Annex I).

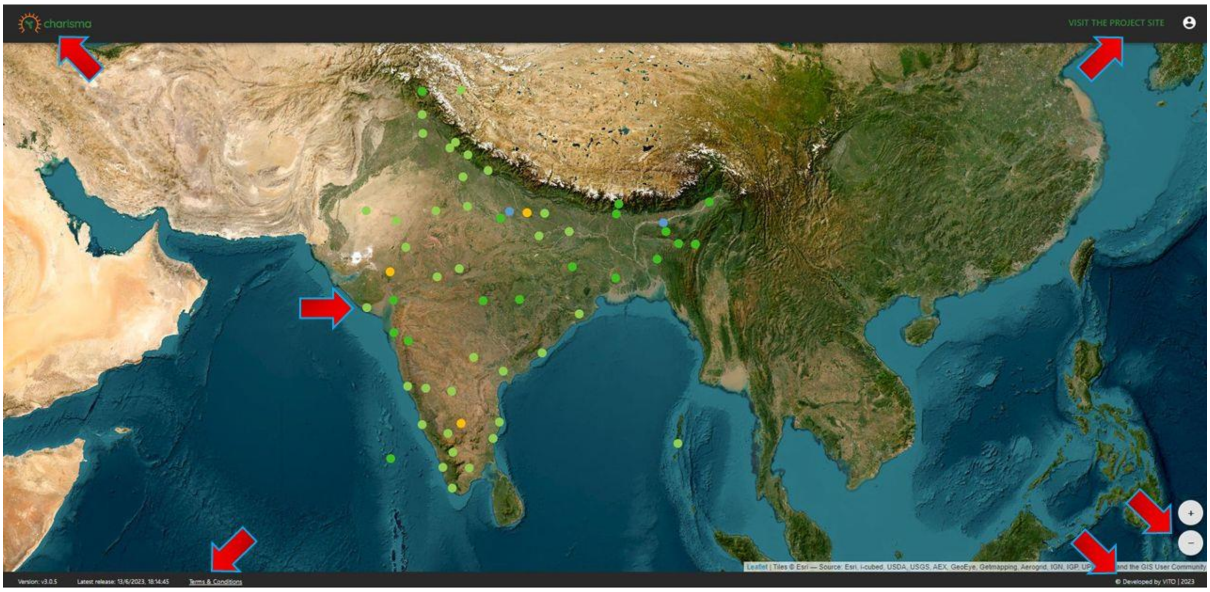


Figure 4: Landing page of the CHARISMA dashboard, giving an overview of the various Indian cities for which data has been generated..

The landing page already offers the user multiple options (going clockwise in Figure 4):

- In the top left corner, the CHARISMA logo will allow the user to always return to the map providing the overview of the cities.
- The top right corner displays "VISIT THE PROJECT SITE", which will bring the user to the webpage dedicated to the CHARISMA project. Here the user can find more information regarding the project objectives, aims, partners, etc.
- Besides the + and – symbols in the lower right, the user can zoom in and out by scrolling.
- The dashboard has been developed by VITO in collaboration with Indian authorities and experts and project partners (notably Avia-GIS and the Centre of Environmental Health – Public Health Foundation of India). The lower right link will bring the user to the VITO website for more information regarding VITO's activities in the field of sustainable development.
- Related to the use of the dashboard are Terms and Conditions. The user is advised to read and understand these since using the dashboard will imply that the user accepts the terms and conditions.
- Finally, each of the cities can be accessed by clicking on the respective coloured dot (Figure 5).

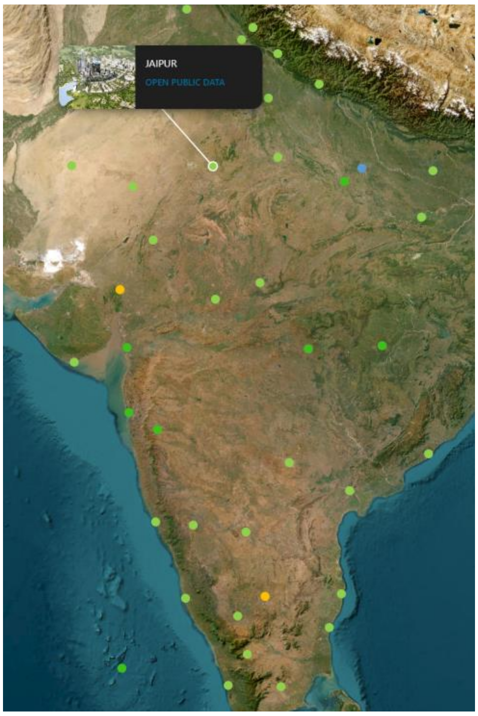


Figure 5: For each city, public data is available.

Colour codes

Each of the cities considered in the dashboard is attributed a colour (Figure 6), indicating the level of data content for that city.

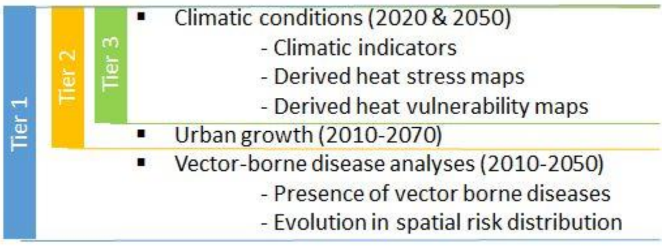


Figure 6: Cities are attributed colours depending on level of data content.

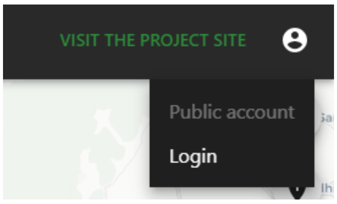
All urban land use is derived from public satellite imagery, which, which allows readily available climate model outputs to be downscaled to approximately 100 meters. In tier 3 (green dots) the future climatic conditions, utilizing the present urban layout are available. In the second tier (orange dot) urban growth is considered and incorporated in future climate assessment. In tier 1 (blue) both urban growth and future climate data is available in the repository. While tier 3 offers approximately 60 data layers, this can go up to over 300 layers in tier 1.
Notice that in tier 1 two shades of green have been applied to distinguish the underlying methodology adopted to retrieve the land use classification. The methodology used is reported in the description of the land use indicators (see Data inventory).

! The dashboard contains only data based on public sources and as such only a selection of data available in Tier 1.

4. Login

All data contained within the information platform available through the Virtual Machine originates from public data sources. As such, no registration is required to access or download the data.
After clicking on a city, the user is able to select multiple indicators for that particular city, without requiring any credentials.

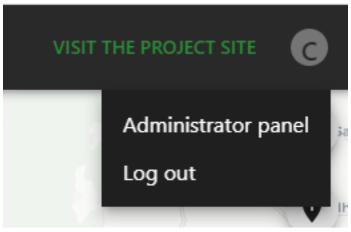
In the landing page of the selected city, by clicking on the user icon in the top right corner, a drop down appears showing the options “Public account” (de-activated) and “Login”.



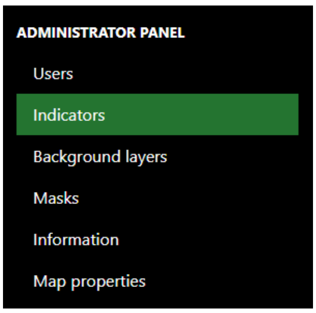
By clicking on “Login” and providing the credentials below, the user can activate administrator rights.

Login : charisma@charisma.local
Password: WeYfGuFiITGe

Now, by clicking on the user icon (notice that the icon has changed), the user will have the ability to open the Administrator panel.



In the Administrator panel the user is able to modify various features, such as the name of the indictors, the addition of users (and allocation of rights), etc.



! **World of caution**: The user is strongly advised **not** to change these settings and **not** to publicly share the above login credentials.

The user is expected to have read and accept the Terms of Use available in Section 9. The Terms of Use inform the user of limitations and restrictions on the use of the dashboard and information contained within. Do not use the dashboard if you do NOT accept the provisions stated in The Terms of Use.

! **World of caution**: The user is advised to read the privacy policy and Terms & Conditions carefully.

5. Map viewer

Start view

Once a city has been selected in the landing page and public data is accessed, the user will see the default starting view which is an empty map (Figure 7) with some place names.

Item (1) indicates that the user is "logged in" and will change if logged in as administrator. Clicking the thumbnail allows the user to log out. Items (2), (3), (9) and (10) are the same features which can be found on the landing page; a link to the CHARISMA project web-page (www.charisma-india.eu), a link to return to the overview map, the relevant Terms & Conditions and a link to the vito web-site (www.vito.be) respectively.
On the left-hand side the icon indicating multiple layers is by default active (4). This is the window in which all data will be displayed. Two other windows can be selected; ⚙ (5) and ⓘ (6). (5) enables the user to select different backgrounds (Figure 8); Low Contrast, Streetplan and Satellite imagery. Low Contrast is the default starting map (Figure 7). Streetplan provides a map detailing streets and toponymy, while Satellite Imagery displays a satellite image as background.
Further information regarding the platform and CHARISMA project can be read by clicking on (6).

Data layers can be added to view through the green thumbnail "Add a map" (7). Any layer added will appear as a selected indicator (8).

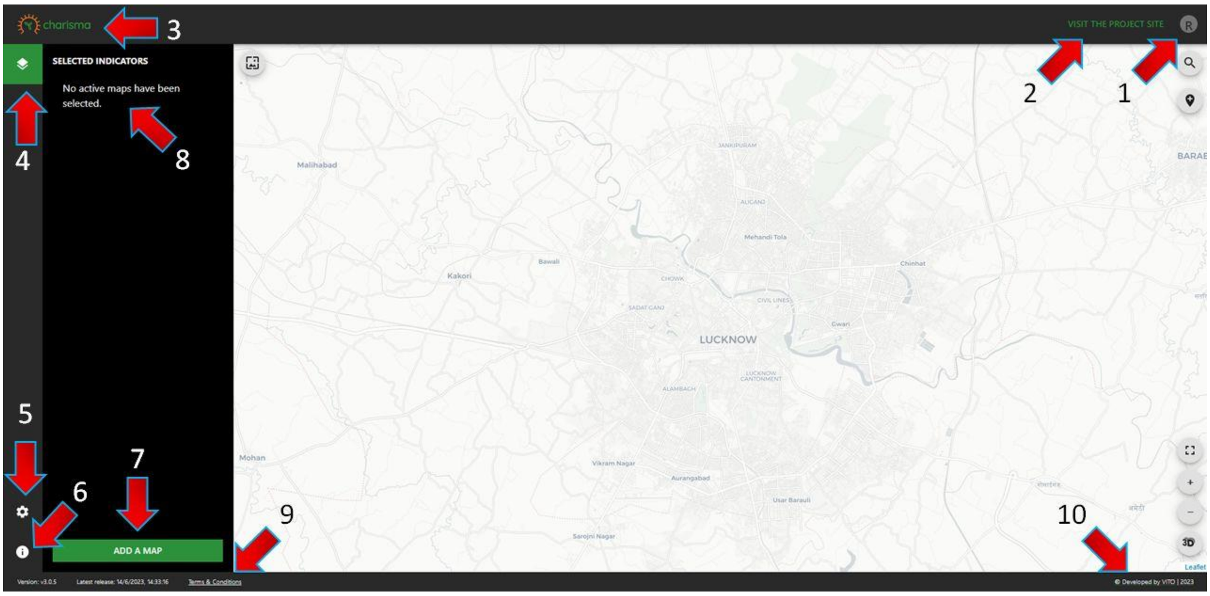


Figure 7: Opening page of a city in the CHARISMA dashboard after log in.

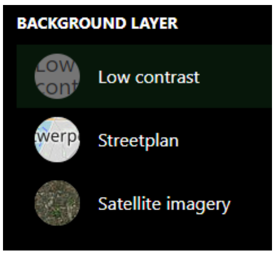


Figure 8: Selectable background layers.

Data view

Once the user has selected the indicator to display from the repository (see Data inventory), the respective layer is displayed in the main window (Figure 9) and will be added to the list of "SELECTED INDICATORS" ((8) in Figure 7).

The green slider (1) allows the visualization of the map to be toggled on/off.
When hovering over the indicator name in the left column, two additional symbols will appear; the litter bin will completely remove the indicator from the view while the slider icon () will open a drop down. The drop down contains the description of the indicator as well as relevant references and allows the user to set the transparency of the map (with respect to the background) by moving the slider (2). If multiple option could be selected in the repository, these options are available again such that the user can change the specifications (3).

Figure 9: Display of selected indicator.

The legend can be shown by clicking in the lower left corner (4). The legend quantifies the various colours and provides information regarding the indicator and selected options.
The magnifying glass (5) in the top right corner enables the user to search the map by location. For example, the user can enter "Devi Khera Road" and the system will automatically present all possible locations. In the example below, there is only one Devi Khera Road. Clicking on the selectable location will subsequently provide a zoom into the location.

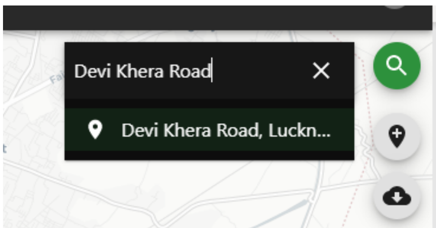


Figure 10: Specific locations can be sought for in the dashboard.

All active maps can be downloaded using the cloud symbol (6). A certain view or map combination can be directly exported in PNG format by clicking the snapshot icon (9).

The map can be visualized in full screen mode by clicking on symbol (7) and can be zoomed in and out through the plus and minus signs (8). The 3D logo (10) allows visualization of maps in 3D.

Point information

While the legend quantifies the various colour scales, the user is also able to obtain the value at a certain location by clicking on the pin icon (1). A hand will appear (👆) of which the index finger indicates the location. Clicking on a location of choice (2), the value of the active indicators at that location are shown in the right-hand window. In the example below, the ward indicator is one of the active layers and the ward of the selected location is highlighted.

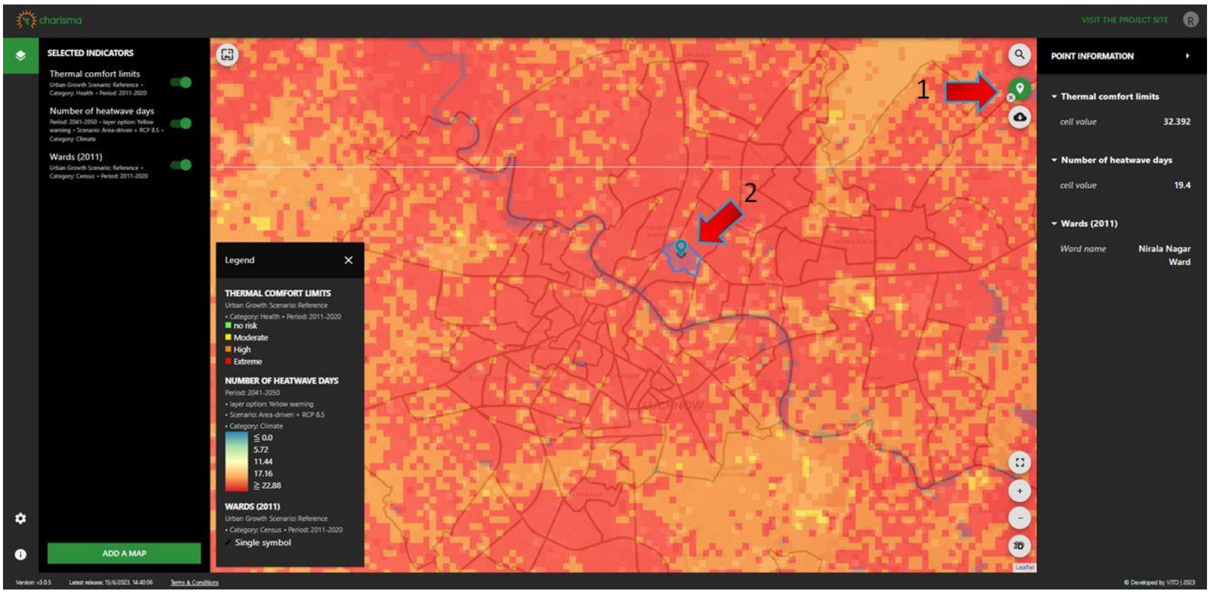


Figure 11: Point-wise extraction of information across multiple data layers.

Multiple layers

The user is able to select and overlay multiple data layers. The legend and point information (see Point information) will be updated accordingly (Figure 11). The order of the maps shown can be altered; when hovering over the selected indicator in the left-hand column, a hand icon appears. Clicking on the left mouse button then allows the indicator to be dragged and dropped, thereby changing the order in which the maps are visualized. The layer on top of the list is also the layer on top in the visualisation.

6. Data inventory

The inventory of all indicators available for the selected city is accessed by clicking on "ADD A MAP" in the start view ((7) in Figure 7). Each indicator map contains a small preview of the type of map and a description of the indicator as well relevant scientific references (Figure 12).
Maps can be selected in 3 ways;

(1) The user can select an indicator map through keywords. By clicking on the magnifying glass the user can enter for example "heat", after which all indicators of which the name contains "heat" will be shown.
(2) The user can filter out the indicators through the tags. By clicking on e.g. the tag "CENSUS", all indicators related to Census will be shown. The tag assigned to each indicator is shown in the bottom of the information window.
(3) The user can scroll through the various maps and can select an indicator by clicking anywhere in the related box.

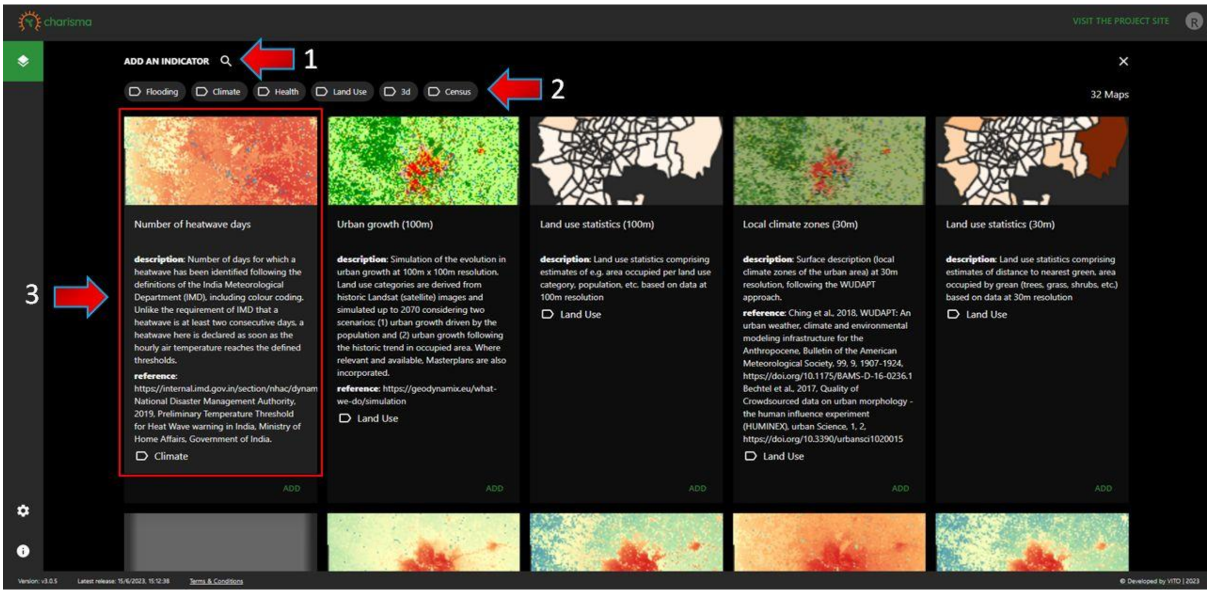


Figure 12: Indicators can be selected using tags.

After selecting the indicator of interest, the user has the option to further specify the options. While the options depend on the indicator and city, broadly speaking the options relate to

(1) the period of interest,
(2) the scenario. Two types of scenario can be distinguished; urban growth and climate.
For urban growth the scenarios can either be
  - "REFERENCE", i.e. data observed,
  - "AREA-DRIVEN", whereby the area of the city grows as per the observed historic trend,
  - "POPULATION-DRIVEN", whereby the area of the city is linked with population and the evolution in population defines the area,
  - "MASTERPLAN", if such a plan was provided by the local administrations.

With respect to climate, two scenarios, expressed as representative concentration paths, are considered
  - RCP2.6, with an expected global warming of 1.5°C by 2100,
  - RCP 8.5, with an expect global warming of approximately 4°C by 2100 (Figure 13)
(3) the season of interest.

An overview of the available indicator options can be found in Annex II.

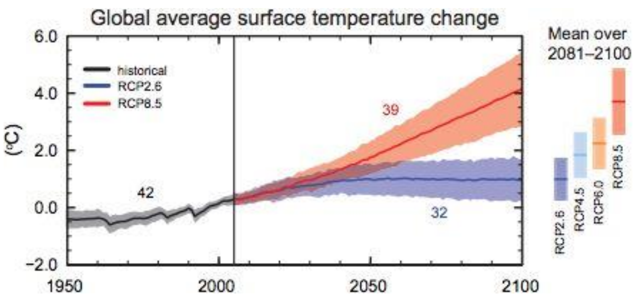


Figure 13: RCP climate change scenarios considered (Taken from https://www.e-education.psu.edu/meteo469/?q=book/export/html/149).

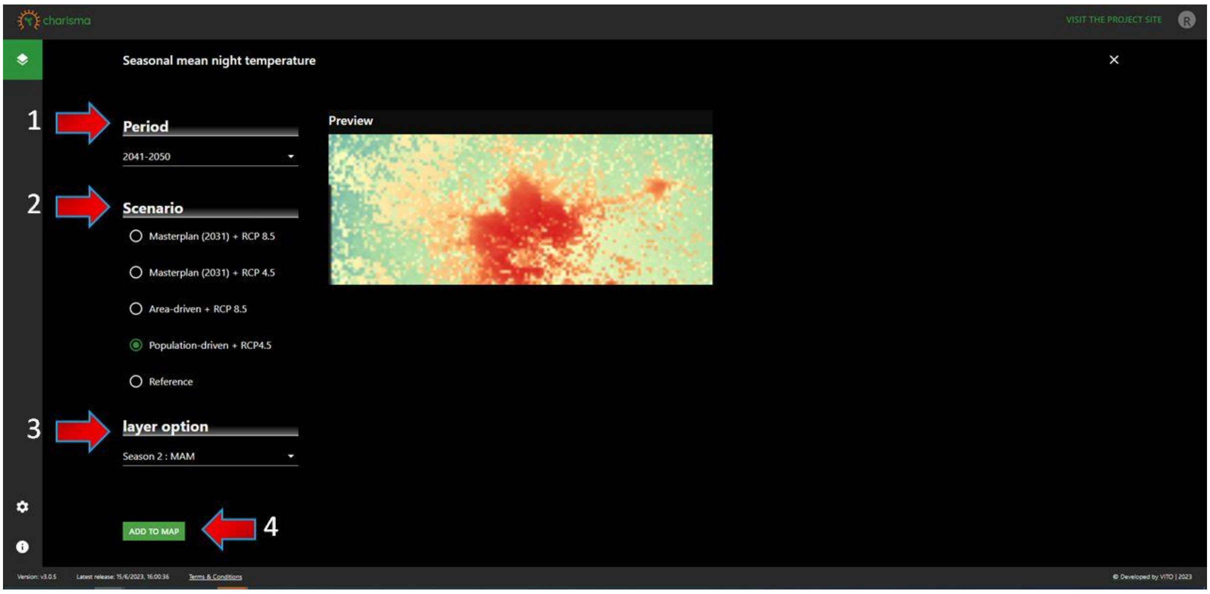


Figure 14: Depending on the indicator, additional options are available.

Once the user has selected the various options, clicking on "ADD TO MAP" (4), will add the map to the main window, displaying the selected indicator.

7. 3D

In a mapping exercise, students of the Faculty of Architecture and Planning of the Abdul Kalam Technical University (Lucknow) in collaboration with VITO mapped selected city quarters at 1m resolution. For these areas thermal comfort has also been analysed.

! 3D data has not been made available in the current dashboard and the description below only demonstrates the potential of the information platform.

The mapping data for these two areas can be found under the tag “3D”. By clicking on the 3D icon (1), a 3D view of the mapped data can be obtained. The thermal comfort analyses are found under the tag “CLIMATE”. When the data has been selected, the mapping is by default presented in 2D (Figure 15). Note that any data layer can be viewed in 3D perspective.

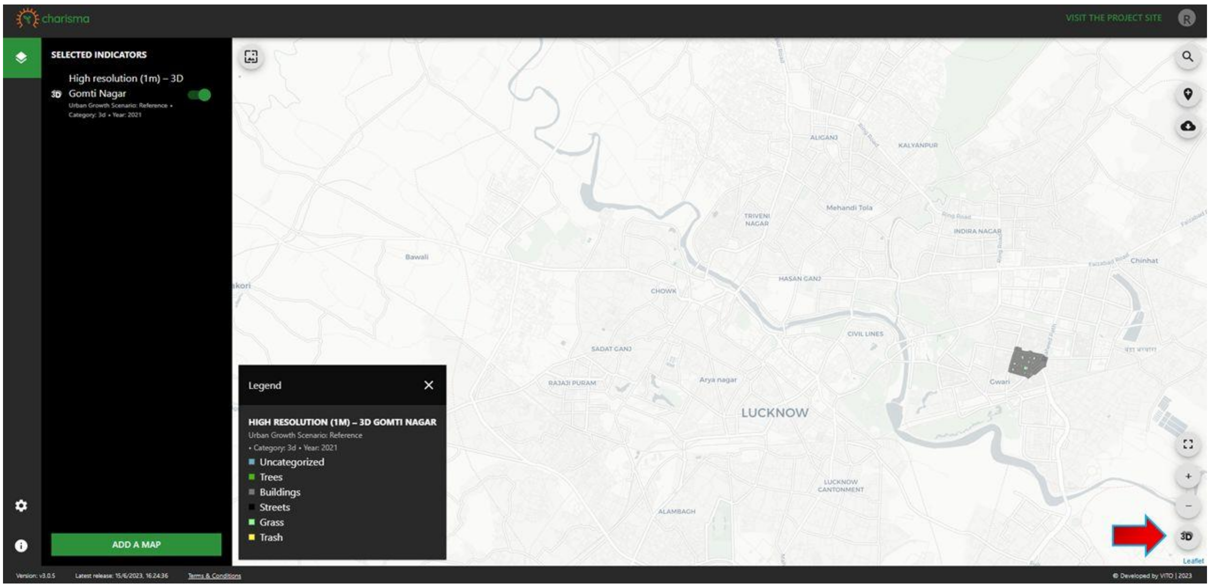


Figure 15: Illustrative areas have been mapped at high resolution and can be viewed in 3D.

Figure 16: The dashboard allows illustrative areas to be viewed in 3D.

Going back to 2D is done by clicking again in the lower right corner (5) on the 2D symbol. The viewing angle can be changed by holding the right mouse button and moving the mouse. The compass (4) will indicate the orientation of the map.

Given its smaller size, a quarter might be difficult to find back in the overall map. The user is advised to first centre the 3D view on the mapped area (3).
The legend indicates the map to contain multiple categories. By clicking on (1) and (2) (Figure 16), the user can toggle respectively buildings and green (trees and gras) on and off. The latter is of particular use when visualizing underlying data, such as for example the WBGT values (available under the tag “CLIMATE”) as illustrated in Figure 17.

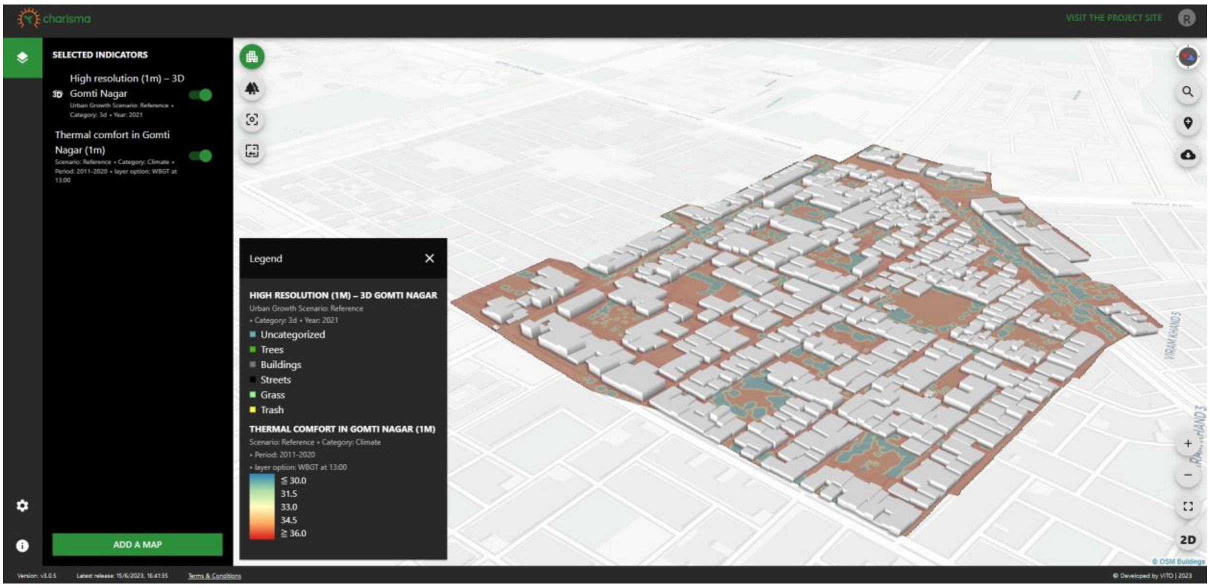


Figure 17: WBGT values at 13.00 on a hot day in the quarter.

8. Exemplary use cases

In this section the utility of the dashboard in informed climate adaptation will be demonstrated through practical examples. Not all use cases can be replicated though as the dashboard is configured to contain only public data. Private data is only shared with respective city authorities. Nevertheless, the use cases below serve to demonstrate the utility of the dashboard, and, even using the public data, many of the use cases can be replicated to an extent and provide useful insights.

Urban growth and masterplan assessment

We first want to visualise how the city is expected to expand by 2050.

1. From the data repository the "URBAN GROWTH (100M)" indicator (tag = "LAND USE") is selected (Figure 18)

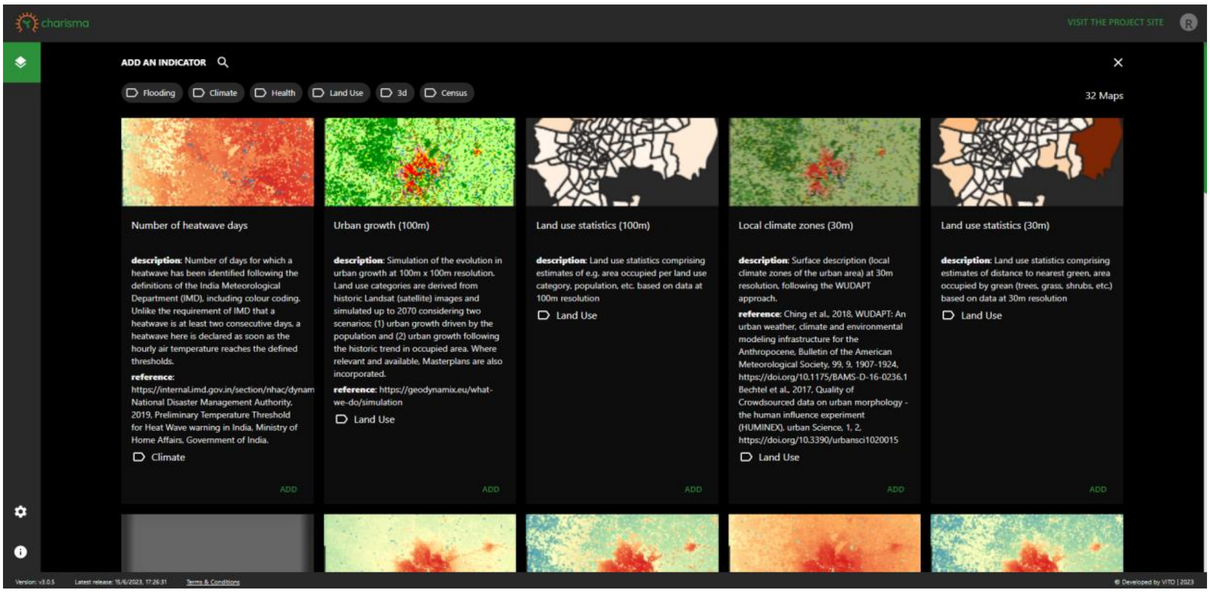


Figure 18.

2. From the options, 2021 is taken as year. As this date is in the past, only "REFERENCE" can be selected as URBAN GROWTH SCENARIO and added to the map (Figure 19).

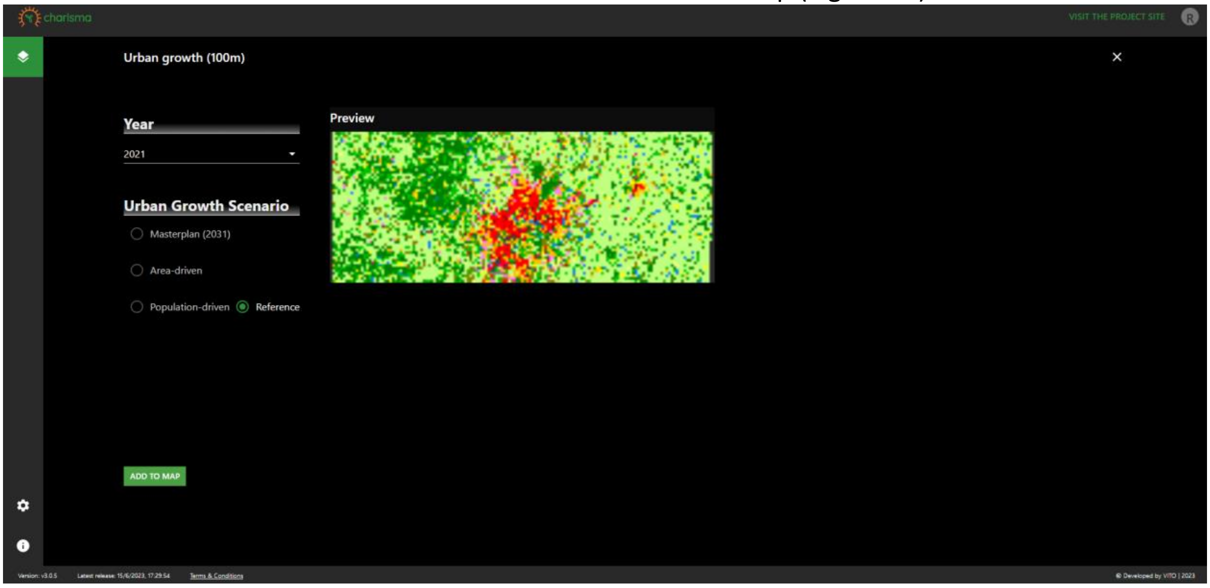


Figure 19.

3. The process is repeated taking 2050 as year and selecting "POPULATION-DRIVEN" as growth scenario.
4. The process in 3. is repeated, taking "MASTERPLAN (2031)" as scenario.

! In the current dashboard the data related to Masterplans has not been included as this data is not considered to be public. As such, the current use case serves to exemplify the potential use of the dashboard to evaluate Masterplans if and when available.

5. Finally, it is useful to overlay the ward boundaries and visually evaluate the land use changes ward wise. To do so, the indicator WARD (2011) is added under the indicator "CENSUS".

! In the current dashboard census data (including ward boundaries) has not been included as this data is not considered to be public. As such, the current use case serves to exemplify the potential use of the dashboard to include census data if and when available.

6. To ensure we always see the ward boundaries, the relevant indicator is dragged and dropped to the first position in the "LIST OF SELECTED INDICATORS" in the main viewing panel.
7. The transparency of each of the indicators is set to 100% by sliding the transparency button to the full right in the settings of each layer.
8. The panel should now look as below (Figure 20).

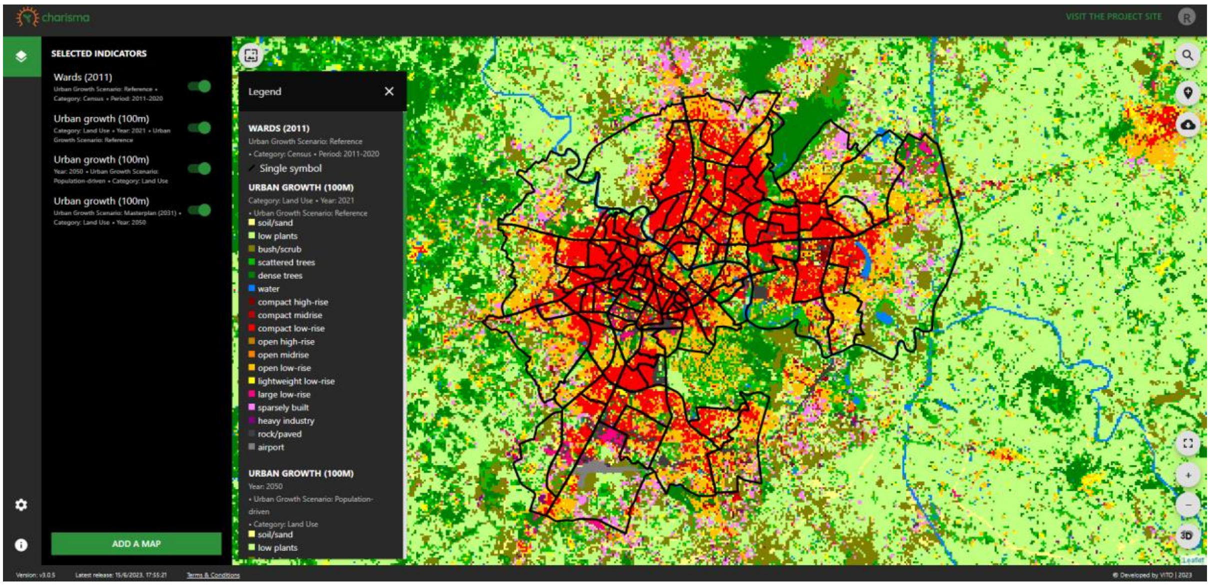


Figure 20.

The legend shows multiple classes, which relate not only to the type of land cover, but also the land use itself (Figure 21). The map reveals the main building type across the city to link to the reddish colour, i.e. compact low-rise.

The urban growth (100m) indicator for the year 2050 for the Masterplan is deactivated. Visible is the land use data for 2021, with ward boundaries overlayed. Because transparency was set to 100%, only the land use data for 2021 is visible. By toggling this layer off, the underlying data for 2050 becomes visible, showing the growth of the city. The outskirts become more orange, indicating more open-low rise buildings to appear. Clearly the city considered can expect a rapid growth.

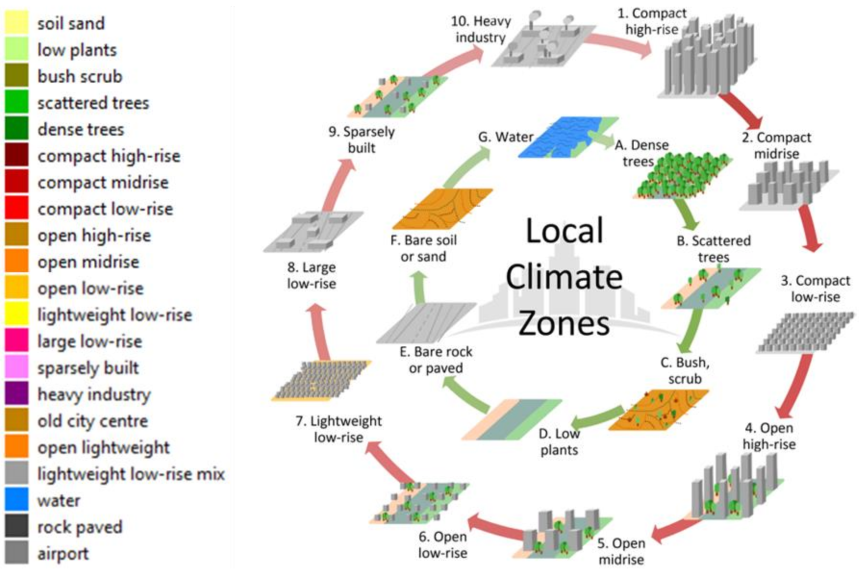


Figure 21: Illustration of land use classes in the urban growth modelling, based on local climate zones (Taken from Bechtel et al., 2017[7]). Note that the legend shown here might vary between maps.

Figure 22: Evolution in urban growth of the selected city. (Left) Land use classification – Figure 21 – based on satellite imagery of 2021. (Right) Simulated urban extent in 2050.

[7] Bechtel B., Demuzere M., Sismanidis P., Fenner D., Brousse O., Beck C., Van Coillie F., Conrad O., Keramitsoglou I., Middel A., Mills G., Niyogi D., Otto M., See L., Verdonck M-L., 2017, *Quality if crowdsourced data on urban morphology-the human influence experiment (HUMINEX)*, Urban Science, 1 (2), 15, https://doi.org/10.3390/urbansci1020015

Next, the layer for 2021 is deactivated and both urban growth data layers for 2050 are activated, allowing a comparison between urban growth with and without a Masterplan. (Note that the Masterplan 2031 in the considered example was provided by the relevant city authorities). Clearly the Masterplan, which essentialy imposes a zoning of pre-defined land use (e.g. industry, park, etc.), retains more green features and causes urban extension to become more structured. Of course, built-up areas present in 2021 do not change in 2050, causing the main changes to be visible near the edges of the city.

Figure 23: Masterplan assessment. (Left) Simulated urban extent in 2050 if population-driven, without intervention. (Right) Urban growth with the 2031 Masterplan in place.

Word of caution: !

The Land Use data is provided at 100m resolution. The land use class in each pixel is therefore the most representative land use class within the pixel. For example, one can overlay the "LAND COVER (10M)" data, or the "LAND USE (30M)" data on top of the "URBAN GROWTH (100M)" data and that each "Urban growth" pixel contains about 100 (!) "Land cover" pixels and 9 "Land use" pixels.
Zooming in on the "URBAN GROWTH (100M)" data layer will rapidly show a mosaic of land uses and mismatches between fine scale details (e.g. the presence of a house) and the attributed land use class become evident. The "URBAN GROWTH (100M)" should therefore be used to obtain a general overview of the distribution in land use classes across the city, without trying to extract too much detail.

Climate change and masterplan assessment

For each of the urban growth scenarios, the urban climate has been modelled. These are available as options in the climate indicators. In this example we will consider the "NUMBER OF COMBINED HOT DAYS AND TROPICAL NIGHTS", these are the number of 24-hour periods in which the day temperature rises above 35°C and the night temperature above 25°C. This combination is important as high night temperatures inhibit the body of cooling down during heatwaves, giving rise to increased risk of mortality[8]. First, the present condition is evaluated.

1. From the data repository the "URBAN GROWTH (100M)" indicator (tag = LAND USE) is selected, taking the year 2021.
2. A second map is added using the "NUMBER OF COMBINED HOT DAYS AND TROPICAL NIGHTS" indicator (tag = "CLIMATE"). Here the period 2011-2020 is selected. Since this period is in the past, only actual data is possible (no urban growth), i.e. "REFERENCE".

Hint: When having difficulties in finding this indicator, the user can click on the magnifying glass in the top and type "NUMBER OF". The available maps will subsequently be filtered down to those of which the indicator containing the searched for strings (Figure 24)

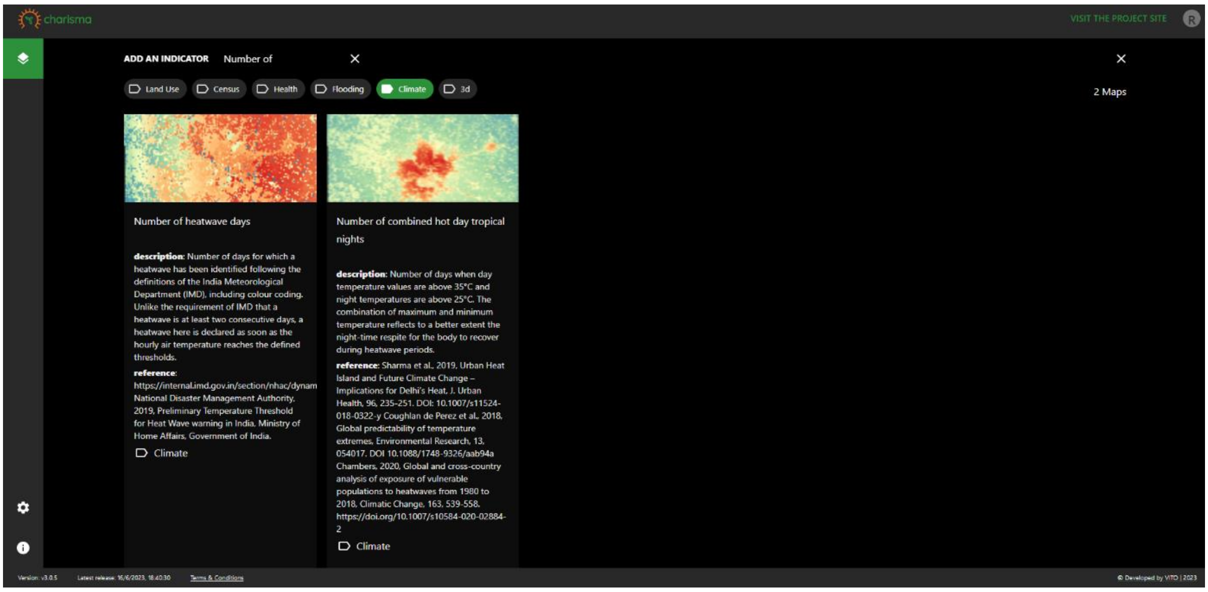


Figure 24: Indicators can be easily found by using the search function.

3. To make it easier to find landmarks, the background layer is changed to "STREETPLAN" (Figure 25).
4. Because the two available layers will mask the underlying streetplan, the transparency of both is increased. This is done by hovering the pointer over the indicator list, clicking on the icon and dragging the TRANSPARENCY slider to the left.
5. Toggling each map on and off, one can already notice that a strong correlation exists between the "NUMBER OF COMBINED HOT DAYS AND TROPICAL NIGHTS" and the land use categories. In fact, compactly built areas (reddish colour in the land use map) correlate with a higher "NUMBER OF COMBINED HOT DAYS AND TROPICAL NIGHTS". This should not come as a surprise. Areas in which houses are built more closely next to each other have less space for green (which provides cooling[9]) and have a higher density of material to store and release heat.
6. Let us evaluate the amount of green area within each ward. To do so, we start by adding the ward boundaries ("ADD A MAP" >> Tag = "CENSUS", indicator = "WARDS (2011)").
7. Next, we add "LAND USE STATISTICS (100M)". We opt for the year 2021 (hence "REFERENCE" as "URBAN GROWTH SCENARIO" and select "TREE AREA/WARD AREA (%)" as "LAYER OPTION".

[8] https://www.sciencedirect.com/science/article/pii/S2542519622001395
[9] https://theconversation.com/urban-greening-can-save-species-cool-warming-cities-and-make-us-happy-116000

If we deactivate the “URBAN GROWTH (100M)” indicator, it becomes evident that wards with few trees are indeed attributed higher temperatures. Trees in fact provide shade, which in turn provides cooling.

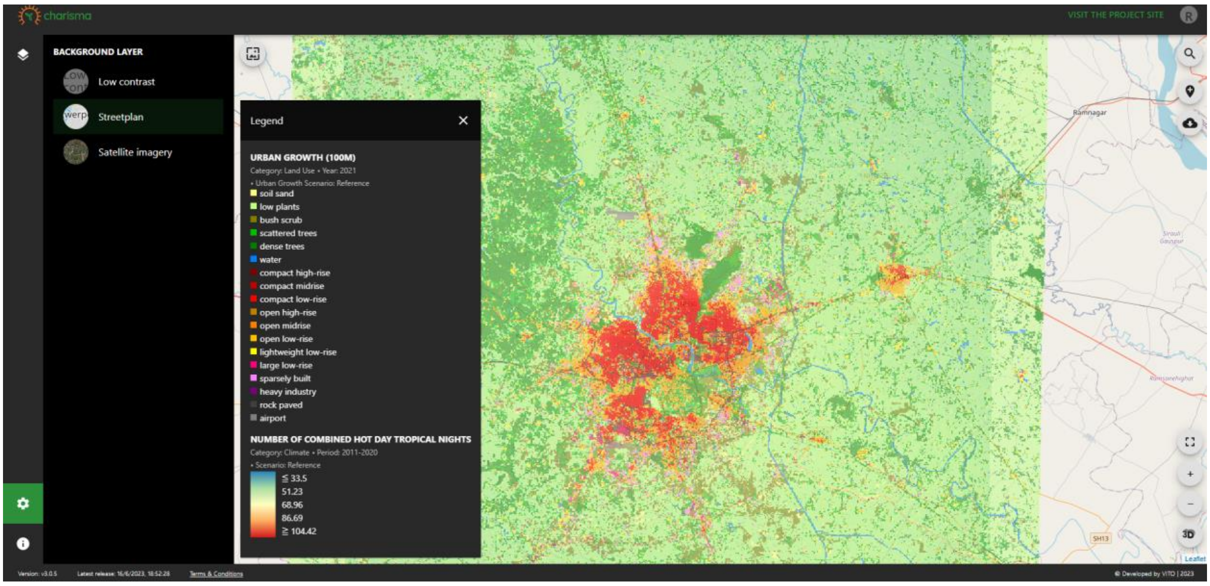


Figure 25: The “STREETPLAN” background can facilitate orientation and recognizing landmarks.

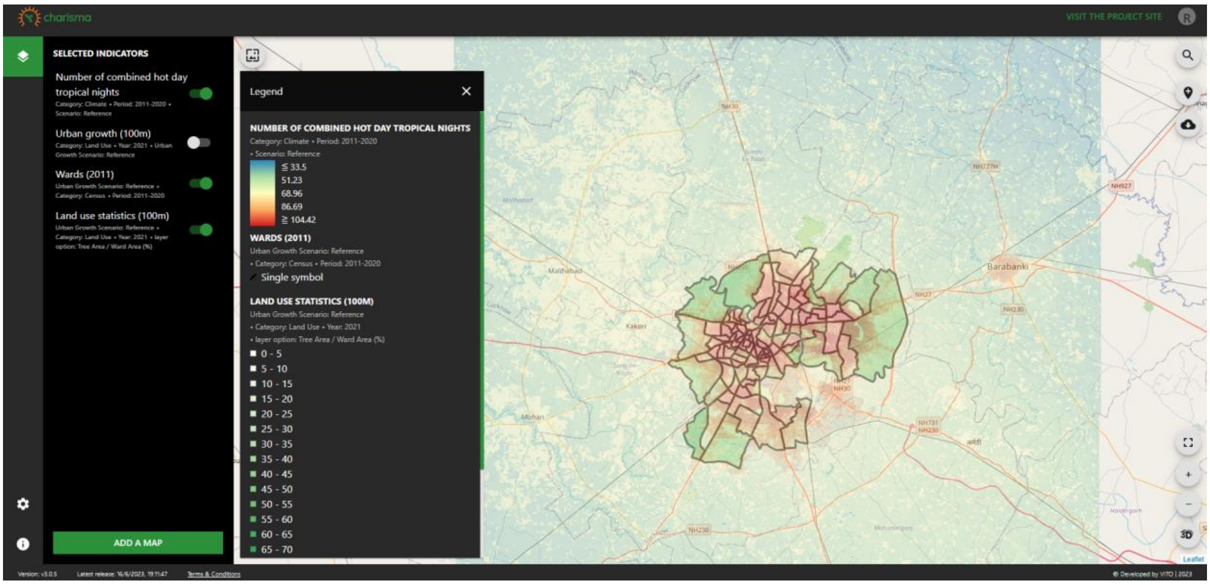


Figure 26: Wards with fewer trees correlate with higher temperatures.

8. For higher resolution statistics, we can resort to an alternative data layer, “LAND COVER (10M)”. This data layer comes from the World Cover Map and displays land cover categories at 10m resolution, distinguishing between built-up and various vegetation types. Toggling the various layers on and off again illustrates built-up areas to be prone to higher temperatures.

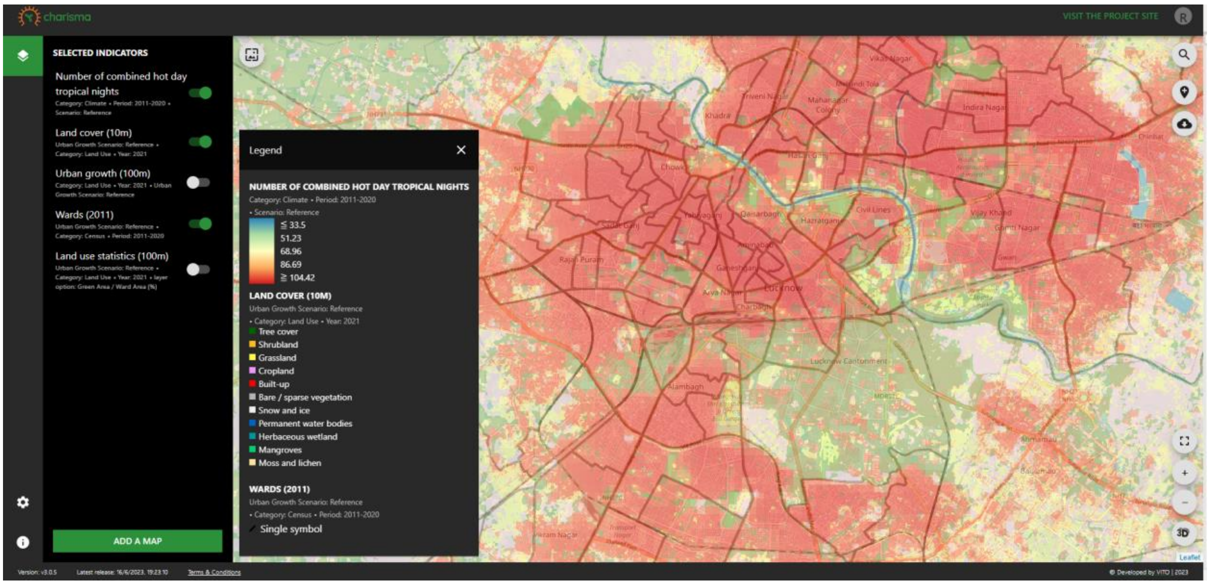


Figure 27: 10m resolution land cover data shows a strong correlation between built-up area and higher temperatures.

A similar analysis can be done for the future period 2040-2050. To compare layers it is easiest to add additional "NUMBER OF COMBINED HOT DAYS AND TROPICAL NIGHTS" layers with scenarios "MASTERPLAN (2031) + RCP 4.5" and "POPULATION-DRIVEN + RCP4.5". Note that in the data repository, the user is informed of the number of active layers of each indicator (Figure 28).

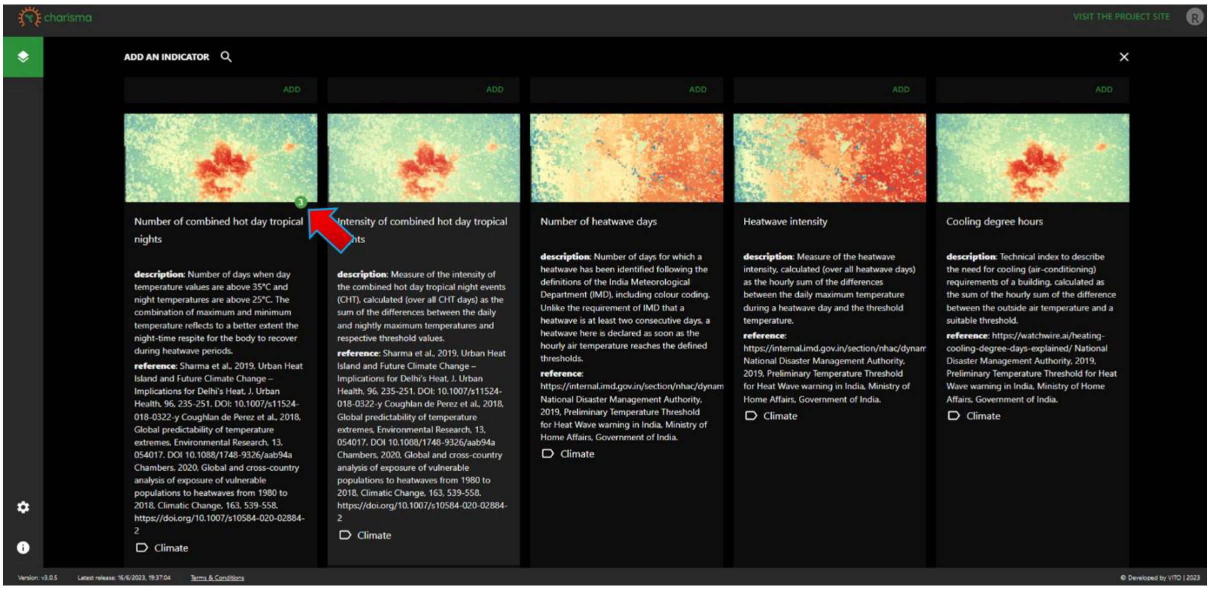


Figure 28: The number of active layers for each indicator is shown in the data inventory.

To juxtapose the layers, layers are set to be not transparent. The overview, by activating and de-activating the layers, is presented in Figure 29. At first sight urban growth does not drastically change the pattern (middle); the red contours expand slightly compared to the reference case (top). However, observing the legend, one can notice the maximum value to have increased from 104 to 137. The Masterplan does bring solace as many of the areas previously exposed to high temperatures, are now attributed lower numbers. However, the maximum value remains 137 days.

One may conclude the Masterplan to have a positive influence, though the net effect of urban growth and climate change remains worsened living conditions (read higher temperatures) for the citizens. In these locations additional interventions aimed at climate adaptation will be required. Adaptation measures are oriented towards minimization of impact and can involve either pro-active actions to lower temperatures e.g. more greening or re-active measures to accommodate citizens suffering from higher temperatures e.g. adequate heat action plans.

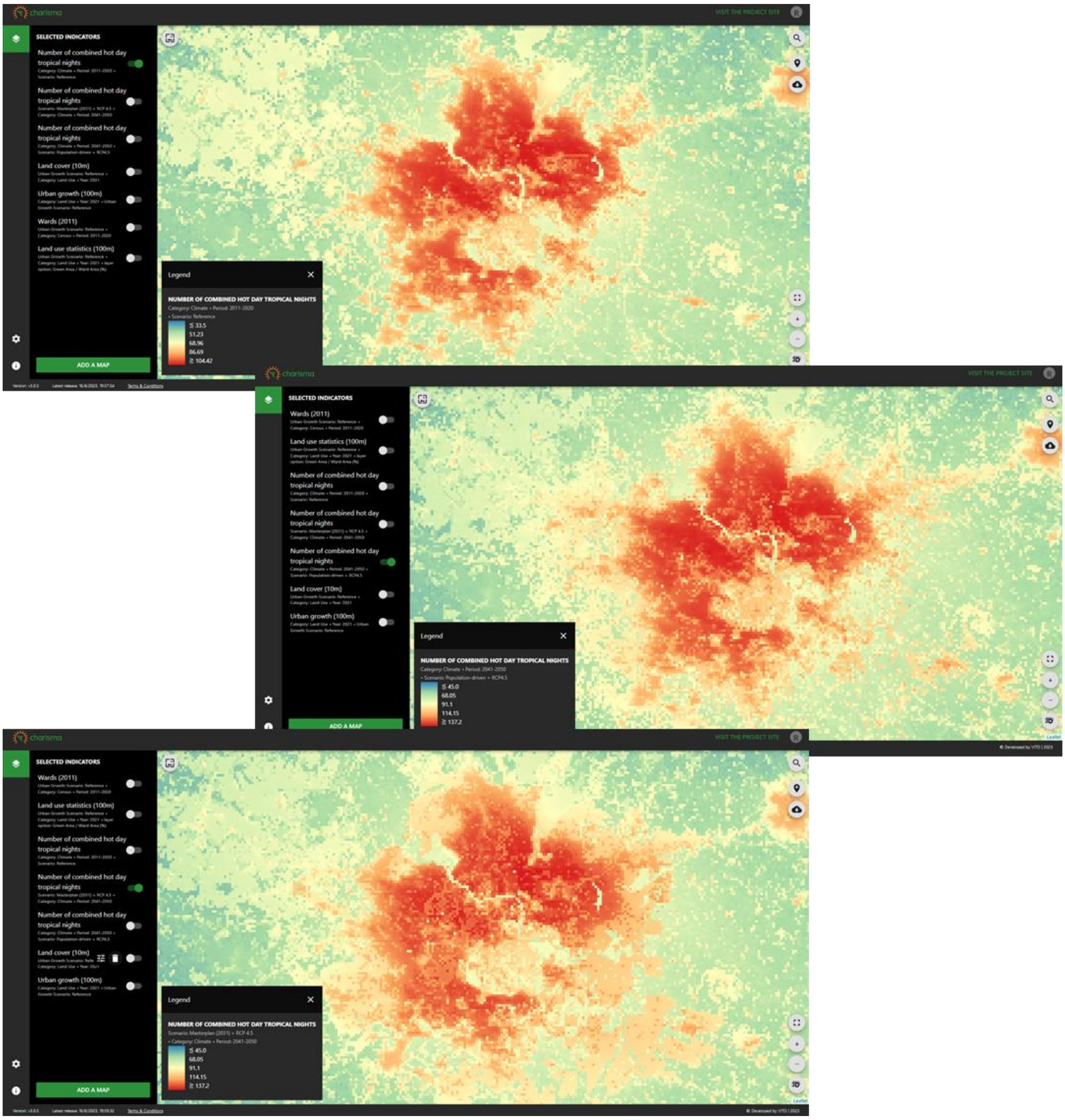


Figure 29: "NUMBER OF COMBINED HOT DAYS AND TROPICAL NIGHTS". (Top) 2011-2020; (Middle) 2040-2050, "POPULATION-DRIVEN + RCP4.5"; (Bottom) 2040-2050, "MASTERPLAN (2031) + RCP4.5".

Prioritizing wards

It is well known that heat stress has a drastic impact on human health, especially women, children and elderly people[10,11,12,13]. These demographic groups are therefore more susceptible to heat stress[14]. To prioritize wards which will require attention to safeguard, the indicator "HEAT VULNERABILITY" has been incorporated in the dashboard.

! In the current dashboard census data (including ward boundaries) has not been included as this data is not considered to be public. As such, "HEAT VULNERABILITY", which takes into account socio-demographic data (originating from Census data) has not been included neither.

The "HEAT VULNERABILITY" indicator is based on the work of Azhar *et al.*[15] and takes into account the level of heat stress (i.e. the temperature), as per the simulations, and the number of women and children living in a ward. The latter is based on 2011 Census data. "HEAT VULNERABILITY" is found under the tag "HEALTH" and is available only for the period 2041-2050 (Figure 30).

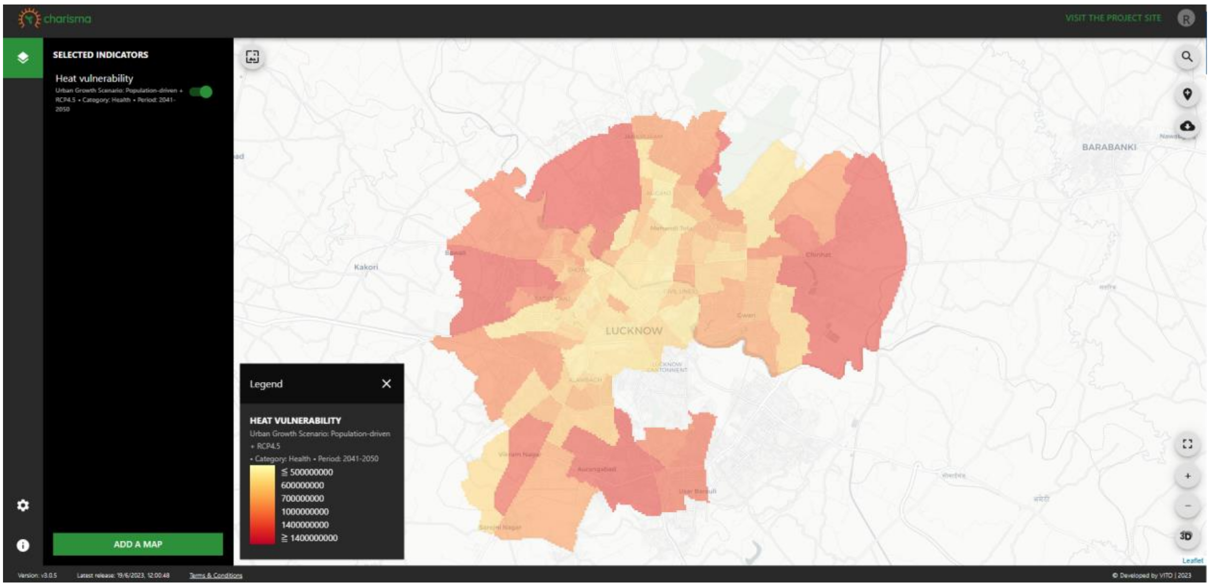


Figure 30.

From the figure, the wards in which more women and children can be found and where temperatures will reach higher levels are attributed a darker colour red. Note that we could have achieved a similar result by overlaying the data layer of "TOTAL NUMBER OF WOMEN AND CHILDREN" from the 2011 Census data and e.g. the "URBAN HEAT ISLAND INDEX" (Figure 31). Because the UHI indicator is at 100m resolution and Census data at ward level, this combination yields more granularity compared to the ward-wise "HEAT VULNERABILITY" map.

[10] https://news.abplive.com/blog/climate-change-impacts-elderly-population-in-india-particularly-vulnerable-how-to-protect-them-1591588
[11] https://www.unicef.org/india/what-we-do/climate-change
[12] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7007102/
[13] https://www.globalcitizen.org/en/content/how-climate-change-affects-women/
[14] Son J.-Y., Liu J. C., Bell M. L., 2019, *Temperature-related mortality: a systematic review and investigation of effect modifiers*, Environmental Research Letters, 14, 073004
[15] Azhar G, Saha S, Ganguly P., Mavalankar D., Madrigano J., 2017, *Heat wave vulnerability mapping for India*, Int. J. Environ. Res. Public Health, 14(4): 357, DOI: 10.3390/ijerph14040357

Figure 31.

Planning of adaptation measures

Electricity provision

As it gets warmer, people will resort to AC's for cooling. The higher the temperature, the more cooling effort is required, hence, more energy consumption. This is reflected in the "COOLING DEGREE HOURS" indicator, which quantifies the hour-wise summation of the difference between the actual temperature and a comfort limit, taking into account only those hours for which the temperature is above the threshold.

Within the dashboard, several options are available, both in terms of period and urban growth, but also temperature threshold (Figure 32). It should be noted that the IMD-defined limits (i.e. the temperature above which a yellow heatwave warning is issued and the limit to consider a heatwave) will not take into account the use of AC during the night, as night temperatures drop below these thresholds. This can be verified by displaying the "SEASONAL MEAN NIGHT TEMPERATURE", which is the average of all nights during a selected season and has maxima in the order of 32°C (Figure 33). Observe that "SEASONAL MEAN NIGHT TEMPERATURE" layer clearly exhibits the Urban Heat Island effect in that the night temperatures in the urban area are higher compared to the rural outskirts.

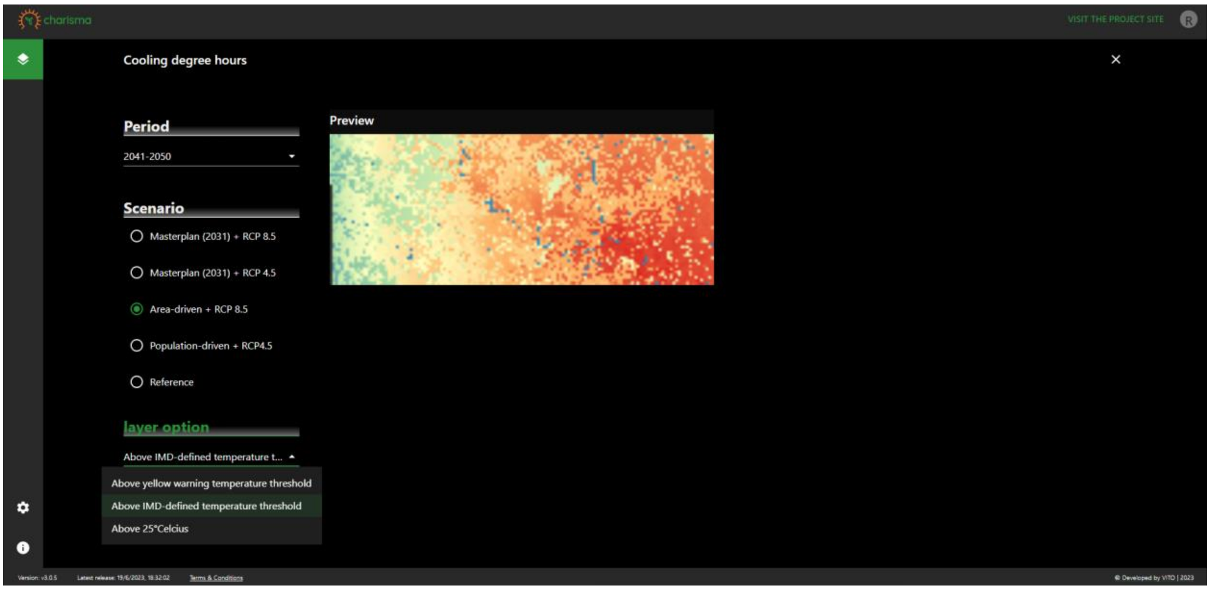


Figure 32: When selecting the COOLING DEGREE HOURS *indicator, the user can vary the period, urban growth scenario and temperature limits.*

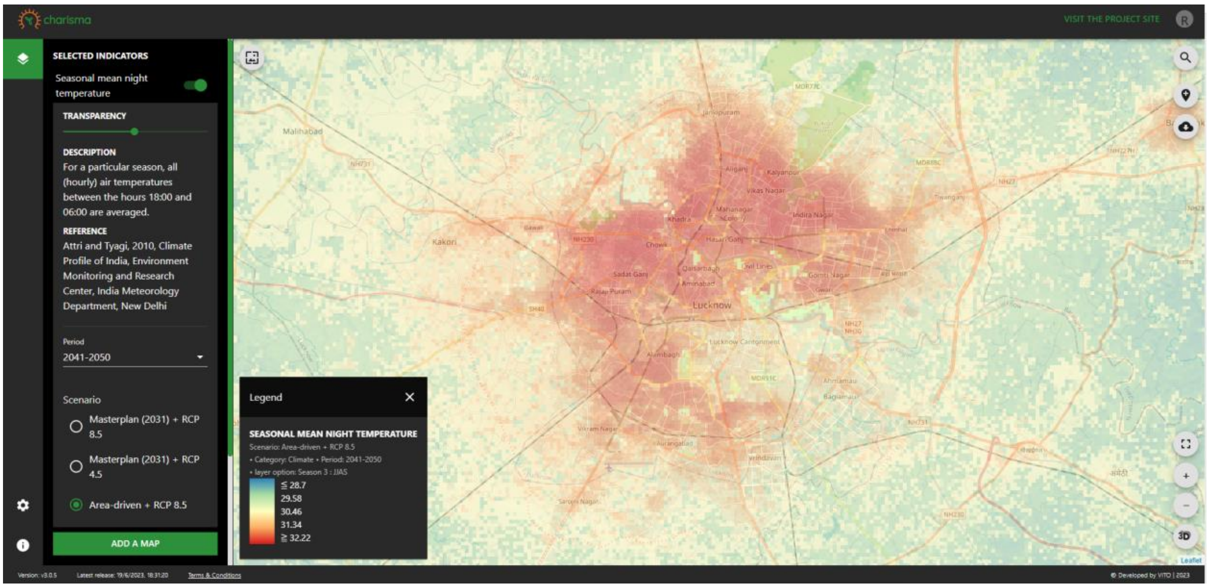


Figure 33: The SEASONAL MEAN NIGHT TEMPERATURE *gives an indication of typical night temperatures.*

In the following the temperature limit of 25°C is considered. This limit is more representative of the human behaviour as well as physiological limitations since night-temperatures need to be sufficiently low to allow the body to shed heat[16], i.e. citizens will utilize air conditioning also throughout the night. Comparing the "COOLING DEGREE HOURS" between the present and future reveals that associated values increase, as is to be expected. However, climate change will not only cause temperatures to increase, but also the duration over which such temperatures are attained. As such the "COOLING DEGREE HOURS" increases in a non-linear fashion (Figure 34) and combined with the growing urban population, indicates a drastic increase in future electricity demand. Simultaneously, the layer shows the cooling requirements across the city at a typical resolution of 100m.

[16] Obradovich N., Migliorini R., Mednick S.C., Fowler J.H., 2017, *Nighttime temperature and human sleep loss in a changing climate*, Science Advances, 3: e1601555

Based on this data, authorities can a) make necessary provisions to accommodate future electricity demand, b) ensure related infrastructure (cabling, transformers, etc.) are capable of handling the future demand such that blackouts can be avoided.

Figure 34: The "COOLING DEGREE HOURS" represent the cooling requirement in a spatially explicit manner. Urban growth combined with climate change cause the cooling requirement to increase in a non-linear fashion.

It is known that mortality increases under elevated night-time temperatures[17,18] and studies have shown mortality to increase in hospitals due to elevated indoor temperatures. The data can thus be used to identify health centres which will be at higher risk of elevated temperatures.

1. Select the background "STREETPLAN".
2. Zoom into the displayed data. The map will indicate health centres (Figure 35).

[17] He C., Kim H., Hashizume M. Lee W., Honda Y. Kim S. E. Kinney P.L. Schneider A., Zhang Y., Zhu Y, Zhou L., Chen R., Kan H., 2022, *The effects of night-time warning on mortality burden under future climate change scenarios: a modelling study*, Lancet Planet Health, 6: e648-57

[18] Murage P., Hajat S., Kovats R.S., 2017, *Effect of night-time temperatures on cause and age-specific mortality in London*, Environmental Epidemiology, 2: e005

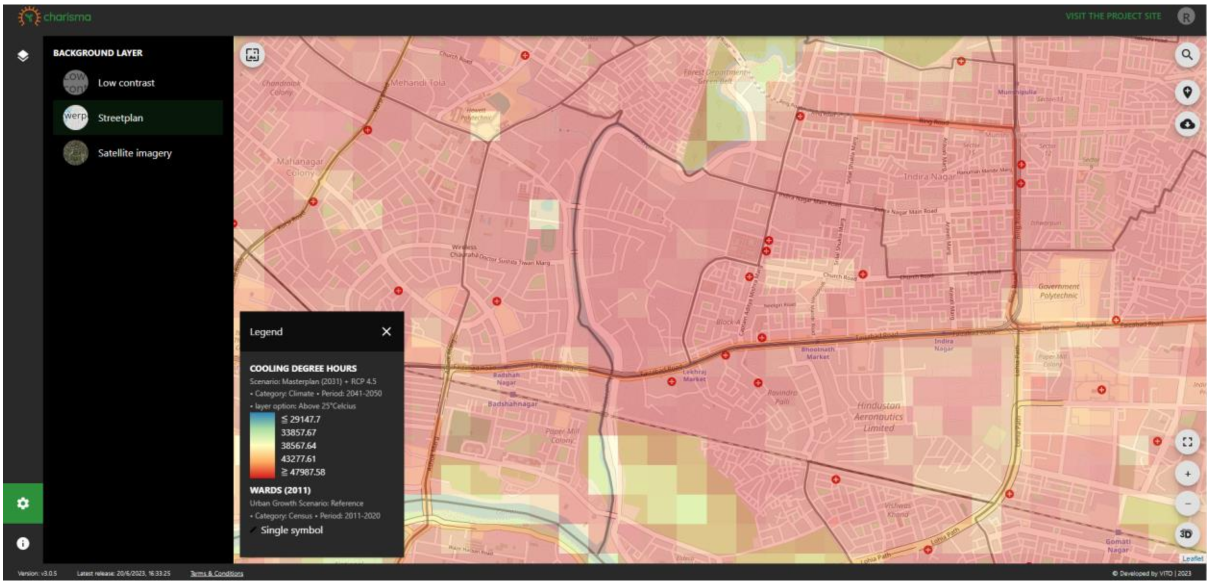


Figure 35: The "COOLING DEGREE HOURS" represent the cooling requirement in a spatially explicit manner. Urban growth combined with climate change cause the cooling requirement to increase in a non-linear fashion.

Health centres exposed to higher "COOLING DEGREE HOURS" will need to take necessary precautions. For example;

- provision of sufficient support systems to accommodate the future electricity demand for cooling. This could be for example additional generators (though these will contribute to additional anthropogenic heat in the city and will increase carbon-exhaust) or, ideally, photovoltaic cells on the roof (which have the additional benefit of providing some cooling in case of roofs that are prone to absorbing heat[19]);
- re-organization of the various wards such that vulnerable demographic groups (women, children, elderly) are treated in naturally cooler areas of the hospital. This can be achieved for example by having maternity and geriatric wards at lower levels of the hospital, by having sufficient cooling in waiting areas, etc.;
- by improving natural/passive cooling of the hospital through appropriate roofing using reflective colours and materials, sun shading devices[20],
- etc.

Spatial planning of health facilities, heat shelters, etc.

Another aspect is the availability of sufficient health centres to treat patients with heat stress. This can be done by overlaying the "COOLING DEGREE HOURS" with census data of the vulnerable population. As the need for cooling increases and the number of women, children, elderly is higher in a particular ward, sufficient health centres need to be foreseen.

In the figure below, 4 data layers are superimposed onto the "STREETPLAN" background; "COOLING DEGREE HOURS" (as indicator of the increase in heat), "CENSUS (2011)"; "WARDS (2011)" and "LAND COVER (10M)".

1. Change the background layer to "STREETPLAN".
2. Add the indicator "COOLING DEGREE HOURS"', under the tag "CLIMATE", selecting 2041-2050 as period, "MASTERPLAN (2031) + RCP4.5" as urban growth and climate scenario, and 25°C as temperature threshold.

[19] Wang Y., Wang D., Liu Y., 2017, *Study on comprehensive energy-saving of shading and photovoltaics of roof added PV module*, Energy Procedia, 132, 598-603, https://doi.org/10.1016/j.egypro.2017.09.672

[20] https://www.who.int/publications/i/item/9789289071918

3. Add "CENSUS (2011)", under the tag "CENSUS" with "TOTAL NUMBER OF WOMEN AND CHILDREN" as layer option.
4. Add WARDS (2011)" under the tag "CENSUS".
5. Add "LAND COVER (10M)" under the tag "LAND USE".
6. Add "URBAN GROWTH (100M)" under the tag "LAND USE", selecting "MASTERPLAN (2031)" as growth scenario and 2050 as year. This layer is added to a) obtain more granularity and b) to visually evaluate the population density (compactly built areas for example are associated with higher population densities compared to open building types).
7. Activate all layers, but deactivate the land cover layer.

Figure 36: By overlaying multiple layers ("COOLING DEGREE HOURS", "CENSUS (2011)", "URBAN GROWTH (100M)") areas within the city which require interactions in terms of cooling requirement, become evident.

In wards which are filled with a darker colour, meaning higher temperatures will be experienced, there are relatively more women and children, and a higher density of people is encountered, necessitating ample number of health centres, health centres of sufficient capacity, water points, cool spots, etc. (Figure 36)

Because of the selected background layer the locations of registered health centres are indicated and the user can evaluate the situation;

- are a sufficient number of health centres located in the critical area?
- do the present health centres have sufficient capacity to accommodate the expected increase in heat stress cases?

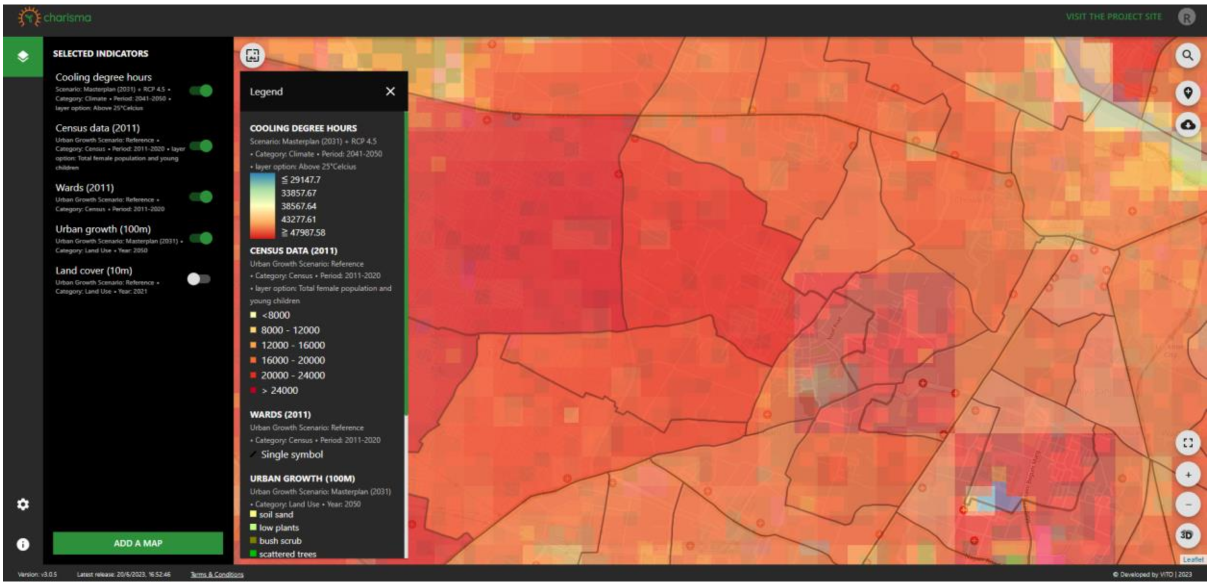


Figure 37: With "STREETPLAN" as background, the location of health centres becomes visible in the map, based on which the accessibility of health centres for vulnerable demographic groups can be assessed.

To further facilitate urban planning, all data layers can be de-activated while toggling on the land cover layer. In the zoomed in area the user is now shown the present land cover classification. As green, especially trees, are important to provide shading and cooling, the associated areas are ideally left untouched. Bare areas however can be used to construct health centres, even if only temporary. After all, the user can evaluate the ambient temperatures per season, assessing the season during which heat stress cases are more likely. Knowing each pixel corresponds to 100m^2, the user also has an immediate estimate of the presently available area.

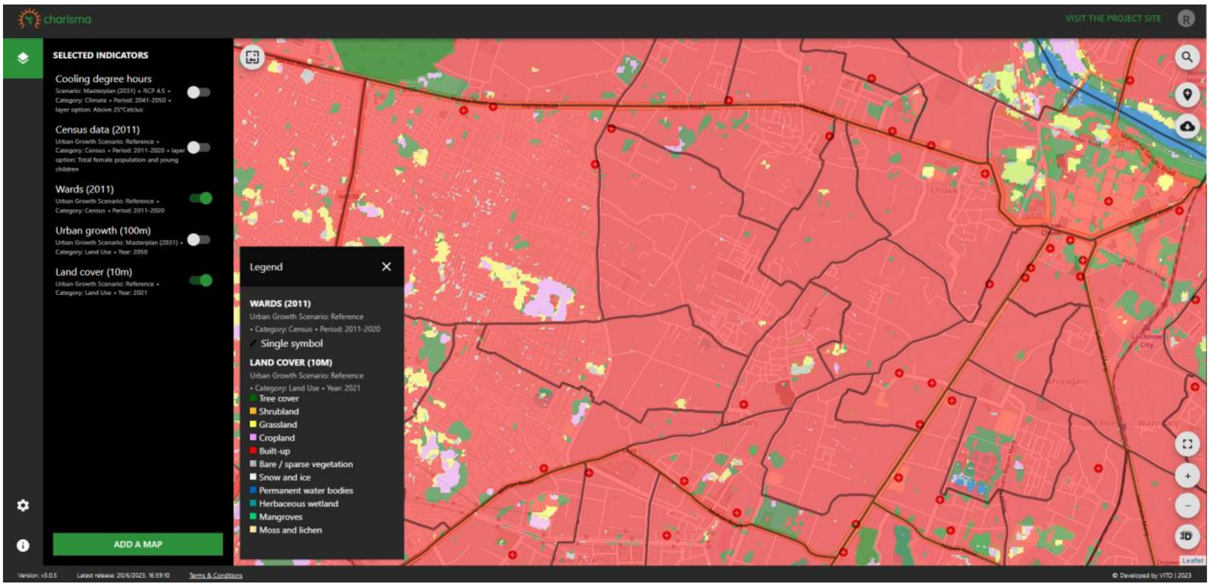


Figure 38: The "Land cover (10m)" data layer provides a quick overview of available space (bare land) at a pixel resolution of 10-by-10 m^2.

Thermal comfort

While all indicators discussed so far relate to ambient temperature, thermal comfort refers to the temperature that is felt. In the dashboard thermal comfort is expressed in terms of WBGT (i.e. wet bulb globe temperature), which takes into account humidity and radiation. While the air temperature might be high, a soft breeze or shade will provide direct cooling. Such effects are reflected in the WBGT temperature. It is for this reason the India Meteorological Department (IMD) has recently (2023) introduced thermal comfort as reference to determine health impacts of heat[21].

The dashboard offers thermal comfort data in three manners and at two resolutions. Under the tag "CLIMATE" the user can find the indicator "THERMAL COMFORT". Here the WBGT temperature, expressed in degrees Celcius, is quantified at 100m resolution, for one particular day and time. Since the WBGT is humidity and temperature dependent, the average annual value (which would have to be calculated on an hourly basis) would not provide more in-depth understanding. Instead, the WBGT is calculated for one particular day and time, on which the temperature and humidity were both high, such as to indicate areas in the city which are at risk of thermal discomfort. These values (°C) are subsequently categorized into four risk-levels (no risk, moderate, high, extreme[22]) and can be found under the tag "HEALTH". Finally, for illustration purposes the result of a mapping exercise (1m resolution) in collaboration with students of the Dr. A.P.J. Abdul-Kalam Technical University is presented. Here, detailed information regarding the height of buildings and trees (obtained through the in-the-field mapping exercise) is collected and utilized to calculate the projected shade. For these selected quarters the WBGT at 08.00, 13.00 and 18.00 can be visualized, depicting the evolution of WBGT throughout the day, the maximum WBGT and average (over that particular day). These detailed maps can be retrieved via the tag "CLIMATE".

! In the current dashboard the high-resolution WBGT data has not been incorporated as this data is not considered to be public. As such, the current use case serves to exemplify the potential use of the dashboard to evaluate thermal comfort at high resolution and assess adaptation measures.

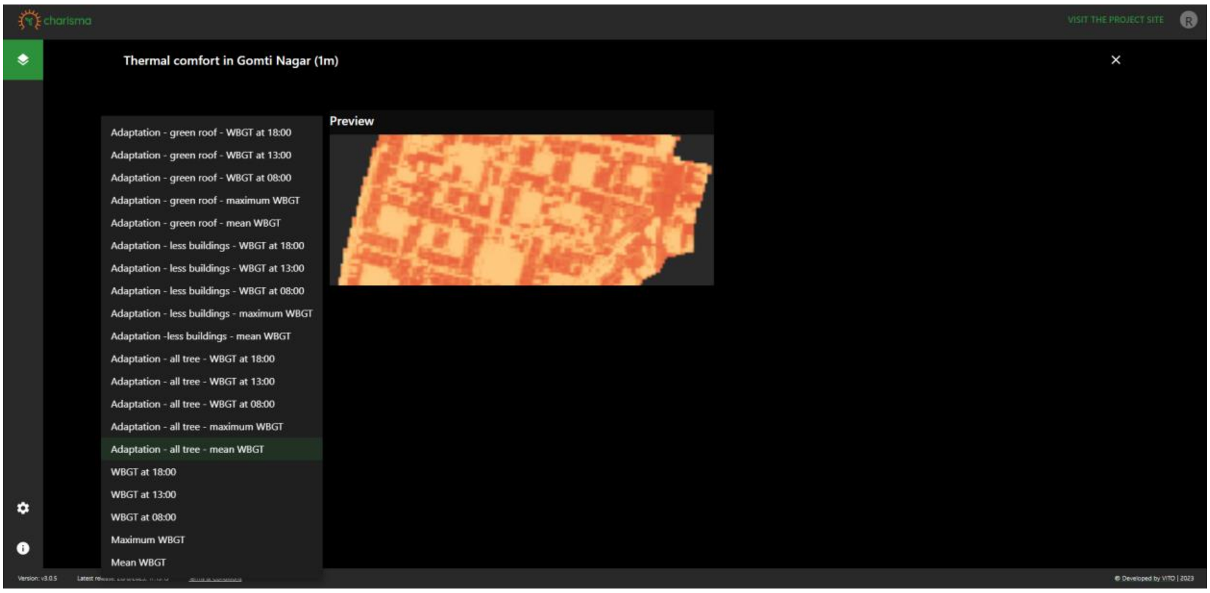


Figure 39: For illustration purposes, city areas have been mapped at very high resolution, based on which detailed thermal comfort analyses have been performed.

The high resolution WBGT data shows an interesting find, namely that park areas consisting solely of grass do not offer any cooling (Compare Figure 15 and Figure 40). While green spaces are beneficial for mental health[23], it is the shade cast by tall structures/trees that show up in the WBGT maps as cool

[21] https://bharatexpress.com/india/india-to-get-its-own-index-to-quantify-heat-impact-next-year-imd-chief-45463
[22] https://www.osha.gov/otm/section-3-health-hazards/chapter-4
[23] https://apps.who.int/iris/bitstream/handle/10665/342931/9789289055666-eng.pdf

spots. WBGT varies throughout the day reaching peaks around mid-day. At this time the cooling provided by the shades becomes more prominent. As the sun moves across the sky, the shades travel and elongate, still providing cooling, though less effective. In terms of adaptation, the WBGT has been simulated in the hypothetical case that all bare and grass areas would be covered with trees. The outcome are distinct cool spots. Such maps can be used to interact with local committees to design, implement and maintain localized cooling interventions.

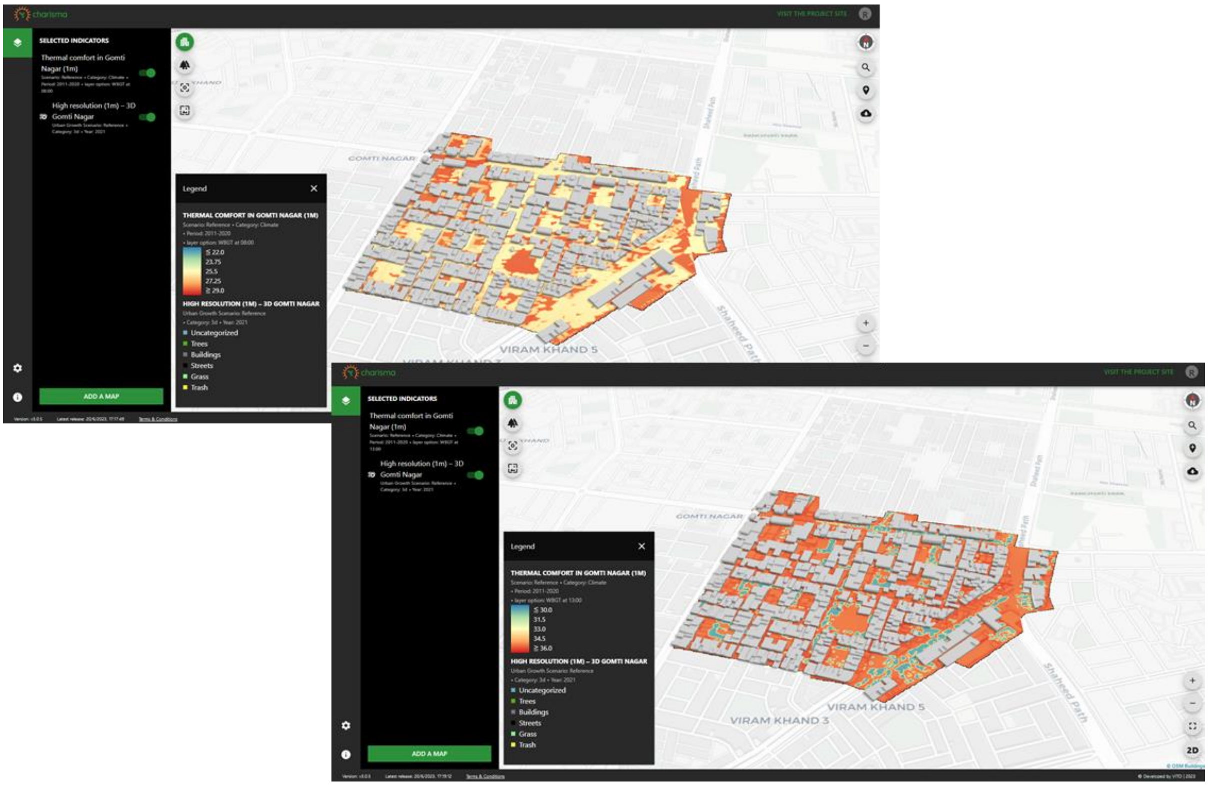


Figure 40: WBGT simulations are provided for several time instances during the day, visualizing the cooling impact of shadows.

Alternative adaptation measures are also assessed such as incorporating green roofs and having more space between buildings (Figure 39).

Word of caution: !

It is important to note that the impact of these measures has been assessed only by considering implementation in the quarter itself. When implemented only in the quarter, green roofs for example can be seen to have little apparent impact on thermal comfort although their beneficial impact, in terms of both indoor and outdoor cooling (though limited on outdoor cooling), has been widely recognized[24,25,26].

[24] Razzaghmanesh M., Beecham S., Salemi T., 2016, *The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia*, Urban Forestry & Urban Greening, 15, 89-102, https://doi.org/10.1016/j.ufug.2015.11.013

[25] Dwivedi A., Mohan B. K., 2018, *Impact of green roof on micro climate to reduce Urban Heat Island*, Remote Sensing Applications: Society and Environment, 10, 56-69, https://doi.org/10.1016/j.rsase.2018.01.003

[26] Joshi M. Y., Teller J., 2021, *Urban integration of green roofs: current challenges and perspectives*, Sustainability, 13, 132378, https://doi.org/10.3390/su132212378

Loss of labour

WBGT is used to flag safety conditions for how long an individual can safely work in hot humid conditions[27]. Beyond a certain temperature it becomes simply too hot for any form of physical labour. Based on the WBGT the amount of labour hours lost (because it is too hot) has been calculated, depending on the intensity of the physical exercise. Three categories are defined: light labour (e.g. standing guard), moderate labour (e.g. pushing carts) and heavy labour (e.g. construction work). Estimations of the loss in working hours (at approximately 100m resolution) due to unsuitable climatic conditions in the city can be found under the tag "HEALTH", "LOST WORKING HOURS DUE TO HEAT STRESS". In the example below (Figure 41) the number of lost hours for light labour can reach 800 hours. This gives a clear indication that in the future ample provision, for example water points or shading for police officers who stand in the street to direct traffic, needs to be foreseen.
For heavy work, values can go up to 3000 hours. The metabolic rate of walking at a fast pace, i.e. playing or running, is comparable to heavy work. Children in the playground are therefore subject to heat stress and will need to be protected. School hours or working hours for construction workers could be shifted to take place later during the day to avoid the peak in heat.

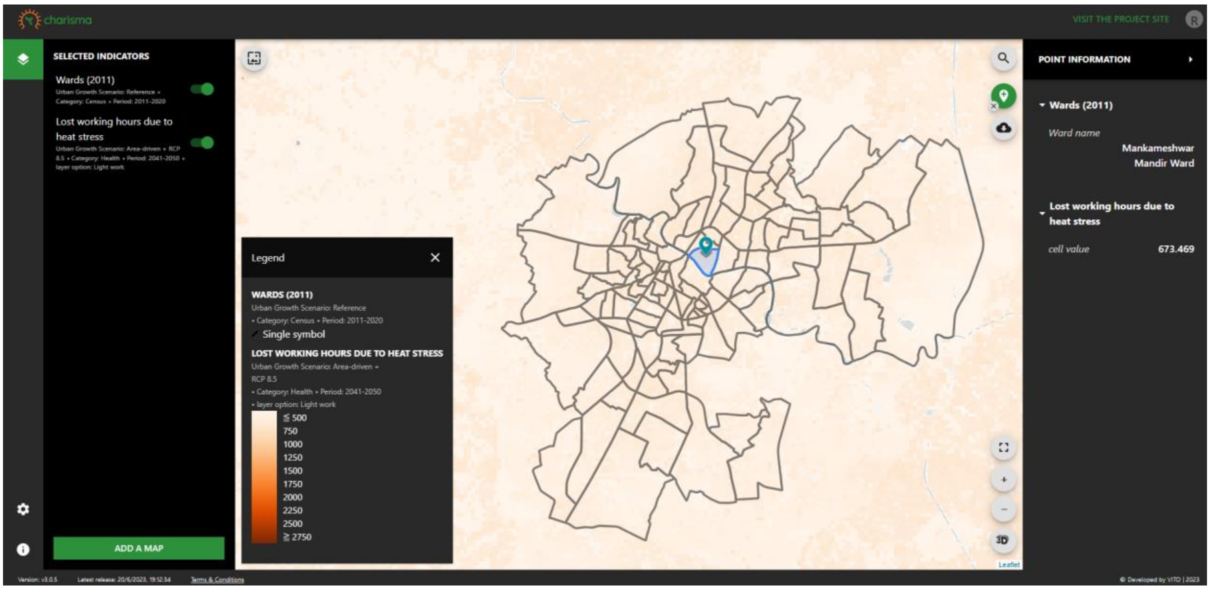


Figure 41: Even light labour will be hampered because of climate change.

[27] https://www.osha.gov/heat-exposure/hazards

9. Terms of use

The CHARISMA dashboard has been developed by VITO in consultation with Avia-GIS and Public Health Foundation India – Centre of Environmental Health, with International Climate Finance funding through the Department of Omgeving, Flanders (Belgium). The tool offers land use data, urban climate data and risk maps for vector borne diseases, for multiple cities across India, for the present and the future situation, together with diverse functionalities to visualize and download data.

When you use the dashboard, you acknowledge that you have read, understood and agree to abide by the following terms of use, detailing your rights and obligations with regard to the access and the use of the dashboard.

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Annex I: List of Indian cities included in dashboard

No.	Tier	City	Land Use (2011, 2021)	Urban Growth (decadal up to 2070)		Urban climate (2021)	Urban climate (2040-2050)		Dengue risk map
				without Masterplan	with Masterplan		without urban growth	with urban growth	
1		Lucknow	X	X	X	X		X	X
2		Guwahati	X	X	X	X		X	
3		Ahmedabad	X	X		X		X	
4		Bangalore	X	X		X		X	
5		Agartala	X	X		X		X	
6		Agra	X			X	X		
7		Amaravati	X			X	X		
8		Amritsar	X			X	X		
9		Ballari	X			X	X		
10		Bhopal	X			X	X		
11		Bhubaneswar	X			X	X		
12		Chandigarh	X			X	X		
13		Chennai	X			X	X		
14		Coimbatore	X			X	X		
15		Dehradun	X			X	X		
16		Dehradun	X			X	X		
17		Dibrugarh	X			X	X		
18		Diu	X			X	X		
19		Gangtok	X			X	X		
20		Gorakhpur	X			X	X		
21		HubliDharwad	X			X	X		
22		Hyderabad	X			X	X		

No.	Tier	City	Land Use (2011, 2021)	Urban Growth (decadal up to 2070)		Urban climate (2021)	Urban climate (2040-2050)		Dengue risk map
				without Masterplan	with Masterplan		without urban growth	with urban growth	
23		Imphal	X			X	X		
24		Indore	X			X	X		
25		Jaipur	X			X	X		
26		Jaisalmer	X			X	X		
27		Jammu	X			X	X		
28		Jodhpur	X			X	X		
29		Kanpur	X			X	X		
30		Kavaratti	X			X	X		
31		Kochi	X			X	X		
32		Kolkata	X			X	X		
33		Leh	X			X	X		
34		Madurai	X			X	X		
35		Mangalore	X			X	X		
36		Meerut	X			X	X		
37		Mumbai	X			X	X		
38		Mysore	X			X	X		
39		Nagpur	X			X	X		
40		Nainital	X			X	X		
41		Panaji	X			X	X		
42		Patna	X			X	X		
43		Pondicherry	X			X	X		

No.	Tier	City	Land Use (2011, 2021)	Urban Growth (decadal up to 2070)		Urban climate (2021)	Urban climate (2040-2050)		Dengue risk map
				without Masterplan	with Masterplan		without urban growth	with urban growth	
44		Port Blair	X			X	X		
45		Pune	X			X	X		
46		Raipur	X			X	X		
47		Ranchi	X			X	X		
48		Shillong	X			X	X		
49		Shimla	X			X	X		
50		Silchar	X			X	X		
51		Siliguri	X			X	X		
52		Srinagar	X			X	X		
53		Surat	X			X	X		
54		Thiruvananthapuram	X			X	X		
55		Udaipur	X			X	X		
56		Varanasi	X			X	X		
57		Visakhapatnam	X			X	X		

Annex II: List of indicator options

Category	Indicator	Options
Land Use	Urban Growth (100m)	Reference
		Area-driven
		Population-driven
		Masterplan
	Land use statistics (100m)	Ward area (square meter)
		Built Area / Ward Area (%)
		Compact high-rise Area / Built Area (%)
		Compact midrise Area / Built Area (%)
		Compact low-rise Area / Built Area (%)
		Open high-rise Area / Built Area (%)
		Open midrise Area / Built Area (%)
		Open low-rise Area / Built Area (%)
		Lightweight low-rise Area / Built Area (%)
		Large low-rise Area/ Built Area (%)
		Sparsely built Area / Built Area (%)
		Heavy Industry Area / Built Area (%)
		Open Area / Ward Area (%)
		Green Area / Ward Area (%)
		Tree Area / Ward Area (%)
		Population
		Population in compact high-rise
		Population in compact midrise
		Population in compact low-rise
		Population in open high-rise
		Population in open midrise
		Population in open low-rise
		Population in lightweight low-rise
		Population in sparsely built
		Population-weighted average distance to nearest green
		Built Area per person
		Green Area (incl. shrubs, grass, trees) per person
	Local climate zones (30m)	
	Land use statistics (30m)	Ward area (square meter)
		Green Area / Ward Area (%)
		Population-weighted average distance to nearest green
	Land cover (10m)	

Category	Indicator	Options
Health	Heat vulnerability	
	Thermal comfort limits	
	Relative risk of mortality due to heat stress	All ages
		Ages 70+
	Lost working hours due to heat stress	Light work
		Moderate work
		Heavy work
	Dengue hotspot frequency	

Category	Indicator	Options
Climate	Climate zone classification	
	Seasonal mean day temperature	Season 1 : JF Season 2 : MAM Season 3 : JJAS Season 4 : OND
	Seasonal mean night temperature	Season 1 : JF Season 2 : MAM Season 3 : JJAS Season 4 : OND
	Seasonal average of maximum day temperature	Season 1 : JF Season 2 : MAM Season 3 : JJAS Season 4 : OND
	Seasonal average of minimum day temperature	Season 1 : JF Season 2 : MAM Season 3 : JJAS Season 4 : OND
	Annual mean temperature	
	Urban heat island index	
	Number of combined hot days and tropical nights	
	Intensity of combined hot days and tropical nights	
	Number of heatwave days	IMD standard IMD severe standard Yellow warning Orange warning Red warning
	Heatwave intensity	IMD standard Yellow warning
	Cooling degree hours	Above 25°Celcius Above IMD-defined temperature threshold Above yellow warning temperature threshold
	Thermal comfort (~100m)	
	Average Cooling requirement	Above IMD-defined temperature threshold Above yellow warning temperature threshold

Category	Indicator	Options
Census	Census data (2011)	Total number of households Total population Population density Total Female population Percentage of female population Total Population below 6 years Percentage of population below 6 years Total number of illiterates Percentage of illiterates Male population below 6 years Female population below 6 years Total female population and young children Percentage of female population and young children
	Slum locations (2005	
	Wards (2011)	

Note that the available indicators will depend on the city's tier (cf. Figure 6).