

iWEF 1.0: A WEB-BASED AND GIS-ENABLED INTEGRATIVE WATER-ENERGY-FOOD (WEF) NEXUS ANALYTICAL MODEL



User Manual

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Background of the iWEF modelling tool

The web-based and GIS-enabled integrative water-energy-food (WEF) nexus analytical model (iWEF) was originally developed by Nhamo et al. (2020a) as an MS Excel-based model for establishing quantitative relationships among WEF nexus sectors to indicate resource utilisation and performance over time, thereby providing evidence of WEF nexus to decision-makers and indicating priority areas for intervention. It was recently further developed into an open-source web-based GIS-enabled integrative WEF nexus analytical model with geospatial analytic abilities. To facilitate WEF nexus performance assessment, monitoring and evaluation, iWEF holistically evaluates synergies and trade-offs to improve efficiency and productivity in resource use and management for sustainable development.

After identifying and defining relevant WEF sustainability indicators, Nhamo et al. (2020a) developed a methodology to compute composite indices. The key input data for iWEF modelling are the six WEF sustainability indicators, per annum, including water availability (m^3/capita), water productivity ($\$/\text{m}^3$), energy accessibility (%), energy productivity (MJ/GDP), food self-sufficiency (%) and cereal productivity (kg/ha). These indicators are compared pairwise in a pairwise comparison matrix (PCM) based on expert opinion/advice,

literature, or recognized databases (e.g., national statistics, World Bank, Aquastat, etc) that can provide the baseline to establish the numerical relationship among indicators (Mabhaudhi *et al.*, 2019; Nhamo *et al.*, 2019; Nhamo *et al.*, 2020a; Nhamo *et al.*, 2020b). Water availability is the proportion of available freshwater resources per capita, which estimates the total available freshwater water resources per person. Water productivity is the proportion of crops produced per unit of water used, which measures the output from an agricultural system in relation to the water it consumes. Energy accessibility is the proportion of the population with access to electricity, expressed as a percentage (%) of the total population. Energy productivity is synonymous with energy intensity, which is the energy supplied to the economy per unit value of economic output. Food self-sufficiency is the percentage (%) of individuals in the population, out of total population, who have experienced food insecurity at moderate or severe levels during the reference year. Cereal productivity is considered the proportion of sustainable agricultural production per unit area (Nhamo *et al.*, 2020a).

The iWEF tool integrates the six WEF indicators through the Analytic Hierarchy Process (AHP) multi-criteria decision-making (MCDM) approach (Brunelli, 2015) by normalising WEF indicators data to determine composite indices used to compute the weighted average WEF nexus index. According to Saaty (1987), the AHP is a theory of measurement for deriving ratio scales from both discrete and continuous paired comparisons to set priorities and make the best decisions. The AHP comparison matrix is determined by comparing two indicators at a time using Saaty's scale, which ranges between 1/9 and nine as indicated in the Table 1 (Saaty, 1987). To create the PCM for your case study, be guided by Table 1 wherein *a* and *b* are the row and column factors/indicators, respectively.

Table 1: Saaty's scale of relative importance for pairwise comparisons in an AHP

Intensity of Importance	Definition	Explanation
1	Equal importance	Element <i>a</i> and <i>b</i> contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favour element <i>a</i> over <i>b</i>
5	Essential or strong importance	Experience and judgment strongly favour element <i>a</i> over <i>b</i>
7	Very strong or demonstrated importance	Element <i>a</i> is favoured very strongly over <i>b</i> ; its dominance is demonstrated in practice
9	Extreme or absolute importance	The evidence favouring element <i>a</i> over <i>b</i> is of the highest possible order of affirmation
2 (weak), 4 (moderate plus), 6 (strong plus), 8 (very, very strong), 1/2, 1/4, 1/6, 1/8	Intermediate values between the two adjacent judgments	When compromise is needed. For example, 2 can be used for the intermediate value between 1 and 3
1/3	Moderately less important	
1/5	Strongly less important	

1/7	Very strongly less important	
1/9	Extremely less important	
Reciprocals of above nonzero	If a has one of the above nonzero numbers assigned to it when compared with b , then b has the reciprocal value when compared with a	A reasonable assumption

Source: Saaty and Vargas (2012)

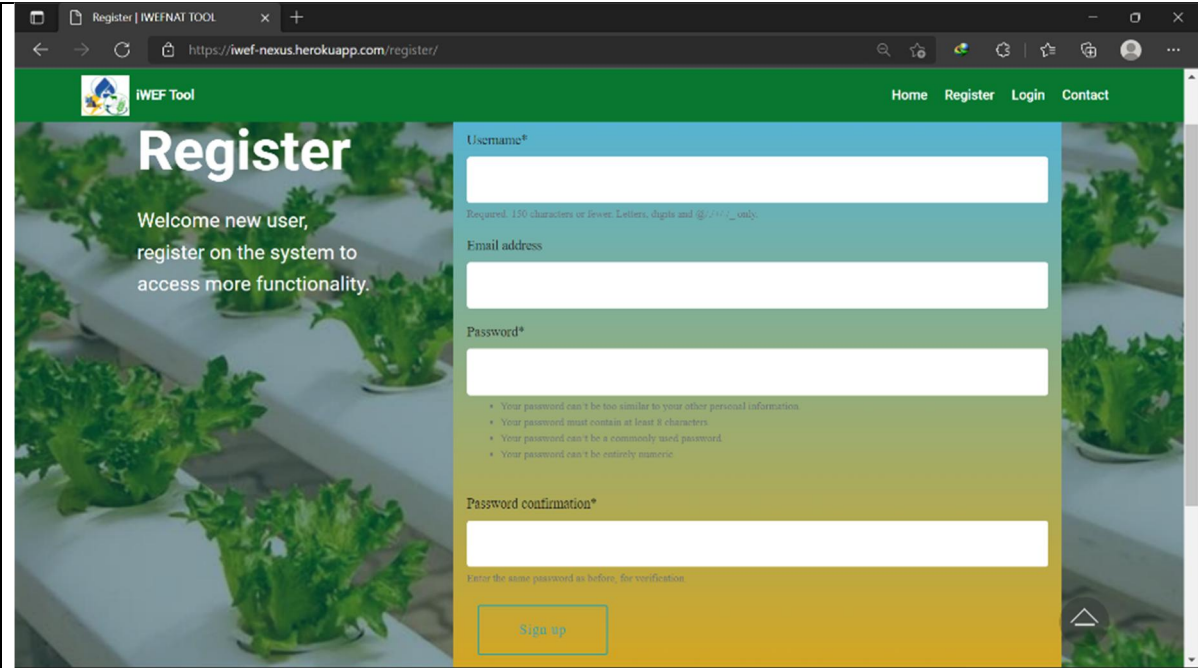
The iWEF model determines the integrated WEF nexus composite index (i) whose value can be interpreted on its level or class of sustainability (Table 2) (Nhamo et al., 2020a). Key outputs in iWEF include a spider graph (radar chart or sustainability polygon) of normalised indices and maps. The shape of the radar chart illustrates WEF nexus indicator performance and inter-relationships, providing a synopsis of the level of interactions, interdependencies and inter-connectedness among WEF nexus sectors, whose management is perceived as either sustainable or unsustainable. The maps show spatial distribution of the WEF nexus in the locations of interest, thus highlighting the hotspots and champions.

Using the iWFEF modelling tool

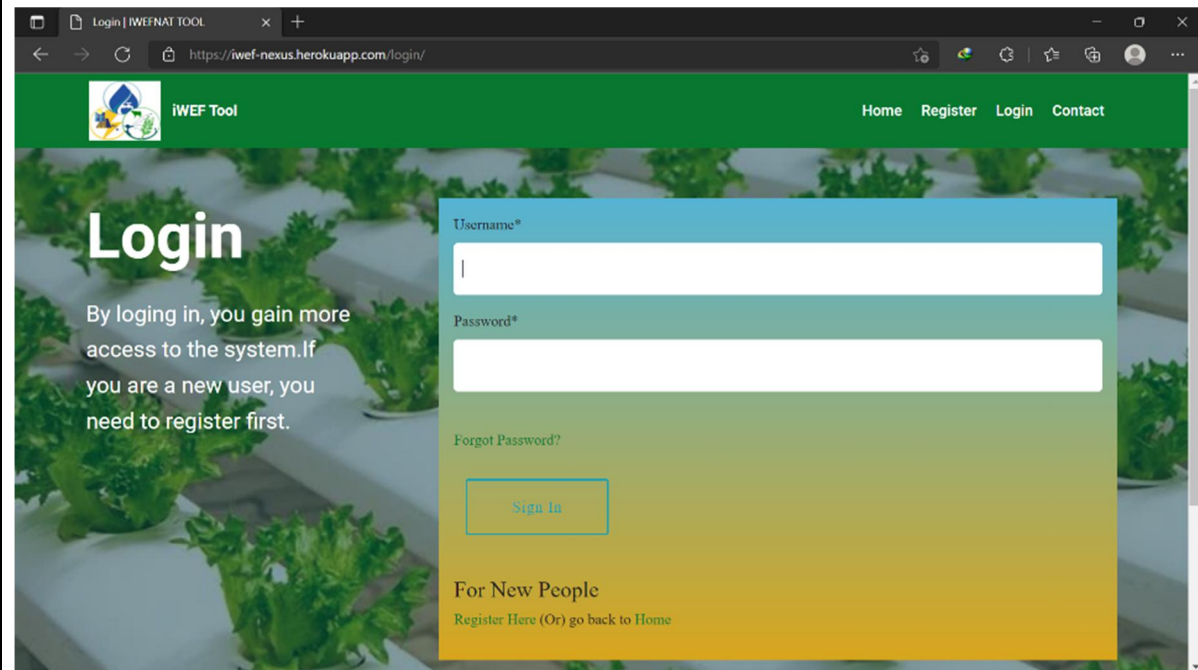
The user interface and corresponding stepwise operating procedures for iWFEF are shown in the succeeding section. Six steps need to be followed to carry out a WEF nexus study with the iWFEF tool.

User interface and corresponding operating procedures of iWFEF

Operating procedures and user interface	
Step 0: Home page	<ul style="list-style-type: none">Visit iWFEF tool's landing home page (https://iwef.app/) where you can access the different modules of the tool.
Step 1: User registration and login	<ul style="list-style-type: none">If you are a new user, click the 'Register' tab and populate the pop-up form with a unique username, email address and password. Click the 'Sign up' tab and your personal account will be created.



- Click the **'Login'** tab and populate the pop-up form with your username and password, then click the **'Sign In'** tab to access and use the iWEF tool.
- In case you forget your password, click the **'Forgot Password'** tab, and a password renewal link will be sent to your personal email, in the **'Inbox'** or **'Spam'** folder.



Step 2: Preparing input data

- Click the **'Data'** tab and be guided by Table 1 in filling your input data into all the editable coloured cells above the main / leading diagonal in the indicators data table to replace the default values. The reciprocal cells below the diagonal will be automatically

filled for you. For accuracy, it is recommended to fill in fractions instead of decimals for numbers, for example 1/3 for 0.33; 1/6 for 0.17; 1/7 for 0.14; and 1/9 instead of 0.11.

- Click “**Download**” tab to save your data in your local computer (by default, as ‘*exported-table (1)*’ in **Downloads**’ folder). Depending on the consistency and randomness of the pairwise comparison judgements, the user will either (i) be able to download their data for analysis if consistency ratio (CR) value is less than 0.10, or (i) be unable to download their data and be prompted to re-evaluate their judgements if CR value is greater than or equal to 0.10. In case of outcome (i) above, the process will be repeated until they get an acceptable CR value (≤ 0.1 or 10%) and download their data for analysis. Renaming the downloaded .csv file is optional.

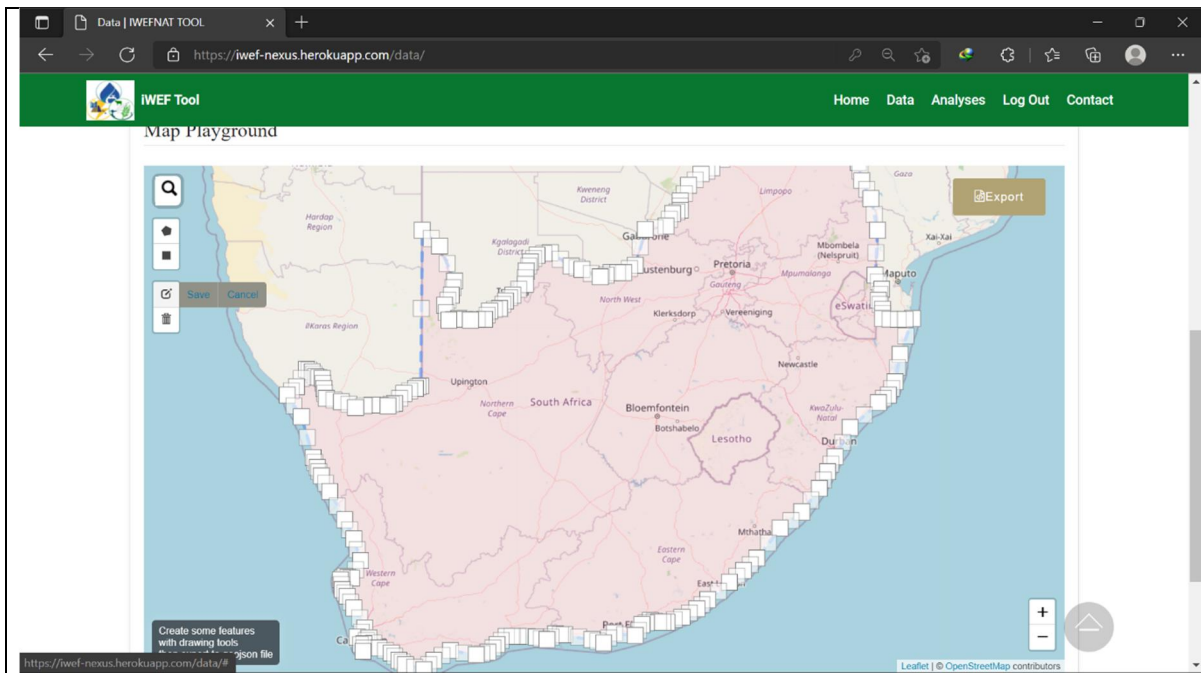
The screenshot shows the IWEF Tool web interface. The main content area is titled "Data Playground" and contains a pairwise comparison matrix. The matrix has 7 rows and 7 columns, with the following values:

	Water availability	Water productivity	Energy accessibility	Energy productivity	Food self-sufficiency	Crop productivity
Water availability	1.00	1.00	1.00	1.00	1.00	1.00
Water productivity	1.00	1.00	1.00	1.00	1.00	1.00
Energy accessibility	1.00	1.00	1.00	1.00	1.00	1.00
Energy productivity	1.00	1.00	1.00	1.00	1.00	1.00
Food self-sufficiency	1.00	1.00	1.00	1.00	1.00	1.00
Crop productivity	1.00	1.00	1.00	1.00	1.00	1.00

Below the matrix are "Download" and "Refresh" buttons. To the right, there is a "List of study areas" section with a text box containing "No table yet uploaded" and a "New" button.

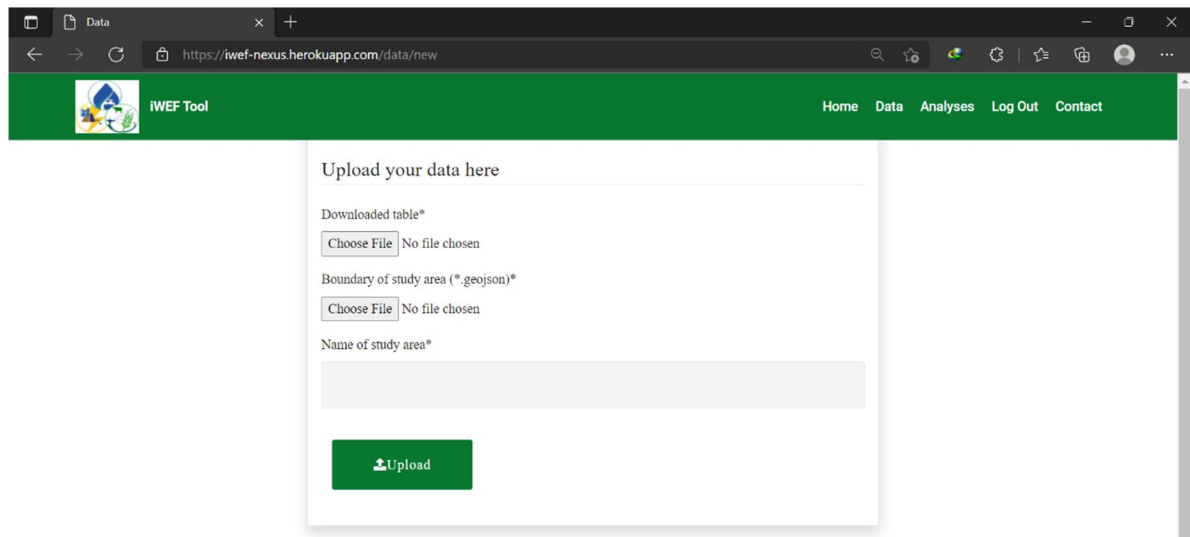
Step 3: Delineating the case study area

- If the user has a conventional .shp shapefile for the case study area, they must create a .geojson shapefile by using (i) the web-based tool <http://geojson.io/>, or (ii) the QGIS software.
- If the user lacks a conventional .shp shapefile for the case study area, go down to the ‘*Map Playground*’, select your polygon shape (regular or rectangle), then use the mouse cursor arrow to delineate the boundaries of your case study area in the base map. Zoom in the base map to fine tune the boundaries. Click on the ‘**Export**’ tab to download the shapefile of your selected case study area in your local computer (by default, as ‘*export_draw_day_month_year*’ in **Downloads**’ folder). Renaming the saved .geojson file is optional.

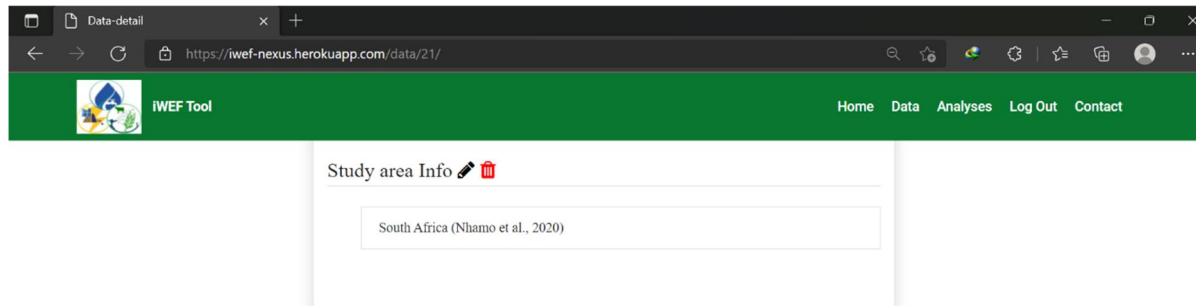


Step 4: Uploading and editing input data

- In the 'List of study areas' area, click on the '+New' tab to open the 'Upload your data here' area where you will upload your recently saved .csv and .geojson files into the 'Downloaded table' and 'Boundary of study area' fields, respectively.
- Specify the preferred name for your case study area in the 'Name of study area' field. Click the 'Upload' tab.

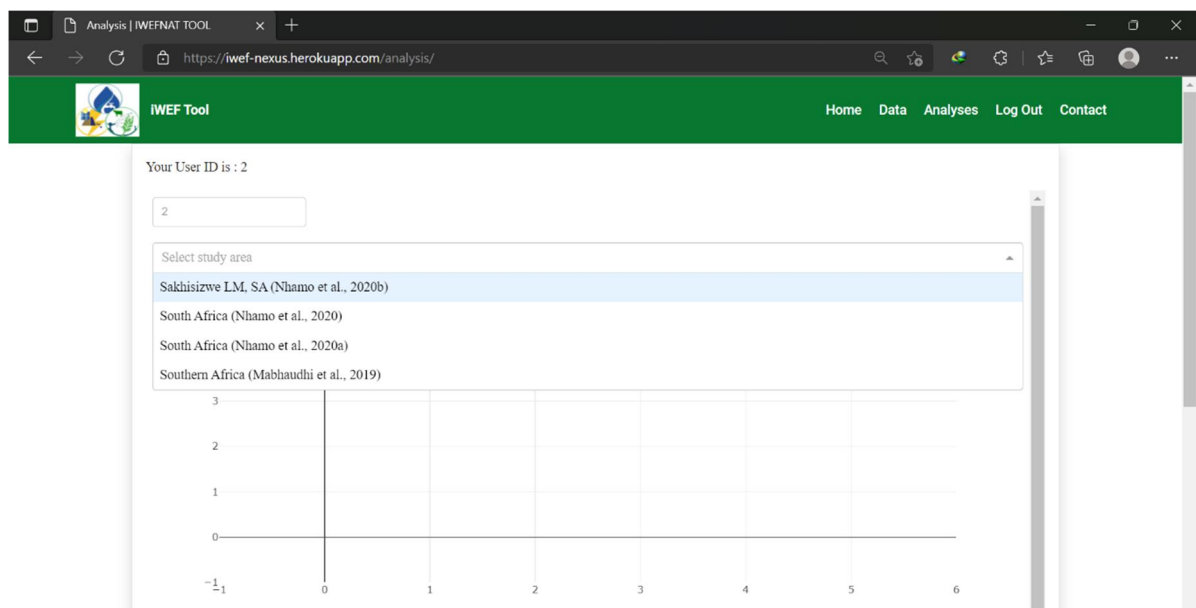


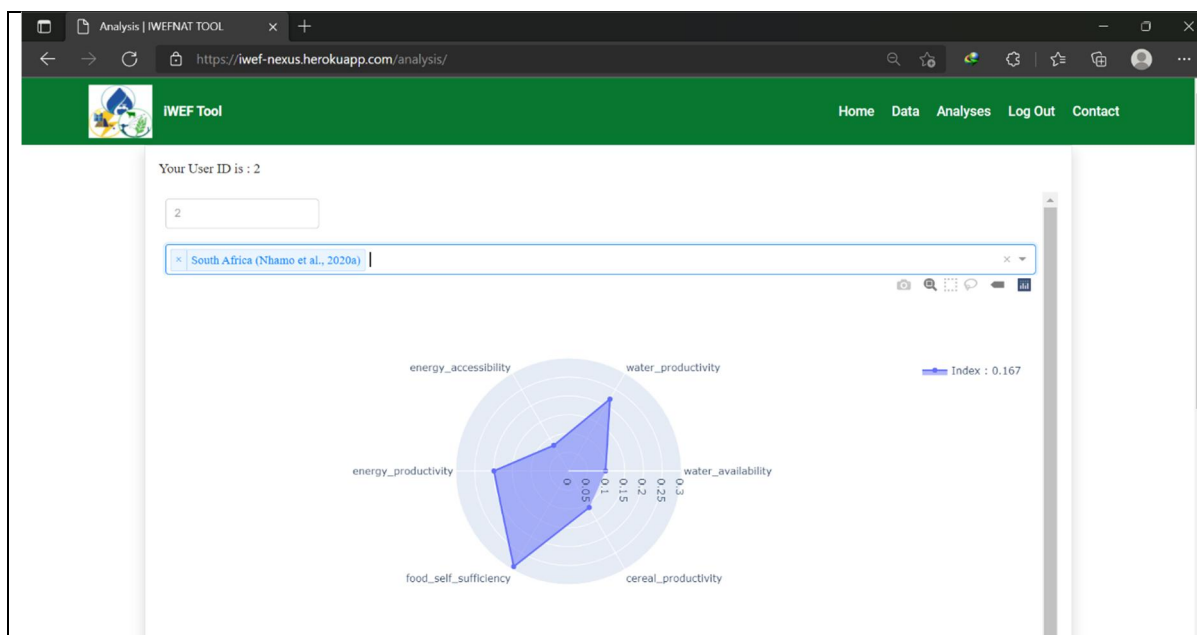
- To edit your uploaded data, click the specific case study and go to the ‘Study area Info’ area where you can either **edit** or **delete** your data and case study shapefile.



Step 5: Computing and displaying the WEF nexus index

- Click the ‘Analyses’ tab and enter your system randomly generated and assigned ID which is displayed near the top part of page. Click in the ‘Select study area’ field and your uniquely identified case studies will appear in a draw-down list. Select the case study of interest and your results will be displayed as a radar chart (or spider diagram) and a colour coded map. Download these results as .png for exporting and reporting.

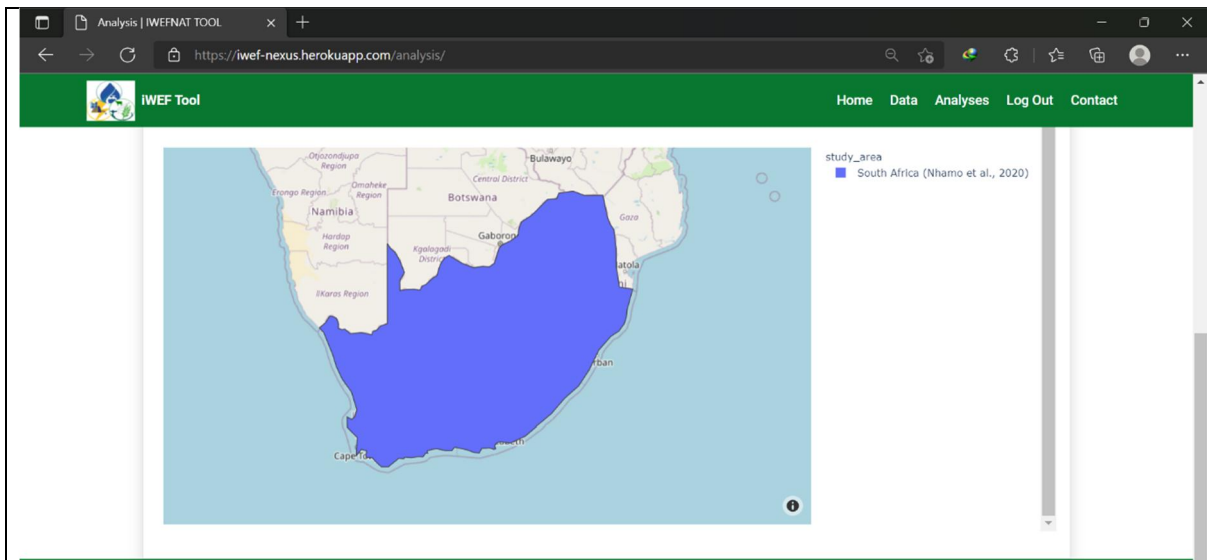




- The value(s) of the individual indices, integrated WEF nexus composite index (i), and quantitative values for the six indicators can be interpreted according to Table 2.

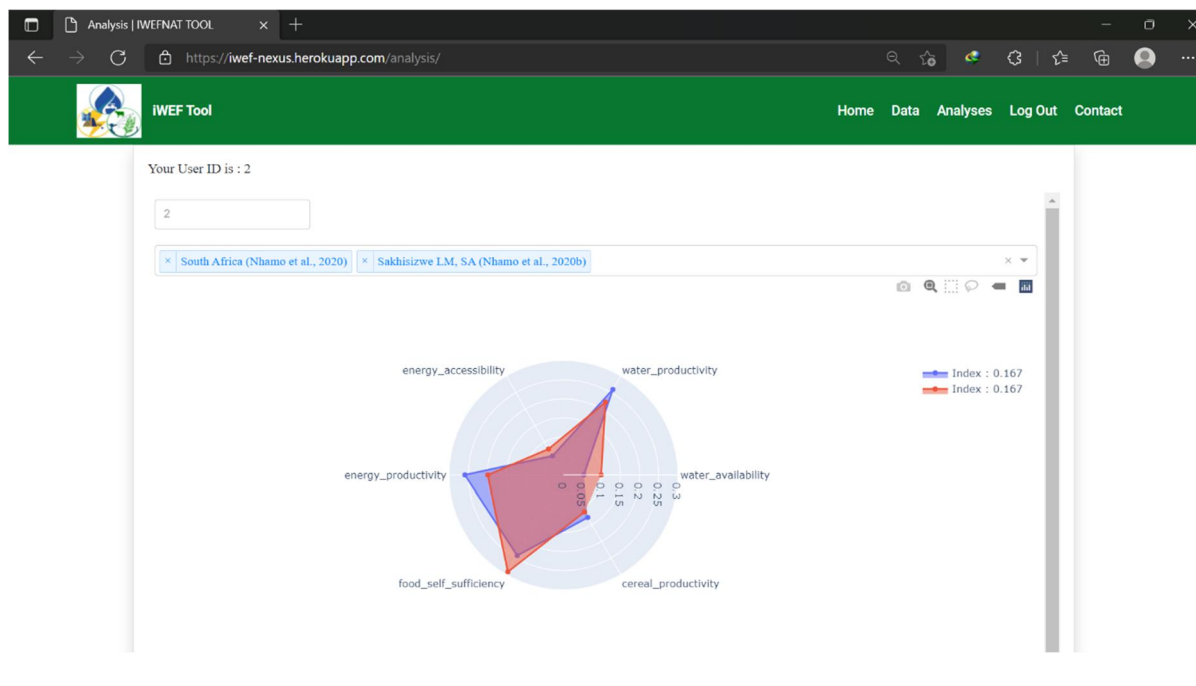
Table 2: WEF nexus indicators performance classification categories (Taguta *et al.*, 2023)

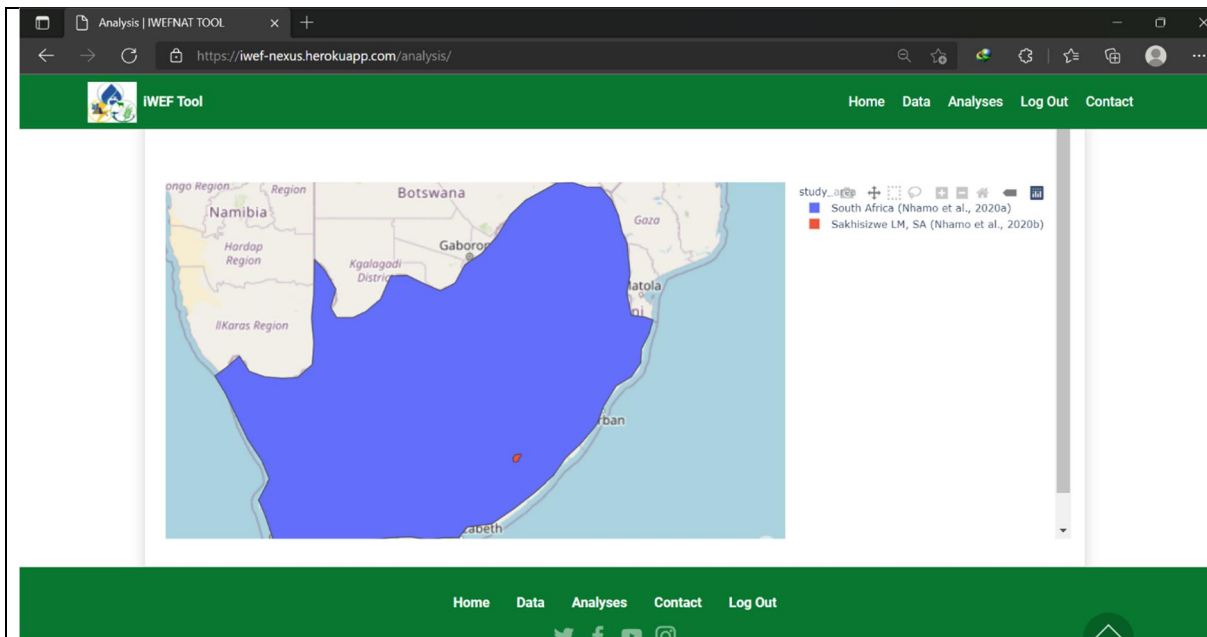
Sustainability	Unsustainable	Marginally sustainable	Moderately sustainable	Highly sustainable
Integrated WEF nexus composite index (i)	$0.048 \leq i < 0.107$	$0.108 \leq i < 0.167$	$0.168 \leq i < 0.226$	$0.227 \leq i \leq 0.286$
Water availability (m ³ /per capita)	$< 1\ 700$	$1\ 700 \leq x \leq 6\ 000$	$6\ 000 < x \leq 15\ 000$	$> 15\ 000$
Water productivity (US\$/m ³)	< 10	$10 \leq x \leq 20$	$20 < x \leq 100$	> 100
Energy accessibility (% of population)	< 20	$20 \leq x \leq 50$	$50 < x < 90$	$90 \leq x \leq 100$
Energy productivity (\$GDP/MJ)	< 0.11	$0.11 \leq x < 0.2$	$0.2 \leq x \leq 0.33$	> 0.33
Food self-sufficiency (% of population)	< 70	$70 \leq x \leq 85$	$85 < x \leq 95$	> 95
Crop productivity (kg/ha)	< 500	$500 < x \leq 2\ 000$	$2\ 000 < x \leq 4\ 000$	$> 4\ 000$



Step 6: Multiple case studies

- Repeat steps 2-5 to prepare and upload data for multiple case studies.
- To display multiple results from many case studies, select multiple names of cases studies from your list in the “Analyses” section. In case of an invisible map among multiple results, click the name of map of interest in the map index and the hidden map will appear with other maps. Download these results as .png for exporting and reporting.





After the session, log out of your account by clicking the ‘Logout’ tab.

Sample (prototype) data for iWef model

Tables 3 and 4 present sample (prototype) consistent and inconsistent data for familiarizing with the CR concept in the iWef model.

Table 3: A typical inconsistent pairwise comparison judgement dataset

Indicator Name	Water availability	Water productivity	Energy accessibility	Energy productivity	Food self-sufficiency	Cereal productivity
Water availability	1,00	1,00	1,00	0,33	0,33	1,00
Water productivity	1,00	1,00	3,00	5,00	1,00	1,00
Energy accessibility	1,00	0,33	1,00	3,00	0,20	0,33
Energy productivity	3,00	0,20	0,33	1,00	1,00	5,00
Food self-sufficiency	3,00	1,00	5,00	1,00	1,00	7,00
Cereal productivity	1,00	1,00	3,00	0,20	0,14	1,00

CR value = 0.31

Interpretation: $0.31 > 0.1$ thus the pairwise comparison matrix is inconsistent

Table 4: A typical consistent pairwise comparison judgement dataset

Indicator Name	Water availability	Water productivity	Energy accessibility	Energy productivity	Food self-sufficiency	Cereal productivity
Water availability	1,00	1,00	1,00	0,33	0,33	1,00
Water productivity	1,00	1,00	3,00	1,00	1,00	1,00
Energy accessibility	1,00	0,33	1,00	0,33	0,20	0,33
Energy productivity	3,00	1,00	3,00	1,00	1,00	2,00
Food self-sufficiency	3,00	1,00	5,00	1,00	1,00	7,00
Cereal productivity	1,00	1,00	3,00	0,50	0,14	1,00

CR value = 0.07

Interpretation: $0.07 < 0.1$ thus the pairwise comparison matrix is consistent

Enquiries and help

- Click the ‘Help’ tab to access instruction manuals and video tutorials on how to use the iWEF tool.
- Sample data, results and interpretations are available as well.
- The background paper on the current version of the iWEF model is freely available here: <https://www.frontiersin.org/journals/water/articles/10.3389/frwa.2023.1305373/full>
- The data were extracted from previous related work by:
 - i. Mabhaudhi et al. (2019) for Southern Africa (SADC) economic region at regional scale (<https://dx.doi.org/10.3390/ijerph16162970>),
 - ii. Nhamo et al. (2020a) for South Africa country at national scale (<https://doi.org/10.1016/j.envsci.2020.04.010>), and
 - iii. Nhamo et al. (2020b) for Sakhisizwe Local Municipality (in Eastern Cape Province, South Africa) at municipal scale (<https://dx.doi.org/10.3390/su12208582>).
- For further enquiries about iWEF, click the ‘Contact’ tab, fill the form and click the ‘Send’ tab. The iWEF system administrator will respond and address your issue.

Notes: The current version of iWEF can only process .csv and .geojson files for indicators table and shapefiles, respectively. Any other file formats will return errors.

How to cite the iWEF modeling tool:

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