Global Metropolitan-Detector : Application of Global-Detector for worldwide detection of metropolitan land use options

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1 Introduction

The concept of Global-Detector

Global-Detector is a Knowledge-based Geographic Information System for the global detection of the potential for production, supply and demand. This tool is developed by Wageningen University & Research (Hennen, 2016). The concept of Global-Detector is illustrated in the Figure 1.

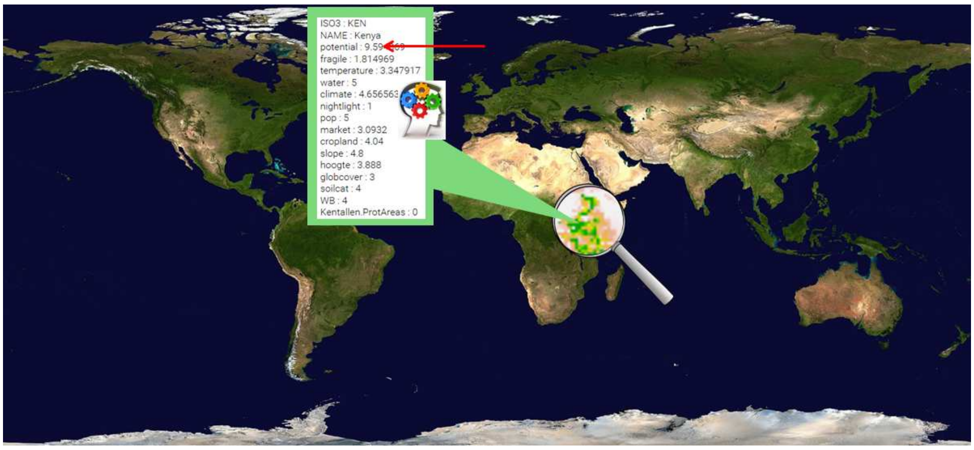


Figure 1 The concept of Global-Detector

At any spot on the world, i.e. a grid of 5'x5' (about 10x10 kilometres), the tool can show the values from a large amount of indicators. The knowledge from one or more experts is applied to combine relevant indicators to create a new indicator. For each case a knowledge-based model is developed that contains a set of arithmetic rules to prescribe how the indicators chosen by the expert have to be combined. After the calculation of all grids (worldwide or a specified region), the result is presented on a map. This can be a region as in figure 2, or worldwide.

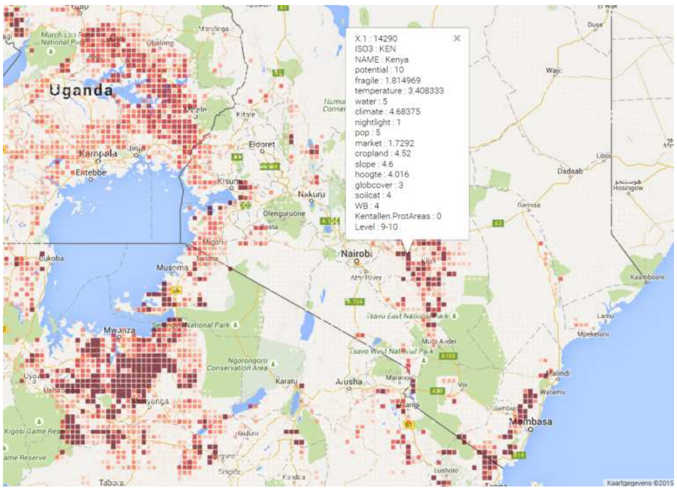


Figure 2 Example of a presentation of the result of Global-Detector (case potential Tilapia production)

Objective of Global Metropolitan-Detector

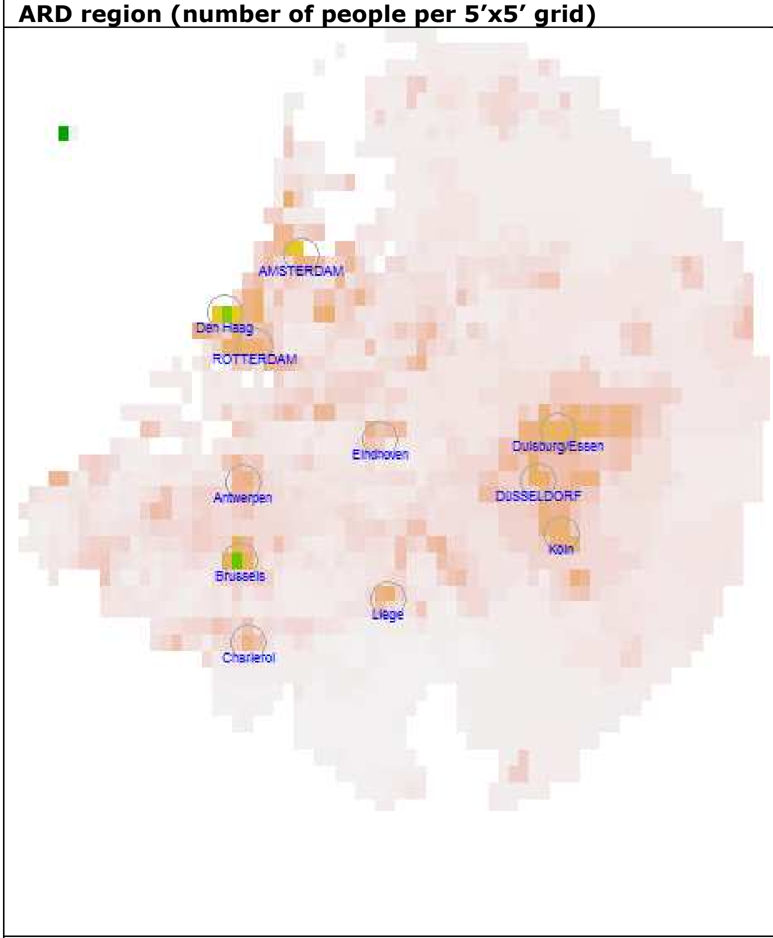
The objective of the application of the tool Global-Detector for Metropolitan Solutions is to show if and to what extend this tool is useful to give an indication of various modes of land-use around areas with a high population density to meet the demand for food and recreation. This will be illustrated in great detail for the European case Antwerp-Rotterdam-Düsseldorf (ARD). For the other European cases, i.e. London and Milan, and for two worldwide cases, i.e. Shanghai and Nairobi, only the area will be shown. To prove the global usage of the model some findings for the Shanghai case are illustrated.

2 Case studies

For each case grids within a distance of about 200 km from the centre of the metropolitan area are selected. This selection accounts for the position on the globe since the distance of 1 degree latitude differs from North to South, therefore the projection with longitude/latitude of Global-Detector had to be transformed. Because of differences in latitude the area of a 5'x5' grid around e.g. Milan is larger than in London.

The three European areas are shown below (longitude/latitude), for this the population density map has been transformed to the number of people per 5'x5'-grid (figure 3). Furthermore, the two additional cases outside Europe are shown in figure 4 (Shanghai and Nairobi).

ARD region (number of people per 5'x5' grid)



Milan and London

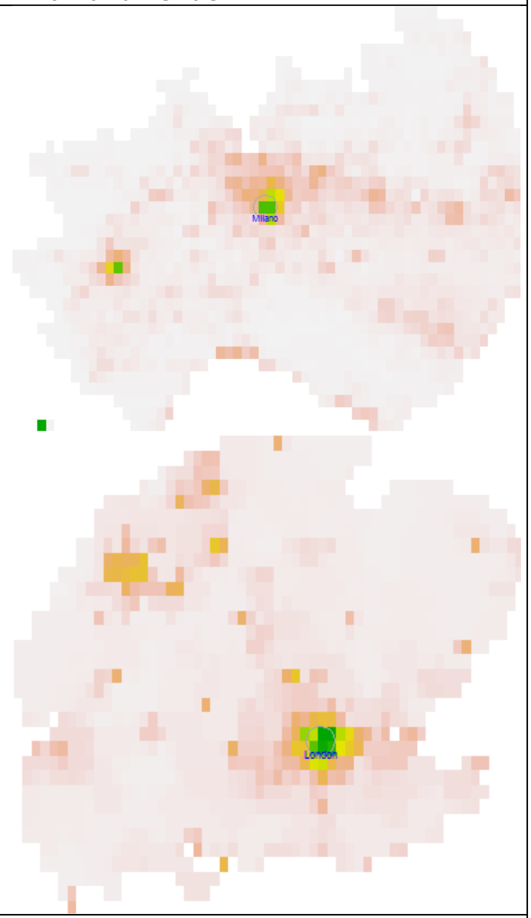


Figure 3 Number of people per 5'x5' grid for the three European Metropolitan Solution cases

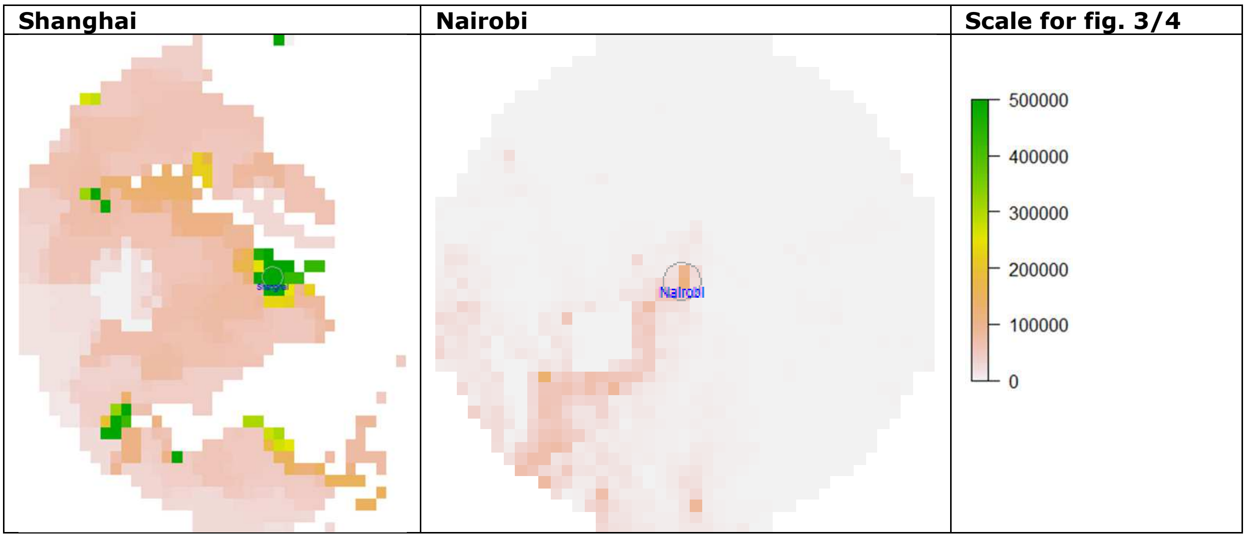


Figure 4 *Number of people per 5’x5’ grid for two example case worldwide*

Note: there are two grids outside each region, these have no meaning and only used to set uniform scales. For all graphs: colours range from white (lowest value) to dark green (highest value), intermediate values are yellow.

3 Data and method (illustrated by ARD case)

3.1 Indicators from Global-Detector

Only indicators from Global-Detector are used for the calculations. These indicators are available for all metropolitan area worldwide:

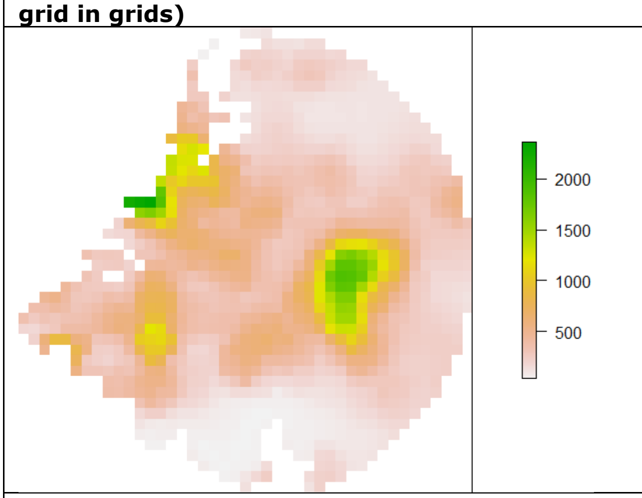
- Population density per km2
- Protected areas (in this application no agricultural activity allowed, recreation is allowed)
- Altitude (if too high, no agricultural activity is allowed)
- Slope (if too steep, no agricultural activity is allowed)
- Aridity (used as exclusion for areas that are too dry for agricultural production)
- Land cover (GlobCover dataset)
- Percentage cropland (Note: validation with ARD showed overestimation in regions with some woodlands and grassland, 15% of this percentage has been allocated to the derived indicators grassland and woodland)
- Population in radius of 40 km from a grid
- Population in radius of 250 km from a grid
- Green space near city [20 km]: Grids very near densely population areas that have a low density itself (and may have opportunities for city agriculture or recreation). An example is a grid in the “Groene Hart” in the ARD region
- Green space near city [40 km]: same as previous, but not too close to densely populated areas
- Far from urban regions (derived from the population in 40 km radius)

Derived indicators from the original Global-Detector indicators

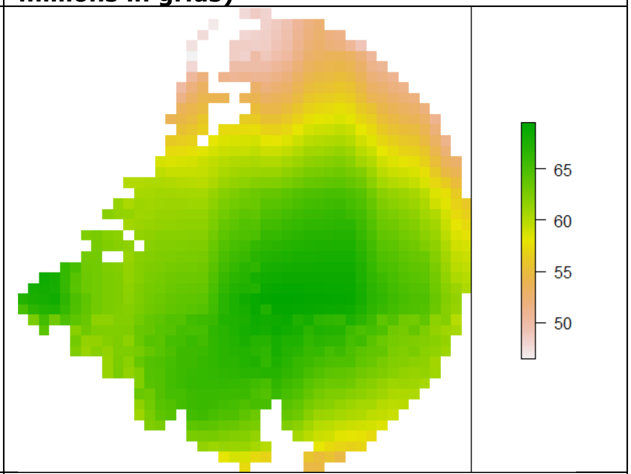
- Number of people per 5’x5’ grid (derived from population density)
- Exclude factor (derived from protected areas, altitude, slope and aridity); no agriculture activities allowed, for recreation no such restriction
- Artificial area in ha per grid (derived from land cover category artificial area and population per ha)
- Ha cropland per grid (derived from % cropland)
- Ha grassland per grid (derived from land cover categories that may correspond to grassland, validated with ARD area)
- Ha woodland and recreation area (derived from land cover categories that may correspond to woodland and recreation, validated with ARD area)

In figure 5 shows some Global-Detector indicators that are derived from the population density indicator. These give information of the population density in the area. Grids with high values (in green) for the "Green space near city" indicators have low population density but have a large population in the area.

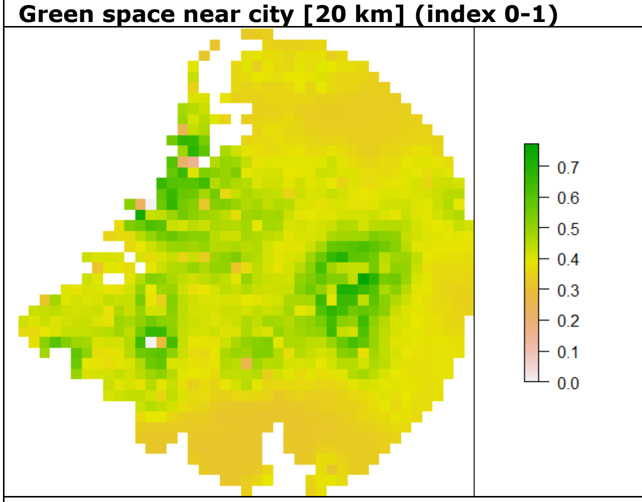
Population radius 40 km (average number per grid in grids)



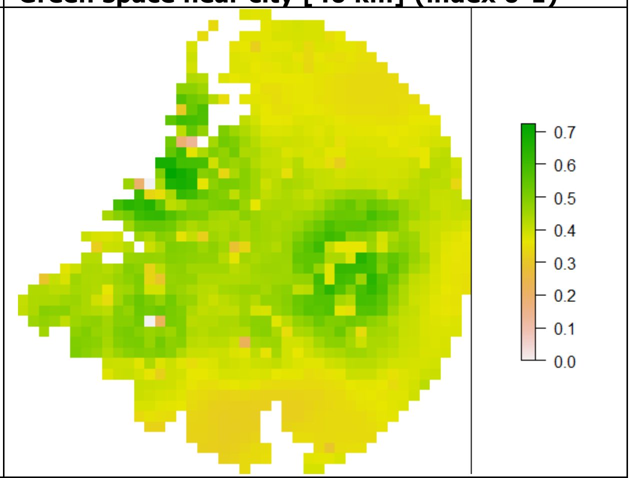
Population radius 250 km (total number in millions in grids)



Green space near city [20 km] (index 0-1)



Green space near city [40 km] (index 0-1)



Far from urban regions

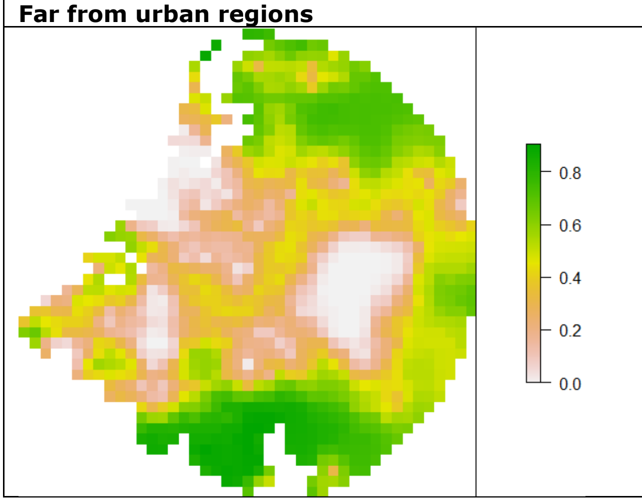


Figure 5 Indicators from Global-Detector for local usage

3.1 Land use options

NOTE: The illustrations below only give a coarse grained (5'x5') indication of preferable land use at 200 km around the metropolitan region of ARD. The results are not validated and only demonstrate the possibilities of the use of the tool Global-Detector for Metropolitan Solutions. Consider this as a first step that should be followed by a more detailed investigation with additional data and GIS-software.

Urban recreation
From the Global-Detector indicator "Green space near city [20 km]" and the derived indicator "Ha woodland and potential recreation area", the opportunities for recreation in the approximation of highly dense area's (cities) are calculated. The number of hectares for "Ha woodland and potential recreation area" is assumed to be the total area (about 5350 ha per grid) minus the area cropland, grassland and artificial land (e.g. buildings). It is assumed that 0-50% of this area can be used for urban recreation depending on the value of "Green space near city [20 km]" (factor 0-1).
In figure 6 the areas for urban recreation are shown. Note the range in the heading of each graph. Much opportunity for urban recreation (about 1600 ha in green colour) is in grids with a low population density combined with much woodland and recreation possibilities and situated near (large) cities.

Non-urban recreation
The map "Green space near city [40 km]" is used in a reversed way to make areas close to urban areas less attractive. This result is combined with the derived indicator "Ha woodland and potential recreation area" to yield a map that shows opportunities of recreation further away from urban areas. It is assumed that protected areas, altitude, slope and aridity are no restrictions for recreation, and that a maximum of 75% of the available area can be used for rural recreation.

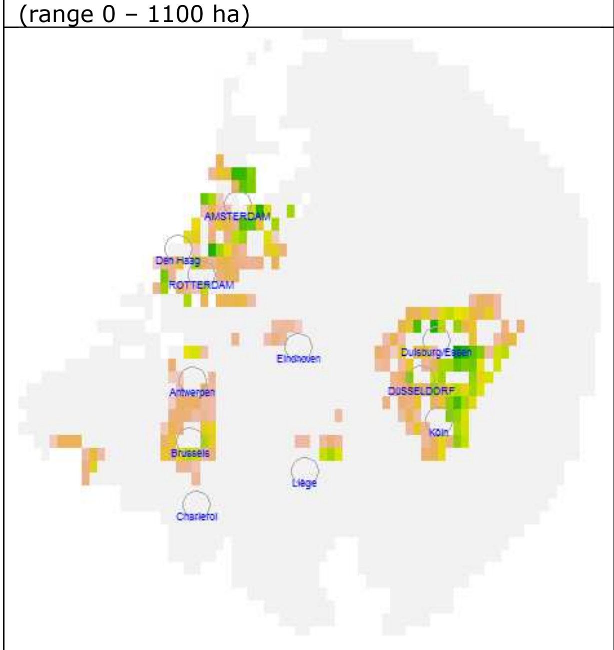
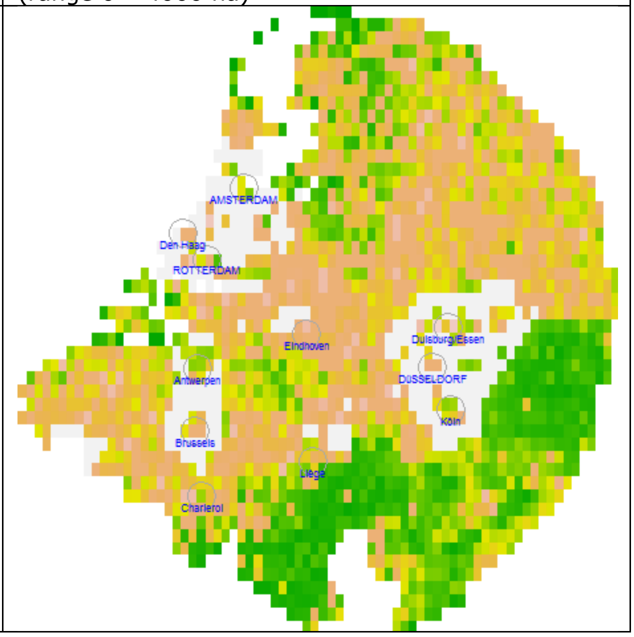
Urban recreation (ha per 5'x5' grid) (range 0 – 1100 ha)	**Rural recreation (ha per 5'x5' grid)** (range 0 – 4000 ha)
	

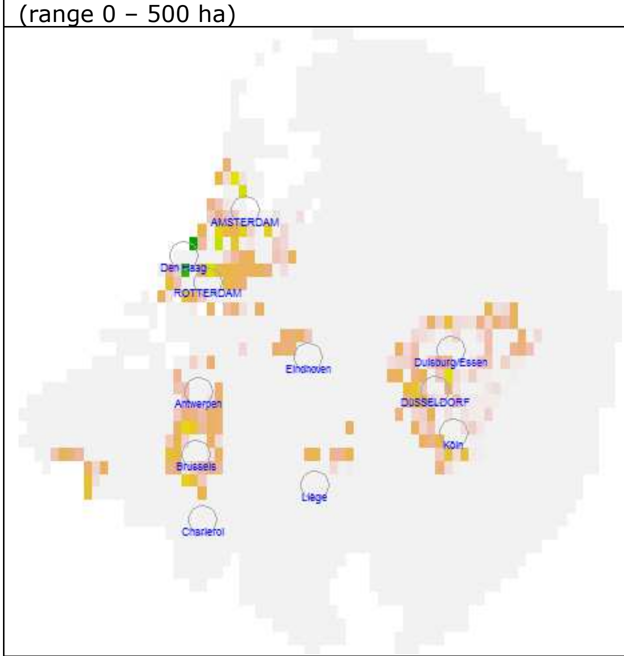
Figure 6 Opportunities for urban and rural recreation in the ARD region

Short chain fresh food
For this calculations it is assumed that the production of fresh food should be produced near cities on parcels currently used for cropland and grassland. This allows producers to bring their products to the markets within a few hours. Especially in regions where perishable products have to be on the market with no delay (tropical regions with bad or expensive transport facilities). The maps "Green space near city [20 km]" and the derived maps for cropland and grassland are used. See illustration below.

Intensive meat production

Areas that are far from highly population dense areas may be attractive for intensive meat production. The derived map "Far from urban regions" is used for this. With this map the model accounts for spots (i.e. cities) in rural areas with high population density, grids nearby these are made less attractive. Additionally the map "Population radius 250" is used to make sure that production is not in the middle of nowhere. The area for intensive meat production is small since it is assumed that parcels for feed production are excluded here, feed can be produced on arable land in the same grid (see later). So, a higher percentage of cropland results in more opportunities for intensive meat production (e.g. feed production by farmers).

Short chain fresh food (ha per grid) (range 0 – 500 ha)	**Intensive meat production (ha per grid)** (range 0 – 18 ha)



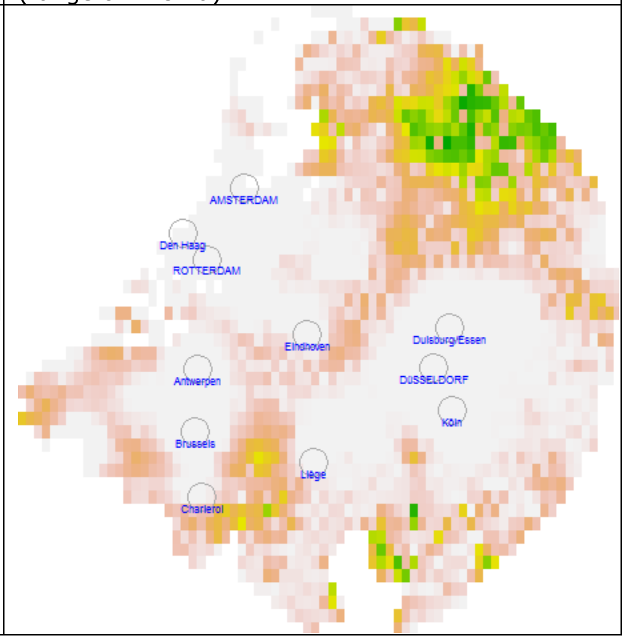


Figure 7 Opportunities for production of short chain fresh food (near urban regions) and intensive meat production (far from urban regions but accounting for population within 250 km radius)

Vegetables and fruit production

It is assumed that the production of vegetables and fruit should not be too close to urban areas (because of production fresh products) and not too far away (because of logistics and processing). The derived maps "Far from urban regions" and the area cropland (assumed maximum share of 50%) and grassland (assumed maximum share of 10%) are used for this.

Arable crops

Cropland not intended for vegetables is used for arable crop production, meaning that the remaining area of cropland is used for this. Production is further away from urban areas than in case of vegetable and fruit production. On grids with intensive meat production part of the crop production is used for animal feed production. There will be no distinction made between the intended use (animal feed versus products for human consumption).

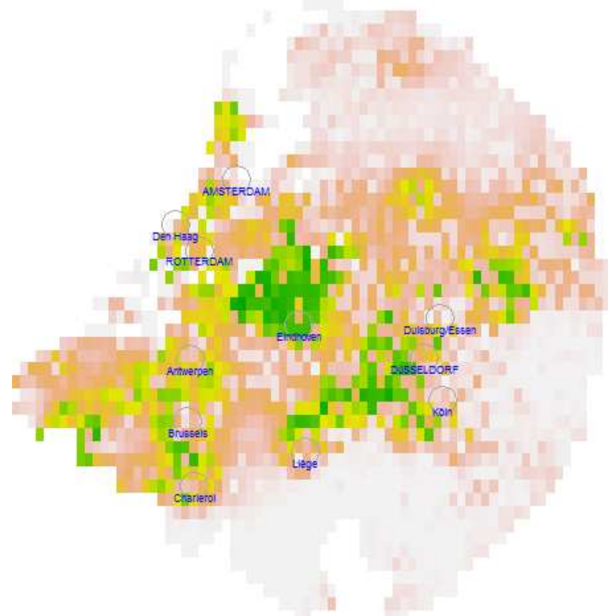
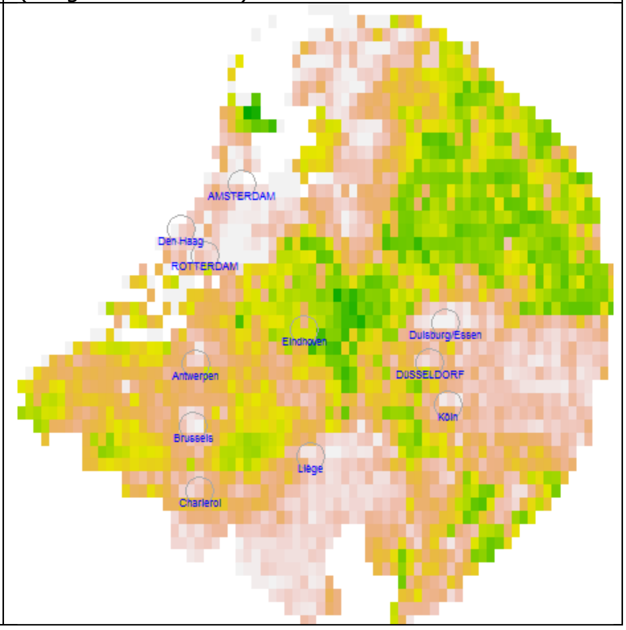
Vegetables and fruit (ha per grid) (range 0 – 1200 ha)	**Arable crops (ha per grid)** (range 0 – 3500 ha)
	

Figure 8 Opportunities for production of vegetables and fruit, and the production of arable crops

Grassland and other areas suitable for cattle, sheep and goat (meat and milk production)
Derived grassland not intended for fruit is used for cattle, sheep and goat. Maize, alfalfa or other crops used as animal feed are assumed to be produced in areas with arable crops.

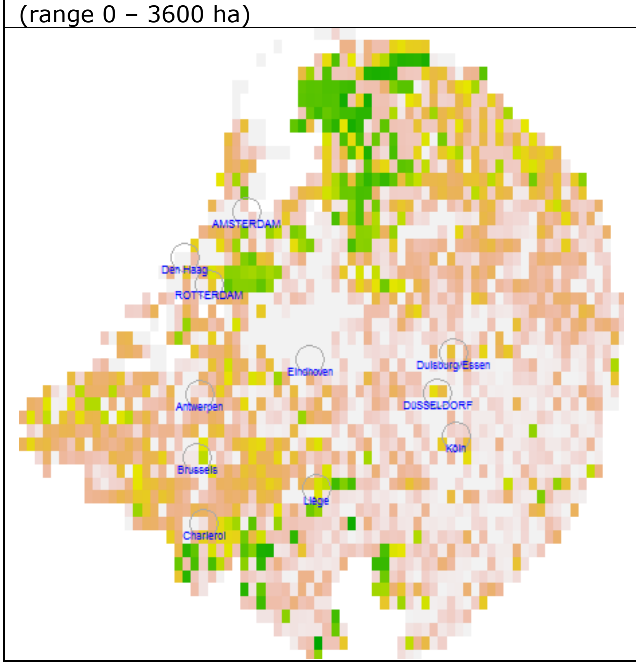
Grazing area (ha per grid) (range 0 – 3600 ha)	
	

Figure 9 Grazing areas (for ruminant meat and milk production)

NOTE: Projections of figures 9 and 10 differ. It appears that in figure 10 the distance horizontally (longitude) is larger than vertically (latitude). Due to the curvature of the earth, 1 degree longitude in the ARD area is about 70 km while 1 degree latitude is about 110 km. Worldwide 1 degree of latitude is always the same. For the same distance in km more degrees longitude are required when moving further away from the equator (see e.g. Movable Type 2016).

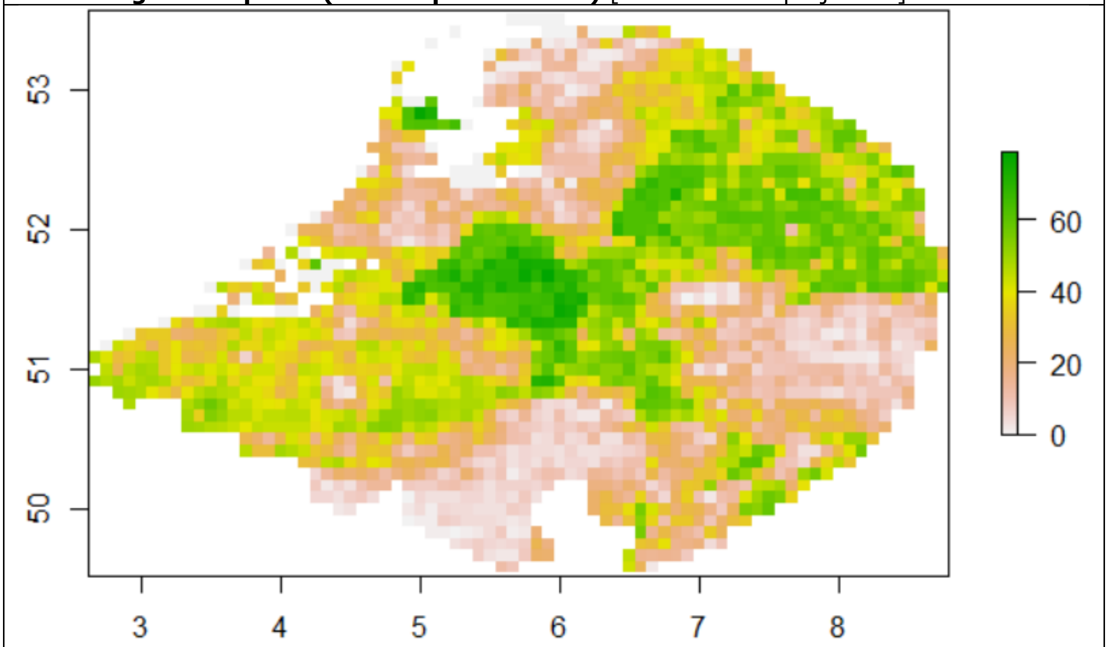
Land use of cropland

Summarising from the previous, existing cropland can have the following usages:

- Short chain fresh food
- Vegetables and fruit (ha per grid)
- Arable crops

Figure 10 shows the percentage of cropland (FAO, 2015) of the ARD area and the allocation over the 3 types of usages. The red grids on the second map of figure 10 represent short chain fresh food locations that are situated near the cities, the blue grids representing arable crops that are situated far from the populated areas, and the yellow grids represent locations with vegetables. Note that green grids are a mix of yellow vegetables grids and blue arable grids, thus both types can be found on these grids.

Percentage of cropland (FAO map worldwide) [Note: WSG84 projection]



Allocation of cropland (redish=fresh food, yellow=vegetables, blue=arable)

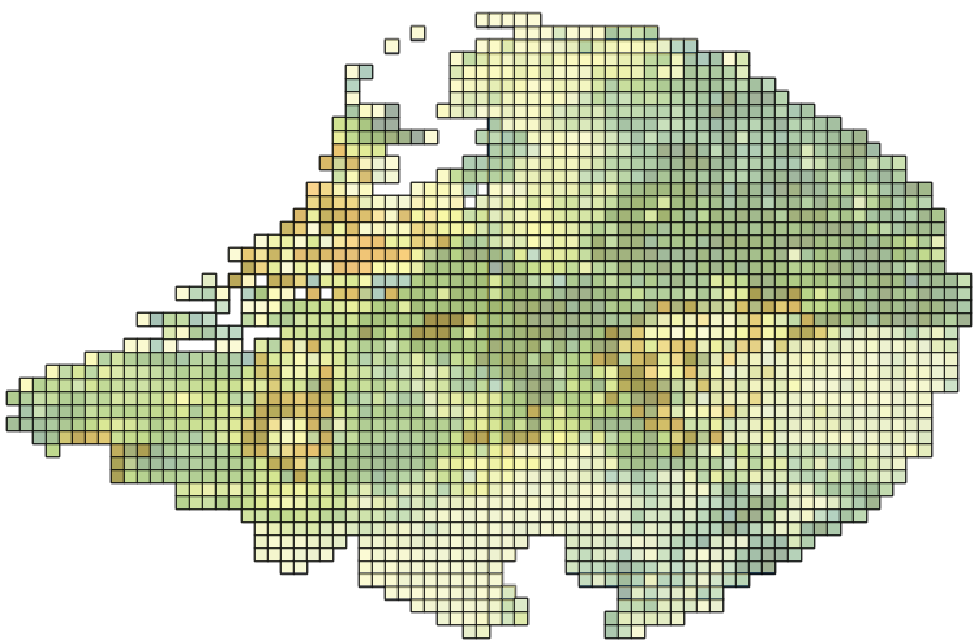


Figure 10 Allocation of cropland for (1) short chain fresh food [red], (2) vegetables and fruit [yellow] and (3) arable crops [red]. Due to combinations colours are mixed.

4 Scenarios

The knowledge-base of Global-Detector can be programmed in such a way that it can deal with scenarios. Two scenario will be illustrated: the effect of population growth (4.1) and rise of sea level by 2 meter due to global warming and a flood catastrophe (4.2).

4.1 Population growth

In this example it is assumed that the population will increase by 25% over a certain period of time. This growth can predominantly be urban or rural, or a combination of urban/rural. The maps below show 4 situations: current population density (number of people per 5′x5′ grid), urban population growth, both urban/rural growth and rural growth. Note that differences in the density maps (top row) appear to be indistinctive, this is due to the large maximum density (green grid). In the bottom row the differences with the current situation are shown and this reveals more increase in urban areas with "urban growth" and little increase in urban areas with "rural growth". The allocated increase is calculated by an iterative procedure in the model in which small steps are taken until full allocation is accomplished.

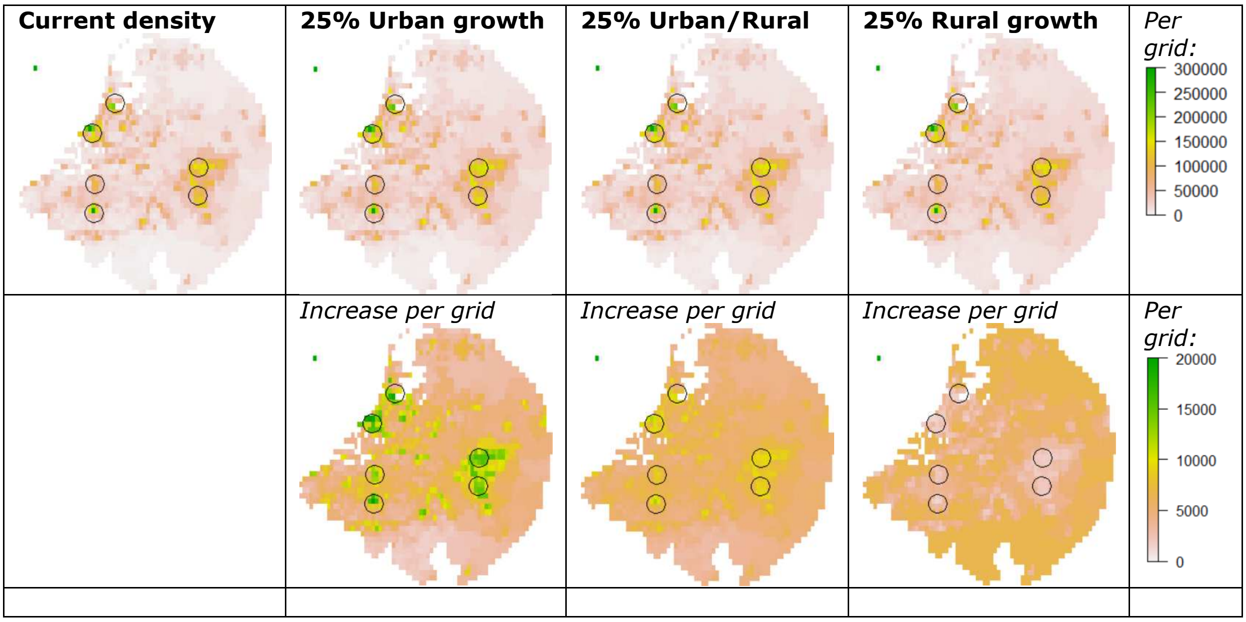


Figure 11 Population density and increase of population due to three scenarios

Food metres

The areas for agricultural production enable the supply of food for the people living in the metropolitan area and surroundings (up to 200 km). The supply is compared to the demand for the different types, expressed in ha for 1000 people.

Just for demonstration purposes the demand is set to the values below (food metres table). These need to be validated and replaced with proper values.

- Urban recreation = 1.5 ha/1000pp
- Short chain fresh food (near location with high density) = 1 ha/1000pp
- Intensive livestock (stables) = 0.10 ha/1000pp
- Vegetables and fruit = 2.2 ha/1000pp
- Arable crops =22 ha/1000pp
- Grazing ruminants=16.7 ha/1000pp

The total number of people is calculated from the grids in the area, the same procedure is applied for the hectares. The demand in ha is the number of people multiplied by the food metres table. The supply for each type of food product is just the sum of the hectares. The difference between supply and demand is the surplus for this region.

Results : supply, demand and surplus of scenarios

For each scenario the demand based on the food metrics is calculated. This is compared with the available area (supply), resulting in a surplus or balance.

A Current situation

AreaUse	HaDemand	HaSupply	HaSurplus	%Surplus
Short chain fresh food	9086	22166	13080	144.0
Intensive livestock	4593	4403	-190	-4.1
Vegetables and fruit	101050	480056	379006	375.1
Arable crops	1010498	2497072	1486574	147.1
Ruminants (grazing)	767060	1480395	713335	93.0
Urban recreation	13629	109715	96086	705.0

B Population growth 25% (mainly urban)

AreaUse	HaDemand	HaSupply	HaSurplus	%Surplus
Short chain fresh food	12598	21913	9315	73.9
Intensive livestock	5744	4403	-1341	-23.3
Vegetables and fruit	126367	477752	351385	278.1
Arable crops	1263674	2495772	1232098	97.5
Ruminants (grazing)	959244	1460947	501703	52.3
Urban recreation	18898	107244	88346	467.5

C Population growth 25% (urban and rural)

AreaUse	HaDemand	HaSupply	HaSurplus	%Surplus
Short chain fresh food	11339	21950	10611	93.6
Intensive livestock	5745	4403	-1342	-23.4
Vegetables and fruit	126386	478028	351642	278.2
Arable crops	1263856	2495812	1231956	97.5
Ruminants (grazing)	959382	1461077	501695	52.3
Urban recreation	17009	107608	90599	532.7

D Population growth 25% (mainly rural)

AreaUse	HaDemand	HaSupply	HaSurplus	%Surplus
Short chain fresh food	9408	22036	12628	134.2
Intensive livestock	5742	4403	-1339	-23.3
Vegetables and fruit	126331	478657	352326	278.9
Arable crops	1263305	2496015	1232710	97.6
Ruminants (grazing)	958964	1461433	502469	52.4
Urban recreation	14112	108423	94311	668.3

4.2 Flood by increased sea level

In this scenario the rise of the sea level with two meter is simulated together with flood of land below this new level. For the Netherlands this scenario would be highly improbable, but this illustrates the application of another Global-Detector indicator (i.e. altitude) for a scenario. It is assumed that the migration will lead to more urbanisation of non-flooded regions regardless of the location (so no preference for Dutch cities).

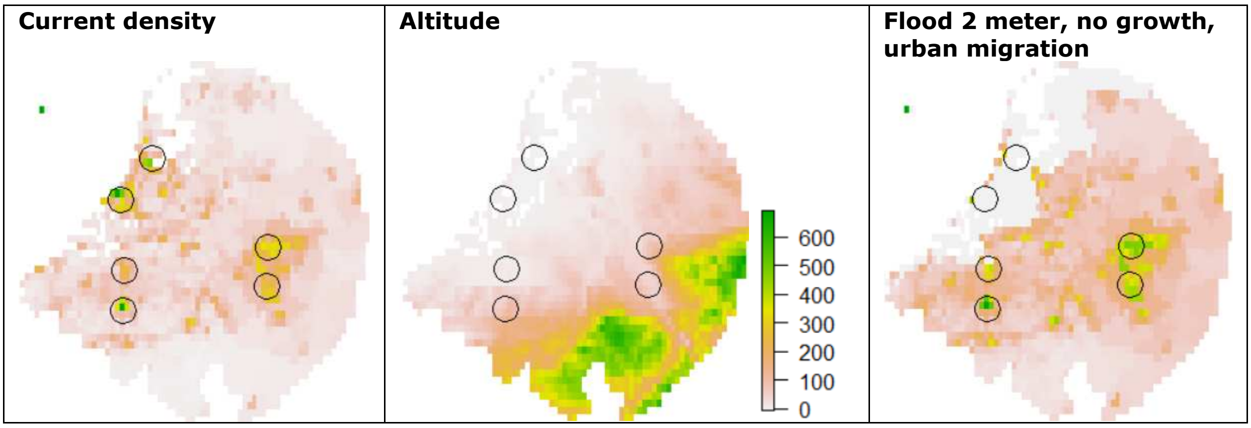


Figure 12 Effect of increased sea level (2 meters) and urban migration due to flood on the population density

Results

The results show considerable shortage of grazing area. The area intended for arable crops should be reallocated to meet the demands, e.g. the production of maize to replace grass intake by dairy cows or fattening bulls.

AreaUse	HaDemand	HaSupply	HaSurplus	%Surplus
Short chain fresh food	8156	15293	7137	87.5
Intensive livestock	8290	4083	-4207	-50.7
Vegetables and fruit	182386	429889	247503	135.7
Arable crops	1823864	2324798	500934	27.5
Ruminants (grazing)	1384478	1087548	-296930	-21.4
Urban recreation	12234	78446	66212	541.2

5 Proof-of-concept for regions worldwide: Case Shanghai

The Global Metropolitan-Detector can be applied for any region worldwide, this will be illustrated by some graphs for the Shanghai case. These figures and the resulting supply-demand table will not be discussed.

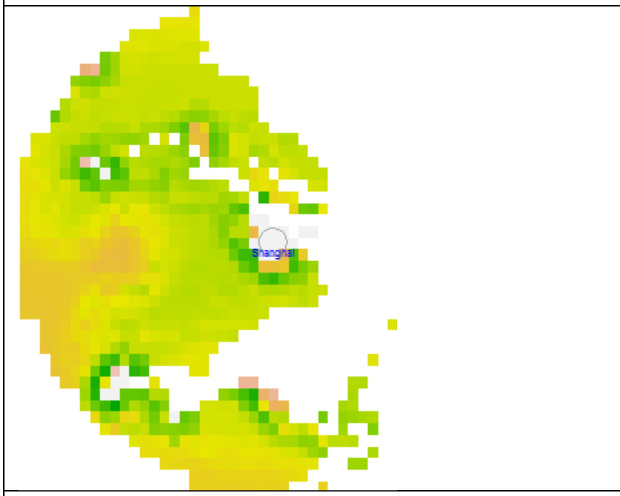
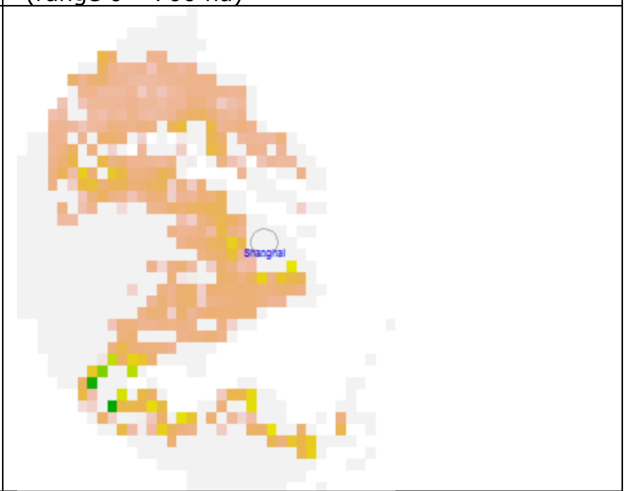
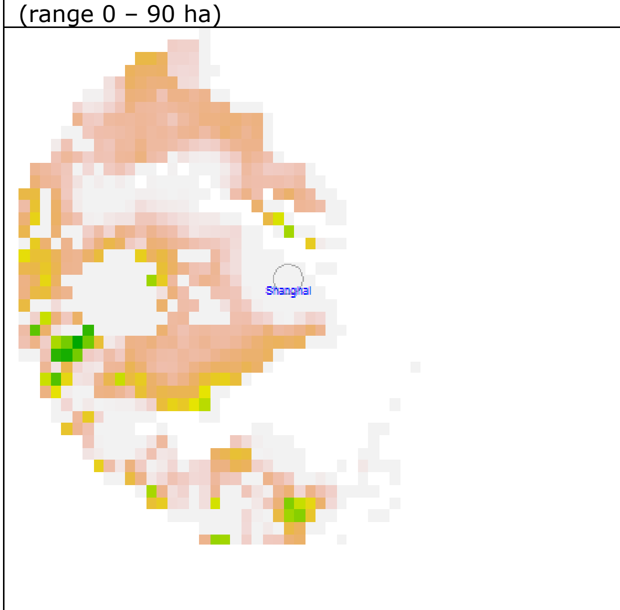
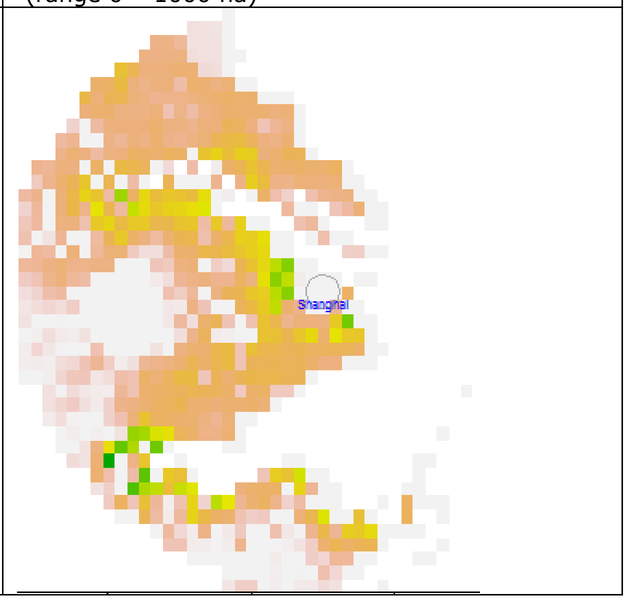
Green space near city [20 km]	**Short chain fresh food (ha per grid)** (range 0 – 700 ha)
	
Intensive meat production (ha per grid) (range 0 – 90 ha)	**Vegetables and fruit (ha per grid)** (range 0 – 1000 ha)
	

Figure 13 Some results of the use of Global-Detector for the Shanghai region

AreaUse	HaDemand	HaSupply	HaSurplus	%Surplus
Short chain fresh food	29152	64546	35394	121.4
Intensive livestock	9973	10415	442	4.4
Vegetables and fruit	156240	156640	400	0.3
Arable crops	2360221	2304560	-55661	-2.4
Ruminants (grazing)	202780	174676	-28104	-13.9
Urban recreation	43729	73944	30215	69.1

6 Discussion

Advantages

- Applicable worldwide
- Many indicators available to add specifications
- Fast modelling since all indicators have uniform format
- Opportunities for scenario studies

Restrictions

- Indicators can only be world wide
- Coarse-grained: a resolution of 5'x5' (approximately 10x10 km)
- Products are highly aggregated (e.g. "ruminants"), in a second step (e.g. by "Ruimtescanner") this could be specified

The proof of concept of the model, as described in this paper, can further be extended by additionally aspects (e.g. sustainability or bio-diversity) or accounting for (changing) climatic conditions (e.g. temperature or precipitation that affect yield). The "Short chain fresh food" allocation can be improved by taking the accessibility by (the quality of) roads into account (indicator "Market access"), or other improvements with infrastructural information.
The demand for food products must account for differences between countries when the model should be applied worldwide due to cultural and welfare aspects that affect the consumption pattern, and within a country differences between urban and rural consumption patterns.

References

FAO (2015) Accessed May 23, 2016. http://www.climatechange-foodsecurity.org/uploads/crops_map_fao.png
Hennen, W., A. Daane and K. van Duijvendijk (2016) Global-Detector; GIS- and Knowledge-based tool for a global detection of the potential for production, supply and demand. Prepared paper for The 3rd International Conference on Geographical Information Systems Theory, Applications and Management; Porto, Portugal, 27-28 April 2017
Movable Type (2016) Accessed May 23, 2016. http://www.movable-type.co.uk/scripts/latlong.html

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