Mapping opportunities for rainwater harvesting and forest landscape restoration in Ghana's Bono-East region

A participatory modelling approach

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1 Introduction to nature-based solutions

Food production in sub-Saharan Africa faces a myriad of challenges. One of the most urgent amongst these challenges is the lack of adequate water availability throughout the year for continued crop production. Over 95% of croplands in sub-Saharan Africa are under rainfed production (You et al., 2011), making them highly vulnerable to droughts and seasonal changes in rainfall. Rainwater harvesting and forest landscape restoration are widely recognised as two cost-effective nature-based solutions that can increase the climate resilience of smallholder production systems in sub-Saharan Africa. Whereas rainwater harvesting for irrigation measures is specifically targeted at increasing climate resilience to droughts (Linderhof et al., 2022), particular types of forest-landscape restoration measures provide a mix of benefits key amongst them are reduction in heat stress as well as increased resilience to droughts (van Oosten et al., 2022).

A critical step towards increased adoption and scaling of these solutions is identifying potentially suitable areas within a landscape where these solutions can be implemented. This requires insights into a broad range of factors, including biophysical, climatic and socio-economic factors explaining how they support nature-based solutions in delivering ecosystem services. Furthermore, such nature-based solutions are often randomly implemented in isolation, without considering their broader ecological, socio-economic and institutional context. This undermines the ability to maximise synergies between different solutions proposed in food systems and minimise their trade-offs. Identifying potentially promising nature-based solutions within a landscape and integrating these through smart spatial planning would be an effective pathway to enhance climate resilience, more efficient water use and stronger circularity of food systems. Against this background, we assess and map opportunities for rainwater harvesting and forest landscape restoration as a function of bioclimatic, terrain, hydrologic and edaphic factors. We demonstrate our approach using the Bono East region in Ghana as a test case.

The Bono East Region in Ghana forms an ideal case to test our proposed integrated spatial approach, as it harbours one of Ghana's most important domestic food systems, which is heavily under climate stress. Climate change has made farming in this Region more difficult and risky because farmers can no longer predict the onset of the rainy season and experience prolonged dry spells and erratic rainfall, making agriculture an unreliable and unprofitable investment. In the adjacent northern Region, rainfall patterns have changed even more dramatically, putting pressure on extensive animal husbandry. Scarcity of pastures, periodic water shortage, heat stress, prevalence of pests and diseases have motivated herders to move southward, putting more pressure on the increasingly scarce resources in the Bono region. To cope with these climate–induced challenges, people tend to increase their dependence on natural resources, not only through intensifying their agricultural and animal husbandry activities but also by increasing their use of naturally occurring trees for charcoal production, massive illegal chainsaw operations in forest reserves, and encroachment into forest reserves. Increased pressure on land is increasingly leading to conflict between stakeholders, especially farmers, pastoralists and forest-dependent communities. This has consequences not only for the Bono East Region but for the entire country and West African sub-region, supported by the Bono East Region food system.

To map opportunities for nature-based solutions for climate-resilient food systems in the Bono East Region in Ghana, we applied a landscape-based approach within a participatory context. In this regard, we used the QUICKScan tool, which is a participatory modelling approach that links stakeholder- and decision-maker knowledge and preferences to available spatial- and spatio-statistical data and is designed for group use, e.g. in a multi-stakeholder workshop setting (Verweij et al., 2016), see Figure 1. As described in Figure 1, we applied the QUICKScan approach to:

a. map rainwater harvesting for irrigation under present and future climate and socio-economic conditions, and
b. map forest landscape restoration opportunities under present and future climate and socio-economic conditions.

The following chapters describe the participatory modelling approach, including the workshop's outcomes (chapter 1), the scoping phase (chapter 2), the development of the evidence base (chapter 3), the creation of a common understanding based on workshop outcomes (chapter 4), and finally the reflections and conclusions (chapter 5).

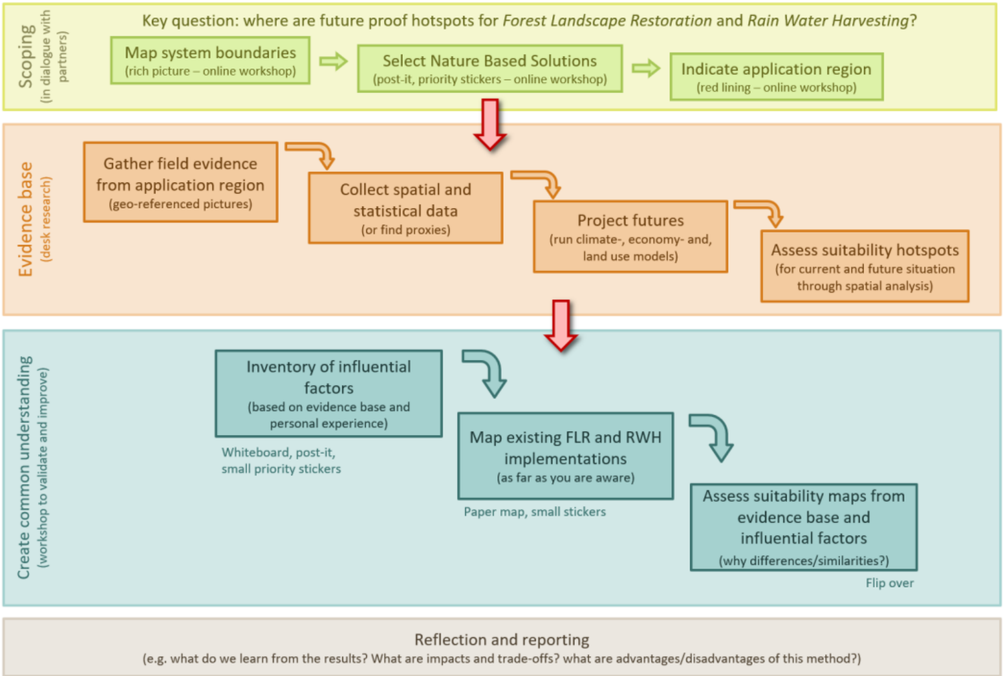


Figure 1 *Sequence of QUICKScan phases: scoping, evidence base, creating common understanding and reporting (inspired by (Verweij et al., 2016)*

2 Scoping NBS for food system enhancement

The scoping phase involved a joint exploration of the food system in the case study area, and the suitability for potential nature-based solutions herein. Landscape stakeholders familiar with the area and its food system created a storyline by showing their random pictures integrated into google maps. In this way, a 'virtual learning journey' was created, during which participants familiar and not familiar with the landscape could virtually travel through, obtain a 'sense of place', and become familiar with the major spatial features and characteristics of the landscape. MURAL was used with Google Map for participants to describe and map the components of the landscape's food system, identify its strengths, failures and challenges, and identify the major drivers behind it. A set of icons was developed with which participants could sketch the major elements of the food system (based on Van Berkum et al. (2018)), discuss the recent changes, the drivers behind these changes, identify the stakeholders who affect or are affected by these changes, and describe their responses. MURAL was used in combination with Google Earth, to explore the potential positive impact of RWH and FLR, identify those areas most suitable for applying these, and predict the potential impact of these. While exploring, stakeholders were discussing the advantages and disadvantages of both NBS, herewith contributing to building the knowledge rules.

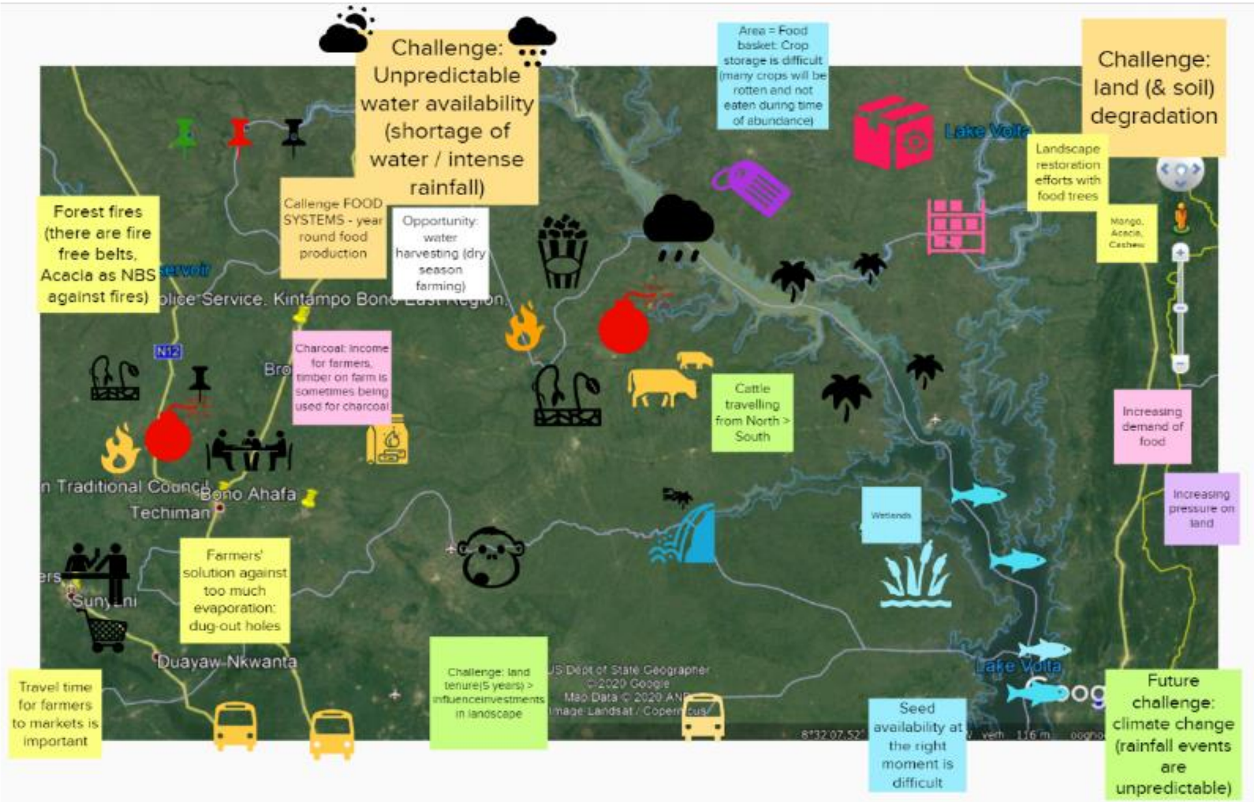


Figure 2 *Screenshot from MURAL-based scoping exercise*

3 Building the evidence base: rainwater harvesting and forest landscape restoration

Based on the gathered information, spatial data were collected both in the field, as well as from online global datasets. Four categories of spatial input data were defined based on the drivers identified by Linderhof et al. (2021) and stakeholder interactions. They included soil and terrain data, hydro-climatic data, socio-economic data, and data on land use constraints. The data are described below and summarized in Table 1, including the data sources.

3.1 Gathering field data

From 30th November to the 4th of December 2021, partners in Ghana conducted field research on the physical occurrence of rainwater harvesting and forest landscape restoration in Bono East Region. The two studies both included a phase of pre-field training in methodology, and a phase of field data collection. Two-day pre-field training for the field team from UENR on the 24th and 26th of November 2021, and resulted in a detailed design of the field guides and the identification of the sites to be visited. These identified sites were Kintampo North, Atebubu Amantin, Nkoranza South, and Techiman North and Sene West, all Districts and Municipalities in the Bono East Region.

The outcomes of the field visits were reported separately, and let to:

a. Better insight in the nature of rainwater harvesting and forest landscape restoration in the Region, which helped to identify the spatial and statistical data to be collected;
b. Verification of the desk top analysis of spatial and statistical data, and validation of the results.

3.2 Collection of spatial and statistical data

Simultaneous to the field work, a desk top exercise was started to collect several types of data: soil and terrain data, hydro-climatic data, socio-economic data, and otherwise data relevant to land use constraints.

Soil and terrain data
Spatially explicit elevation, soil drainage and hydrologic soil group were obtained from reliable global databases (see Table 1). The elevation data describe the bare ground topographic surface of the Earth, excluding trees, buildings and any other surface objects. The elevation data was used to compute slope, reflecting flow direction and accumulation across a landscape. The soil drainage data reflects the capacity of different soil types to retain soil. This data describes the capacity of the landscape to retain runoff after rainfall events. Hydrologic soil group is a soil characteristic classification system defined by the U.S. Soil Conservation Service in which a soil may be categorized into one of four soil groups (A, B, C, or D) based upon texture, land use and consequently infiltration rate (Ross et al., 2018). Type A soils have high infiltration rates and hence low runoff potential; Type B soils have moderately low runoff potential; Type C soils have moderately high runoff potential, and Type D soils have high runoff potential.

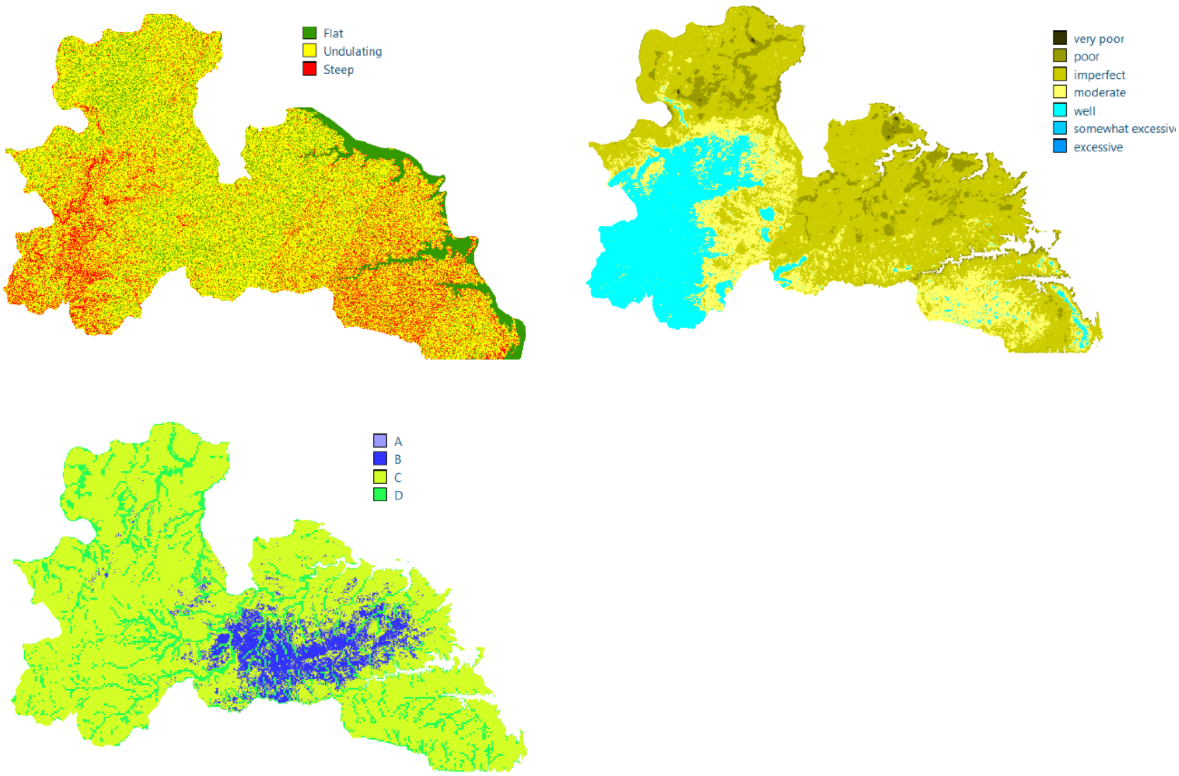


Figure 3 *Classified soil and terrain variables: slope (top left), soil drainage (top right), soil hydrologic group (bottom left)*

Hydro-climatic data
We estimated the water retention capacity of the Bono East landscape as a function of land cover, soil hydrologic group and rainfall. We first computed the runoff potential of the landscape as a function of land cover and soil hydrologic group based on the Soil Conservation Services (SCS) curve number methodology developed by the United States Department of Agriculture (Boughton, 1989). Subsequently, water retention capacity was estimated as a function of the runoff potential and annual rainfall (Figure 4).

Soil hydrology \ landcover : runoff potential

	Degraded f...	Shrubland	Grassland	Cropland	Aquatic ve...	Sparse ve...	Bareland	Built up	Open water	Forests	Unknown	Roads/Tra...
A	little	high	high	little	no runoff	little	high	high	no runoff	little	no runoff	moderate
B	little	high	high	moderate	no runoff	little	high	high	no runoff	little	no runoff	high
C	little	high	high	moderate	no runoff	moderate	high	high	no runoff	little	no runoff	high
D	moderate	high	high	high	no runoff	moderate	high	high	no runoff	moderate	no runoff	high

Rainfall \ runoff potential : water retention

	no runoff	very little	little	moderate	high
Low	High	Medium	Medium	Low	Low
Medium	High	High	Medium	Medium	Low
High	High	High	High	Medium	Low

Figure 4 *Knowledge matrices developed in the QUICKScan software between soil hydrological group and land cover (top) and runoff potential and rainfall (bottom)*

Socio-economic data

Because of the lack of data and the challenge of data collection imposed by COVID-19, no socio-economic data could be collected in the field, while socio-economic data at this level of aggregation are hard to find online. For this reason, the "distance to farm" and travel time to urban areas were the only variables used to characterize socio-economic conditions. Other socio-economic data, such as those related to livelihood conditions, farm income, land tenure and cost, are not included.

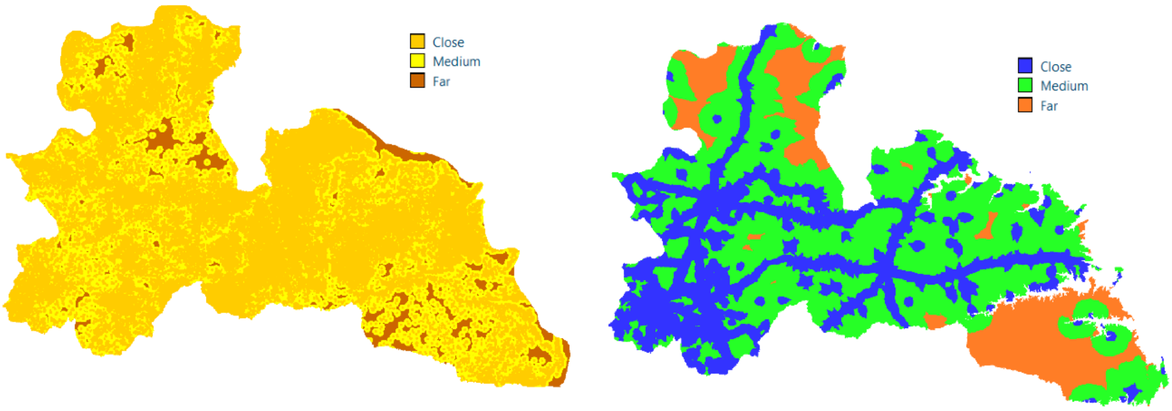


Figure 5 *Classified socio-economic variables: distance to the nearest farm (left); travel time to the nearest urban area (right)*

Land use constraints

Land use and land cover affect land availability for siting rainwater harvesting facilities. For example, areas designated as national parks or protected areas are off limits for crop production and other human interventions, such as rainwater harvesting facilities. To capture these constraints, we obtained data on protected areas from the UNEP world database on protected areas (Bingham et al., 2019). In addition, we also obtained tree cover data, which describes the percentage of a grid cell that is covered by trees.

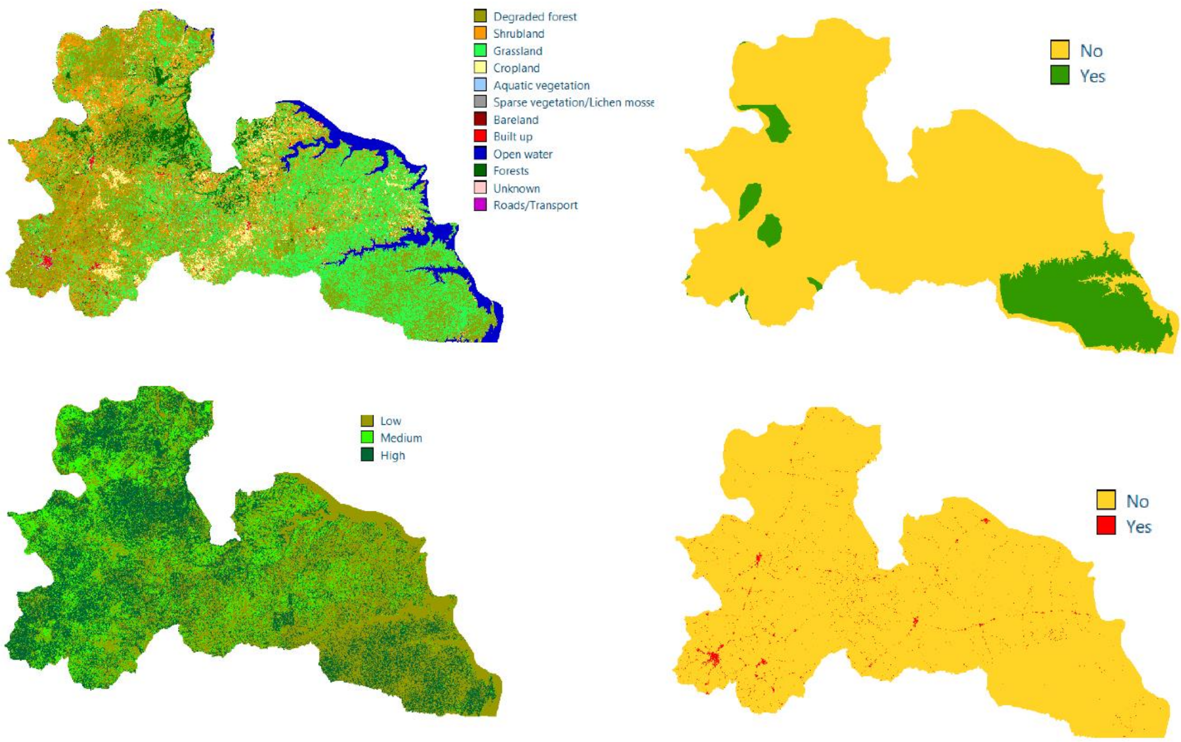


Figure 6 *Current land cover (top left), protected areas (top right), tree cover (bottom left) and settlements (bottom right). These were used to define constraints for rainwater harvesting.*

Table 1 *Input data and sources used in mapping land suitability for RWHI and FLR*

Input data	**Description (DE), Data source (SO) and Link (LI)**	
Land cover	**DE**	
	SO	European Space Agency
	LI	http://2016africalandcover20m.esrin.esa.int/viewer.php
Protected areas	**DE**	Spatial database of protected areas (including forests and national parks)
	SO	United Nations Environment Program-World Conservation Monitoring Center
	LI	https://www.protectedplanet.net/en/thematic-areas/wdpa
Elevation/Slope	**DE**	Digital elevation model at 30m resolution
	SO	National Aeronautics Space Administration
	LI	https://asterweb.jpl.nasa.gov/gdem.asp
Soil drainage classes	**DE**	Soil drainage classes
	SO	International Soil Reference and Information Center
		https://data.isric.org/geonetwork/srv/api/records/f36117ea-9be5-4afd-bb7d-7a3e77bf392a
Rainfall	**DE**	Long-term mean annual rainfall at 1km resolution
	SO	WorldClim
	LI	https://www.worldclim.org/
Tree cover	**DE**	Percentage of tree cover per spatial unit (30m by 30m). Tree cover refers to all vegetation with a height greater than 5m
	SO	Hansen et al. (2013)
	LI	https://data.globalforestwatch.org/datasets/14228e6347c44f5691572169e9e107ad
Distance to farms	**DE**	Euclidean distance
	SO	Computed in ArcGIS
Runoff potential	**DE**	The capacity of a land surface to generate runoff based on precipitation, soil and terrain conditions
	SO	Computed in ArcGIS
Hydrologic Soil Groups	**DE**	Hydrologic soil groups as defined by the United States Department of Agriculture (250m resolution)
	SO	Ross et al. (2018)
	LI	https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html
Agro-economic maps (Net Present Value)	**DE**	
	SO	Diogo et al. (2019)
	LI	https://www.wur.nl/nl/Publicatie-details.htm?publicationId=publication-way-353632303435

3.3 Projection of possible futures

The next phase of the exercise was the projection of possible futures for Bono East Region, taking into account the expected changes in climate conditions, socio-economic developments and land use. With this, so it was assumed, it would be easier to identify the current and the future potential for an effective implementation of RWH and FLR in the future. To capture these likely changes in the analysis projected climate data was obtained and future land use and agricultural related socio-economic developments were simulated using the iCLUE and MAGNET models respectively.

Climate change
Projected annual rainfall data under the SSP58.5 climate change scenario as defined by the Intergovernmental Panel on Climate Change was obtained from WorldClim Database (Fick and Hijmans, 2017). The SSP58.5 climate change scenario is a high emission scenario driven by global fossil-fuelled development with high challenges to mitigation and low challenges to adaptation (Kriegler et al., 2017). The data obtained represents average annual rainfall for the period (2041 – 2060) and is the multi-model mean from five global climate models that capture the spread of variations (ref).

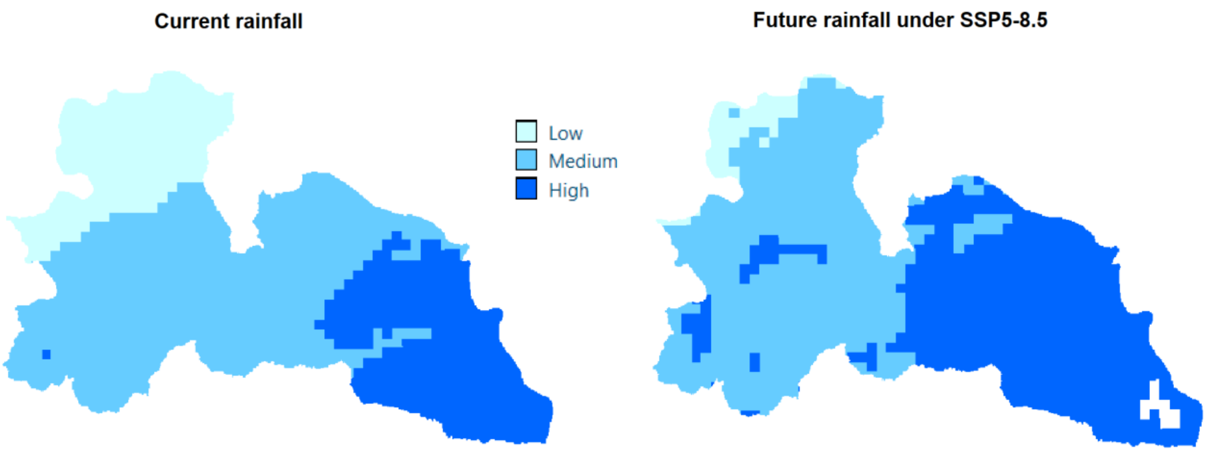


Figure 7 *Classified current and future mean annual rainfall*

Socio-economic development
We made use of MagnetGrid (Diogo et al., 2020), a land use gridded extension of MAGNET macro-economic model (Woltjer et al., 2014) to understand the agricultural related socio-economic developments in Ghana and more specifically in Bono-East. During the workshop, maps of key agro-economic dynamics over time and potential land change trends in Bono-East were presented to the stakeholders in order to get their feedback on the implication of such information on the implementation of NBS. Figure 8 and 9 are two examples of indicators, of which the stakeholders ratified that the NBS would be of large importance.

Figure 8 presents the spatial distribution of edible crops (vegetables and fruits) in Bono-East in 2020 and 2050. A hypothetical adoption of RWH in these areas can assure food security as the majority of these crops are directly linked to human consumption. The implementation of RWH where these crops are grown could avoid food disruption caused by rainfall shortage, which is critical for food availability (lower production) and accessibility (higher prices). Moreover, edible crops can also be linked with agroforestry systems due to the large presence of fruit trees.

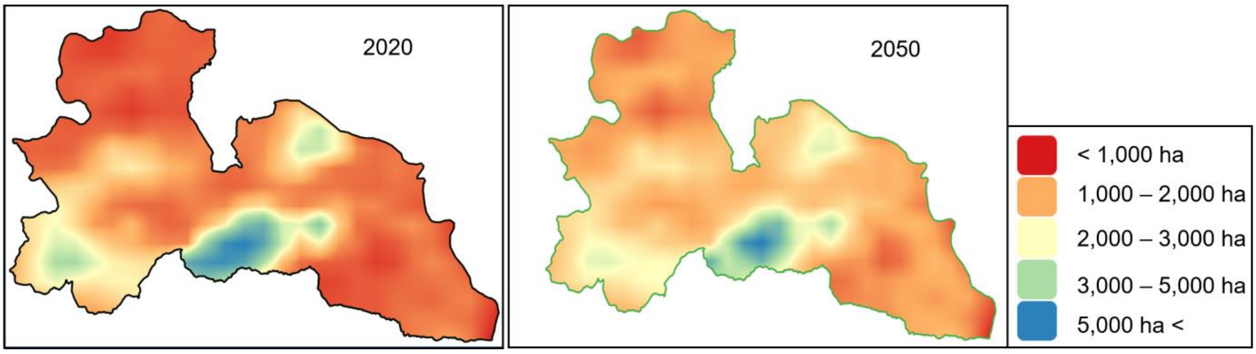


Figure 8 *Spatial distribution of edible crops in Bono-East over time*

Figure 9 reflects the identified areas with high concentration of crops produced at high production costs (i.e. highly sensitive to major disruptions in food supply). These marginal areas may not only need irrigation from RWH to become more affordable, but if QUICKScan shows that they eventually present good biophysical conditions for RWH installation (e.g. rainfall and slope), the implementation of RWH may reduce their production costs in the future. Similarly, these marginal lands should also be restored through FLR initiatives. This may not necessarily reduce the production costs, but FLR may add new assets to the area (e.g. through payment for ecosystem services, revenues from agroforestry).

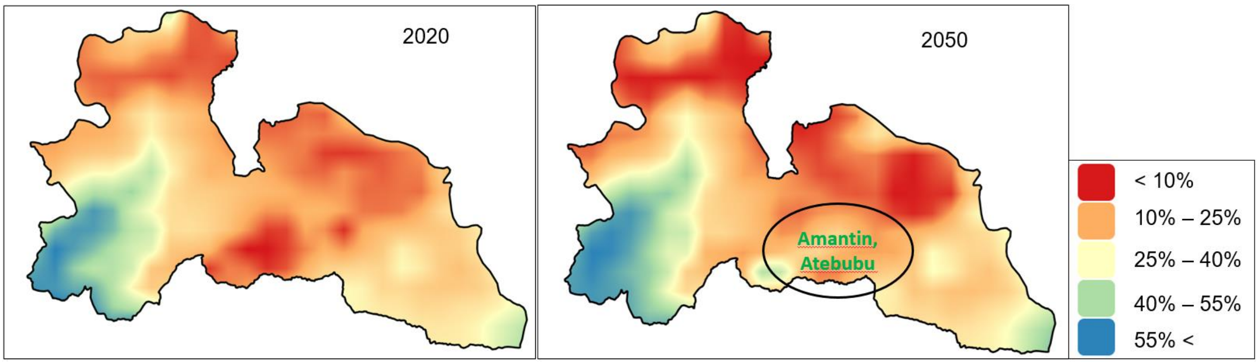


Figure 9 *Percentage of areas with the presence of crops and high productions costs*

Land-use change

Land use plays a pivotal role in understanding provisioning services (e.g. food production, biomass for fibres and fuel, and habitat for flora and fauna), regulating services (e.g. water retention) and supporting services (e.g. nutrient cycling and soil formation). Understanding how land is likely to change in the future, will therefore help to be better prepared for the inevitable (e.g. climate change), or to avoid moving unconsciously into future situations that would be harmful and undesirable (e.g. removal of all natural vegetation increasing flood risk and erosion).

In this study the future land use was projected for the Bono East region based on a future with less precipitation, an increasing population (more urban areas and roads) and increasing food production (more cropland and grassland for grazing). To make room for this development, shrublands and forest are cleared. Quantities of these areal changes can be found in Figure 10 (bottom). The spatial allocations (the maps) of the land use classes are illustrated in Figure 10 (top). Projections of the future land use map have been modelled with the iClue model.

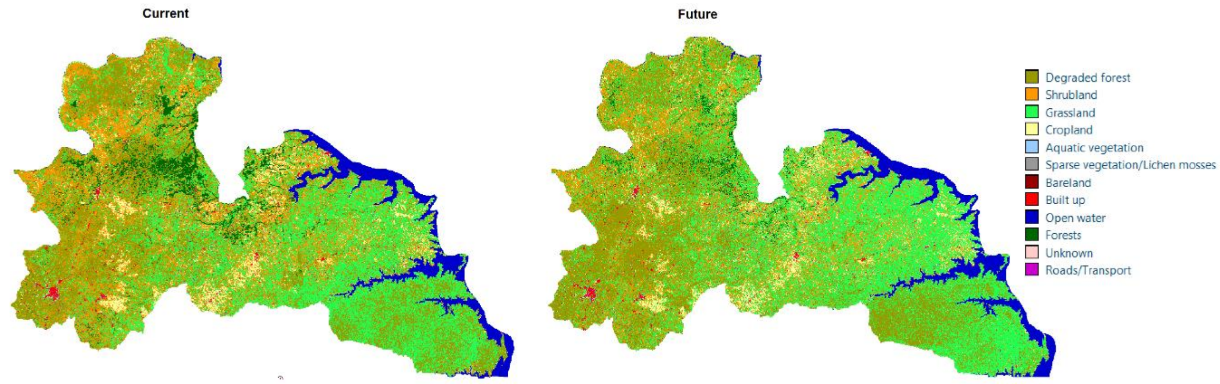
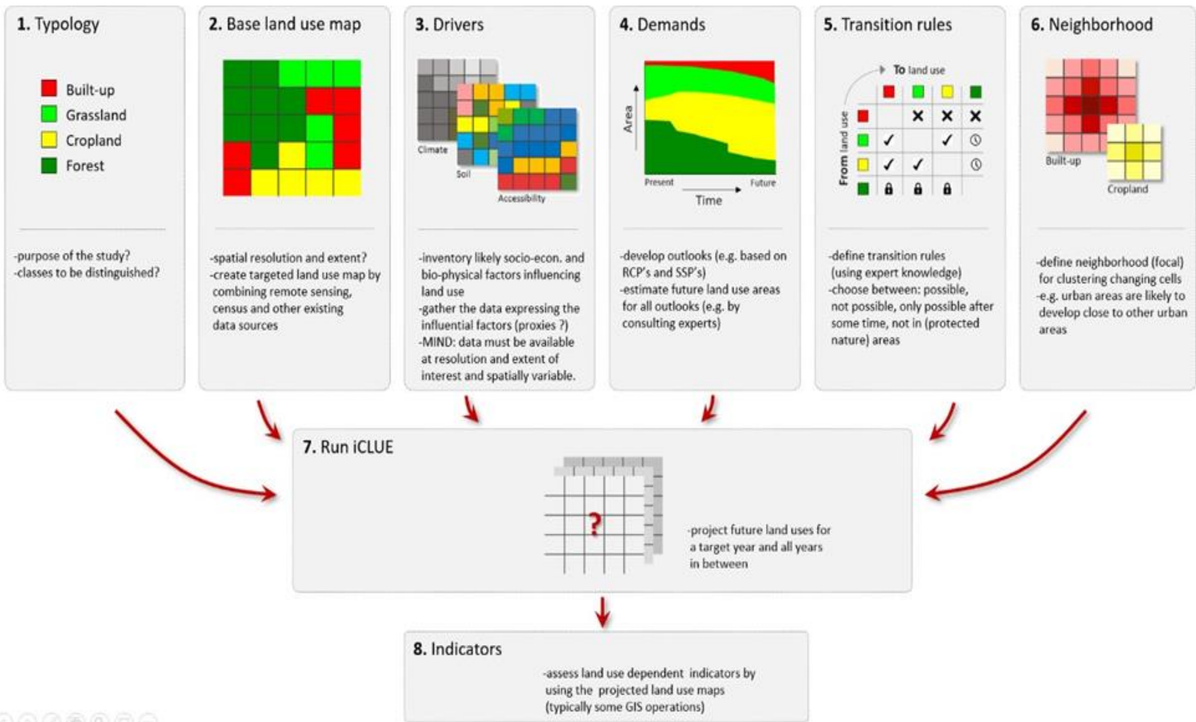


Figure 10 *Present and future land cover of the Bono East region (top). Quantities of areal change in land use (bottom). Future land cover was simulated using the iCLUE model*

	Land use	2020 *[ha]*	2050 *[ha]*	Area change *[ha]*	Area change *[%]*
	Built-up	166752	175923	9171.36	5.5
	Roads/transport	177585	186464	8879.25	5
	Grassland	7908005	8659265	751260.475	9.5
	Cropland	1499643	1739586	239942.88	16
	Shrubland	5121035	4352880	-768155.25	-15
	Forest	1204711	469837	-734873.71	-61
	Degraded forest	8301185	8799256	498071.1	6
	Bare land	4806			Cannot change
	Aquatic vegetation	3421			Cannot change
	Open water	1465240			Cannot change

Box – The iClue model

The iCLUE model is part of the CLUE model family (Kok et al., 2001; Veldkamp & Fresco, 1996; Verburg et al., 2002; Verburg & Overmars, 2009) and simulates land use change by looking at the territorial land use demands (Verweij et al., 2018). The components determining the future allocation of land use are: (i) land use suitability, (ii) the areal demand for every land use class, (iii) conversion rules and (iv) neighbouring land use.



In the first place, land use suitability is defined as the suitability of a land use class at a specific location, based on the features of that area, i.e., soil, climate, accessibility and terrain. Secondly, land use requirements (demands) are provided for the year of 2050. Here, the demands were determined through expert consultation. Thirdly, land use type specific conversion settings influence what land conversion can take place (e.g. recently planted tree sprouts are unlikely to be harvested after two years, but more likely after 20 or 30 years when the trees have grown). Lastly, the allocation of land is influenced by the land use surrounding the cell. For example, a built-up area is more likely to expand next to an existing built-up area, rather than in a new spots.

3.4 Assessing the opportunities for RWH and FLR

Bayesian belief networks were developed to map land opportunities for RWH and FLR (see Figure 7). The initial plan was to combine criteria elicited from stakeholders in a participatory workshop with collected geodata through the Bayesian network to map opportunities for RWH and FLR. However, because of COVID-19, this was not possible. We therefore, developed the Bayesian belief networks based on a combination of criteria defined in the literature (FAO 2003; Ammar et al. 2016; Haile and Suryabhagavan 2019) and based on online interactions with partners in Ghana. We first translated quantitative variables into discretized qualitative classes. For example, areas with rainfall less than 200mm/year were designated deserts, whereas areas with rainfall above 1200mm/year were designated as high rainfall areas. This translation from quantitative variables to qualitative classes allows for combining variables based on defined criteria. Rainfall and slope were classified based on (FAO 2003; Ammar et al. 2016; Haile and Suryabhagavan 2019). For the remaining quantitative variables, no reliable and relevant classification scheme could be obtained from the literature; hence we employed data-driven classification schemes based on the Jenks Natural Breaks Classification methodology (ESRI, 2016). The Jenks Natural Breaks Classification Scheme is a data classification method designed to optimize the arrangement of a set of values into "natural" classes. A natural class is the most optimal class range found "naturally" in a data set. A class range comprises items with similar characteristics that form a "natural" group within a data set. This classification method seeks to minimize the average deviation from the class mean while maximizing the deviation from the means of the other groups. The method reduces the variance within classes and maximizes the variance between classes.

Rainwater harvesting

Figure 11 shows the Bayesian belief network developed for RWH. The network was initially developed based on literature and subsequently revised based on outcomes from the workshop (see Section 4.1). We should emphasize that not all underlying factors, especially socio-economic factors identified in the workshop, are captured in the network because of the lack of reliable data sources.

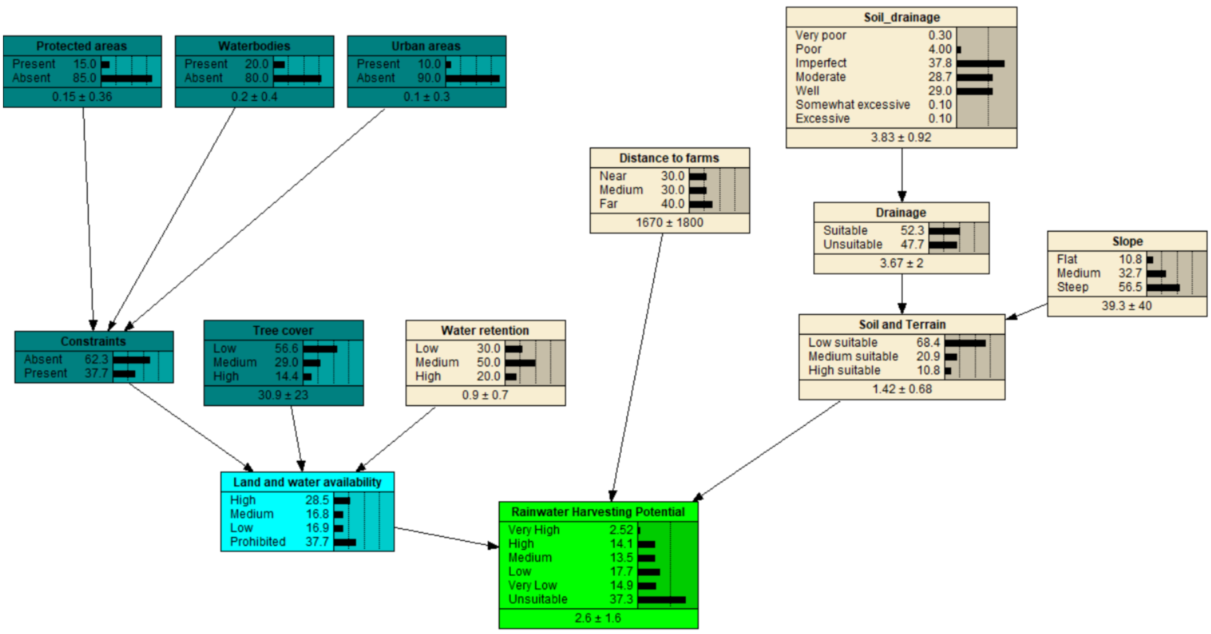


Figure 11 *Rainwater harvesting for irrigation Bayesian belief network. The values indicate total percentage occurrence of each category of each input*

A knowledge matrix was developed to compute water retention capacity of different landscapes as a function of land cover, rainfall and soil hydrologic group. A look-up table was also developed to extract built-up areas from land cover to constrain RWH opportunities outside of these areas. Figure 12 shows the final QUICKScan model comprising the Bayesian belief network for RWH and associated knowledge matrices.

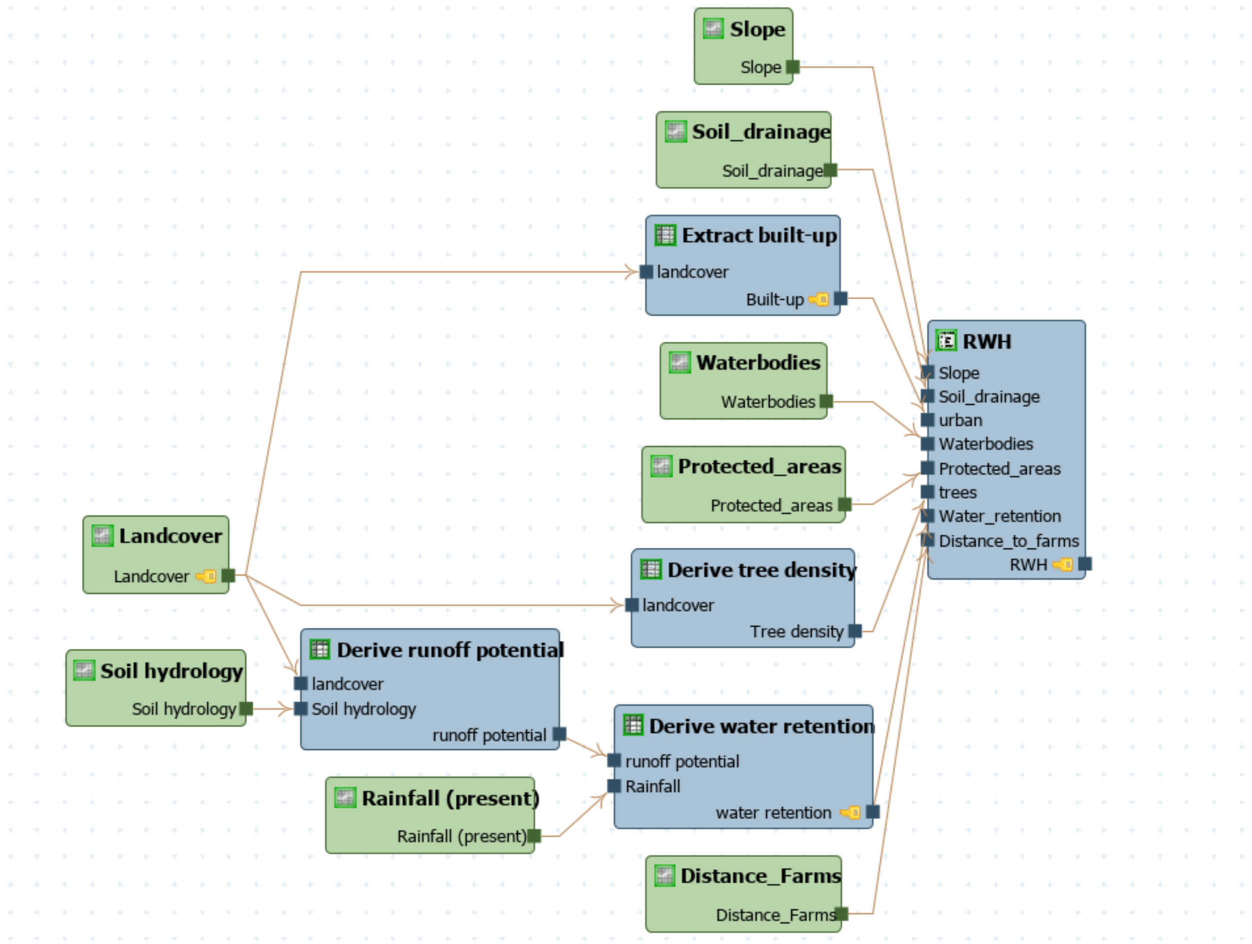


Figure 12 *The QUICKScan model structure comprising the Bayesian belief network for RWH and associated knowledge matrices and look-up tables*

Figure 13 shows the current and future opportunity maps for RWH in Bono East. Currently, most opportunities for RWH are in the eastern part of the, mainly driven by soils with high water retention capacity. In the coming decades, the eastern part of the Region will continue to remain suitable for RWH because of increased rainfall. The western part of the Region will also experience increased opportunities for RWH because rainfall increases in the next decades. We should emphasize that this analysis does not take into consideration intra-annual variability in rainfall. Another factor contributing to increased opportunities for RWH is cropland expansion. We assume that other land cover types, especially forests are likely to be converted for crop cultivation. Even though this conversion itself is not sustainable and undesirable, it will open up more opportunities for RWH.

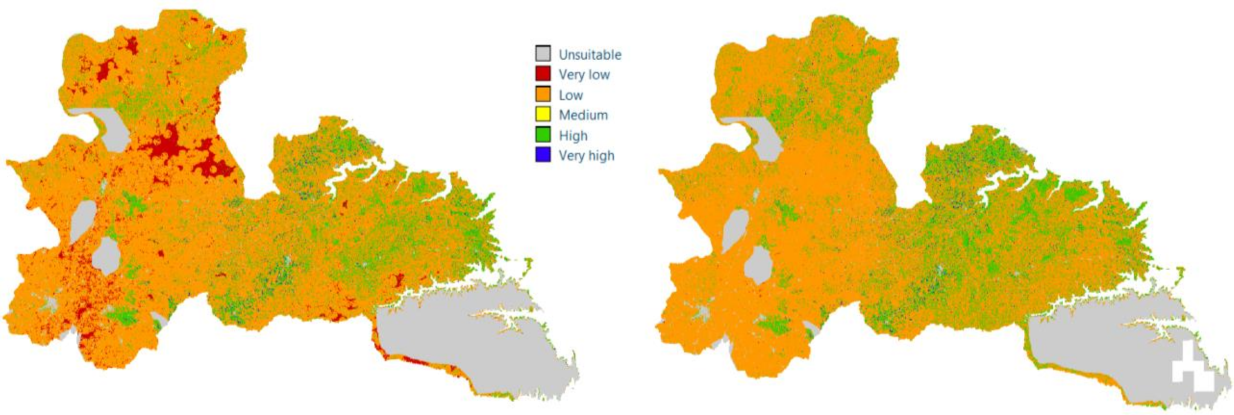


Figure 13 *Current (left) and future (right) opportunity maps of RWHI in Bono East Region derived with QUICKScan*

Forest Landscape Restoration
Similar to RWH, a Bayesian belief network was first developed for FLR and later incorporated into QUICKScan to map FLR opportunities in the Region. Figure 14 shows the Bayesian belief network for FLR developed based on the outcomes from the workshop. It should be noted again that far more underpinning factors, especially socio-economic factors, were identified in the workshop than incorporated in the network because of a lack of data at the desired aggregation level.

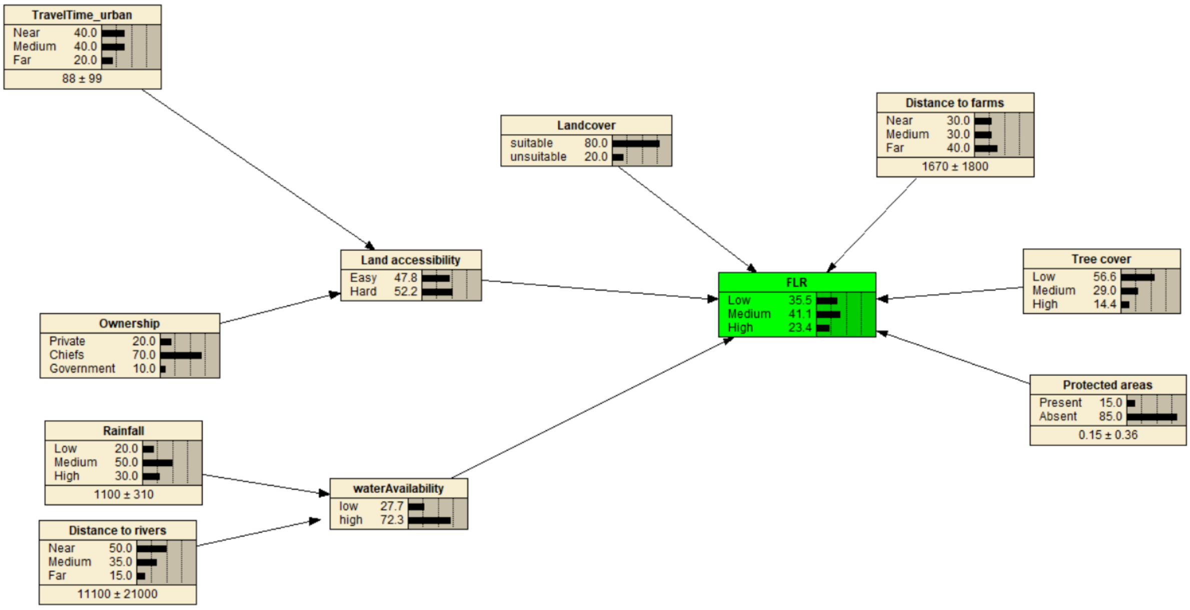


Figure 14 *FLR bayesian belief network. The values indicate total percentage occurrence of each category of each input*

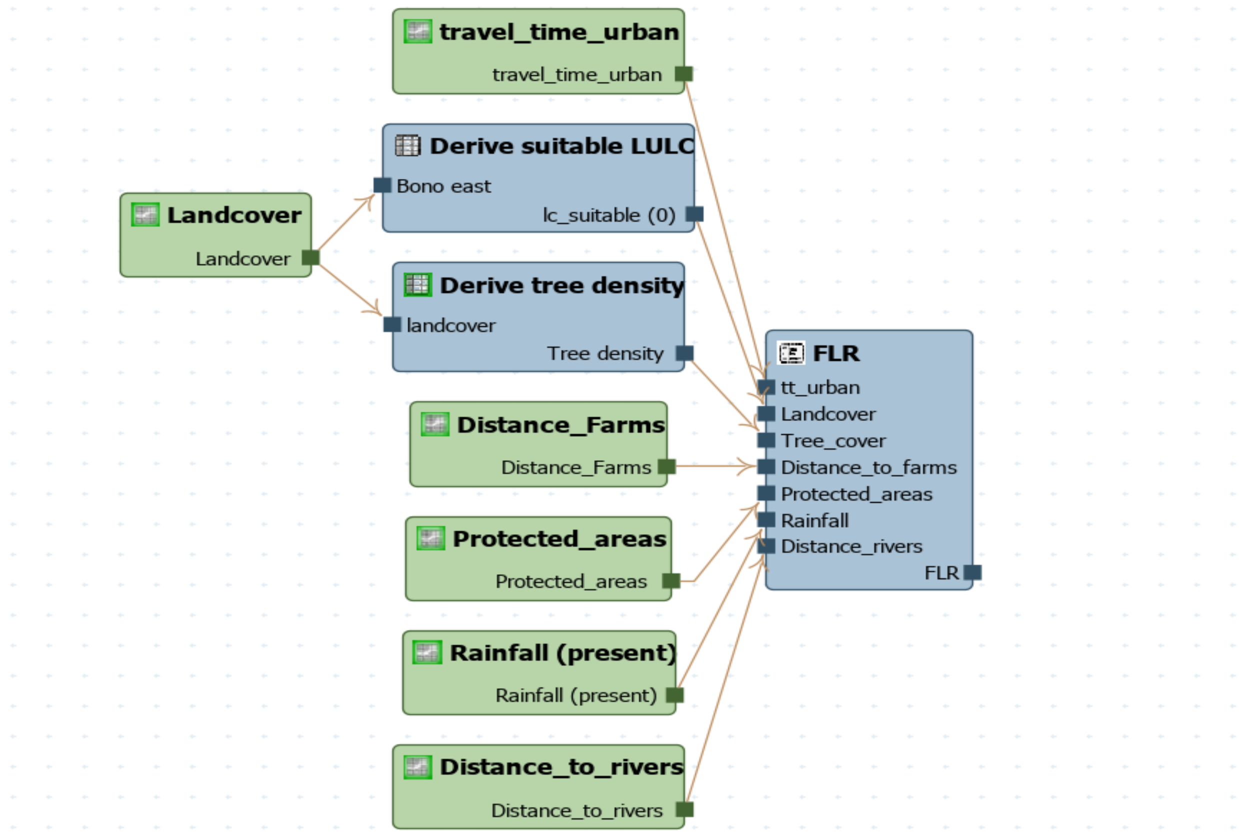


Figure 15 *The QUICKScan FLR model comprising the Bayesian belief network for FLR and associated knowledge matrices*

Figure 16 shows current and future opportunities for FLR. The map shows that opportunities for FLR will increase, especially in the northern part of the Region due to increased annual rainfall and anticipated deforestation.

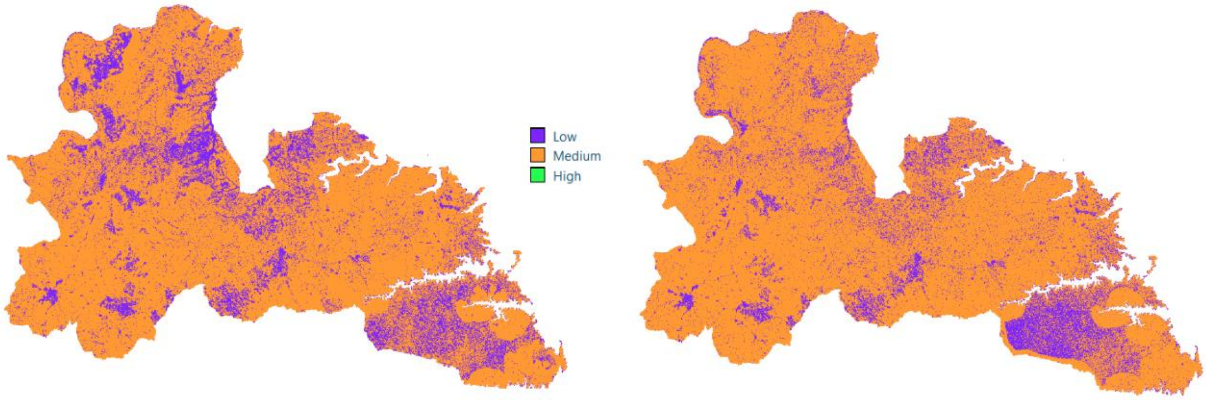


Figure 16 *Current (left) and future (right) opportunity maps for FLR*

4 Creation of a common understanding

Insight in the potential futures of nature-based solutions in a particular spatial setting only makes sense if developed and shared with stakeholders of that particular spatial setting, in this case, Ghana's Bono East Region. Therefore, an essential part of the project was a stakeholder workshop, to present and the findings of the field work and the desk top analysis, co-generate more information, and generate a common vision together. Ideally, this workshop should have been held at the onset of the project. But given the COVID-19 situation, it was held after the studies were carried out.

The Centre for Professional Development (CePDev) of the University of Energy and Natural Resources, together with the Wageningen University & Research, organised the conference/workshop dubbed '*NBS4food; getting prepared for a resilient climate future'.* The conference sought to combine information exchange, group learning, and the creation of potential futures for food security in the Bono East Region. It brought together personnel from the Forestry Commission, Tropenbos Ghana, Solidaridad, SNV Ghana, Land Use and Spatial Planning Authority, The Department of Agriculture (MoFA), Farmers, Blue Deal, Ghana Institutes of Foresters (GIF), International Union Conservation Nature (IUCN), University for Development Studies, Wageningen University and Research, the Netherlands, Partnership for Forest and University of Energy and Natural Resources and Media houses**.** The two-day conference/workshop was in two sessions: the opening ceremony and the technical sessions, coupled with a field trip to Tano-Boase and Boabeng Fiema on the third day.

Figure 17A *Conference/workshop participants in a group photos session*

Figure 18B *Conference/workshop participants in a group photos session*

4.1 Building an inventory of influential factors

During the workshop, stakeholders from public and private institutions, NGOs and farmers exchanged their experiences on nature-based solutions and identified the particular opportunities and challenges regarding two NBSs which are rainwater harvesting and forest landscape restoration. Representatives from the Land Use and Spatial Planning Authority, the Department of Agriculture, the Ghana Forestry Commission, Tropenbos Ghana, IUCN, SNV and many more shared their views on what they do in their jurisdictions and how their activities can be linked to NBS. The UENR research field team presented the findings from the field work on RWH and FLR, to establish a collective knowledge based on nature-based solutions practice in Bono east region. Building on such collective knowledge, participants shared key factors to the consider in implementing FLR and RWH, based on which the potential futures of the Bono East Region were designed.

Figure 19 *Participants sharing their inventory of influential factors*

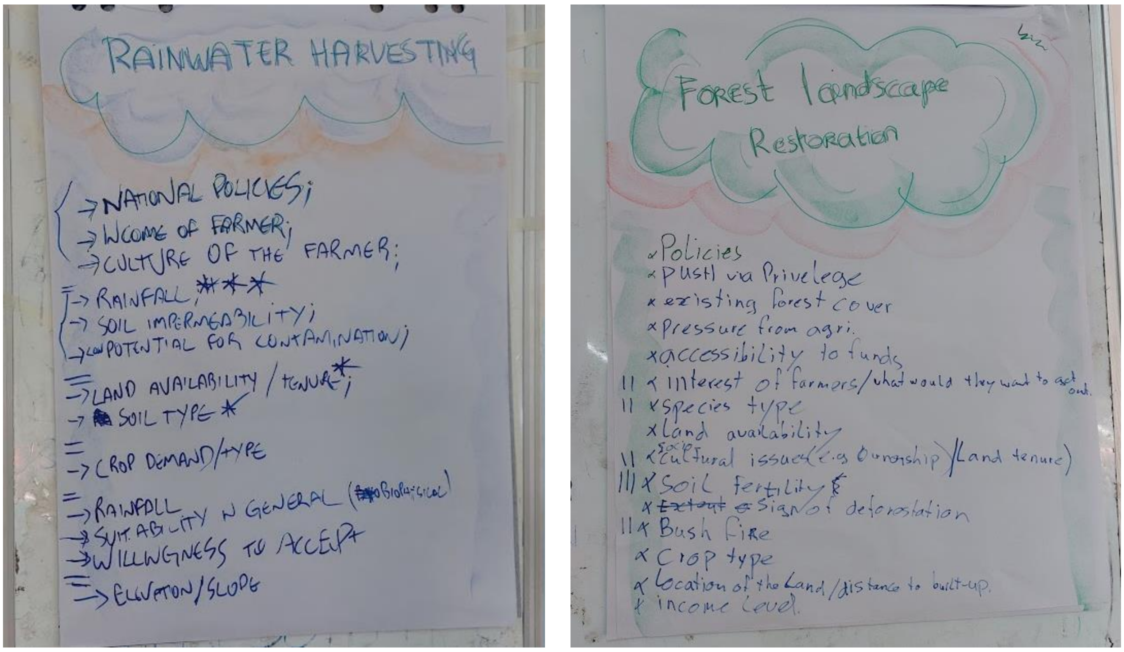


Figure 20 *Collective inventory of influential factors as shared by participants*

4.2 Mapping existing FLR and RWH implementations

Based on their own local knowledge and insights, participants mapped existing implementations of RWH and FLR in the Bono East region. Participants also identified the critical factors that have contributed to the absence of RWH and FLR implementations in certain districts/towns. These included demographics, migrants, changing vegetation patterns, climate, funding and cultivated crop types.

Figure 21 *Participants mapping existing FLR and RWH implementations*

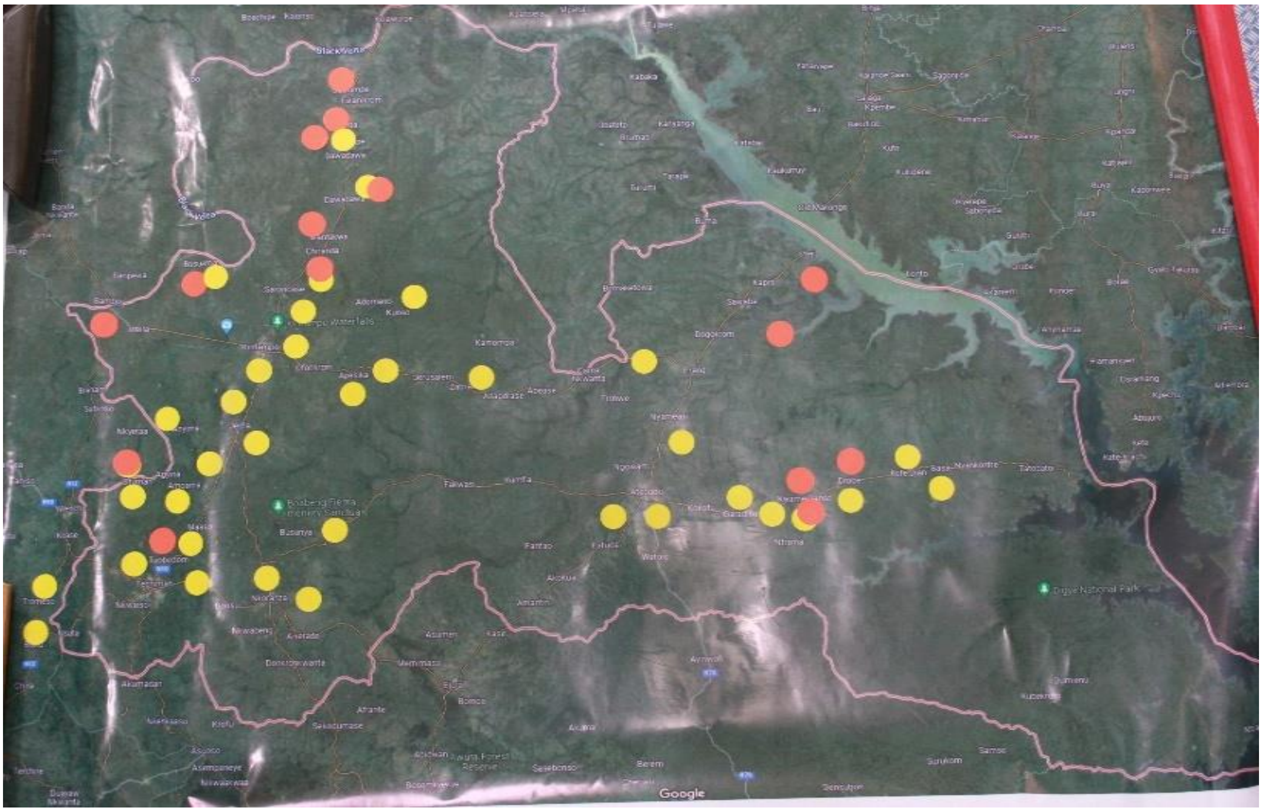


Figure 22 *Collective map of existing FLR (yellow dots) and RWH (red dots) implementations based on 'participants' local knowledge.*

4.3 Creating a road map for nature-based solutions in the Bono East region

Participants were tasked to build their own NBS roadmap to scale NBS throughout the region, and translate these into measures on sectoral policies, spatial planning, project planning, and inter-institutional collaboration. The results of this exercise are shown in Figure 22 and Table 2.

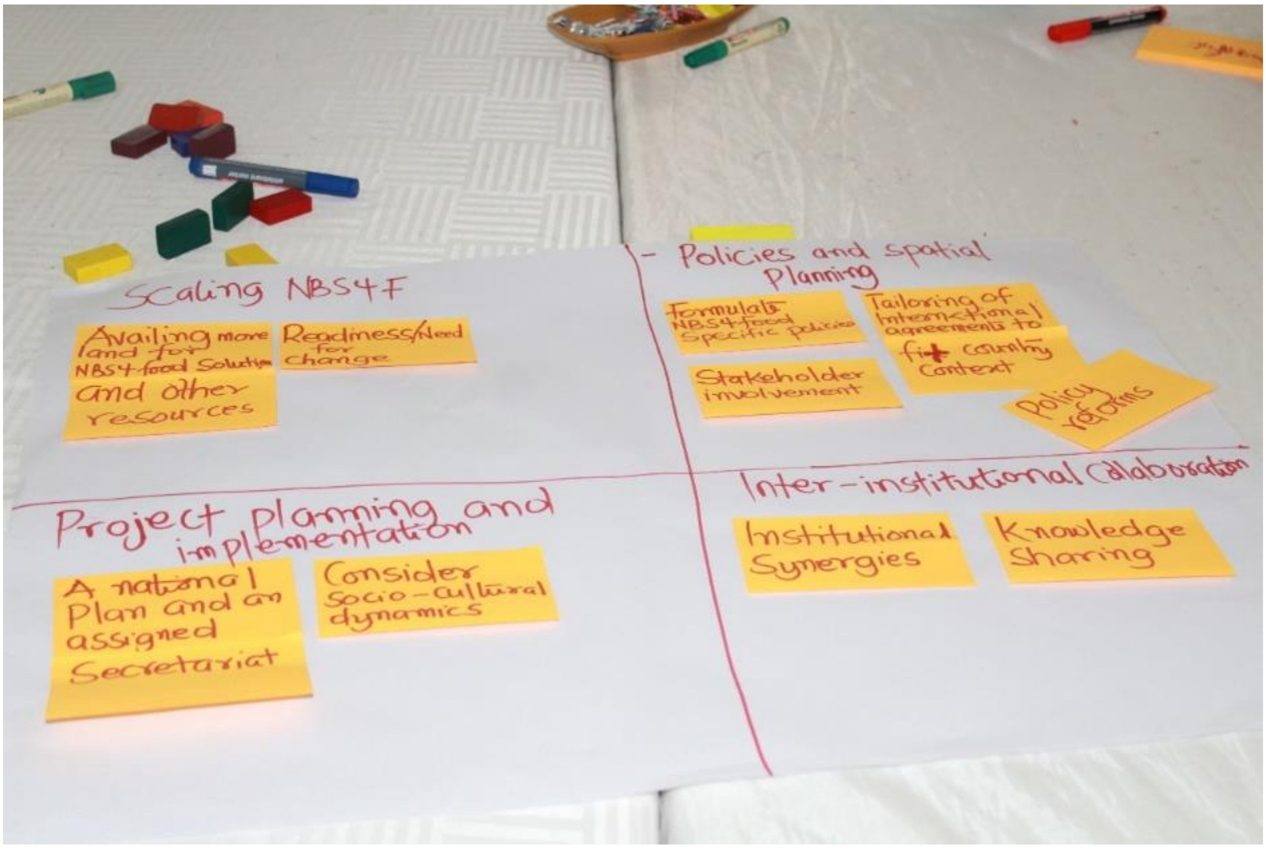


Figure 23 *Participants building the NBS roadmap*

Table 2 *The collective NBS roadmap*

Scaling NBS4F	Policies and Spatial Planning	Project Planning and Implementation	Inter-institutional Collaboration
• Availing more lands for NBS4Food solution and other resources	• Formulate NBS4Food-specific policies	• A national plan and an assigned secretariat	• Institutional synergies
• Readiness/Need for change	• Stakeholder involvement	• Consider socio-cultural dynamics	• Knowledge sharing
• Modification of innovation in other places because of different context	• Tailoring international agreements to fit the country's context	• Stakeholders' consideration in every stage of the project	• Join plan of various institutional bodies
• Identify key elements of critical landscapes that makes NBS work	• Policy reforms	• Education and sensitization of project plans to the public	• Engage both the state and non-state actors and institutions
• Assembly of NBS for each of the landscapes	• Consider existing policies to feature in your NBS plan	• Feasibility study	• Establishment of consortium for partners in NBS
• Identification of hotspot areas	• There is a need to review existing policies to integrate policies to align with NBS	• Consider hotspot areas for NBS.	• Learning platforms
• Land Suitability	• Pay attention to frameworks and policies. E.g. National Determined Contribution (NDC) document	• Allocate specific funds for NBS	• Multi-sectorial engagement of project implementation. • Fill the gap and over the gap by government, private, and NGOs
• Woodlot establishment	• Push for the implementation and enforcement of spatial land use policies	• Planning should take note of existing initiatives and identify gaps to be filled	• Identify relevant institutions.
• Rainwater harvesting	• Land use plan	• Irrigation schemes	• Engage and identify the roles of relevant institutions and partners such as; universities, Agriculture, NGOs, Forestry, Planners
• Riparian buffer reforestation	• Enforcement of existing policies, e.g. buffer land tenure and tree tenure	• Alternatives to the digging of ponds. E.g. use of temporal storage equipment	
• Broader stakeholder consultation	• Identification of appropriate policies that fit into NBS4F	• Baseline Survey	• Information Sharing
• More data on NBS4F	• Mode of implementation of appropriate policies	• Seek the buy-in of all stakeholders	• Adaptive research
• Improvement on the already existing models	• Influencing policies through advocacy	• Identification of measures for sustainability	• Education and sensitization
• Identification of technologies that are feasible with the specific location	• Acquisition and registration of land titles	• Development of a communication strategy	
• Aligning land use practices for synergy	• Enforcement of developmental control policies through notices	• Design an effective monitoring and evaluation system	
• Sensitization and education	• Issuance of development and planning permits	• Identification of stakeholders	
• Monitoring and evaluation	• Recommendations for policies	• Sensitization and education	
• Identifying new stakeholders and beneficiaries		• Integrate gender mainstreaming and vulnerable groups into project design	
• Funding		• Identification and utilization of traditional knowledge	

5 Reflections and conclusions

The main outcomes of this study are the suitability maps for nature-based solutions, in particular rainwater harvesting and forest landscape restoration. The maps were produced based on a combination of key biophysical and socio-economic variables that could have major influence on the adoption of these NBS, both currently and in future. For RWH, we identified that the most suitable areas are located in the west part of Bono-East region and in the northern part of Kintampo city, where new agricultural borders might expand. For FLR, we did not identify large outstanding hotpots of high suitability as almost the entire Region has moderate conditions to adopt FLR. Special attention however should be given to the northern parts of the Region, as the future scenario indicates that deforested areas could provide good opportunities for restoration, while the expected increase in rainfall in the North could offer opportunities for FLR in combination with RWH, to restore agricultural land and enhance the potential for crop production.

The novelty of our spatial NBS modeling approach is the incorporation of stakeholders' views in tuning the main modeling parameters, and give a much more realistic insight into the specific spatial suitability within Bono-East Region. This is particularly relevant to the inclusion of those socio-cultural parameters which are hard to capture in spatial data or proxies (i.e. land tenure, land use conflict, etc.). With their contributions, the stakeholders clearly pointed out the limitations in our approach by complementing the methodology with relevant parameters to be considered in future applications. This was not entirely unexpected, as commonly experienced in spatial modelling at this scale, given the general importance of contextual factors. Yet more importantly is that the interactive approach of QUICKSCAN had a real-time effect on stakeholders` awareness and triggered their active participation. This generated many additional views and insights, having an effect on the modelling results, and increasing the appetite for the implementation of NBS. It was confirmed that stakeholders are indeed eager to take part in a modelling analysis based on data and local knowledge combined, to be translated into land use policies, and otherwise incentives for the implementation of NBS. We do therefore see the outcome of the exercise not as an end result, but as the beginning of a regional dialogue, in search for the best NBS for the best location. The QUICKSCAN methodology has proven to be a valuable tool to do so, was it aims to involve a wide group of stakeholders (e.g. local chiefs, policymakers, development banks) that provide better guidance on the readiness of a region to implement NBS.

We realise that the strong stakeholder engagement should have happened at the onset of the project rather than at the end. This would have increased the participatory element of the approach, which could have enhanced the value of the outcomes. However, the global COVID-19 pandemic did not allow for such a start. Instead, time and efforts were invested in developing an alternative methodology for direct stakeholder engagement, through a series of online mapping exercises and verification/validation of field work. We experimented with a range of new online tools such as MURAL, MIRO, Polarsteps, StoryMaps and more, to maximally involve stakeholders, directly from their homes or their working stations. We feel that with this, despite the restraining conditions, a maximum of stakeholder engagement has been achieved. With these additional online tools, we enriched the QUICKSCAN methodology, and made it even more suitable for application in the Global South. Besides, we believe that we have strengthened the UENR -Geoscience team through more robust collaboration, and supporting them in the development of a user friendly way to engage stakeholders in identifying suitable nature-based solutions, and to find the right locations to have these implemented in a participatory manner.

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Appendix 1 Powerpoint presentation locating hotspots for FLR and RWH

Contents

- Approach to locate hotspots *[Peter Verweij]*
- Results of academic study
  - Socio-economic drivers *[Walter Rossi Cervi]*
  - Bio-physical assessment *[Confidence Duku]*
- Confront with field-knowledge *[All, facilitated by Cora van Oosten]*
  to validate and improve results

Hands-on

How to locate future proof hotspots?

broad range of tools and methods to do such a spatial assessment

-Quickly to organize
-Different perspectives
-Dialogue
-Transparent

Expert groups and decision makers

-spatially explicit (where lies what)
-wealth of analysis options

Mapping software (GIS)

Solid evidence base –
(usually peer reviewed)
Many visualisations -
Explanations -
Recommendations -

Detailed modeling studies

How to locate future proof hotspots?

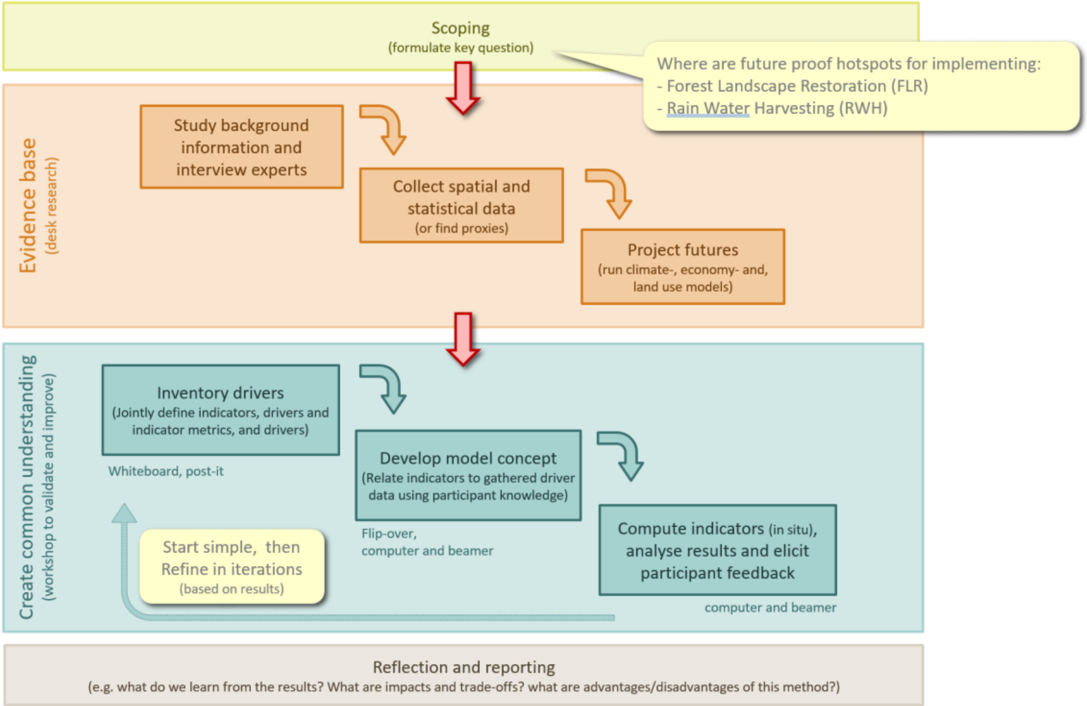
broad range of tools and methods to do such a spatial assessment

Expert groups and decision makers

Mapping software (GIS)

Mixed method

Detailed modeling studies

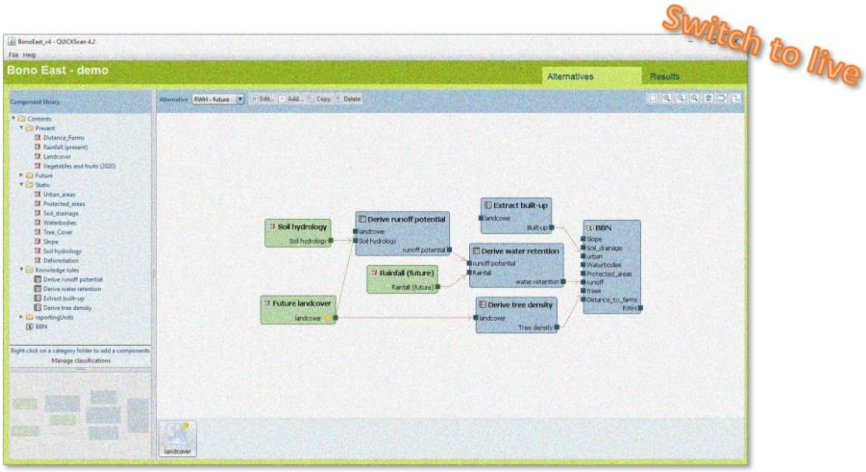


QUICKScan
impression from workshop

Mix paper and digital tools

QUICKScan – tool demo

to get a feeling of how it works

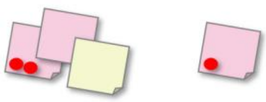


Assignment 1: inventory of drivers

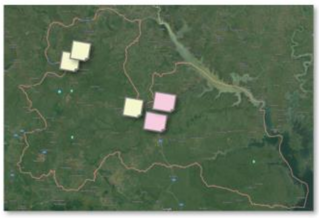
- Write down each drivers on a post-it *[individual, 10 min.]*
  - based on your personal knowledge and experience, or inspiration from presentations
  - Yellow post-it for Forest Landscape Restoration (FLR)
  - Pink post-it for Rain Water Harvesting (RWH)

- Group post-it *[plenary, 20 min.]*
  - Name groups

- Put priority stickers *[individual, 5 min.]*
  - Each individual gets 3 stickers
  - Decide for yourself whether to put all 3 on a single post-it, or distribute

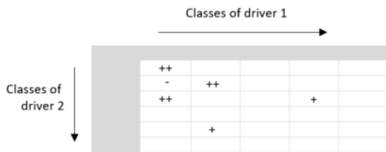


Assignment 2: map <u>existing</u> implementations



- Put post-it on map *[groups, 20 minutes]*
  - Use yellow ▢ for Forest Landscape Restoration (FLR)
  - Use pink ▢ for Rain Water Harvesting (RWH)
  - Possibly include explanation
    (e.g. characteristics of area, ownership, type of trees (food? fruits? nuts?))
- Present and analyse *[plenary, 20 minutes]*
  - What are similarities and differences between the groups?
  - Are there hot spots of implementations? Cold spots – no implementations?
  - What is different in these hot-cold spots?
  - Did we get the drivers right in assignment 1?

Assignment 3: develop knowledge matrix



- Choose 2 drivers *[groups, 20 minutes]*
  - Fill in matrix using {'**++** *good*', '**+** *possible*', '**-** *unfavourable*'}
  - Mind: use legend of available data
- Present *[plenary, 15 minutes]*

=== Short break to let the team include the matrix into the system ===

- Apply and discuss *[plenary, 15 minutes]*
  - Where is map in-line with your expectations? Where not?
  - Why do you think this is?

Assignment 4: compare to desk research
(maps produced after literature and result from model runs)

- How do the maps differ from your maps?
- Do they better fit your expectations?
- Where yes? Where not?
- Why do you think this is?

Appendix 2 Powerpoint presentation iClue land use projection model

Land use modelling to understand land use changes

- Land use change through agriculture, forestry and urbanisation
  (increase food production, changing diets, biofuels to reduce fossil fuels, growing demand for wood products)
- impact environmental change
  (e.g. land degradation, biodiversity loss, change in ecosystem services, Green House Gas emissions)

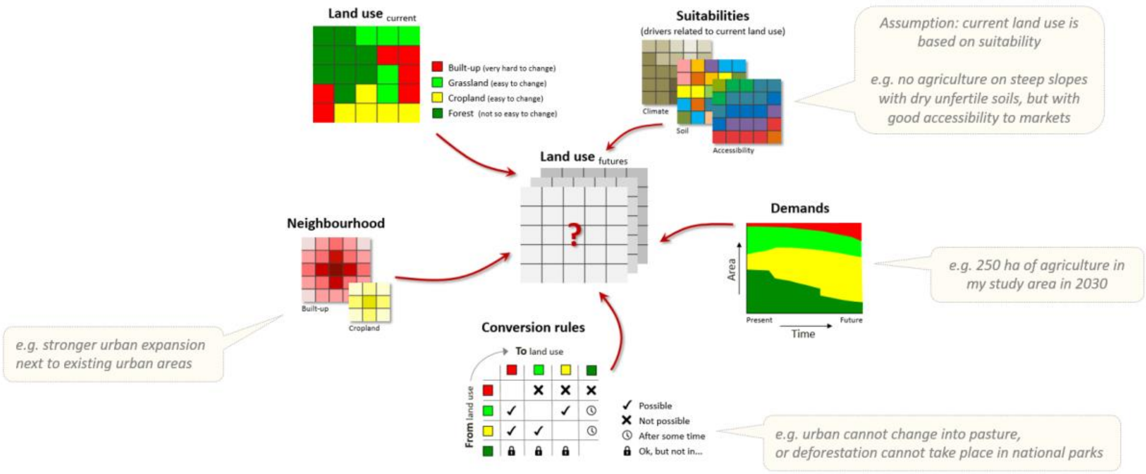
- Land use models help to understand impacts of (economic) drivers
  1. Models that predict the amount of expected land use demand
     (e.g. '*how much'* of what land use type is needed in 2040?)
  2. Models that allocate the demand
     (e.g. '*where'* is agriculture likely to develop and '*where'* is deforestation likely to happen)

iCLUE model history

Newest member of CLUE model family

- 1996 – CLUE (Veldkamp and Fresco)
- 2002 – CLUE-S (Kok et al.)
- 2009 – Dyna-CLUE (Verburg and Overmars)
- 2018 – iCLUE (Verweij et al.)

iCLUE - land allocation



Deriving suitability maps using statistical analysis

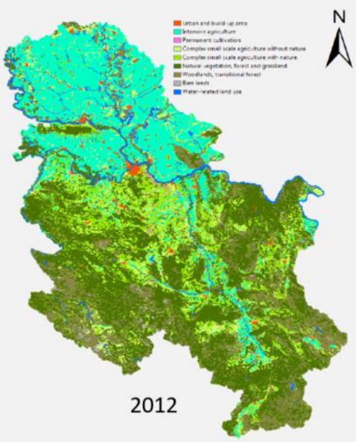
Example from Serbia

- Warm-humid continental climate with cold -relatively dry- winters and warm humid summers.
- The country experiences an increase in droughts and heavy rains
- Population grows after the civil war of 1991-1995

Deriving suitability maps using statistical analysis

Example from Serbia

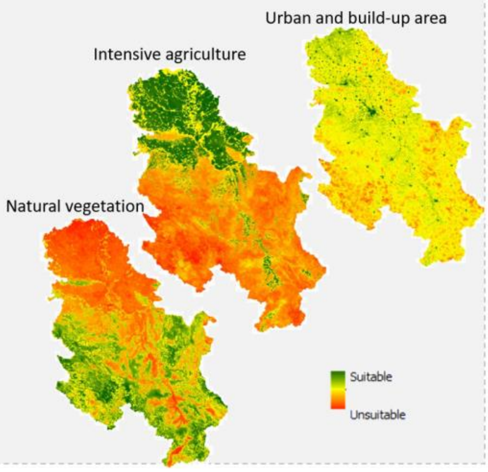
Land use



Drivers

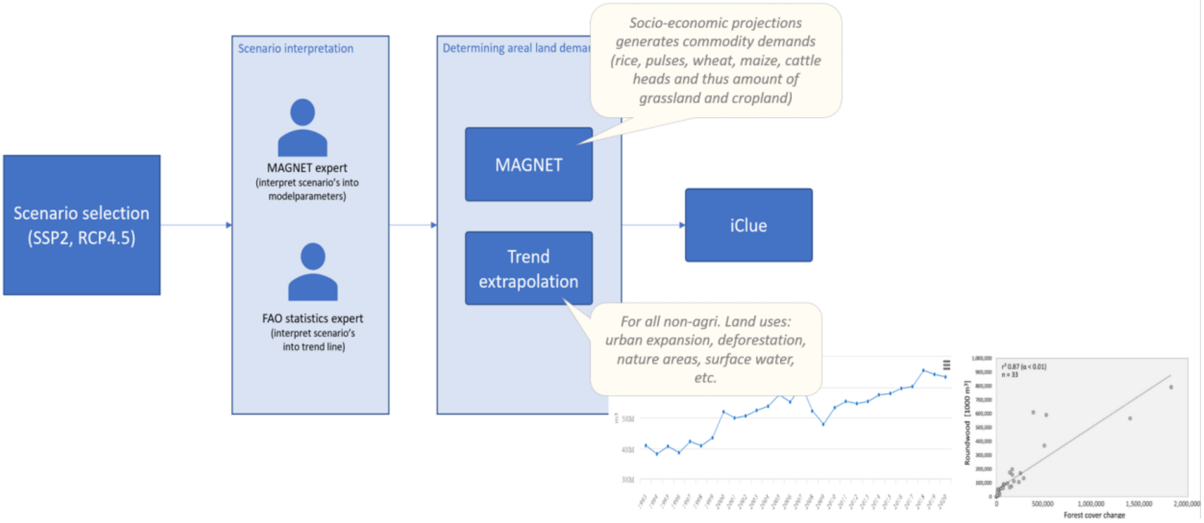
Slope *[degree]*
Distance to cities *[km]*
Depth of bedrock *[cm]*
Soil organic carbon *[tons/ha]*
Soil clay content *[%]*
Soil sand content *[%]*
Distance to roads *[km]*
Rural population *[heads]*
Precipitation *[mm/year]*

Suitability maps



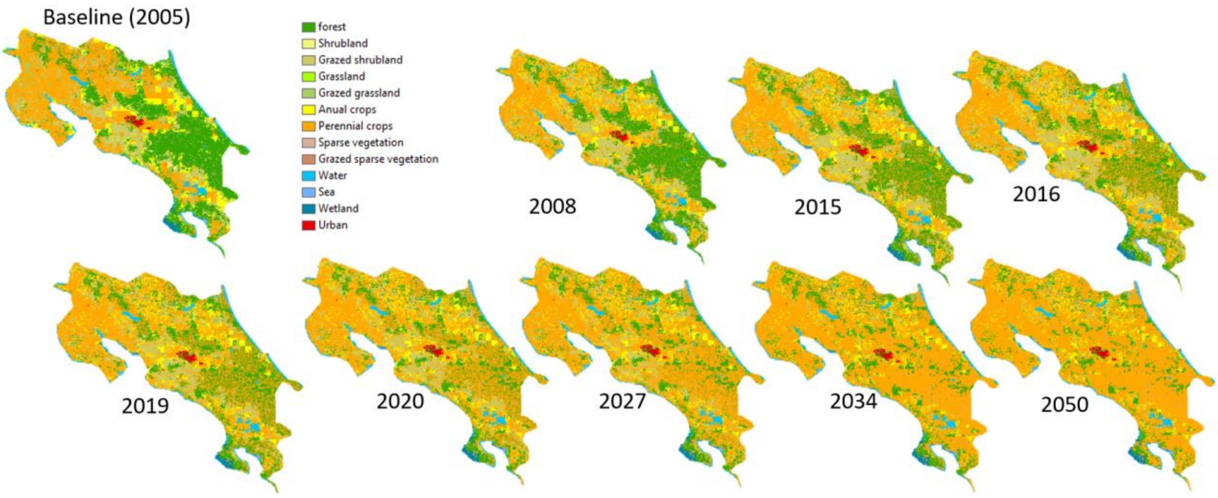
Determining future land use demands

through expert consultation, trend extrapolation or modelling

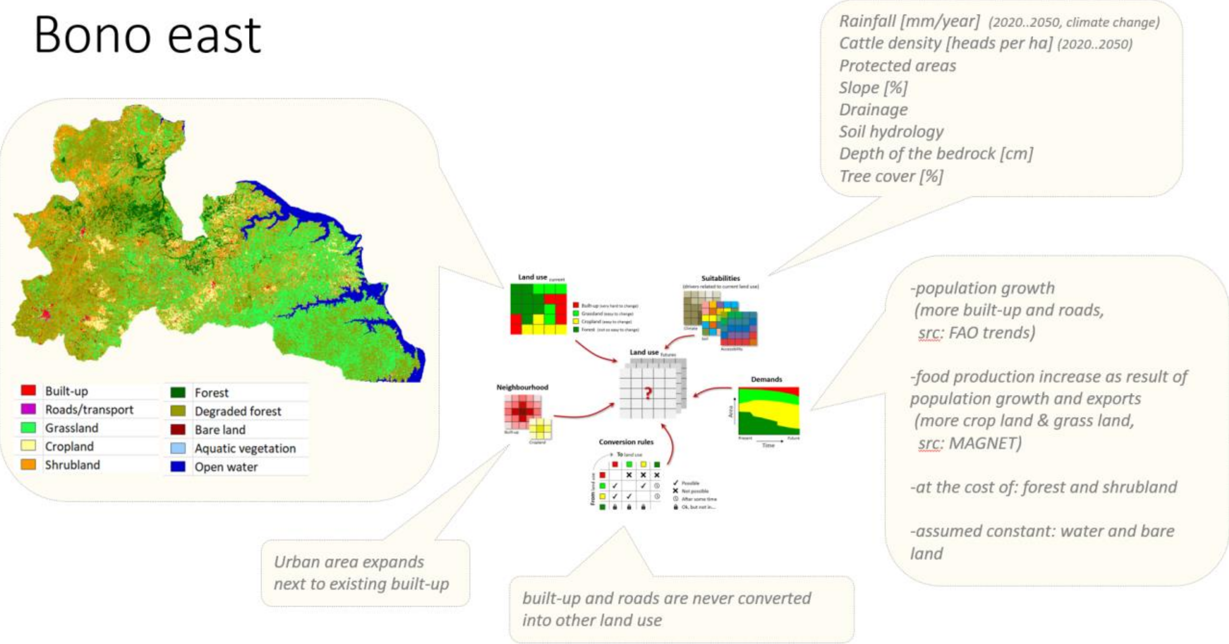


Projected land use based on scenario

Growing demand for crops and timber in Costa Rica



Bono east



Bono east

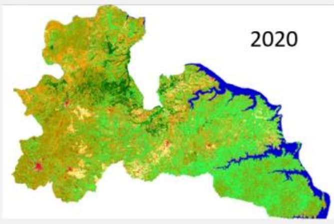
Scenario

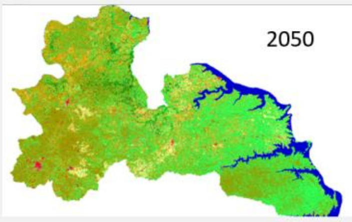
-climate change
-population growth
(more built-up and roads)
-food production increase
(more crop land & grass land)
-built-up and roads are never converted into other land use

Land suitability drivers

Rainfall *[mm/year]* (2020..2050)
Cattle density *[heads per ha]* (2020..2050)
Protected areas
Slope
Drainage
Soil hydrology
Depth of the bedrock
Tree cover

Land use





Land use	2020 *[ha]*	2050 *[ha]*	Area change *[ha]*	Area change *[%]*
Built-up	166752	175923	9171.36	5.5
Roads/transport	177585	186464	8879.25	5
Grassland	7908005	8659265	751260.475	9.5
Cropland	1499643	1739586	239942.88	16
Shrubland	5121035	4352880	-768155.25	-15
Forest	1204711	469837	-734873.71	-61
Degraded forest	8301185	8799256	498071.1	6
Bare land	4806			Cannot change
Aquatic vegetation	3421			Cannot change
Open water	1465240			Cannot change

Bono east

Urban expands. Same for road infrastructure

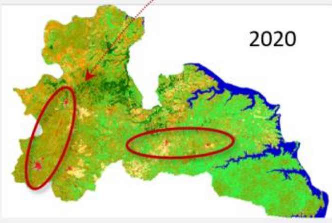
Scenario

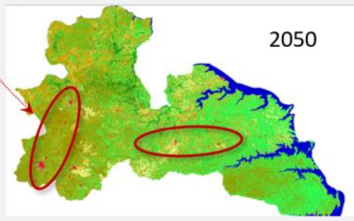
-climate change
-population growth
(more built-up and roads)
-food production increase
(more crop land & grass land)
-built-up and roads are never converted into other land use

Land suitability drivers

Rainfall *[mm/year]*
(2020..2050)
Cattle density *[heads per ha]*
(2020..2050)
Protected areas
Slope
Drainage
Soil hydrology
Depth of the bedrock
Tree cover

Land use





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Degraded forest	8301185	8799256	498071.1	6
Bare land	4806			Cannot change
Aquatic vegetation	3421			Cannot change
Open water	1465240			Cannot change

Bono east

Forest is degrading and replaced by grassland

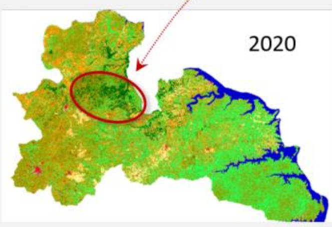
Scenario

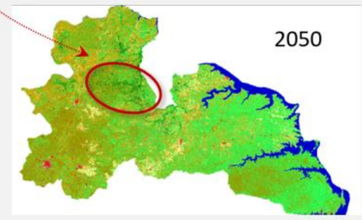
-climate change
-population growth
(more built-up and roads)
-food production increase
(more crop land & grass land)
-built-up and roads are never converted into other land use

Land suitability drivers

Rainfall *[mm/year]*
(2020..2050)
Cattle density *[heads per ha]*
(2020..2050)
Protected areas
Slope
Drainage
Soil hydrology
Depth of the bedrock
Tree cover

Land use





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Degraded forest	8301185	8799256	498071.1	6
Bare land	4806			Cannot change
Aquatic vegetation	3421			Cannot change
Open water	1465240			Cannot change

Bono east

Shrubs are replaced by grassland and (further south) cropland

Scenario

- -climate change
- -population growth
  (more built-up and roads)
- -food production increase
  (more crop land & grass land)
- -built-up and roads are never converted into other land use

Land suitability drivers

Rainfall *[mm/year]*
(2020..2050)
Cattle density *[heads per ha]*
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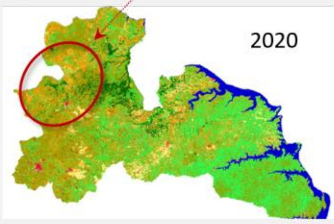
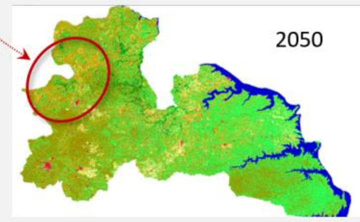
Land use





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Bare land	4806			Cannot change
Aquatic vegetation	3421			Cannot change
Open water	1465240			Cannot change

Bono east

Patterns shift forest is replaced by grassland, while other grasslands are overgrown

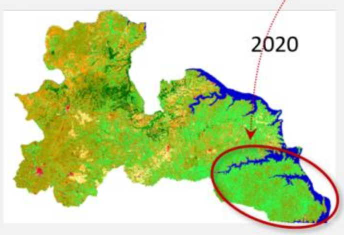
Scenario

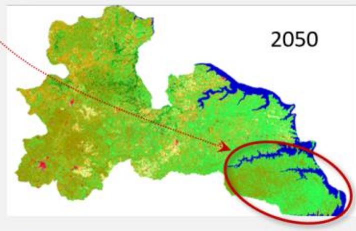
- -climate change
- -population growth
  (more built-up and roads)
- -food production increase
  (more crop land & grass land)
- -built-up and roads are never converted into other land use

Land suitability drivers

Rainfall *[mm/year]*
(2020..2050)
Cattle density *[heads per ha]*
(2020..2050)
Protected areas
Slope
Drainage
Soil hydrology
Depth of the bedrock
Tree cover

Land use





Land use	2020 *[ha]*	2050 *[ha]*	Area change *[ha]*	Area change *[%]*
Built-up	166752	175923	9171.36	5.5
Roads/transport	177585	186464	8879.25	5
Grassland	7908005	8659265	751260.475	9.5
Cropland	1499643	1739586	239942.88	16
Shrubland	5121035	4352880	-768155.25	-15
Forest	1204711	469837	-734873.71	-61
Degraded forest	8301185	8799256	498071.1	6
Bare land	4806			Cannot change
Aquatic vegetation	3421			Cannot change
Open water	1465240			Cannot change

Bono east

(degraded) forests are is replaced by cropland and grassland

Scenario

-climate change
-population growth
(more built-up and roads)
-food production increase
(more crop land & grass land)
-built-up and roads are never converted into other land use

Land suitability drivers

Rainfall *[mm/year]* (2020..2050)
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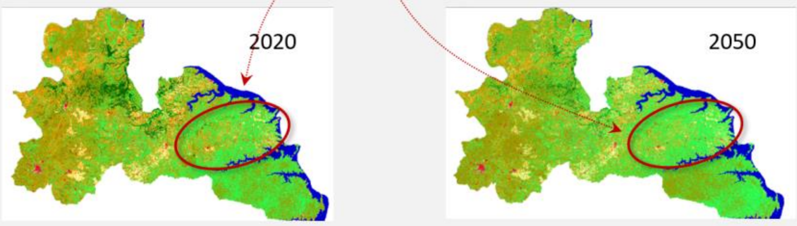

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Report WCDI-22-231

To explore the potential of nature to improve the quality of life

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR's Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.