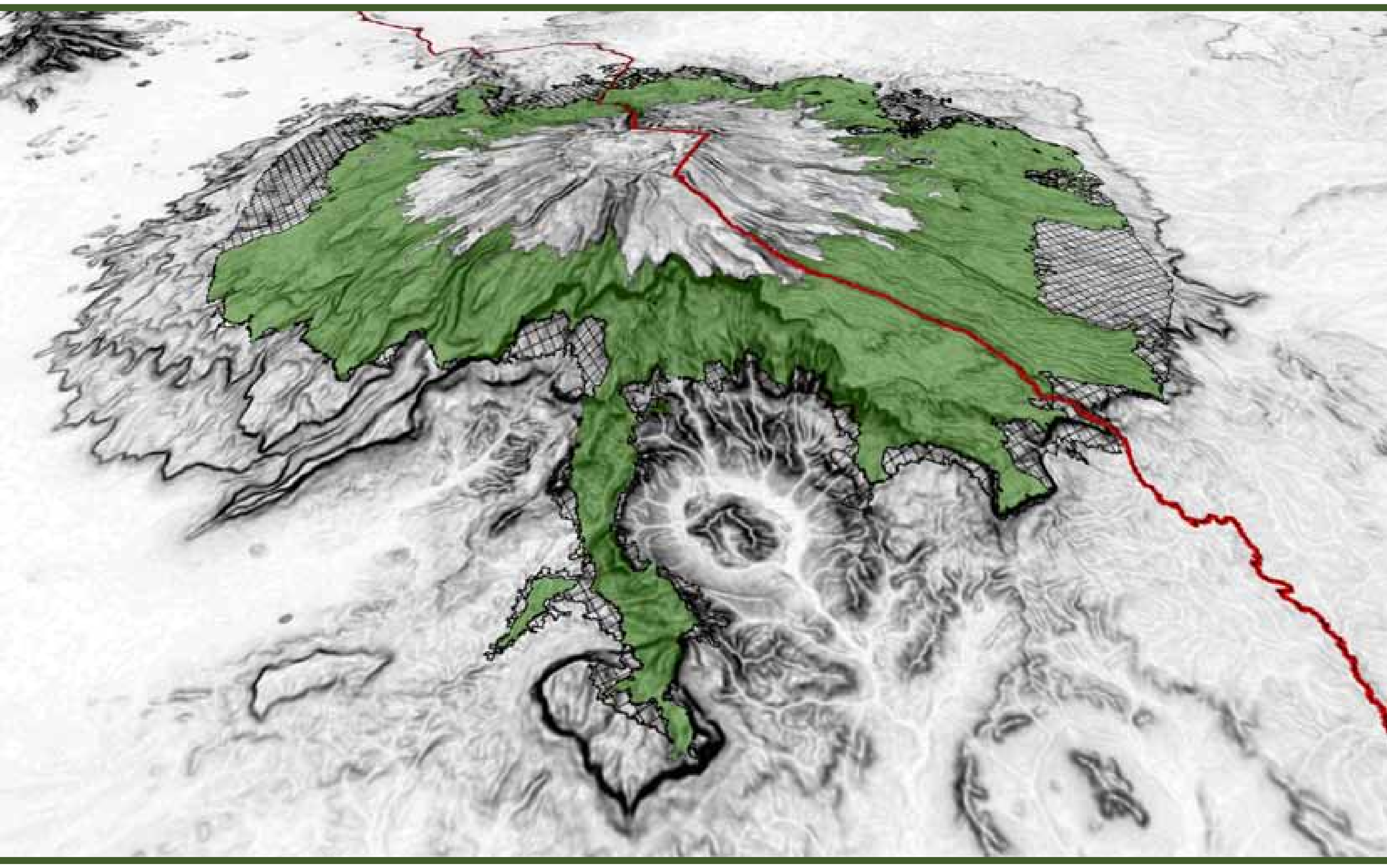
Geospatial analyses for implementing a resilience framework for climate change adaptation in the Mt. Elgon Region of the Lake Victoria basin



About the Project

USAID/IUCN Implementing a resilience framework to support climate change adaptation in the Mt Elgon region of the Lake Victoria Basin project is implemented by IUCN's Eastern and Southern Africa Regional Office (ESARO) and Uganda Country Office (UCO) through their Water and Wetlands programme. The project is implemented in collaboration with the African Collaborative Centre for Earth System Science (ACCESS) based at the University of Nairobi and the Lake Victoria Basin Commission (LVBC) and Global Water Partnership Eastern Africa, with financial support from the United States Agency for International Development (USAID). The project's goal is to enhance coordination and adaptation action between stakeholders using informed, timely, accurate and comprehensive information to promote societal and ecological resilience to adverse climate impacts within the Mt. Elgon Region, Lake Victoria Basin. The project aims to achieve this goal through the following four main objectives:

1. Improving scientific knowledge and demonstrating preparedness for a changing climate future in the Mt. Elgon region of the Lake Victoria Basin;
2. Demonstrating increased social and ecological resilience in hotspots of climate vulnerability using adaptation strategies which mainstream ecosystem services, economic diversification, adaptive management and learning in water and land management;
3. Influencing regional policy frameworks to better utilise systems approaches for building climate resilience and integrating these approaches across sectors and into poverty reduction strategies and national development plans; and
4. Enhancing learning at local to regional levels, through better access to information, networking, capacity building and leadership development

Under objective 1, ACCESS undertook various pieces of work or studies for and on behalf of IUCN and this report is a compilation of some of this work.

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Geospatial analyses for implementing a resilience framework for climate change adaptation in the Mt. Elgon Region of the Lake Victoria basin

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Data Access and Questions: For access to the GIS files referred to in this report or for any questions and/or clarifications, please write to ACCESS at access@uonbi.ac.ke.

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Table of Contents

Executive Summary

This report describes the data and methods used by ACCESS to produce the geospatial outputs for the USAID/IUCN Project on *Implementing a Resilience Framework for Climate Change Adaptation in the Mt. Elgon Region of the Lake Victoria Basin*. The information in this report has been used by the project to identify specific sites and/or Areas of Concerns on the Mt. Elgon Ecosystem where Climate Change Adaptation Actions are being demonstrated to improve both societal and ecosystem resilience. In addition, the output described here forms an important basis for decisions on where and what issues to address when tackling climate change adaptation issues. It is expected to be applicable to regions beyond Mt. Elgon as well.

Consistent with the project objective to improve the scientific knowledge, this report is designed so that a person with proficiency in GIS could use it and the associated GIS files to reproduce and extend the work carried out by ACCESS.

The report describes a novel approach to data gathering that relied heavily on global datasets and on the creation of information from analysis of remotely-sensed images and other auxiliary sources.

This approach was necessitated by the general lack of data that is common in many African countries and was compounded in part by not only the remoteness of Mt. Elgon from national capitals but also by the international nature of the region (shared by Kenya and Uganda).

The report is divided into sections based on nine geospatial themes:

- Topography
- Surface water
- Administrative areas
- Protected areas
- Geology
- Soils
- Climate
- Landuse/Landcover, and
- Areas of concern (including Landslide Risk, Flooding Risk, Temperature Impacts, Cumulative Risk, and Stakeholder-identified AOCs)

Each section starts with a short summary aimed at a non-technical audience and is followed by a detailed discussion aimed at a technical audience.

List of Acronyms

ACCESS....African Collaborative Centre for Earth System Science

AOC..........Area of Concern

CGIAR ....Consultative Group on International Agriculture Research

CMIP5 ....Coupled Model Intercomparison Project-Phase 5

DEM..........Digital Elevation Model

ETM ....Enhanced Thematic Mapper

GADM........Global Administrative Areas Database

GDEM........Global Digital Elevation Map (by NASA/METI)

GIS ....Geographic Information System

GLWD ....Global Lake and Wetland Database

HWSD........Harmonized World Soil Database

IUCN..........International Union for Conservation of Nature

IPCC ....Intergovernmental Panel on Climate Change

LVBC..........Lake Victoria Basin Commission

LULC ....Land Use/Land Cover

MERECP....Mount Elgon Regional Ecosystem Conservation Programme

METI ....Ministry of Economy, Trade and Industry (Japan)

NASA ....National Aeronautics and Space Administration

NDVI ....Normalized Difference Vegetation Index

RCP ....Representative Concentration Pathways

SLC............Scan Line Corrector

SRTM.........Shuttle Radar Topography Mission

SWBD ....SRTM Water Body Dataset

USAID........United States Agency for International Development

UTM...........Universal Transverse Mercator

WDPA ....World Database on Protected Areas

1. Introduction

1.1 Purpose and Scope

The purpose of this report is to provide sufficient information on the data and methods used to prepare the geospatial outputs of the USAID/IUCN Project on *Implementing a Resilience Framework for Climate Change Adaptation in the Mt. Elgon Region of the Lake Victoria Basin* so that a person proficient in GIS can replicate and build upon the findings.

A technical training program was carried out at the University of Nairobi in November 2013 and provided detailed step-by-step methods and training in GIS. The tutorials presented there are available upon request and would be of interest to beginner and intermediate level GIS users who might benefit from a more instruction-based approach than provided here.

The report is divided into sections based on nine main themes: topography, surface water, administrative areas, protected areas, geology, soils, climate, landuse/landcover, and areas of concern. Each section starts with a short summary aimed at a non-technical audience and is followed by a detailed discussion aimed at a technical audience.

1.2 Software and Hardware

The majority of spatial analysis and all the cartography were done with ArcGIS 10.2 for Desktop (Advanced). A local histogram matching tool was used in Envi 5.0 (SP3) to mosaic the two 2013 Landsat images discussed in the Land Use/Land Cover section (Section 10). Finally, eCognition 8.64 was used to segment the mosaicked image for the object-based classification.

For those without access to one or more of the above programs, similar work can be done with open source programs such as QGIS. Additionally, for those with earlier versions of ArcGIS such as 9.3~10.1, as well as lower license levels such as Basic and Intermediate, the vast majority of work described here can be completed without any problem.

All work was done on a computer running Windows 7, 64-bit, SP1 with 8GB of RAM and Intel Core 2 Duo CPUs at 2.93GHz. It is important to note that a computer with lower specifications could also be used to complete the work: none of the processes/tools run here require more than average performance computing power.

1.3 Outputs

In order to facilitate widespread use of the project's outputs, a complete archive of the essential GIS files (section 12.2) is made available upon request. The available files are given in bold in this document. Each file contains full metadata following the ISO19139 standard. This annex describes these files and how they were created in detail.

Temporary and intermediate files, however, are not provided on the assumption that users can easily produce them and, although large in size, are not necessary for replicating and extending the results. Additionally, information on cartographic settings used while making the various maps is also not catalogued because it represents stylistic choices rather than actual data outputs[1].

1.4 Peer Review and Novelty

A peer review of the remote sensing, GIS and climate change modelling work detailed carried out by ACCESS was conducted at the request of IUCN by Hatfield Consultants in November 2013. The work was found to be satisfactory and the peer-review recommendations have been addressed in follow-up work, including in this Technical Annex.

Under one of the project's main objectives (improving scientific knowledge), ACCESS undertook various pieces of work for and on behalf of IUCN, including the following:

- GIS Mapping historical changes in land use, land cover (LULC) with particular reference to deforestation;
- Improving the digital elevation model (DEM) of the mountain;
- Improving mapping of watercourses and district and county boundaries;
- GIS Mapping and refining elements such as slope, aspect, etc;
- GIS Mapping soil type and its characteristics, such as drainability; and
- Downscaling regional climate change models to determine the likely changes in rainfall and temperature up until 2080.

The general lack of data that is common in many African countries was compounded in part by not only the remoteness of Mt. Elgon from national capitals but also by the international nature of the region (shared by Kenya and Uganda). This necessitated a novel approach to data gathering that relied heavily on global datasets and on the creation of information from analysis of remotely-sensed images and other auxiliary sources.

Overall, the output described here forms an important basis for decisions on where and what issues to address when tackling climate change adaptation issues. It is expected to be applicable to regions beyond Mt. Elgon as well.

2. Topography

Summary. Elevation is perhaps the most basic type of information required for the geospatial analysis carried out in this Mt. Elgon project: it forms the basis of the surface water network and drainage basin delineation and it is essential for calculating slope, aspect and curvature, which are all required for landslide analysis. Accordingly, particular efforts were made to produce a higher quality digital elevation model (DEM) that surpasses the readily available ones. This section describes the various freely-available DEMs and the methods used to produce the final DEM (a composite based mainly on NASA's SRTM data).

1 Anyone interested in these details or any other questions should contact ACCESS at access@uonbi.ac.ke

2.1 Digital Elevation Models (DEM)

Ideally, a high-resolution DEM derived from local surveys would be used; however, topographic maps with contour lines were not available for the whole Mt. Elgon area. Additionally, each country has its own standards and the topographic maps are not necessarily comparable. Digitizing and confirming the accuracy of such a DEM was beyond the scope of this work. Therefore, globally available, free DEM were used. The most widely used DEM is NASA's Shuttle Radar Topography Mission (SRTM) data. Currently at version 2.1, it has been available since the early 2000s and has an approximate resolution of 90m in the Mt. Elgon region.

One of the problems with the raw SRTM data as provided by NASA is the presence of "no-data" areas (voids). These are present due to poor radar return from a variety of surfaces such as sand or highly sloped, northwestern facing land (due to sensor and orbit geometry). For the Mt. Elgon area, these data voids are not too severe and SRTM is still quite usable; nevertheless, the voids need to be patched. This patching can be done by users on a case-by-case basis using auxiliary data and/or methods; however, several groups have already attempted to do this for the whole globe. Here, the use of CGIAR-SRTM and deFerranti-SRTM for this purpose is discussed. Finally, the use of GDEM, a ~30m DEM now in version 2, that potentially could have been a substitute for SRTM, is examined. Unfortunately, GDEM was found to not be useful for the Mt. Elgon region due to the presence of artifacts (as discussed below).

Note: After completion of most of the geospatial work in this project, a new global DEM called WorldDEM from Astrium became available. This DEM has a reported resolution of 12m; however, the cost for the Mt. Elgon region would be in the range of ~US$50,000 and the gains in resolution for the work described here did not justify its purchase.

2.2 Target Area Definition

First, there was a need to spatially define what is meant by the "Mt. Elgon Region". For the elevation and other raster data, this was taken as a 2 degree x 2 degree area ranging from E34~E36 longitude and N00~N02 latitude. Square degree tiles were taken as the basis because (1) that is the format in which NASA releases the data and (2) all areas of interest, including all of Mt. Elgon itself was covered with this 2x2 degree area.

When working with vector (shapefile) data, a slightly smaller area ~120km across centered on the Elgon crater was chosen. This area is provided as a polygon called **bounding_box.shp**. This extent allowed inclusion of all relevant administrative areas but made analysis a bit simpler by excluding non-Elgon areas that were present in the 2x2 degree DEM area.

2.3 NASA-SRTM3 (Version 2.1)

The following four, original NASA-SRTM3 files (each 1 square degree with the latitude and longitude given in the file name as the lower left corner of each tile): **N00E34.zip**, **N00E35.zip**, **N01E34.zip** and **N01E35.zip** were downloaded from http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Africa/ and unzipped.

The extension was changed to .bil, then header files (.hdr) were made for each, and the Batch Define Coordinate System tool was used to set the projection as GCS_WGS84 as per NASA's metadata[2]. Note, however, that with ArcGIS 10.0 and above, these steps are no longer necessary as the data is read and projected natively by ArcGIS.

The four tiles were merged into a single raster and the data void cells (originally given as values of 32768) classified as "no-data". The extent of no-data cells was examined and found to be acceptable and mainly confined to a few highly-sloping, western-facing areas on the mountain. For convenience, these no-data areas are provided in a polygon shapefile called **srtm_dem1_nodata.shp**.

In order to fill these voids, three other potential DEM sources were examined and are discussed below in order.

2.4 CGIAR-SRTM3 (version 4)

CGIAR has been providing void-filled SRTM data in various resolutions (from the native ~90m up to ~1km) for several years. They have used a number of void-fill methods for different types of no-data voids.

A geotiff file called **srtm_43_12.zip** was downloaded from the Harvest Choice server at http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

This was unzipped and added to the map. The CGIAR data has a 0.5 arcsec shift in both the north and east directions due to a legacy issue with how they originally acquired the SRTM data[3]. The Shift tool was used to move the grids by 0.00041666667 degrees (0.5 arcsec) to the south and west. The raster was snapped and trimmed to the same extent as the NASA-SRTM DEM.

While no-data voids are indeed filled in the CGIAR DEM, there are some other issues with CGIAR that made it unusable. For example, cells that border on the equator (such as E34N00) appear to have been accidentally shifted up a single cell with the top row of cells being simply repeated with the bottom row in E34N01. This is not part of the Shift issue discussed above but is likely an error introduced when they were processing tiles around the equator. Additionally, inspection of the filled areas versus the deFerranti DEM discussed below showed that CGIAR did not match terrain as well as expected from satellite images. Therefore, use of CGIAR-SRTM was abandoned for this project.

2.5 deFerranti-SRTM3

Jonathan de Ferranti has been filling SRTM voids with a number of methods, focusing on mountainous areas. In past work, this DEM has produced good results and is recommended. 1x1 degree SRTM void-filled tiles are available at: http://www.viewfinderpanoramas.org/dem3.html

The file **A36.zip** was downloaded and unzipped. Only the 4 tiles of interest were used (consistent with the NASA-SRTM3 tiles given below). The same method used to prepare the data as given in the NASA-SRTM3 section was used on the deFerranti DEM.

2 For instructions on how to make .hdr files, please contact access@uonbi.ac.ke.

3 Write access@uonbi.ac.ke for more details, if desired.

It was confirmed that all voids within the bounding box had been filled. Also, inspection of the void fills against hillshade maps and satellite images showed that the expected slopes as revealed by shadows were closely fit by deFerranti's void fills. Based on information on his website, it seems likely that he used topographic maps (contours) to fill in the voids for the Mt. Elgon region. Another possibility is that deFerranti used GDEM (discussed below) to fill the voids but inspection of GDEM shows that it would not have produced such an accurate surface so that possibility was ruled out. Some spline interpolations were also performed with a range of settings but it was found that the deFerranti fills contained information that spline interpolations could not emulate. This strengthens the case that deFerranti had made use of topographic maps or other auxiliary data (perhaps, but not likely, shadows from satellite images).

One minor issue with the deFerranti-SRTM DEM is that it seems to be based on NASA's Version 2 instead of the latest Version 2.1. The differences are quite minor for the Mt. Elgon region but there are up to several metres difference in certain cells (Version 2 is no longer available from NASA but is available upon request). Therefore, it was decided to use only the "filled" areas of the deFerranti DEM (merging them into the NASA-SRTM (V2.1) DEM) as described in "Final DEM" below.

2.6 GDEM (version 2)

The final DEM examined was GDEM which is available from NASA/METI. GDEM is offered at 1 arc second resolution, or ~30 m at the equator. The first version was called "research grade" due to the abundance of artifacts. A second version has been release that made many improvements to the first version, although as shown below, it still is not comparable to SRTM for the Mt. Elgon work.

The following four tiles: **ASTGTM2_N00E034_dem.tif**, **ASTGTM2_N00E035_dem.tif**, **ASTGTM2_N01E034_dem.tif** and **ASTGTM2_N01E035_dem.tif** were downloaded from http://gdex.cr.usgs.gov/gdex/.

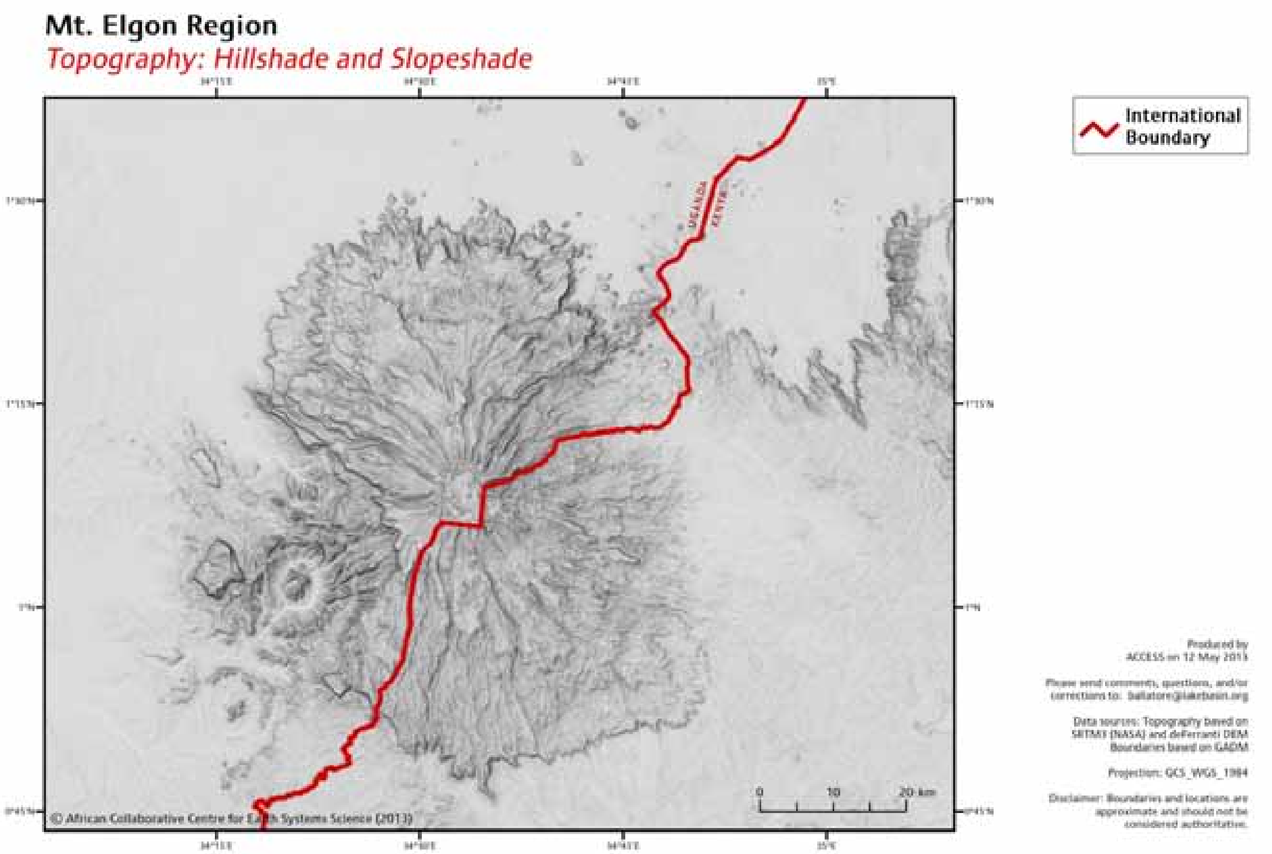
These were unzipped and added to the map. Hillshades were created and inspected for the areas where SRTM has voids. Unfortunately, GDEM V2 still contains numerous pits and spikes, some several hundred or more metres above/below the surrounding land. Interestingly, these are most prominent in areas where SRTM has voids. While GDEM was made with data completely independent of SRTM, it seems likely that they have somehow made use of SRTM to edit their data. When SRTM was unavailable (due to voids), their correction methods seem to have particularly failed. Overall, these problems led to the abandonment of GDEM in this work.

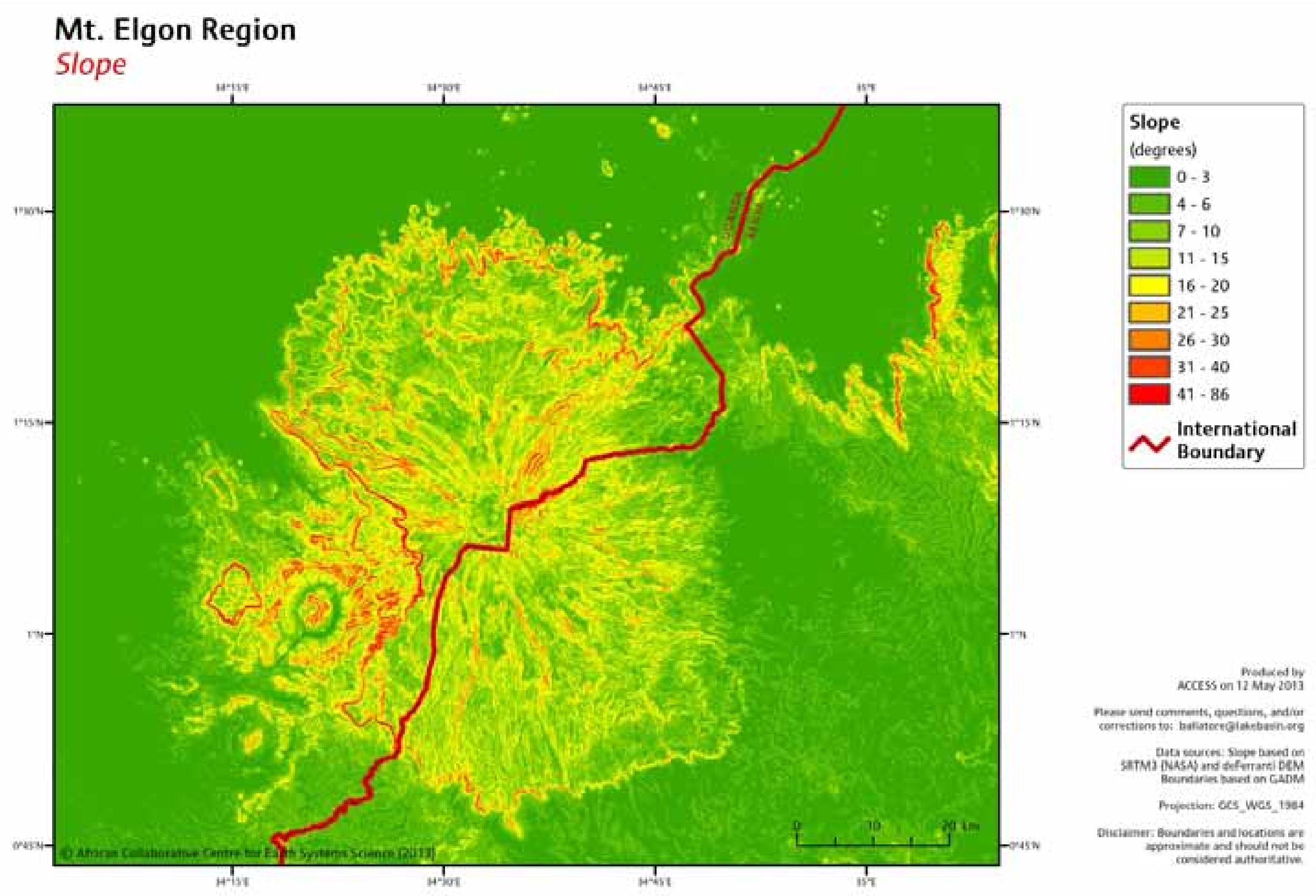
2.7 Final Composite DEM

The following steps were carried out to produce the final DEM used in subsequent analysis.

A raster that contained only cells from the deFerranti DEM that were "no-data" in the NASA-SRTM DEM was created. This new raster was then merged with the NASA-SRTM DEM in the Raster Calculator using the Conditional command and the output was saved as **dem1**. This is an ESRI grid file and has a GCS_WGS84 projection (as per the native SRTM data). This DEM can be supplied in other formats such as geotiff.

The final composite DEM (dem1), shown with hillshade and slopeshade, is shown below.





2.8 Derived Parameters (Slope, Aspect, Plan Curvature)

The final composite DEM was used to produce three rasters which were necessary for the Landslide analysis. These are described below.

2.8.1 Slope

Slope was calculated with the Slope Tool using the following settings:

Output measurement: Degrees

Z-Factor: 0.00000898

The Z-factor was set as such because with the GCS_WGS84 projection, latitude (y) and longitude (x) are in decimal degrees but height (z) is in metres. The value of 0.00000898 is explained at: http://blogs.esri.com/esri/arcgis/2007/06/12/setting-the-z-factor-parameter-correctly/. The need for a z-factor could have been obviated by re-projecting the DEM into a "projected coordinate system" such as UTM but this was not done at this stage because most of the data being worked with was natively in GCS_WGS_84. The output raster is called **dem1_slope**.

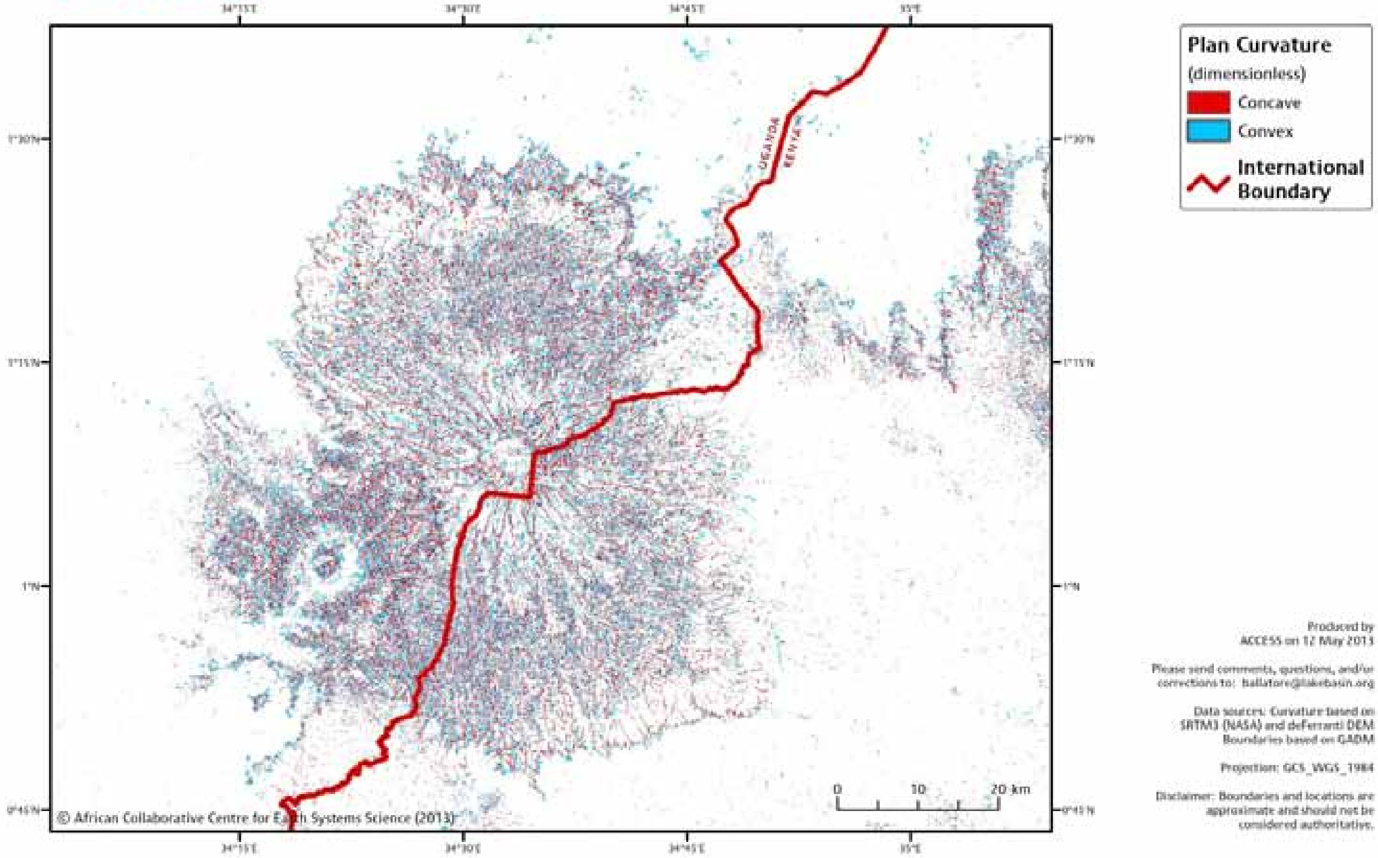
2.8.2 Plan Curvature

The curvature of a hillside (the slope of the slope) is an important factor in predicting the occurrence of landslides. The Curvature Tool was used with a z-factor of 0.00000898 to generate a plan curvature output raster as shown below. The output raster is called **dem1_curve**.

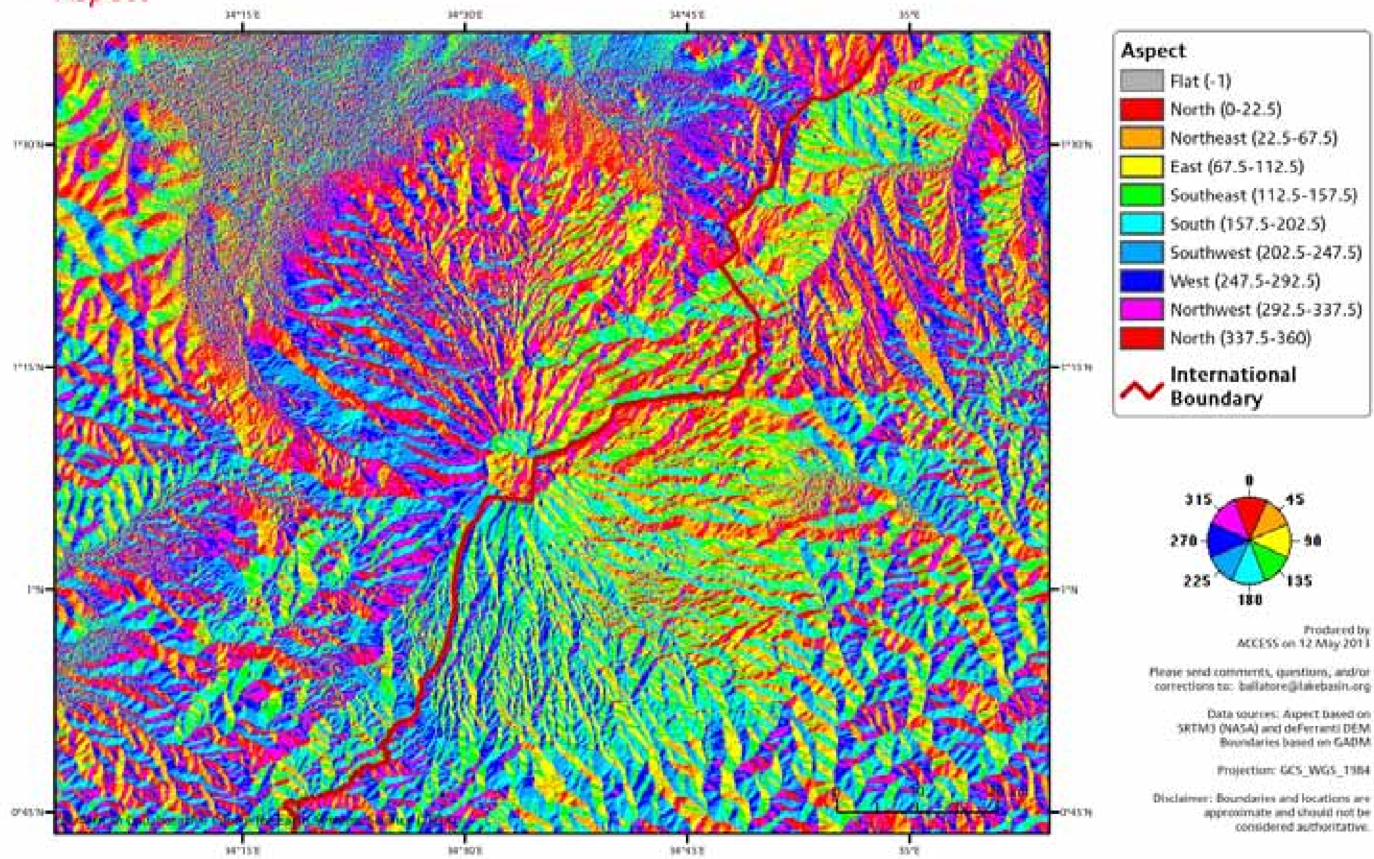
2.8.3 Aspect

Finally, the aspect, another crucial parameter in landslide analysis, which can be thought of as the "direction" a given slope is facing, was calculated with the Aspect tool with z-factor = 0.00000898. The output can be found at **dem1_aspect** and is shown below.

Mt. Elgon Region
Plan Curvature



Mt. Elgon Region
Aspect



3. Surface Water

Summary. A geographical representation of the river network, lakes and wetlands that make up the surface water of the Mt. Elgon Region is essential for a number of tasks including delineating drainage basins and identifying flood-prone areas. Unfortunately, like elevation data, there was no pre-existing set of files readily available for this purpose. This section describes a variety of methods and data sources that were used to create the several surface water-related files presented here. The main sources of data were (1) the final DEM, (2) satellite images, (3) the Surface Water Body Dataset and (4) the Global Lake and Wetland Database.

3.1 Lakes

Given the nature of the terrain, soils and geology, there are only a few, very small lakes present on Mt. Elgon itself. In the lower, flatter areas to the northwest, however, there are a number of lakes which are within the area of **bounding_box.shp** and therefore represented here even though their distance from Mt. Elgon means that they were not directly part of any Area of Concern (see Section 11) mapping.

Two different sources were used to create the lake polygon shapefiles.

First, the NASA-SRTM team has released a Surface Water Body Dataset (SWBD) available at http://dds.cr.usgs.gov/srtm/version2_1/SWBD/. Four tiles corresponding to the SRTM-DEM tiles were downloaded, unzipped and added to the map. They were merged, dissolved and then exploded (multipart to singlepart tool). This file is made available as **swbd.shp**. Within the bounding box, only parts of Lake Kyoga are present; however, there are a number of lakes outside the bounding box yet within the extent of dem1 and provided for those wishing to do broader mapping.

A second source was head-up digitization of lakes from satellite images available on Google Earth. This was not a systematic process done to identify all small lakes on Mt. Elgon; rather, when conducting the Land Cover analysis (described below), occasionally a lake would be noted through visual inspection of satellite images available on Google Earth. These lakes were then manually traced as polygons in Google Earth and converted to shapefiles in ArcGIS. The complete file containing the traced lakes is provided as **traced_lakes.shp**.

3.2 Wetlands

Wetlands are not well-represented in SWBD due to their typical high-vegetation cover as well as intermittent nature. Therefore, the Global Lake and Wetland Database (GLWD) was used to get geospatial information on the extent of wetlands in the Mt. Elgon region.

In GLWD, wetlands are included as part of "level 3". Accordingly, this file was downloaded from: https://www.worldwildlife.org/publications/global-lakes-and-wetlands-database-lakes-and-wetlands-grid-level-3, unzipped, and added to the map. The projection was defined as GCS_WGS84 and the extent of the shapefile was trimmed to match that of dem1. Non-wetland records were removed and the final dataset is made available as **glwd.shp**.

3.3 Rivers

Creation of a river network was a much more intensive process than that for lakes or wetlands. Essentially, all rivers needed to be derived from elevation data, confirmed and then often edited with auxiliary satellite images.

3.3.1 First Iteration

The procedure to generate the first iteration of the river network is as follows:

1. **Fill.** The Fill tool was used to generate a "hydrologically correct" DEM using dem1 as the input. This tool essentially fills in depressions in the landscape so that water on the surface can flow downhill. These depressions area sometimes real (e.g. an internally drained lake) but are often spurious results from slight inaccuracies in the DEM (from the nature of the SRTM sensor). They also tend to occur in areas where there are clearings in a forest through which a stream is flowing: the SRTM sensor returns values for the top of the tree canopy and bare land which can suddenly register as a drop in surface height when in fact it is simply a change in land cover.
2. **Fill minus Dem.** Then original DEM was then subtracted (using the Raster Calculator tool) from the output of step 1 to reveal which areas have positive values (indicating they were filled). Significantly filled areas were then inspected to see the nature of the fill and to determine how it should be corrected.
3. **Flow Direction.** The Flow Direction tool was used to determine the direction to which each cell in the Filled raster flows.
4. **Flow Accumulation.** The Flow Accumulation tool was used to generate a raster containing cells above a certain threshold (with the Fill output as the input). The threshold was determined from experience and iteration with a threshold of 200 producing good results. The result was a raster containing only cells that have significant upstream areas, i.e. those likely to be river courses.
5. **Stream Order.** The Stream Order tool was used to convert the Flow Accumulation raster to one containing "streams" classified on order based on the Strahler method.
6. **Stream to Feature.** The Stream Order raster was converted into a shapefile.
7. **Examination of Results.** The stream shapefile was exported to Google Earth and then visually examined against the background of high-resolution imagery.

3.3.2 Editing with Auxiliary Data

A question that arises in this type of work is "How far to edit?" One could theoretically go through the whole Google Earth archive of images for the Mt. Elgon region and manually digitize all rivers through visual inspection. That, however, would take a tremendous amount of time and would yield very little total improvement over the DEM-based river network discussed above. Elevation data is actually surprisingly good at identifying where streams are likely to flow, especially in moderate to highly sloping areas like Mt. Elgon.

Accordingly, for this work, only the most important areas were edited with auxiliary data. These included: areas with particularly high "fill" as discussed in step 2 above; areas within a selected radius (20 cells) of low slope areas; and areas close to or coincident with administrative boundaries.

The process of editing rivers was as follows:

1. A given river in the stream shapefile from Step 7 above was examined relative to the actual river location as revealed in satellite images.
2. If the river was significantly off course (decided on a case-by-case basis but usually if it was more than 50~100 m off), the actual river was traced with the Path tool in Google Earth.
3. This .kml file was then brought into ArcGIS, converted to a shapefile, converted to a raster and "burned" into the original dem (dem1) at an elevation of 0 m. This excessively low, new elevation value essentially forces the surrounding land to "flow" into the defined river courses.
4. The above steps were repeated for all target rivers.

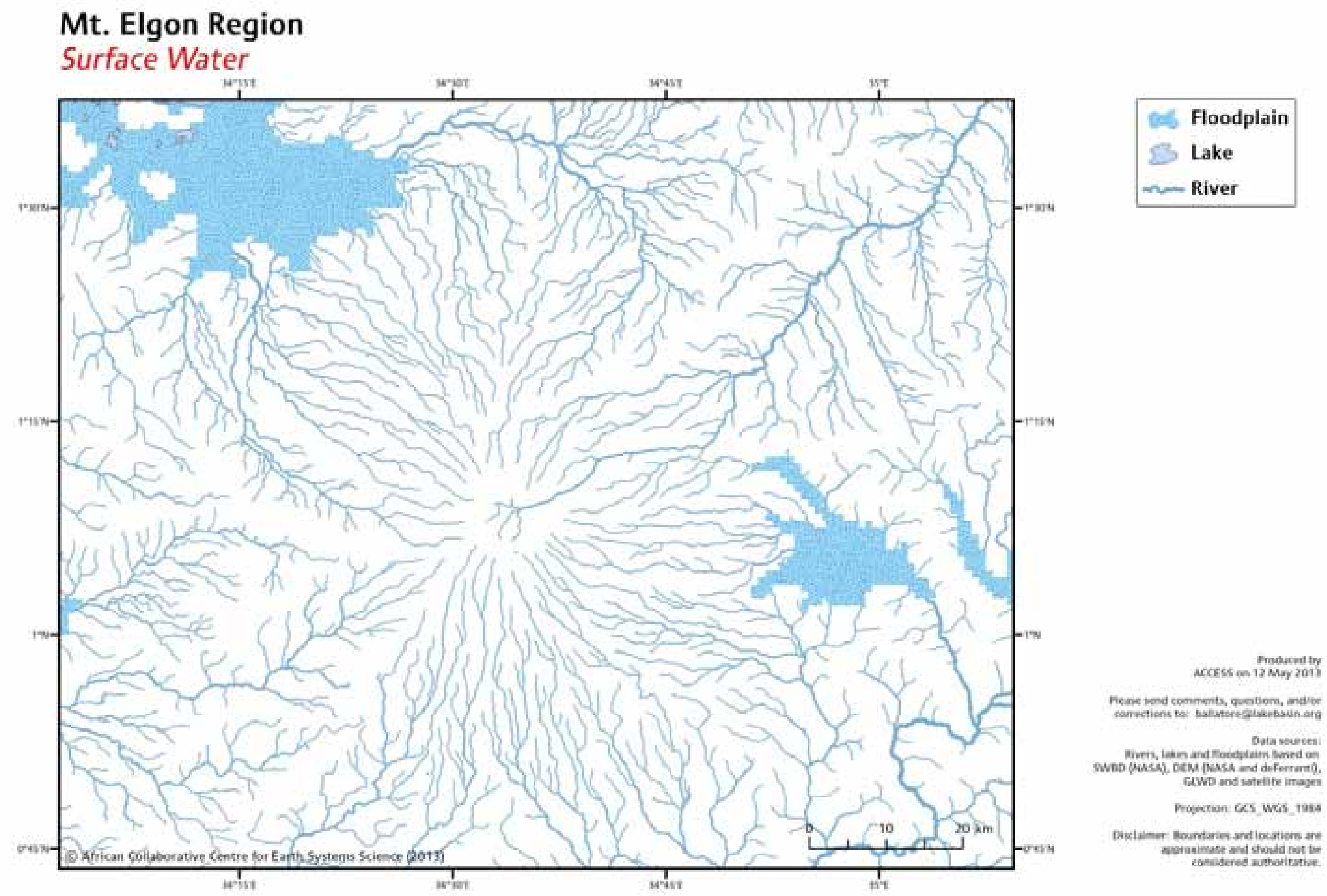
3.3.3 Production of Final River Network

The above process was repeated a number of times until there were no obvious inconsistencies between the dem-generated river network and that shown in satellite images.

The final set of river edits is provided as **river_edits.shp**. The final set of rivers is provided as **final_rivers.shp**. It should be noted that streams less than approximately 1.8 km were visually pruned and deleted from this file as they tended to be spurious.

Note that in the area of lakes Bisina, Okilotorum, and Opeta, rivers were hard to identify because of vegetation cover in the swamp. A few minor edits were made here so that the river network would flow "under" the GLWD-identified wetland area but the "rivers" shown in this area should not be taken as definitive.

The complete surface water map including the river network, lakes and wetlands is shown below.



4. Administrative Boundaries

Summary. Accurate geospatial information on the location of administrative boundaries was essential for virtually all of the mapping carried out during this project. Unfortunately, like the Elevation and Surface Water themes discussed above, no readily-available, accurate shapefiles were available from either country. Accordingly, globally-available, free shapefiles for Kenya and Uganda were used as a base upon which auxiliary data were used to edit boundaries to arrive at a more complete and correct final data set.

4.1 Global Administrative Areas (GADM) database

The Global Administrative Areas (GADM) database is a convenient source of spatially consistent, country-level shapefiles (and feature classes). The level of sub-national detail available depends on the country. For Kenya, GADM has data down to the 4th level (sub-locations) and for Uganda down to the 5th level (parishes).

The original sources of these files are unfortunately not provided by GADM and the only way to judge the quality is through inspection. Overall, the files seem to be surprisingly accurate, as confirmed at the February 2013 Stakeholder meeting in Mbale, Uganda. They were therefore used in this project as the basis of the administrative areas discussed below.

Two files, **KEN_adm.zip** and **UGA_adm.zip**, were downloaded from http://www.gadm.org/country and unzipped. For Kenya, the **KEN_adm3.shp** shapefile containing 3rd level boundaries (called Divisions) and for Uganda the **UGA_adm2.shp** shapefile containing 2nd level boundaries (called Counties) were used. The polygons identified as administrative areas of interest at the Mbale meeting were selected and exported as **gadm_trimmed.shp** and are referred to collectively as "districts" from here onwards.

4.2 Editing Districts

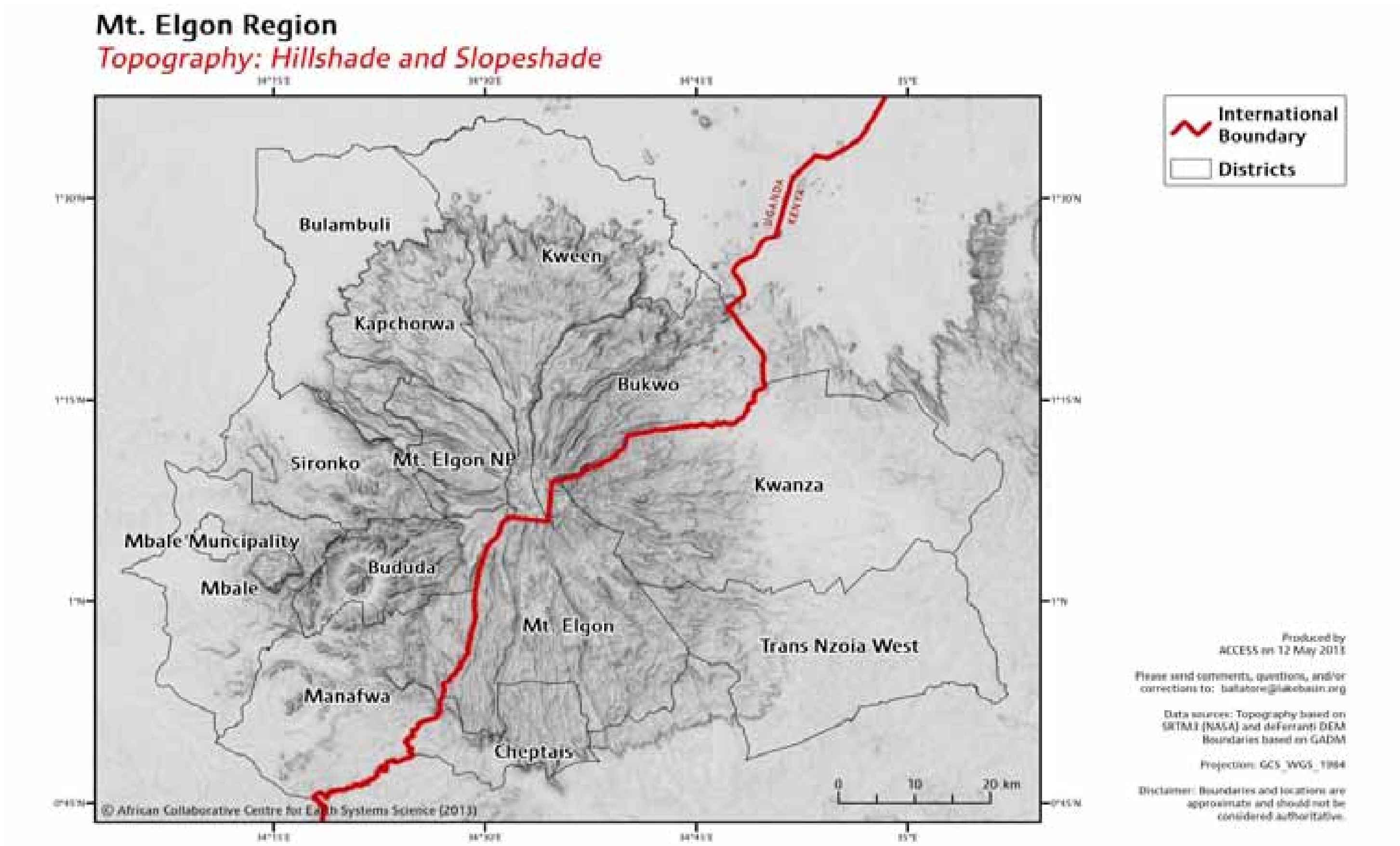
Unfortunately, GADM has some obvious problems. The polygons on both the Kenyan and Ugandan sides appear to be shifted by several hundred metres to the northwest. This is a common artifact seen in datasets converted from a previously commonly used datum to a modern one. Additionally, there are areas where, even with this shift taken account of, the boundaries do not follow features such as known rivers or ridges that are boundaries.

To arrive at a more accurate administrative boundary dataset, the GADM shapefiles were edited through a long and detailed process using rivers, ridges, and use of other obvious features such as fences in high-resolution imagery available from Google Earth. The original shapefiles were converted to file geodatabase feature classes to take advantage of topological editing.

The editing process involved creation of a large number of files as well as a large number of small, hard-to-document manual edits in ArcGIS. The final output is provided as **final_boundaries.shp**. The edits can be reconstructed from comparing the original GADM file with this final file[4].

The final set of districts is shown in the map below.

4 For those interested in details, the intermediate files and detailed steps are available upon request.

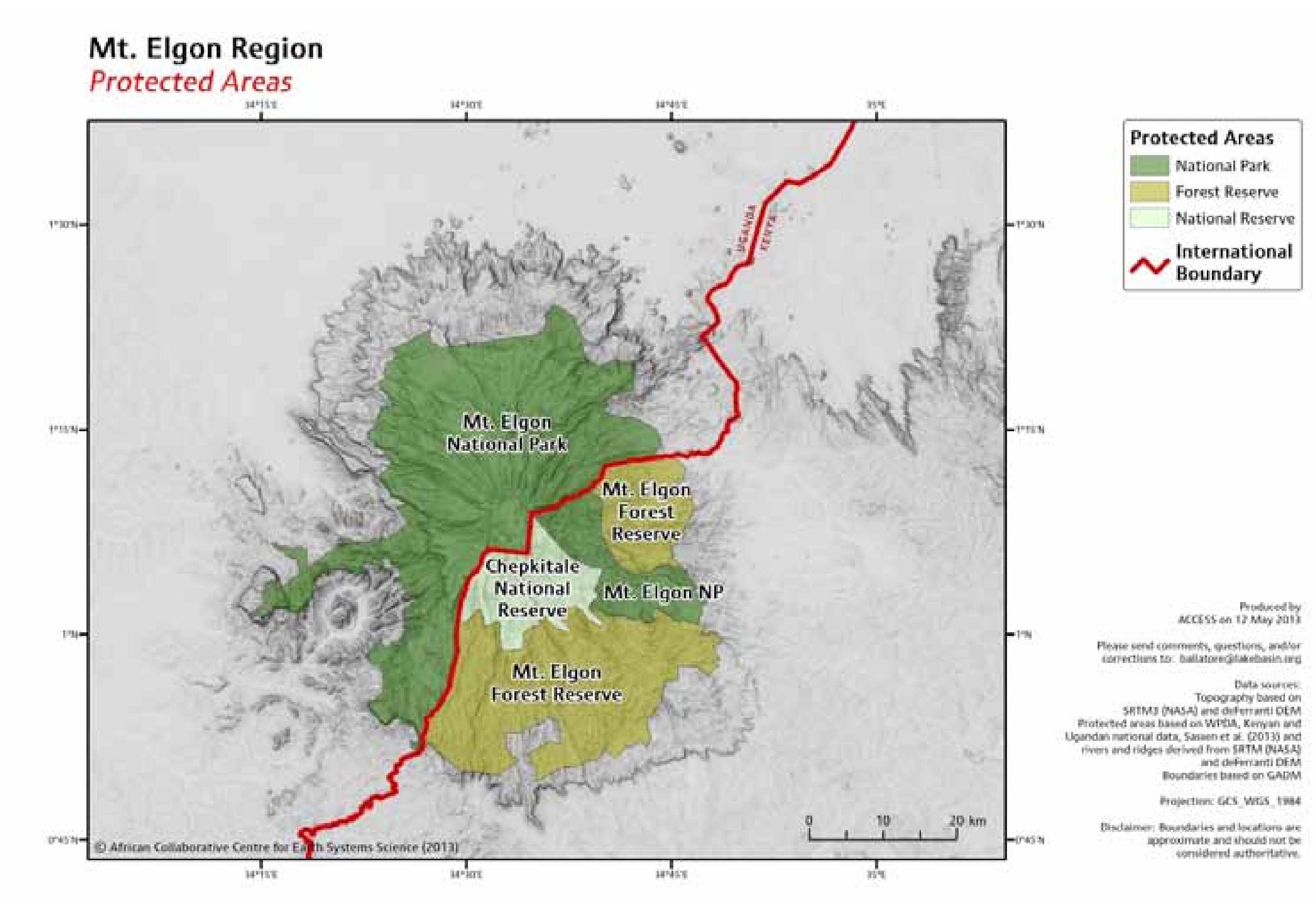


5. Protected Areas

Summary. Much of the land at high elevations on Mt. Elgon is designated as some form of protected area. Boundaries of national parks, forest reserves, and national reserves in both Kenya and Uganda were mapped using information from published sources.

5.1 Georeferenced Map

Again, readily-available and accurate geospatial files on the protected areas of the region were not available. Furthermore, the globally-available World Database on Protected Areas (WDPA) at http://www.protectedplanet.net/ did not have boundaries of the required accuracy. The best source available was a paper map from Sassen *et al*. (2013). A high resolution image of Figure 1 of Sassen *et al*. (2013) was scanned and georeferenced with a series of tie points linking locations on the figure with known locations in GIS data that had been assembled at that point. Then, lines were traced over the georeferenced figure for all the various protected area boundaries (the international border developed above was used to simplify the process). The completed lines were converted to polygons and are shown below and available as **protected_areas.shp**.

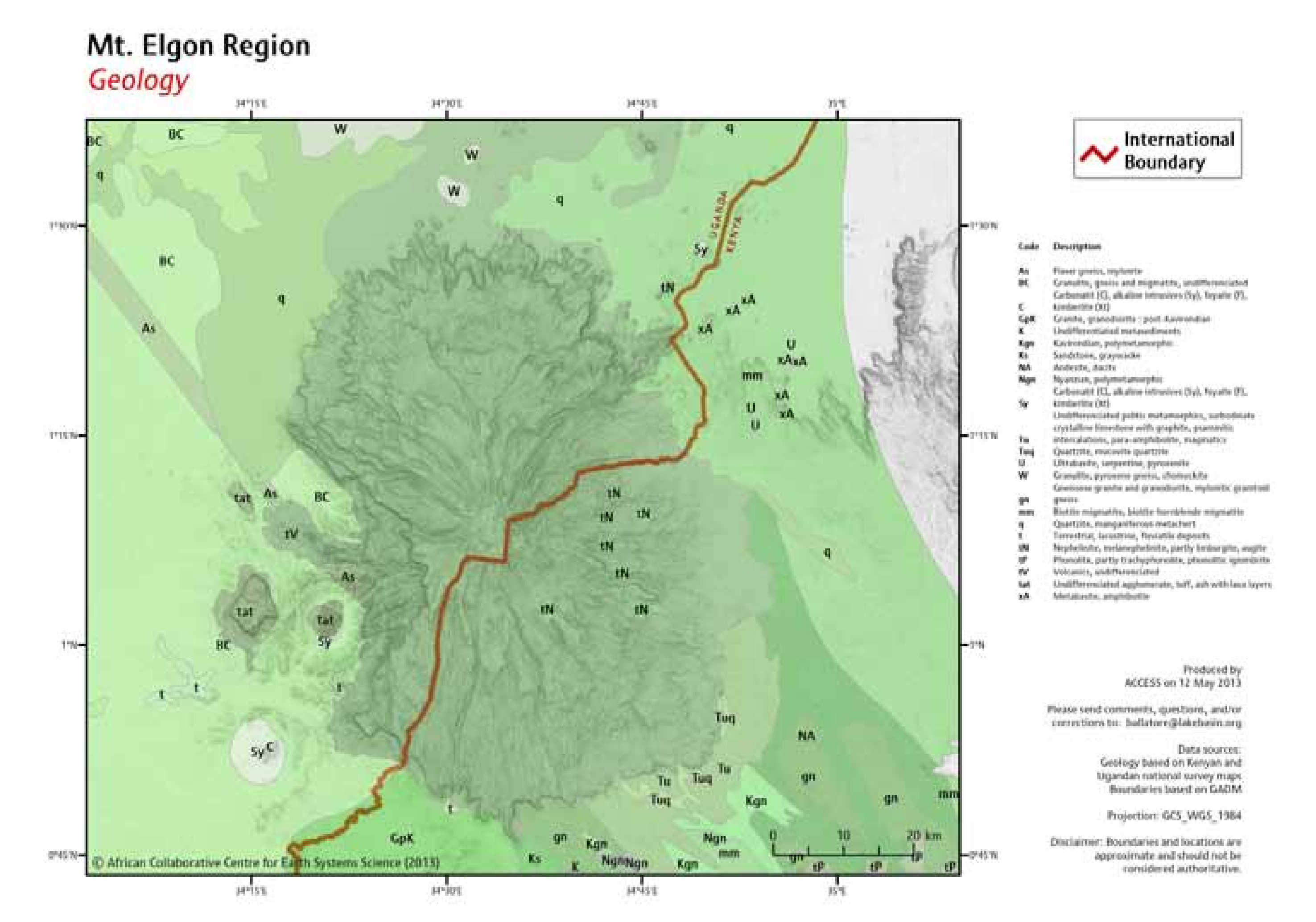


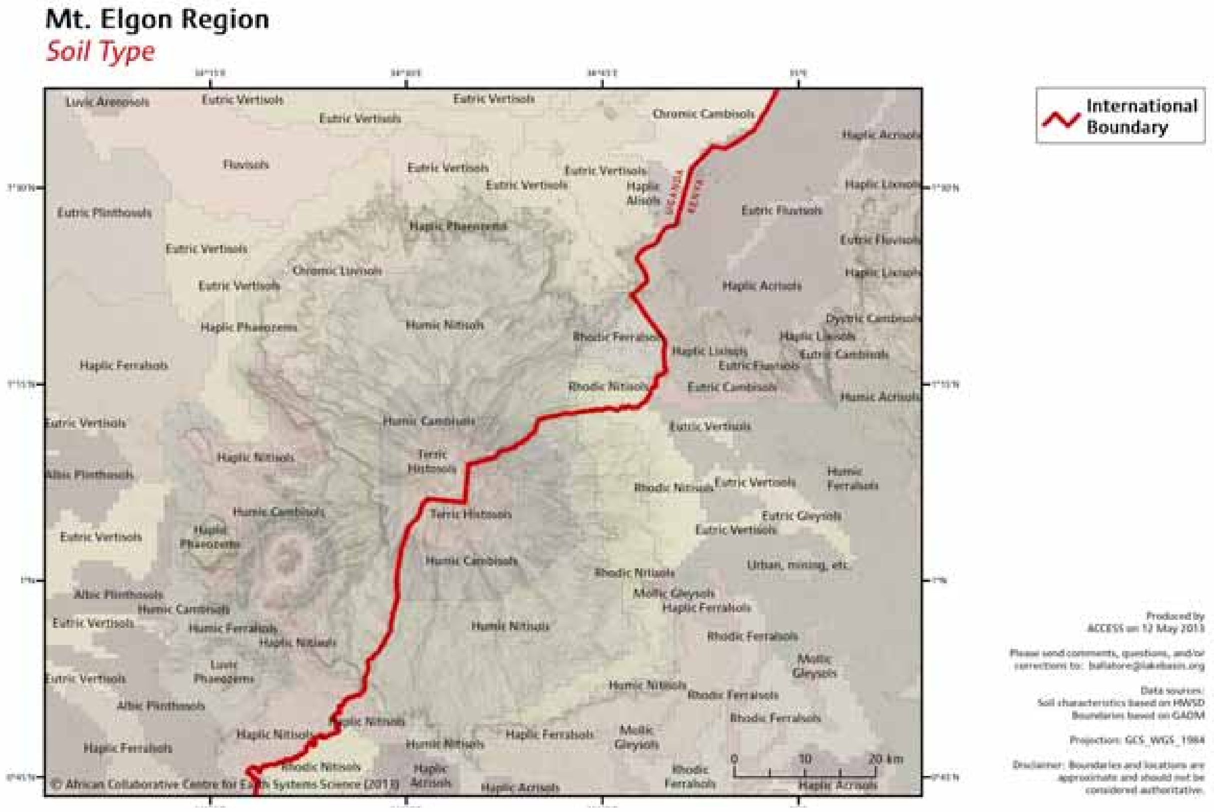
6. Geology

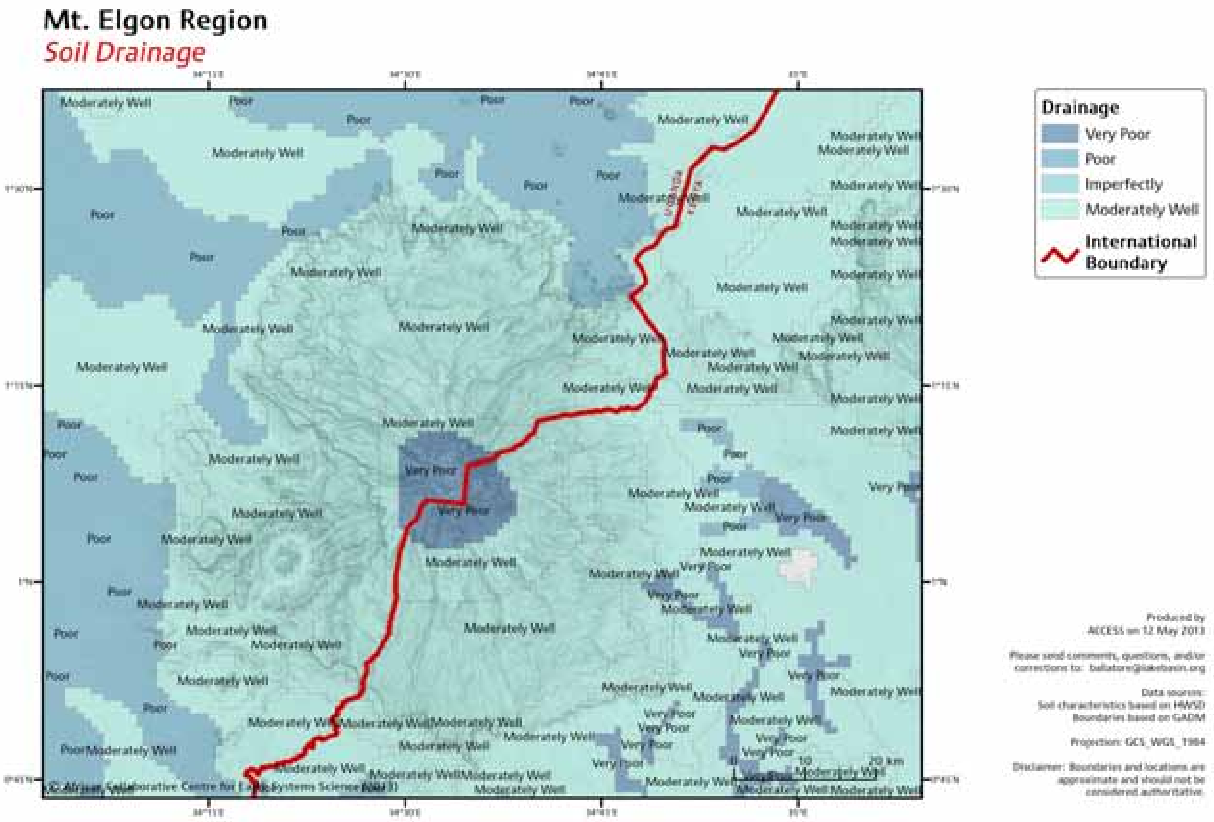
Summary. Information on the geological formations in the Mt. Elgon region was used as a source of auxiliary information when performing the Land Use/Land Cover classification as well as when determining the areas likely to be prone to flooding but was not directly used in the AOC analysis.

6.1 National Survey Maps

The geological map was digitized from the African Kartenwerk Geological map of East Africa produced by U. Freitag and others (2001) at 1:1,000,000 scale. The areas coincident with the dem1 extent were selected and are provided as **geology.shp** and shown below.







7. Soils

Summary. Information on soils was used mainly for flood risk analysis but also contributed to the LULC classification as a source of auxiliary data to the satellite images.

7.1 Harmonized World Soil Database

There were no readily-accessible, digital versions of the Kenyan and Ugandan soil survey maps. Therefore, the Harmonized World Soil Database (HWSD), a 30 arc-second (~1km) raster data set, was used for information on soil type as well as soil drainage.

The HWSD data was downloaded from http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/. One raster dataset on soil type and one on drainage type were extracted and trimmed to the extent of dem1. These were converted to shapefiles and are made available as **soil_type.shp** and **soil_drainage.shp**.

8. Climate

Summary. Both temperature and precipitation are among the most important factors affecting livelihoods in the Mt. Elgon region. This holds for both current conditions as well as changes projected for future climates. The highly variable topography of the Mt. Elgon region required acquisition of high-resolution (~0.9 km) raster data for baseline (1950-2000) and future (2060-2080) temperature and precipitation.

8.1 Note

During the course of this work, the Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report and the associated models and outputs used to generate future scenarios through the Coupled Model Intercomparison Project-Phase 5 (CMIP5) of the World Climate Research Programme at http://cmip-pcmdi.llnl.gov/cmip5/. Previous maps and data released during the February 2013 Mbale Stakeholder meeting and after were based on an earlier IPCC Assessment. Here, updated results based on the latest Fifth Assessment Report are presented.

8.2 Baseline Climate

WorldClim is a global repository for climate data (http://www.worldclim.org/) including baseline and IPCC projections discussed above. WorldClim also employs a suite of methods to downscale raw model outputs to finer resolutions. For the Mt. Elgon region, the 30 arcsec product (~0.9km) was used in this work.

For current climate, Mean Annual Temperature and Mean Annual Precipitation rasters were downloaded from http://www.worldclim.org/tiles.php?Zone=37 in GeoTIFF format. These files were unzipped, added to the map, trimmed to fit the extent of dem1, and converted from 32-bit floating point to 16-bit integer files. These are made available as: **baseline_temp.tif** (temperature) and **baseline_precip.tif** (precipitation).

8.3 Projected Climate

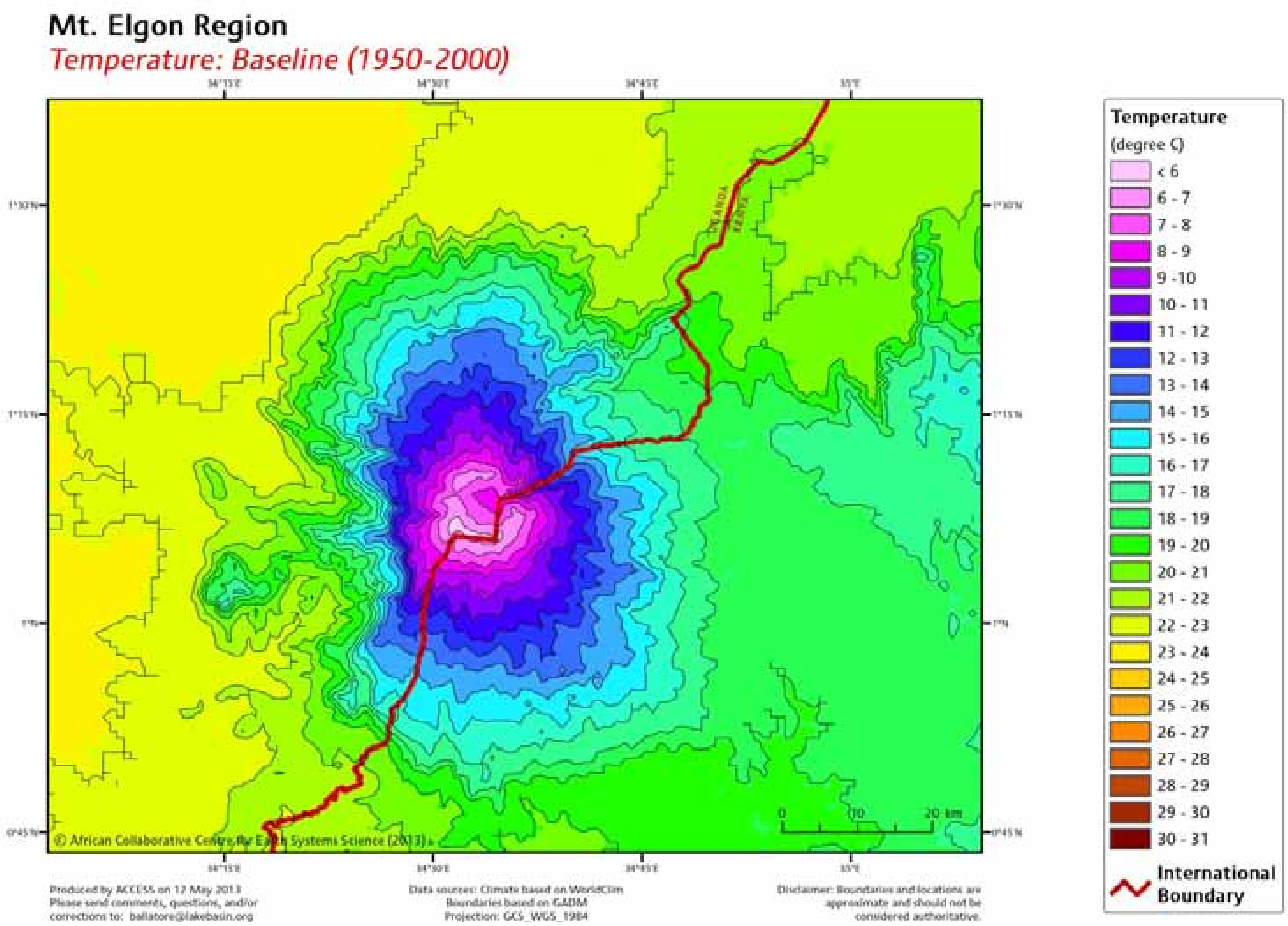
For future climate, WorldClim provides a range of outputs at different spatial resolutions for the CMIP5 models following four main Representative Concentration Pathways (RCPs).

8.3.1 Resolution

Data is available in the following spatial resolutions: 10 minutes, 5 minutes, 2.5 minutes, 30 arc seconds. Given the relatively small area of the Mt. Elgon and the large changes in elevation present within it, the highest resolution rasters at 30 arc seconds (~0.9km) were chosen.

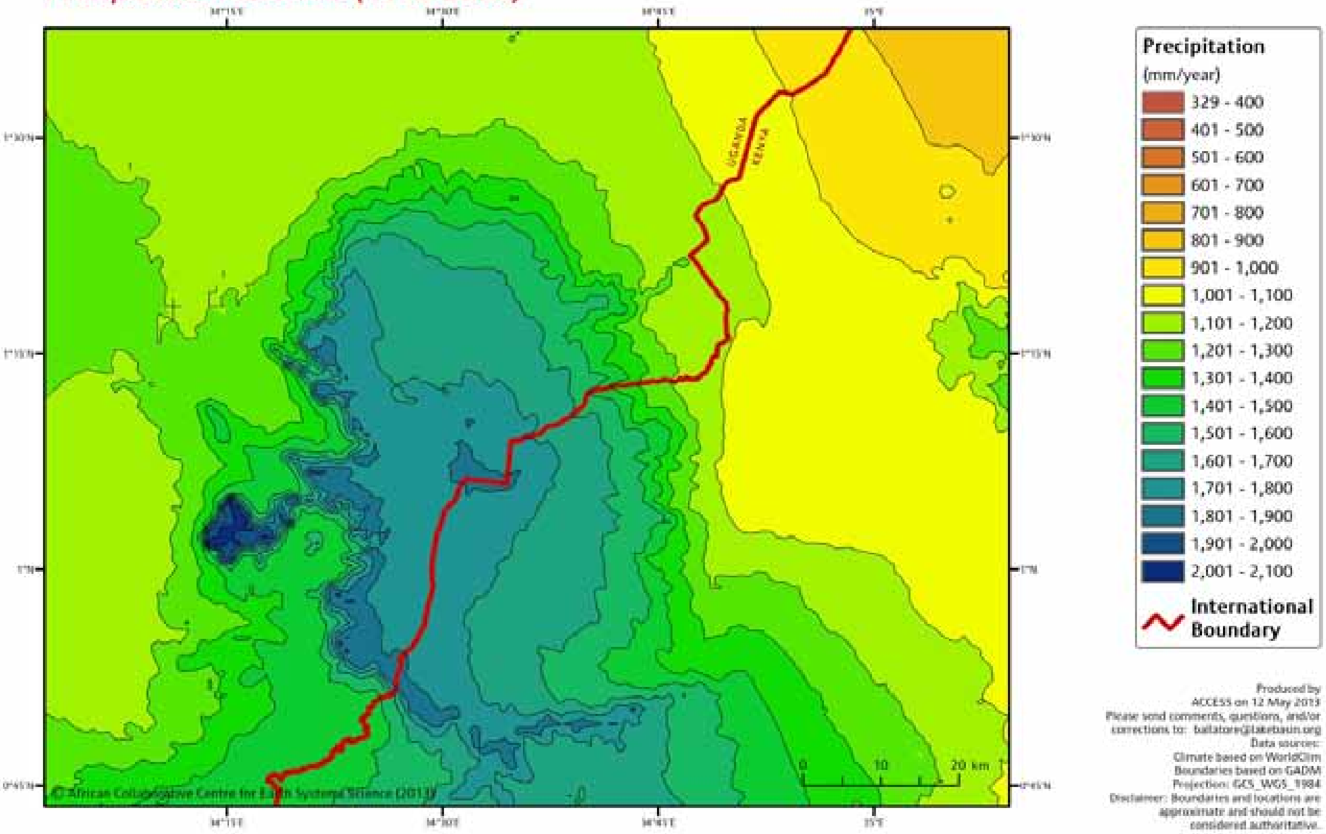
8.3.2 Model

In the early part of the project, the HadCAM model output was selected because of its widespread use and a consensus that it was appropriate for the East African region. In this updated work, a new generation of the model, HadGEM2 used in CMIP5 is used. In particular,



Mt. Elgon Region

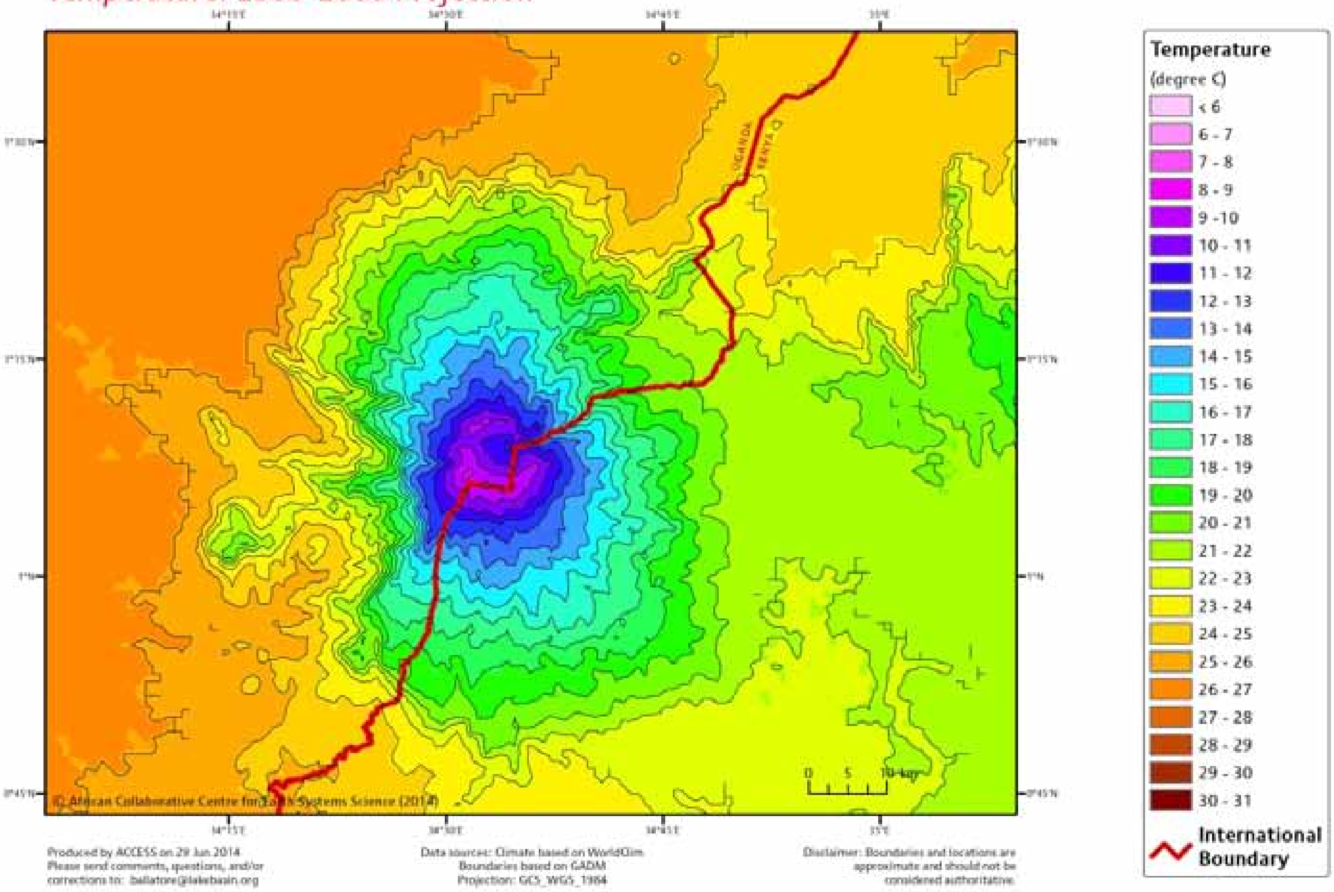
Precipitation: Baseline (1950-2000)



Produced by ACCESS on 12 May 2013
Please send comments, questions, and/or corrections to: ballatore@lakebasin.org
Data sources:
Climate based on WorldClim
Boundaries based on GADM
Projection: GCS_WGS_1984
Disclaimer: Boundaries and locations are approximate and should not be considered authoritative.

Mt. Elgon Region

Temperature: 2060-2080 Projection



Produced by ACCESS on 29 Jun 2014
Please send comments, questions, and/or corrections to: ballatore@lakebasin.org

Data sources: Climate based on WorldClim
Boundaries based on GADM
Projection: GCS_WGS_1984

Disclaimer: Boundaries and locations are approximate and should not be considered authoritative.

the HadGEM2-ES (Earth System) model was chosen based on review of other models and the conclusion that it would be appropriate for the Mt. Elgon region (http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem2).

8.3.3 Emission Scenarios

All climate models make assumptions about future greenhouse gas emissions, called Representative Concentration Pathways (RCPs). WorldClim provides data for four of these. RCP45 was chosen because it is the most well-represented among the four (all models use this as an input; some models do not use other RCPs) and because of arguments against the realism of other RCPs as discussed at http://www.nature.com/nclimate/journal/v1/n1/box/nclimate1058_BX1.html

8.3.4 Data

A bulk "bioclimatic" file containing many climate rasters including annual temperature and annual precipitation was download from http://worldclim.org/cmip5_30s (specifically, http://biogeo.ucdavis.edu/data/climate/cmip5/30s/he45bi50.zip). This is the 30 arcsec downscaled output of HadGEM-ES for RCP45.

The file was unzipped and the bio1 (temperature) and bio12 (precipitation) rasters were added to the map in GeoTIFF format. These files were trimmed to fit the extent of dem1 and converted from 32-bit floating point to 16-bit integer files. These are made available as: **temp_2070.tif** (temperature) and **precip_2070.tif** (precipitation).

9. Land Use/Land Cover

Summary. The Mt. Elgon region has seen dramatic changes in land use over recent decades. There has been a marked reduction in forest cover due to clearing of land for agricultural production. A continuous record of satellite observations since the early 1970s to present allows mapping of this land use/land cover (LULC) change. The decrease in forest cover from 1973 to 2013 was a crucial input to the landslide and flooding risk analyses.

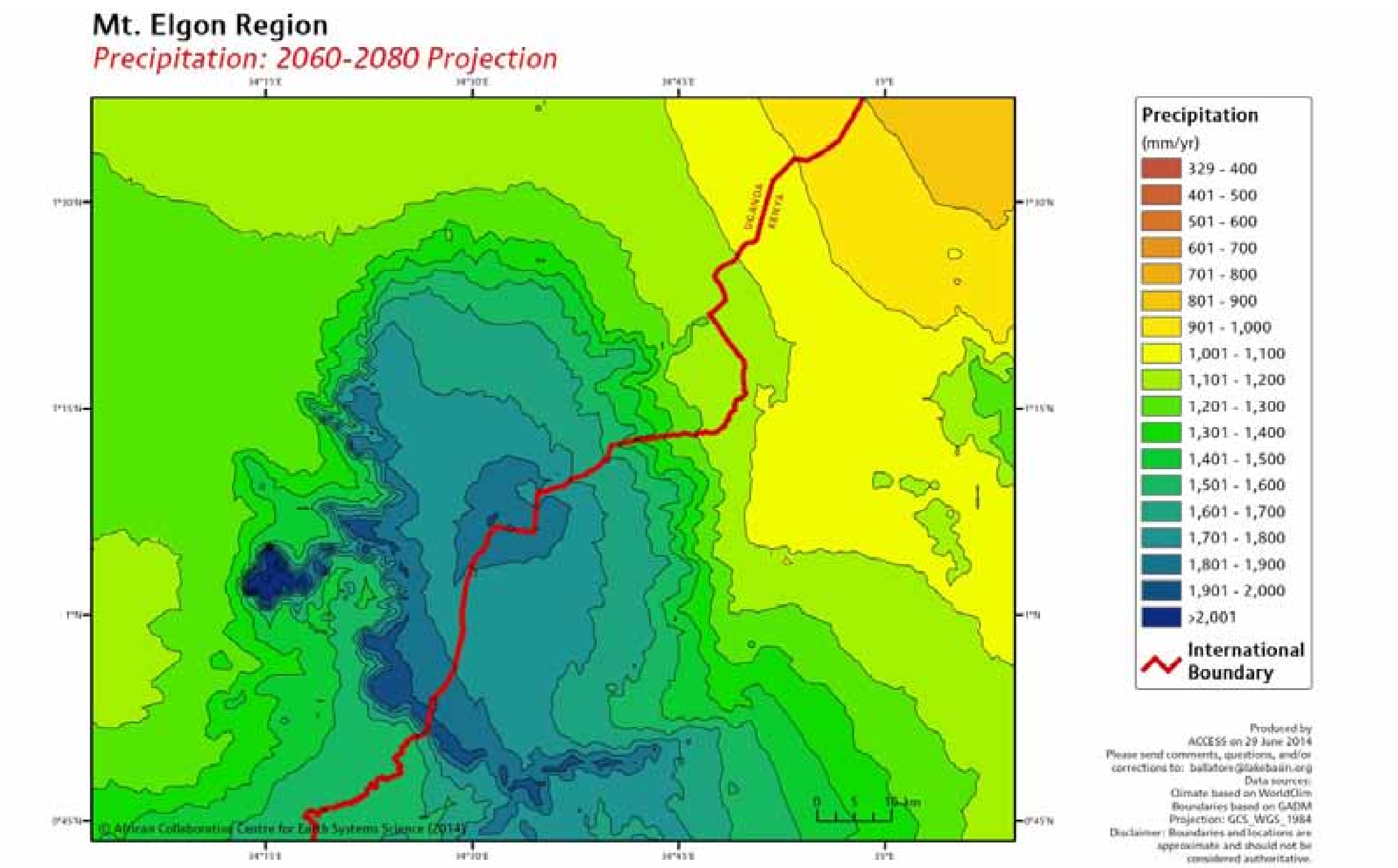
9.1 Image Acquisition

The NASA-operated Landsat satellites have been active since 1972 and a full archive of images is available at http://glovis.usgs.gov/. The archive was scanned for the highest quality images for Mt. Elgon (Path 170, Row 59) for the dry season early in this period and as recent as possible. The common occurrence of clouds on Mt. Elgon (especially the western and southern slopes) limited the number of usable images. Images meeting all selection criteria were identified and downloaded for 1 February 1973, 5 January 2013 (LE71700592013005ASN00), and 21 January 2013 (LE71700592013021ASN00).

9.2 Image Preparation

9.2.1 January 2013 Images

The two images from January 2013 are from the Landsat 7 ETM+ sensor which has a 30 m spatial resolution. Since 2003, the ETM+ sensor has suffered from a scan



line corrector (SLC) malfunction which leaves "no-data" stripes in the images. The location of these no-data areas depends on the date of acquisition; fortunately, temporally-contiguous images (taken 16 days apart) have non-overlapping no-data areas. Therefore, assuming conditions on the ground are sufficiently similar, one image can be used to patch the other. Additional issues that often require pre-processing are the removal of clouds and their shadows.

In the first round of analysis carried out for the 2013 Mbale Stakeholder meeting, the SLC-gaps, clouds, and cloud shadows were masked out in the two 2013 images, and the two images mosaicked using a simple replacement technique. This resulted in marked visual artifacts and problems with classification. These files were not used but are available upon request.

In the final round of analysis, a special gap-fill tool employing local histogram matching in the ENVI software package was used to produce superior images with no visible artifacts. This is the technique described below.

Each image was unzipped. Bands 1 and 6 were not useful for this analysis and therefore removed. Bands 2, 3, 4, 5, and 7 were individually trimmed (as GeoTIFF files) to an area slightly smaller than the bounding box in order to reduce processing times during classification but to still cover all the administrative areas of interest.

Local histogram matching was done to fill gaps in ENVI 5.0 using the plugin called **landsat_gapfill.sav**. The 21 January 2013 image had very few clouds and was chosen as the base image into which the 05 January 2013 data would be used to fill gaps (in the 21 January 2013 image). Each band was individually processed with the **landsat_gapfill.sav** plugin and saved as a **.tif** file.

Once gap filling was completed and verified, the five bands were composited into a single **.img** file. This is available as **composite_2013.img** and is used for the classification described below. (All temporary files are available upon request).

9.2.2 February 1973 Image

Preparation of the 1973 image was more straightforward given the lack of need to do the gap-filling described above.

The image was unzipped and each of the four bands was trimmed to the same extent as the January 2013 composite image. The four bands were composited into a single **.img** file. This is available as **composite_1973.img** and used for the classification described below.

9.3 Classification

9.3.1 January 2013 Composite Image

A pixel-based, supervised classification approach was first attempted but the classification accuracy was not satisfactory. A more successful object-based classification approach was adopted and is described below.

eCognition (version 8.64), a specialized image analysis software package with advanced algorithms for "segmenting" images based on characteristics of neighboring pixels, was used to generate a large number of polygons (groups of neighboring pixels). Specifically, a multi-resolution segmentation algorithm was performed on **composite_2013.img** with double weight given to bands 3 and 4, the scale parameter set to 30, the shape parameter set to 0.2, and compactness set to 0.7. The result was a shapefile with 4025 polygons.

These polygons were then manually classified in ArcGIS into 14 classes by visually inspecting them against the Landsat image (including various band combinations to highlight different LULC classes), higher-resolution images in Google Earth, other auxiliary data such as normalized difference vegetation index (NDVI) derived from the Landsat image, and pictures taken during field work on Mt. Elgon.

The 14 classes are explained below. They were put into four groups (Trees, High-elevation non-forest, Bare and/or deforested, and Grass and tea) for the purpose of accuracy assessment. The final file is made available as **classification.shp**. The class numbers given below are the same as those appearing in the shapefile.

Group 1: Forest

Class 1. Plantation

Judged by color (dark) and shape (with straight edges). Sometimes older plantations look like native forest but Mount Elgon Regional Ecosystem Conservation Programme (MERECP) information was used to help discriminate these.

Class 2. Forest

This is native forest; quite dark, red and with grainy texture. Occasional spots of bamboo growth or other non-forest patches (clearings).

Class 3. Bamboo

The bamboo is bright in infrared. Located between 2000-3000m. Green in 432 band combination. Texture is not uniform like grassland/bareland. Has a "spongy" look. Sometimes contains an occasional tall tree.

Class 6. Mixed Native/Bamboo forest

A mix of trees in a bamboo matrix. The bamboo is evident by elevation and mainly color. Bamboo coverage is between approximately 20-80% for this class.

Class 9. Recovered/recovering forest

This often contains many trees or lots of green vegetation and some trees. It may be regenerating as NDVI shows abundant photosynthesis but the look is not the same as natural forest.

Class 14. Natural vegetation with few trees

This is area within what is considered "forest" but for which tall trees are not abundant. Heavy, native-looking vegetation is present.

Group 2: High-elevation, non-forest

7. High mountain vegetation

This is all the land that appears above the tree line, thus excluding trees. It sometimes includes bare rock but is mainly alpine vegetation and moorland.

Group 3: Bare and/or deforested

4. Bare ground

Much brighter (whiter) in all wavelengths so assumed to not be growing vegetation. Might be light vegetation in some places or possibly fallow fields but usually cleared land.

10. Encroached with mixed vegetation

This is somewhat between recovered and non-recovered encroached land with a lot of heterogeneity.

12. Recently deforested with a few trees or undergrowth left

Bare looking with little undergrowth left. Often a lone tall tree or two indicates that the area was once forest.

13. Supposedly recovering but with low vegetation cover

According to MERECP, these areas are recovering from deforestation but there are still signs of habitation/human activity and a marked lack of trees.

Group 4: Grass (and tea plantations)

15. Tea plantations

These are very dark green in the image and have a shape and height (lack of cast shadows) that indicates non-forest.

16. Grass

Bare-looking land with NDVI higher than bare. Sometimes naturally occurring and sometimes cleared land that has grass.

9.3.2 Accuracy Assessment

To carry out an accuracy assessment of the above classification, 200 spatially randomly distributed points were generated in ArcGIS with the Create Random Points tool. Each point was assigned a Group value of 1 to 4 (as above) depending on the class assigned to the land under it during the process described above.

These points were exported to Google Earth and compared against high-resolution images. Each point was assigned a score as follows: 1 = Correct (identified class same as shown in high-resolution image), 2 = Incorrect (identified class different from that shown in high-resolution image, 3 = Cloud (cloud cover in high-resolution images prevents identification), 4 = Indeterminate (class not clear from high-resolution image).

Overall, 92.1% of the points were correctly classified. This high accuracy is due to the object-based approach as well as the time taken to manually classify each segmented object into a distinct class. The file of points with classes and scores is available as **accuracy_assessment.shp**.

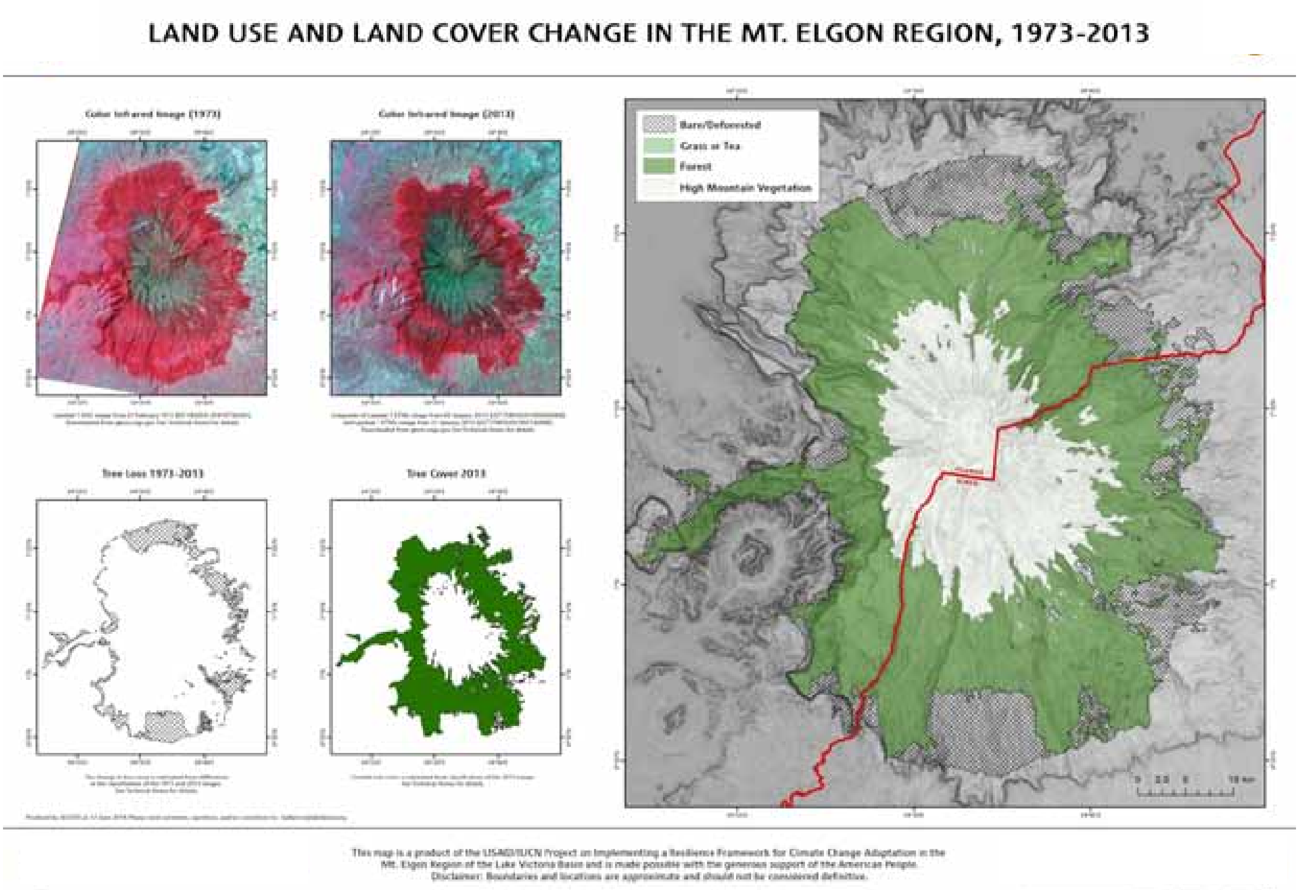
9.3.3 February 1973 Composite Image

Classification of the 1973 image was straightforward and limited due to the lower spatial and spectral resolution of the image compared with the 2013 image.

The image (**composite_1973.img**) was segmented in eCognition with double weight given to bands 2 and 3, the scale parameter set to 30, the shape parameter set to 0.2, and compactness set to 0.7. The result was a shapefile with 1435 polygons.

This shapefile was brought into ArcGIS and, by making use of a false color display (infrared shown as red), forest areas were classified. It was impossible to use high-resolution imagery for this because none is available for this period.

The 1973 forest areas were compared with the 2013 forest areas and forest loss was estimated and is shown in the figure below.



10. Areas of Concern

Summary. Based on the geospatial data described above, and along with conversations with stakeholders and project partners, mapping of five Areas of Concern (AOCs) was carried out: Landslide Risk, Flooding Risk, Temperature Impacts, Cumulative Risk, and Stakeholder Identified AOCs. The purpose of the AOC mapping was to assist stakeholders and partners in selection of a set of locations for pilot projects. It is important to note that the AOC analysis described here should not be considered definitive, but rather indicative of potential risks that may exist. Proper and full analysis of each issue would require a full project in itself.

10.1 Landslide Risk

One of the marked features of Mt. Elgon is the people living on steep, deforested slopes on weak terrain. Landslides are common, often taking tens to hundreds of lives.

Much academic and field work has been done on characterizing the conditions that lead to slope failure. In particular, Knapen *et al*. (2006), Claessens *et al*. (2007), and Mugagga *et al*. (2012) have used field studies at landslide sites to develop a list of causative factors.

In this limited study, it was impossible to develop physical landslide models. Instead, information from the literature was used to assign values to different attributes for each risk factor. These values roughly reflect the weight that a given factor has based on the information provided in the sources noted. Five key factors were apparent from the literature (1) Slope Factor derived from DEM), (2) Plan Curvature Factor (derived from DEM), (3) Aspect Factor (derived from DEM), (4) Precipitation Factor (based on WorldClim data), and (5) Land Cover Factor (based on classification of Landsat images).

10.1.1 Slope Factor

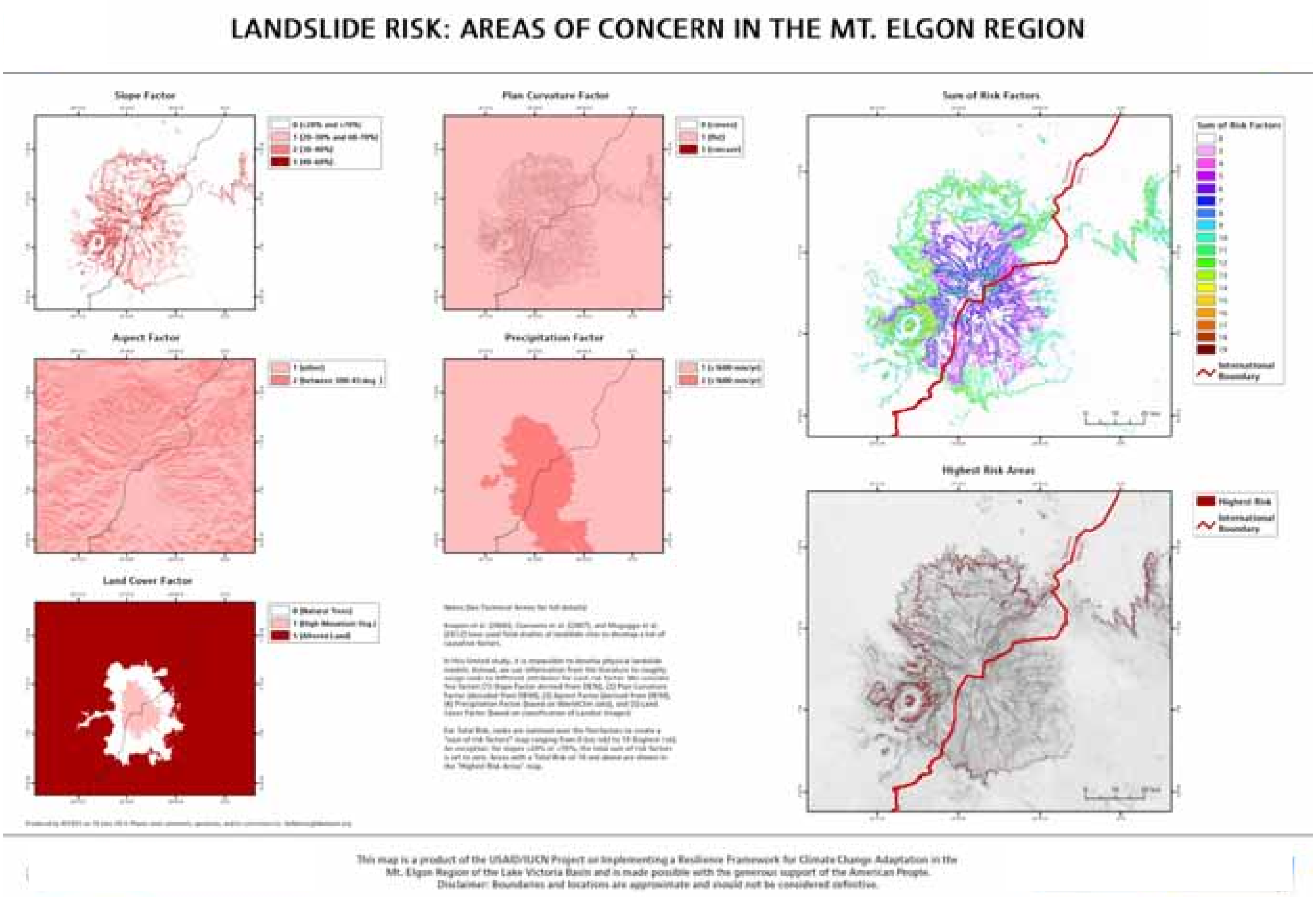
The section on slope gradient in Figure 7 of Knapen *et al*. (2006) was used to reclassify the slope raster **dem1_slope** into four classes representing the relative risks of a given slope based on field data from 98 recent landslides: Risk value 0 (slope less than 20% and greater than 70%), Risk value 1 (slope 20-30% or 60-70%), Risk value 2 (slope 30-40%) and Risk value 5 (slope 40-60%). This represents the fact that landslides are more likely to occur in moderate to steep slopes but unlikely in extreme slopes or flat areas.

10.1.2 Plan Curvature Factor

The "slope of the slope" in the downward direction is called plan curvature and is highlighted by Knapen *et al*. (2006) as a risk factor. Concave slopes show a markedly higher likelihood of landslide than convex slopes. Figure 7 of Knapen *et al*. (2006) was used to reclassify the slope plan curvature raster **dem1_curve** into three classes: Risk value 0 (convex), Risk value 1 (flat), and Risk value 5 (convex).

10.1.3 Aspect Factor

The direction a slope faces also has an effect on the likelihood of a landslide. In particular, for Mt. Elgon, Knapen *et al*. (2006) show that north facing slopes have a higher risk. Accordingly, Figure 7 of Knapen *et al*. (2006) was used to reclassify the aspect raster **dem1_aspect** into two classes: Risk 2 (aspect between 300-360 and 0-45 degrees) and Risk 1 (others).



10.1.4 Precipitation Factor

Sustained rainfall events that saturate and weaken slopes are also identified as a key landslide risk factor. While the data available was for annual average precipitation and not for specific rainfall events, information from Claessens *et al*. (2006) was used to reclassify the precipitation raster **baseline_precip.tif** into two classes: Risk 1 (annual precipitation < 1600 mm) and Risk 2 (annual precipitation > 1600 mm).

10.1.5 Land Cover Factor

Deforested land was shown to also be a critical factor in slope stability. Information in Mugagga *et al*. (2012) was used to reclassify the land use/land cover raster **classification.shp** into three classes: Risk 0 (natural tree cover), Risk 1 (high mountain vegetation) and Risk 5 (altered land).

10.1.6 Total Landslide Risk

To determine Total Landslide Risk, the above five risk factors were summed to create a "sum of risk factors" map ranging from 0 (no risk) to 19 (highest risk). For slopes <20% or >70%, the total sum of risk factors is set to zero. Areas with a Total Risk of 16 and above are shown in the "Highest Risk Areas" map[5].

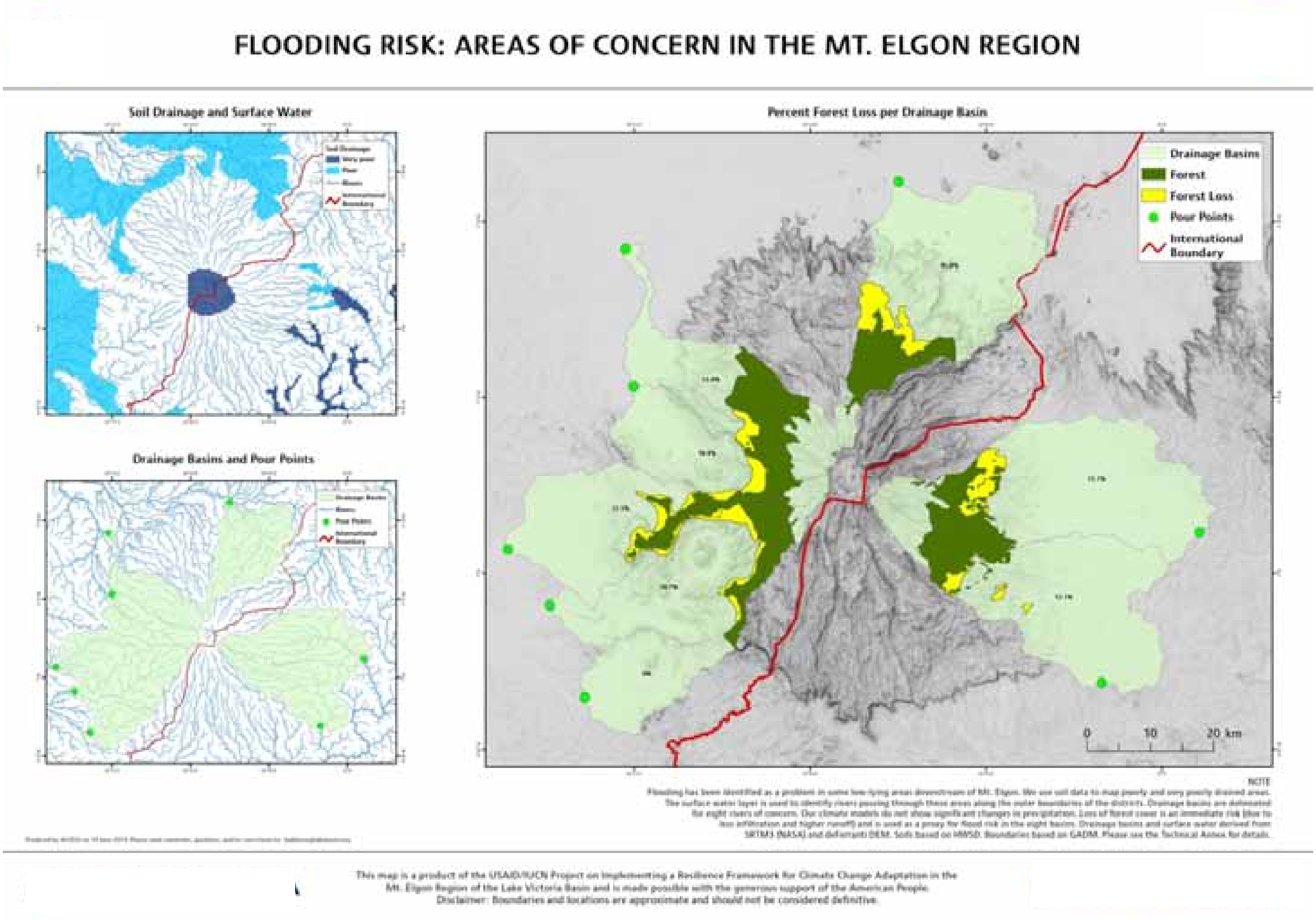
5 Files are available upon request.

10.2 Flooding Risk

The risk of flooding in areas downstream of Mt. Elgon was estimated by considering soil drainage conditions and loss of forest cover in select drainage basins. The lack of a detailed DEM for flat areas as well as absence of hourly rainfall and river discharge data makes the analysis indicative of potential flooding areas for further study.

Eight major rivers from the shapefile containing surface water features (**rivers_final.shp**) that intersected the outer boundary of the administrative boundaries shapefile in areas with poor or very poor soil drainage were selected for study. The points of intersection are given in the shapefile called **pour_points.shp**. These points were converted to rasters and used as pour points in the Watershed tool in ArcGIS with the flow direction based on the edited dem. The final 8 drainage basins are given in **drainage_basins.shp**.

The area of Forest and Forest Loss within each drainage basin was estimated from the LULC analysis (**classification.shp**) with the results shown in the map below.



10.3 Temperature Impacts

The current distribution of forest cover on Mt. Elgon is determined by two factors: natural climate and anthropogenic deforestation (and reforestation). The climate information presented above does not show significant changes in precipitation but does show a significant increase in temperature.

A preliminary analysis was done on potential impacts of the predicted increase in temperature on the range of forest on Mt. Elgon by projecting how temperature ranges currently compatible with tree cover will shift upwards to follow current temperature zones.

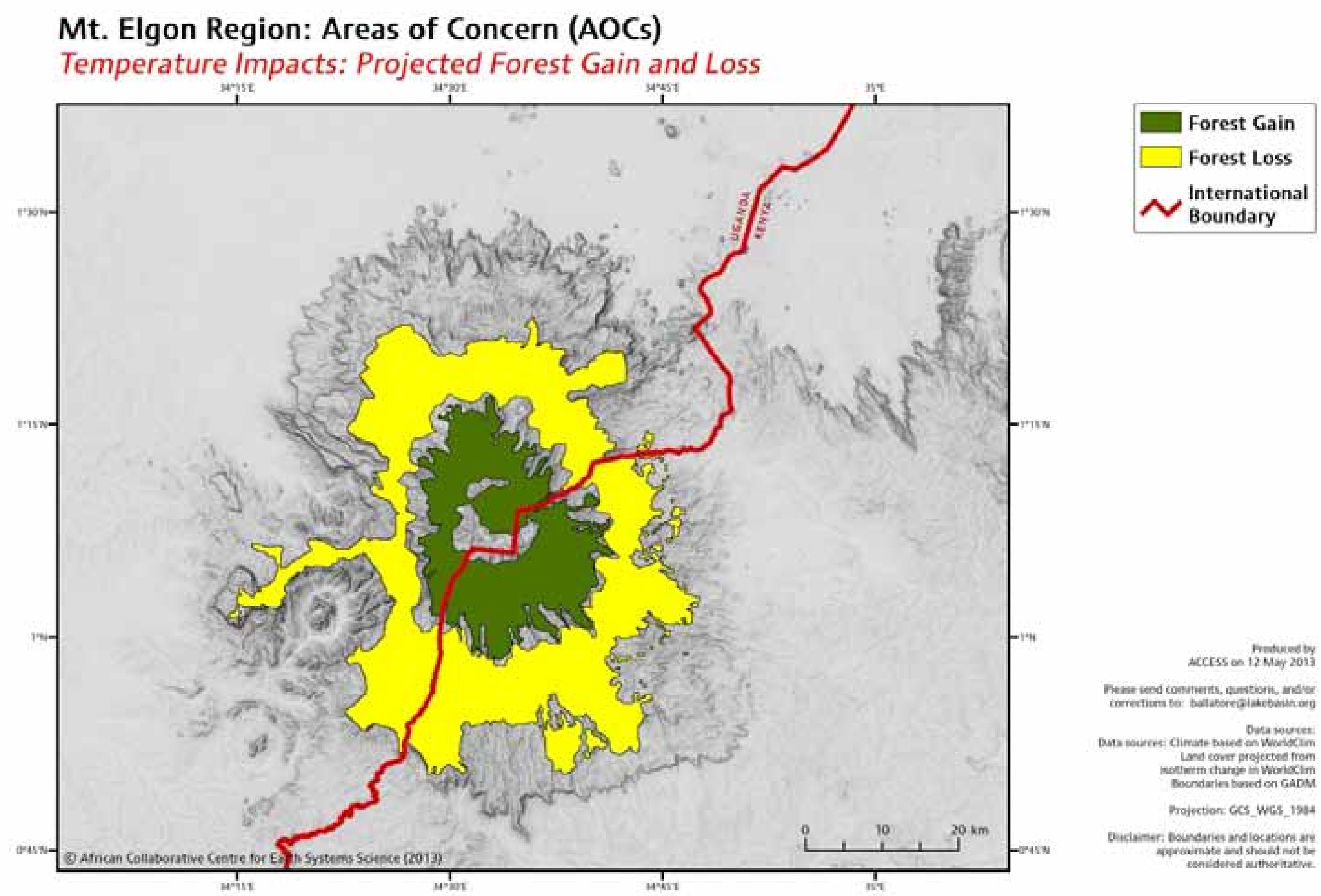
The upper forest boundary (between native forest and high mountain grassland and moorland) is relatively far from human encroachment. The boundary is probably the result mainly of climatic factors including temperature that limits tree growth at higher elevations. The lower forest boundary (between native forest and mostly croplands) is directly influenced by human encroachment.

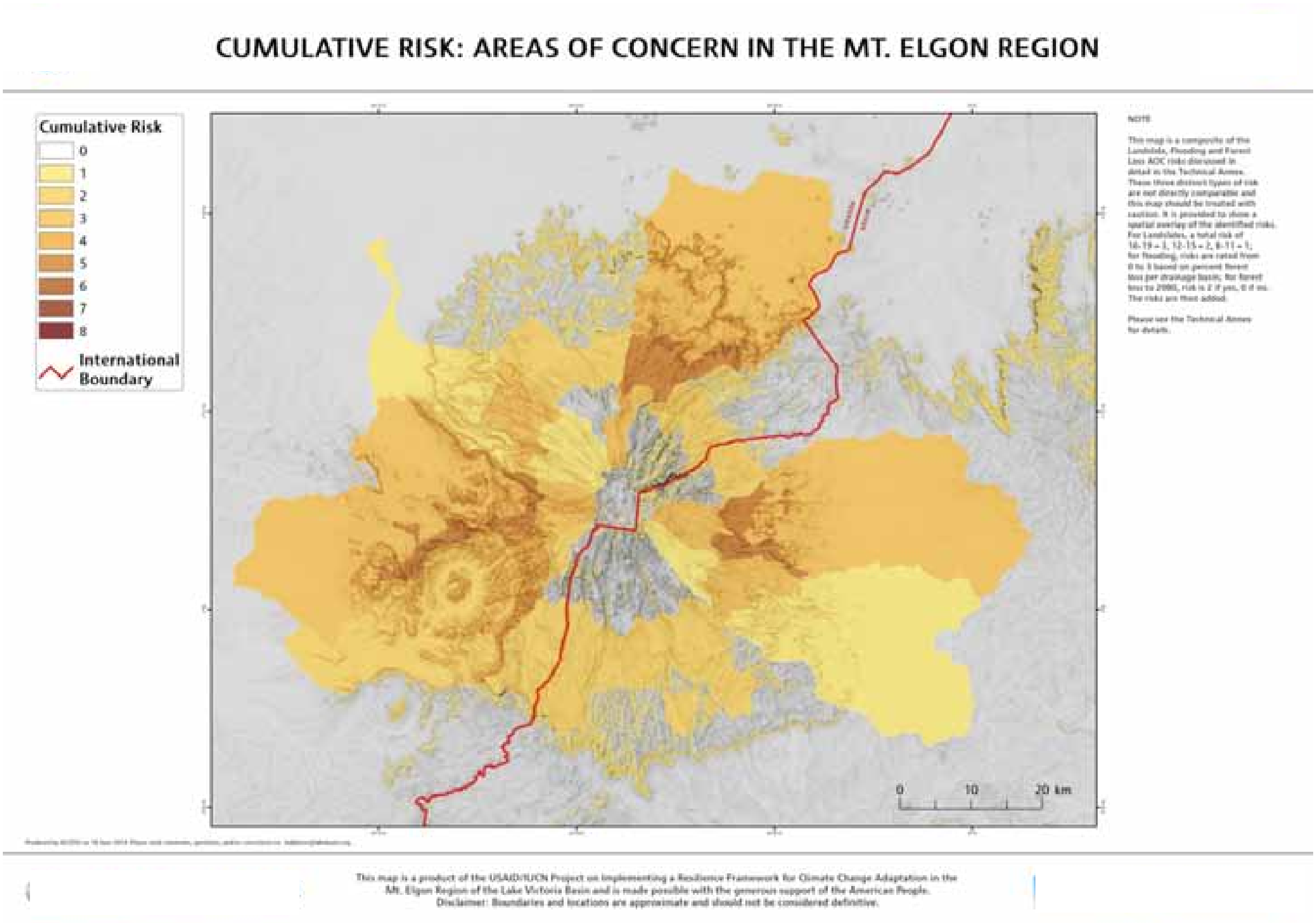
Temperature is no longer likely to be the direct determinant of tree cover at this lower boundary. Full socioeconomic and population movement modeling was beyond the scope of this analysis; however, it seems likely that as temperature increases across the whole region, Mt. Elgon will provide a nearby buffer. Hence, pressure on the lower boundary is likely to increase.

To estimate the upward shift in "tree compatible" temperatures (shift in upper and lower forest boundaries), the current (2013) lower and upper forest boundaries were converted to line features and the value of the baseline temperature for each cell underneath the lines was tallied. An average value was calculated with the mean temperature at the upper forest boundary of 11.2°C with a standard deviation of 0.9, and the mean temperature at the lower forest boundary of 16.5°C with a standard deviation of 1.8.

The temperature predictions for 2060-2080 were then used to map potential future lower and upper forest boundaries with the predicted 16.5°C and 11.2°C isotherms. The areas of potential loss and gain in forest cover are shown in the figure below. It must be noted that other factors besides temperature such as encroachment and clearing land for agriculture will also determine the future forest cover on Mt. Elgon and this analysis is provided to highlight a single issue (temperature).

Files used in this analysis are available upon request.





10.4 Cumulative Risk

A map of "cumulative risk" was produced to show the sum of the Landslide, Flooding, and Forest Loss AOC risks discussed above. These three distinct types of risk are not directly comparable and this analysis should be treated with caution.

For Landslides, the total risk raster was reclassified so that a risk of 16 to 19 = 3, 12 to 15 = 2, 8 to 11 = 1; for flooding, risks were rated from 0 to 3 based on percent forest loss per drainage basin; and for potential forest loss to 2060-2080, risk is 2 if yes, 0 if no. The risks were then added.

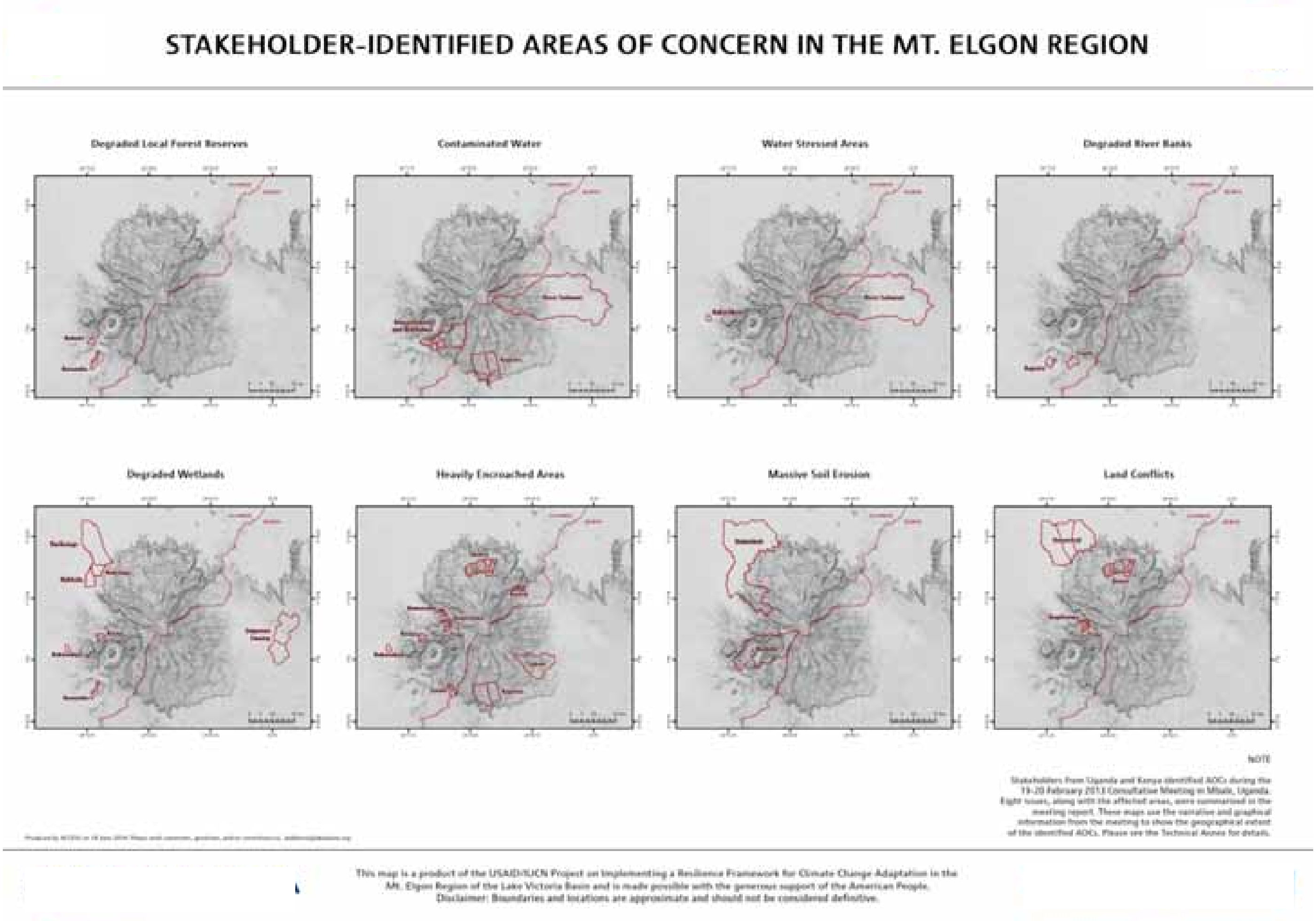
Files used in this analysis are available upon request.

10.5 Stakeholder Identified AOCs

Before the geospatial AOC analysis described in this Technical Annex was carried out, stakeholders from Uganda and Kenya identified AOCs during the 19-20 February 2013 Consultative Meeting in Mbale, Uganda. Eight issues, along with the affected areas, were summarized in the meeting report.

The minutes of the meeting (include abundant maps and photos) were used to turn the words describing AOCs into locations. The finest detail GADM boundary files (4th level sub-locations for Kenya and 5th level parishes for Uganda) were used to match location names with the meeting notes. For the Kenyan side this was relatively straightforward; for the Ugandan side, this was more complicated because of the recent renaming and redrawing of boundaries. Nevertheless, it was usually possible to match a name from the meeting notes with the corresponding location in the GADM shapefile. Auxiliary information was often used to ensure a proper matching.

The final shapefile, depicting the eight issues, is shown below and is available as **stakeholder_AOCs.shp**.



11. Notes on GIS Files

11.1 Availability

The files noted in bold throughout the report and tallied in the list below are available by writing to ACCESS at access@uonbi.ac.ke.

In work of this scope, many intermediate, temporary files were created but are not likely to be of interest to the general user. Therefore, they are made available upon special request.

11.2 List of Files

bounding_box.shp

srtm_dem1_nodata.shp

dem1

dem1_slope

dem1_curve

dem1_aspect

swbd.shp

traced_lakes.shp

glwd.shp

river_edits.shp

final_rivers.shp

gadm_trimmed.shp

final_boundaries.shp

protected_areas.shp

geology.shp

soil_type.shp

soil_drainage.shp

baseline_temp.tif

baseline_precip.tif

temp_2070.tif

precip_2070.tif

composite_2013.img

composite_1973.img

classification.shp

accuracy_assessment.shp

pour_points.shp

drainage_basins.shp

stakeholder_AOCs.shp

11.3 Metadata

All final geospatial outputs are accompanied by a formal description (metadata) conforming to the metadata standard *ISO 19139, Geographic Information – Metadata-XML Schema Implementation*. This standard was chosen because it is a global standard consistent with ISO 19115 but with xml, and because no other standard is currently widely used in either Kenya or Uganda.

For those without access to ArcGIS, each GIS file has an associated .xml file which is readable with a text editor or in a variety of other GIS software packages.

The minimum metadata requirements for each file have been met and the metadata has been validated. To the extent possible, all metadata elements in each item's metadata have been populated; however, some have been left blank.

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