



**AfCAP**  
Africa Community Access Partnership



## The use of appropriate high-tech solutions for road network and condition analysis, with a focus on satellite imagery

Final Trials Report



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TRL Ltd.

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**AFRICA COMMUNITY ACCESS PARTNERSHIP (AfCAP)**  
***Safe and sustainable transport for rural communities***

AfCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa. The AfCAP partnership supports knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. The programme follows on from the AFCAP1 programme that ran from 2008 to 2014. AfCAP is brought together with the Asia Community Access Partnership (AsCAP) under the Research for Community Access Partnership (ReCAP), managed by Cardno Emerging Markets (UK) Ltd.

**See [www.research4cap.org](http://www.research4cap.org)**

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Airbus DS

## **Acronyms, Units and Currencies**

AfCAP	African Community Access Partnership
AfDB	African Development Bank
AoI	Area of Interest
CERSGIS	Centre for Remote Sensing and Geographic Information Services
DEM	Digital Elevation Model
DFID	Department for International Development
ESA	European Space Agency
ESM	Electronic Support Measures
ELINT	Electronic Signals Intelligence
GIS	Geographical Information System
GPS	Global Positioning Satellite
HIC	High Income Country
IoT	Internet of Things
IQL	Information Quality Level
IRI	International Roughness Index
LIC	Low Income Country
LIDAR	Light Detection and Ranging
LVR	Low Volume Road
MTRD	Materials Testing and Research Division
NIIRS	National Imagery Interpretability Rating Scale
NRSC	National Remote Sensing Centre
OSM	Open Street Map
PMU	Programme Management Unit
RAI	Rural Accessibility Index
RAMS	Road Asset Management System
RCMRD	Regional Centre for Mapping of Resources for Development
RDU	Research and Development Unit
ReCAP	Research for Community Access Programme
SAR	Synthetic Aperture Radar
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UNRA	Ugandan National Roads Authority
VHR	Very High Resolution

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## **1. Executive Summary**

This trials report is almost three months later than planned, due to delays in the implementation of the satellite condition trials. These trials have now been completed in all four participating countries, Ghana, Kenya, Uganda and Zambia, which are AfCAP countries and were selected to provide a full range of environments, climates and geographies in which to test the methodology. Other high-tech solutions have been investigated, but no practical trials were completed. The other solutions do however have a role to play in the final methodology for a combined high-tech solution for network analysis on rural roads in Africa.

The focus of this project was to develop a methodology for cost-effective condition assessment using satellite imagery. Imagery was procured for all countries at very high resolution, along with SAR imagery and some lower resolution imagery to test the feasibility of reducing the cost. Training has been completed in all countries in GIS applications and image interpretation, in order to prepare the teams to assess road condition from the imagery.

Some conclusions and recommendations have been made, which focuses on maximising the strengths of the manual assessment system, whilst identifying the weaknesses. These lessons learned were used to develop the methodology to be included in the final guideline. The project will conduct a workshop at the T2 conference in Zambia during May 2017, where the potential for practically implementing the high-tech solutions identified, including the satellite imagery assessment, will be explored.

## **2. Introduction**

This project is designed to look to the future for road management in Africa and explore different and innovative cost-effective solutions to well established problems. There are two main aspects to the project, the high-tech solutions to increase knowledge of rural road networks and the assessment of road condition using high resolution satellite imagery.

There are four participating countries; Ghana, Kenya, Uganda and Zambia. These countries were selected because they have very different climates, geography, levels of vegetation cover and rainfall, which provides the necessary range of conditions in which to test the methodology. This report has been split into two parts due to delays in implementing the trials by some countries; the Interim Trials Report was submitted in February 2017 and is therefore supplemented by this final report.

There have been no practical research trials into the high-tech solutions, but all four countries have participated in the satellite condition assessments. As well as researching the technical and cost aspects of high-tech solutions, the project is considering the sustainability of the system and how it can be designed to be easily used and replicated by local institutions.

## **3. High-tech solutions to increase knowledge of rural road networks**

The high-tech solutions identified in the desk study report have been assessed in the Interim Trials Report. No significant change has occurred since that report, so this section will only report the relatively minor changes that have taken place. The Interim Trials Report should be referred to for the main comments on the high-tech solutions.

### **3.1 Prioritised technologies**

The following technologies were investigated:

- **Social media/Facebook app.** The draft app interface is in the process of being revised to better reflect the requirements of the local road authorities. Before the app can be activated the Ministry of Roads and Highways (MRH) in Ghana has to decide whether it has the capacity to deal with the potential feedback. If an invitation such as this to report road defects is launched, the public will expect some response, so the Ministry must be prepared for this. The public will also expect that response to be rapid, such is the nature of social media. In this case it may be possible to carry out a restricted release within a small area in order to test the possible responses and to see what type and quality of feedback can be expected. This would be a potential subject for future research in AfCAP countries.
- **Back analysis.** As a result of the training course in Ghana, where two partially overlapping images were procured within the Aol, Airbus DS decided to experiment with their change detection algorithm to see if it would prove to be feasible for detecting change on roads. The algorithm is normally used to detect changes in land use or vegetation cover, but it can use the same principles to try and detect changes in the surface of a road.

The initial results can be seen in Annex 1. The algorithm was used initially on areas of badly deteriorating paved roads, where the change should be quite obvious.

- **Unmanned Aerial Vehicles (UAVs).** UNRA in Uganda is still in the process of procuring a UAV, which they intend to use for alignment surveys and other road-related investigations. Some countries were interested to trial this technology, but the capital costs of procuring a UAV were prohibitive and there are very few places in Africa where they can be hired.

The World Bank has used fixed wing UAVs very successfully in Tanzania. One project is called 'Ramani Huria', supported by World Bank and DFID. This was implemented to map areas vulnerable to flooding in Dar es Salaam. It used GPS and UAVs, along with teams of local community volunteers, to help with the mapping. The project uses OpenStreetMap (OSM) as a base map for the work, which is also built up using crowdsourcing from local volunteers. In addition a project is being carried out to map the urban areas of Zanzibar, also using UAVs. This has been extended to cover the whole island, using a similar methodology. Again OSM, QGIS and other freeware is used to make the project as appropriate and sustainable as possible.

A recent development is a high altitude, pseudo-satellite called the 'Zephyr', which is essentially a lightweight UAV. The Zephyr fills the capability gap between satellites and UAVs by flying at higher than 65,000 feet, which is above weather and commercial aircraft. It is solar powered and can stay aloft for long periods of time, at present it has set a world record of 340 hours, whereas other UAVs have only achieved a maximum of 80 hours. There are also environmental benefits to using the Zephyr; the website claims that "Replacing one conventional unmanned aircraft with a Zephyr would save 2,000 tons of fuel per year". <https://airbusdefenceandspace.com/our-portfolio/military-aircraft/uav/zephyr/>

In addition to high resolution still photographs, the Zephyr can also take high resolution video, as well as utilising LIDAR, RADAR, Electronic Support Measures (ESM)/Electronic Signals Intelligence (ELINT) and Broadband communications. Imagery is nominally between NIIRS 6 and NIIRS 8, which is better than the Pleiades imagery used for the satellite condition assessment. NIIRS is the National Imagery Interpretability Rating Scale and is explained in the training materials provided to each country, with 1 being the lowest resolution of imagery and 9 being the highest. An extract showing examples of the NIIRS scale is shown in Annex 2. To date the Zephyr's potential is seen mainly as monitoring extreme natural events and military reconnaissance, but as more becomes known about its capabilities the possibilities for network analysis and knowledge building of roads can be assessed.

At present the cost of such imagery is not clear, although it could be cheaper than conventional satellites. At present condition analysis would probably be more effectively carried out using conventional UAVs, but this would be a potential technology to investigate in the near future.

- **Spectral reflectance.** The aim of considering the spectral reflectance process in this project was to see if the age and possibly the condition of a road could be identified. This particular use is only applicable to paved roads, which have a standardised surface where the materials can be reasonably identified or assumed from the imagery. The possibility of using spectral reflectance was raised in Ghana, as this is where the paved road assessments were tested. This was discussed with the local experts CERSGIS, but the necessary software and resources were not available. It does however remain as a potential technology to identify materials on the road and in the case of paved roads, their age and condition. Reference can be made to the research carried out in California, as shown in the Interim Trials Report.
- **Climate Change:** In terms of climate change and road network assessment, satellite imagery does have some potential uses. It could be used to identify areas vulnerable to flooding, using Digital Elevation Models (DEMs). The training courses included how to manipulate DEMs to show drainage basins and channels, and most participants found it to be useful for their work. Additionally, change detection can be used to identify changes between two visual images very clearly by recognising changes at pixel level, as shown in the Interim Trials Report. This warrants further research to see if change detection can be useful to identify climate vulnerable areas and roads.

### 3.2 Existing technology utilised:

- **DashCams:** As mentioned in the Interim Trials Report, the use of DashCams was very successful. As well as providing a high definition video of the road, the GPS information is also captured so that the route alignment can be mapped. The cameras have been very useful in auditing the ground truthing on the road. In addition they have been useful in helping to identify anomalies that appear on the satellite image, which are not immediately identifiable from the imagery. Examples of such anomalies can be seen in Annex 3.
- **Mobile phone apps:** The RoadLab mobile phone app was used for ground truthing in this project, and was discussed in the Interim Trials Report. Whilst the accuracy for unpaved roads was not found to be very reliable for the poorer conditions in terms of providing an absolute IRI value, it was nevertheless useful for providing an overview of road condition whereby roads within a network could be compared to each other.

### 3.3 Other potential links:

There are also existing high-tech solutions that are being used to solve problems in the rural roads sector, and others that have potential.

#### **Big Data:**

The potential uses of big data for increasing our knowledge of rural roads in LICs was discussed in the Desk Study report. Satellite imagery itself could be classed as big data; if multiple images were used, for example with frequent images from mini-satellites, it would be necessary to find a different way to manage them. There are examples of big data being used in the roads sector, such as for traffic information and ground movements, as mentioned in the Desk Study report, but it was not possible to carry out trials in this area of the project.

#### **Rural Access Index (RAI):**

The RAI was outlined in the Interim Trials Report as a transport headline indicator designed to focus on the critical role of access and mobility in poverty reduction. It is designed to determine the percentage of rural populations that live more than 2 km from an all-weather road, which is an important global indicator.

The Rural Access Index (RAI) has also been implemented in Tanzania under ReCAP with DFID funding. A new methodology was proposed, using more high-tech solutions, and has been trialled in eight pilot countries, which includes Tanzania. The report can be seen using this link: <http://documents.worldbank.org/curated/en/367391472117815229/pdf/107996-REVISED-PUBLIC-MeasuringRuralAccessweb.pdf> . The very high resolution imagery used by this project should be useful in identifying how far people live from the road, and the methodology used on the 'Ramani Huria' project which maps potential flooding areas and people at risk in Dar es Salaam, would also be useful in terms of identifying households.

#### ***Open Street Map (OSM):***

Open Street Map was described in the Interim Trials Report. There are numerous examples of this technology being developed in Africa, and the principle of using local crowdsourcing to help develop the maps is one that can be replicated in other fields, with potential for use in the assessment of road condition by satellite imagery. One factor in the satellite condition analysis process is the calibration, which requires condition information on a wide range of roads in the country. This could be partly provided by local volunteers, either within the road organisation or from local communities. With the ability of smartphones to take high quality photographs and internet connectivity, this could be managed whilst minimising the resources required to carry out the calibration. Linkages to OSM will be considered for the final guideline.

#### ***Google Earth:***

The use of Google Earth imagery was considered, but the main problems were that:

- The imagery quality/resolution is variable. Some is very good and on a par with the Pleiades or DigitalGlobe imagery used on this project. Other imagery is of a much lower resolution and could not be used for condition assessment, but is still useful for mapping.
- Most of the imagery on Google Earth is more than a year old, with some much older. This imagery will be too old for condition assessment because the condition of the unpaved roads will have changed too much over that period of time.

Google Earth is however a good source of maps and most of the main networks have been digitised relatively accurately. Some checks were carried out whilst the ground truthing was under way and there are some areas where the mapping is incomplete or incorrect, but these are relatively few.

#### ***OpenRoads:***

The OpenRoads project in the Philippines is establishing an information base of roads and road projects. It uses a variety of sources, including satellites, drones and any open source material that is available. One aspect is that it uses volunteers to send in geo-tagged photos or information on roads, in order to build up as much information as possible on the road network. The Philippines is very decentralised and as a result the responsibility for roads is fragmented, so this acts as a way to pool information and create maps and project databases.

#### ***Internet of Things, internet solutions:***

The internet is all about connections and is a potentially very powerful tool to help increase our knowledge of road networks. Devices with sensors, such as smartphones, can lead the way as they have been doing in HICs. These concepts were discussed in the Desk Study report, but no practical

applications were identified that could be trialled. The OpenRoads project mentioned above is able to use different data sets in different formats and combine them into a single user interface.

***Machine learning, artificial intelligence:***

These concepts were again discussed in the Desk Study report. The most relevant potential for this technology is the potential automation of road condition assessment using satellite imagery. As mentioned before this is being trialled in Tanzania, with the potential for involvement in any future research carried out as a result of this project.

## **4. Condition assessment by Satellite Imagery**

### **4.1 Imagery procurement:**

The imagery for the road condition assessment by satellite imagery was procured as close to the time of the ground truthing as possible, in order to rule out any discrepancies due to changes in road condition that may have happened as a result of traffic, environment or indeed maintenance. Generally the imagery was tasked with criteria of < 10% cloud cover and < 20° angle of incidence.

A range of different suppliers were checked, in line with comments from the peer review, but ultimately imagery from DigitalGlobe and Pleiades was acquired, as well as some SPOT 7 imagery and TerraSAR-X SAR imagery. Others were available from different suppliers, but those mentioned were the most cost effective as procured through Airbus DS, who are an approved re-seller for many of the main imagery suppliers.

It was planned to acquire the imagery during the dry seasons in each country, in order to maximise the chances of getting cloud-free images. This also happens to be the season when condition surveys are normally carried out. This was largely achieved, although due to delays in the ground truthing some issues with cloud cover were experienced.

All of the imagery was processed by Airbus DS in the UK, in order to provide the best clarity of image for the assessment. The processing was an essential part of the production, as some images suffered from haze or low definition, and the processing provided more definition of the image in the important areas, i.e. the road surfaces.

### **Ghana**

For Ghana a variety of imagery was procured:

- Pleiades 0.5m resolution, acquired on 29<sup>th</sup> January 2017 for the western half of the Aol.
- SAR scene for the Aol located centrally within the main Aol for the Pleiades acquisition.
- SPOT 7 imagery at 1.5m resolution for the whole of the Aol
- Pleiades 0.5m resolution from December 2014 for the whole of the Aol. It was not possible to task Pleiades for the eastern half of the Aol due to persistent cloud cover and haze, so archive imagery was used. The imagery is just over two years old, but little maintenance has been implemented in this area recently, so the conditions are expected to be similar. However, the 2014 imagery was significantly less clear than the new imagery. This is thought to be partly due to the atmospheric conditions and partly due to improvements in processing of the newer imagery.
- The new Pleiades imagery for Ghana was still somewhat hazy. Initially it was assumed that this was the humidity, but on further research it was noted that the seasonal winds from the Sahara often bring sand from the desert over the region at this time. This is called the 'Harmattan' and normally occurs in the West African subcontinent between the end of November and the middle of March. It is characterised by dry and dusty northeasterly trade winds, which blow from the Sahara Desert over West Africa into the Gulf of Guinea.

The Harmattan blows during the dry season, which occurs during the lowest-sun months, when the subtropical ridge of high pressure stays over the central Sahara Desert and when the low-pressure Intertropical Convergence Zone (ITCZ) stays over the Gulf of Guinea. On its passage over the Sahara, it picks up fine dust and sand particles (between 0.5 and 10 microns). In some countries the heavy amount of dust in the air can severely limit visibility and block the sun for several days, comparable to a heavy fog. This effect is known as the Harmattan haze and it can cause airlines to cancel or divert flights. In Ghana this year it was present during late January and early February; the time when the imagery was procured.

#### **Kenya**

- Pleiades 0.5m resolution, acquired in February 2017 for the Training AoI at Kajiado, south of Nairobi. This imagery is very clear and without cloud.
- Pleiades 0.5m resolution, acquired on different days during February and March 2017 for the main AoI area at LogLogo/Laisamis. This area required four different acquisitions due to the longitudinal nature of the AoI. Some of the imagery contains small amounts of cloud, but the roads are relatively clear.

#### **Uganda**

- Pleiades 0.5m resolution, acquired on 6<sup>th</sup> September 2016 for the main AoI at Luweero. There was some cloud present in the imagery for Uganda as the time of acquisition was in the transition between the dry season and the wet season. Although the weather was still predominantly dry, the cloud had started to build at the beginning of the wet season. The quality imagery was clear, despite the cloud, which obscured about 10% of the roads.
- The Pleiades imagery for Uganda was also downsampled to represent 1.0m and 1.5m resolution imagery. This is a process whereby the resolution is reduced artificially to approximate lower resolutions.

#### **Zambia**

- DigitalGlobe 0.5m resolution, acquired on 6<sup>th</sup> September 2016 for the main AoI at Chongwe. This imagery was cloud free, but the definition on the road surface itself did not appear to be as clear as in the other imageries. There is no apparent reason for this, but it could be down to climatic conditions at the time, or the production of the images.

A summary of the imagery costs can be seen in Annex 4.

## **4.2 Ground Truthing**

In line with the principles of this research, it was decided that each country would carry out ground truthing in line with the existing system that is used to collect condition information in each country. This would test the methodology in the real conditions in which it would have to operate, and would allow the results to be put in context, especially in terms of condition surveys in previous years. The exception to this was Zambia, which is involved in the ReCAP GEM project and is introducing a new condition assessment regime based on assessing condition every 5 km.

All partners have completed ground truthing surveys, although some were delayed due to a lack of funding. There was insufficient time to include the project in their annual plans, so it proved difficult for them to allocate funding, with the most common solution being to transfer funding from other projects to this one.

The methodologies employed to complete the ground truthing are shown below:

### **4.2.1 Visual Surveys:**

The basis of the ground truthing in each country was to carry out visual surveys, the details of which are in the Interim Trials Report. These were supplemented in some countries by other means, such

as roughness and speed measurements, but the core assessment was visual. This is even more important for unpaved roads, where the options for using physical measurements are more restricted.

Visual surveys are of course to some extent subjective. In order to minimise the subjectivity, most countries have broken down the condition of a road into several different aspects, such as the area of potholes, the crown or camber, the amount of gravel loss, etc. This forces the assessor to think about all of the aspects of road condition separately, and record them separately. By doing this it reduces the risk of making an incorrect judgement based on a first impression of the road.

The satellite assessment does a similar thing by identifying different aspects of the road that can be assessed, such as width, edge clarity and colour/shading. This is also an attempt to reduce the subjectivity of the assessment.

Each country has a different condition assessment system, which were explained in the Interim Trials Report. All countries used a five-level system, except for Ghana which only uses three; Good, Fair and Poor.

Updates from the Interim Trials Report are shown below:

- **Ghana:** There is no set length that a road should be assessed on, but the aim is to have sections of not less than 1km. Basically, where there is a significant change in road surface type or condition, this forms the start or end of the section. It can be seen from the ground truthing that sections are generally in the region of 500 m to 2 km long. This is reasonable when using a three level system of condition assessment.

Ghana was able to survey unpaved and paved roads. In total 87.289 km of road was ground truthed, with 57.983 km of unpaved road and 29.306 km of paved road.

- **Kenya:** There is no established system of condition assessment for unpaved roads, so when condition assessment is necessary the paved road condition forms are used, filling only the relevant items. For the purposes of the ground truthing for this project a Roughometer was also used, although this is not common practice in Kenya on unpaved roads. It is recognised that the Roughometer is not as effective on unpaved roads, so the results were audited and adjusted using manual assessment and DashCam videos, where available.

Due to logistical issues, only 30 km of ground truthing was carried out using the Roughometer. However, a total of 77.8 km was ground truthed, using visual assessment and DashCam videos to assess the remainder. The researchers are satisfied that the ground truthing is accurate and can be used as a reliable baseline for the roads.

- **Uganda:** In Uganda there are detailed guidelines on how to use the condition assessment forms, with the assessment being made every kilometre, or less if there is a significant change in the road such as a change of surface. In addition to visual assessments, a DashCam was used, as well as the RoadLab roughness app.

For the road condition analysis weighting factors have been used by UNRA to adjust the results in favour of those factors that are more relevant to unpaved roads, and therefore have more impact on their condition. For example a higher weighting is applied to gravel thickness and roughness than to other factors.

UNRA are the main partners with the project, but are not responsible for the more rural roads in Uganda. This responsibility lies with the district administrations, so UNRA were able to liaise with them and ground truth a significant number of minor roads. The total length of ground truthed roads is 145.7 km, of which only 34.8 km were UNRA roads.

- **Zambia:** The team in Zambia carried out ground truthing using the methodology from the GEM project, with conditions assigned to every 5 km of road, but were unable to analyse the conditions as the training had not yet been scheduled. So a manual analysis was carried out using factors that were relevant to the roads and the local conditions. These results were compared to the DashCam videos and RoadLab roughnesses and were found to be appropriate.

In total 52.7 km of ground truthing was achieved. This was less than was hoped, but resources were limited. Similarly to Uganda, RDA is not responsible for the more rural roads, so it was more difficult to survey these. The RDA did liaise with the local districts to carry out some surveys, but there were more roads that could have been surveyed and which would have added to the validity of the results. Only 7.6 km of local road were surveyed.

Because the minimum length of road for assessment of any condition level is quite long at 5 km, a basic survey was carried out to determine if it would have been more accurate to assess the condition from satellite imagery on the same basis. The results can be seen in the analysis section 4.6 of this report.

#### *4.2.2 Roughness:*

As mentioned in the Interim Trials Report, all countries used a mobile phone app to record IRI measurements. This supplemented their visual assessments of the road. Although it was found that the RoadLab app was less accurate for fair and poor condition unpaved roads, it was useful as a tool to compare the relative roughness between roads, or sections of road. There are now several different apps on the market that produce similar outputs, but it would be useful to carry out a research project to compare them against established IRI values.

As mentioned before Kenya is intending to carry out a research project to compare the results from different IRI equipment, including the roughometer, Bump Integrator and smartphone apps. This will be a useful body of research to help determine which equipment is most accurate for unpaved road roughness measurement.

#### *4.2.3 Dashboard cameras:*

As mentioned in the Interim Trials Report, Dashboard cameras (DashCams) were used for all ground truthing surveys. The model used was the Nextbase 402G, which has an integrated GPS.

There were a number of minor issues experienced with DashCams, but overall they were found to be a very effective tool for road condition assessment. The issues were:

- **Clean windscreens:** It is important for the driver to keep the windscreen clean at all times, as the camera is mounted inside the vehicle. This is most important for unpaved roads where dust and mud can restrict visibility.
- **Reflections:** If items are left on the dashboard they can cause reflections in the windscreen, which will show on the video image and restrict the quality of the image and what can be seen. It is important that the dashboard area is kept clear.
- **Downloading and saving from SD card:** Because the SD digital storage card only has 32 GB capacity and the camera will overwrite it when it reaches this capacity, the data needs to be downloaded regularly. Each 32 GB card can store at least 4 hours of HD video at the highest resolution. Two SD cards were supplied with each camera, which is sufficient to capture one day of video, but the data will need to be downloaded at the end of each day to prevent it being overwritten.
- **Size of files.** When a large amount of video is taken, the size of the files builds up quickly. It will be necessary to have external storage for the videos, with backup on a central server.

- **GPS accuracy:** The accuracy of the GPS tracks is nominally between 3 m and 10 m laterally; an example of this can be seen in Annex 5. This accuracy is good enough to locate the GPS track from the video on a satellite image, which at present is sufficient for this project. However, if automated assessment is explored at a later date the track would need to be more accurate.

### 4.3 Issues with ground truthing:

The main issues with ground truthing were identified in the Interim Trials Report, but additional information is shown below:

- **Uganda:** Ground truthing was completed before the Interim Trials Report, so no more issues to add.
- **Zambia:** Ground truthing was completed before the Interim Trials Report, so no more issues to add.
- **Ghana:** Ground truthing was completed before the Interim Trials Report, so no more issues to add.
- **Kenya:** There is no established system to assess the condition of unpaved roads in Kenya. Therefore, the survey team used the paved road assessment forms and filled the areas that were relevant to unpaved roads only. The paved system is based on a five level assessment, but the team are of the opinion that a four or three level system would be adequate for unpaved roads.

Despite the funding issues mentioned in the Interim Trials Report, MTRD were able to carry out the ground truthing survey in advance of the funds being provided. When the ground truthing was eventually carried out only a limited length of road was surveyed, due to logistical issues. As mentioned previously a Roughometer was used to measure IRI, but this information was revised and supplemented by visual surveys and DashCam video analysis.

### 4.4 Local partnerships

Part of the principle of sustainability was to use local remote sensing organisations as partners to the local road organisations. These organisations were identified in the country selection report and are essentially a local remote sensing organisation, usually part of government, who can assist the road department with the remote sensing and GIS aspects of the project. They are particularly useful to assist with the mapping and digitisation activities of the assessment. GIS expertise is often limited in roads departments, so these partnerships will provide robustness to the system that is not dependent on the international consultants.

The local remote sensing organisation also provided supplementary training where necessary, in advance of the formal project training. This was to ensure that everyone was of a similar level of GIS knowledge, which meant that the formal training could be more efficiently delivered.

- **Ghana:** In Ghana the MRH partnered with the Centre for Remote Sensing and Geographic Information Services (CERSGIS). Their services include acquisition or procurement of optical and radar satellite images for individual and corporate uses.
- **Kenya:** In Kenya the main partner for MTRD was The Department of Resource Surveys and Remote Sensing (DRSRS). They are the main government remote sensing body and are a department of the Ministry of Mining. DRSRS is mandated with the collection, storage, analysis, updating and dissemination of geo-spatial information on natural resources to facilitate informed decision-making for sustainable management of these resources with the major aim of alleviating poverty and environmental management.

- **Uganda:** In Uganda UNRA's main partner was Makerere University, Department of Geomatics and Land Management. There was no obvious government based remote sensing partner in Uganda, so Makerere University were selected. They have a relevant department and were very interested to cooperate with the project.
- **Zambia:** In Zambia the main partner for RDA was The National Remote Sensing Centre (NRSC). They are the main national body responsible for remote sensing and were established in 2008 in conjunction with national efforts at mapping and producing inventories of national resources and land-use using remote sensing technology.
- **Other Partners:** Also based in Nairobi are RCMRD, who are an independent regional centre for remote sensing and have 20 contracting member States in East and Southern Africa. RCMRD carried out the training for MTRD in Kenya, so are familiar with the project. CERSGIS in Ghana are a similar type of regional organisation, independent from government.

#### 4.5 Mapping

The status of mapping has remained as shown in the Interim Trials Report. The digitisation from the satellite imagery has produced more accurate and up to date maps than were originally available in each country. As discussed earlier the accuracy of DashCam and RoadLab GPS tracks is approximate, with accuracy of 3-10 m. Digitisation can be much more accurate than this if carried out with care and precision. In order to get accurate digitisation it is necessary to zoom in and out frequently, and estimate the centre line of the road. When the road curves it is necessary to add more points in order to get a smooth line that accurately represents the centreline of the road.

The quality of digitisation between the maps produced by the partner countries does vary, but not greatly. Only in very few cases has the digitised line fallen outside of the road surface area, usually on tight corners. Most errors that have been noticed are due to an insufficient number of digitised points around a corner. It is assumed that the digitisation has been carried out with the road zoomed out too far, and although this is a faster way to digitise the road it is not possible to achieve the required accuracy.

Additionally it is very important to use the correct projection when digitising the roads. There are several different projections that can be used, often within the same country, so for mapping purposes it is important to take time to check the geographical location and select the correct one. It is possible to do a crude check of the digitisation by overlaying the digitised road on an established mapping system, such as Google maps or OpenStreetMap, and see if they match.

With mapping it is also good practice to snap the points at the end of each road to a connecting road. This is covered in the training manual and powerpoint, but it basically means that the roads will connect. In this respect if the roads do connect, the road that starts with a connection to another road will need to start from the centreline of that road, which should be taken into account when measuring the road lengths.

#### 4.6 Condition assessment

The project has completed condition assessments in all partner countries. The main objective of the research was to learn from the process employed and follow through those lessons into the methodology to be developed as part of the final guideline. The principle of using local resources and local staff to carry out the ground truthing and manual assessments was a key aspect of this, so that the research reflected reality if a country was to employ this system to assess the condition of their road network. In addition, the final guideline will recommend how different high-tech solutions can interact with each other to provide a holistic system of network assessment.

A number of issues have been noted in the Interim Trials Report and throughout this report. Most of these issues were not experienced during the Nigeria research, as that was carried out under project condition, using project resources and very advanced equipment. Also the main condition assessment was carried out by Airbus DS staff in the UK, with high quality software and hardware at their disposal. In this respect it would have been optimistic to expect a similar result.

It should be noted that a scoping study was carried out for Tanzania to determine whether they could be included in the project. There is also a pilot research project under way in Tanzania to test the feasibility of using automated assessment of road condition from satellite imagery. This will be very relevant to this project and would be the next logical step to develop this methodology.

This section summarises the results of the research and provides information for the development of the final guideline and methodology.

#### *4.6.1 Training*

The condition assessment was preceded by a training course in GIS and image interpretation, delivered by Airbus DS and TRL in Zambia, Uganda and Ghana, and RCMRD and TRL in Kenya. The training was delivered on the following dates:

- Zambia: 21<sup>st</sup> to 23<sup>rd</sup> November, 2016
- Uganda: 29<sup>th</sup> November to 1<sup>st</sup> December, 2016
- Ghana: 8<sup>th</sup> to 10<sup>th</sup> March, 2017
- Kenya: 5<sup>th</sup> to 7<sup>th</sup> April, 2017

Training was an essential part of the project. The main training in Zambia, Uganda and Ghana was carried out by Ned Chisholm of Airbus DS and Robin Workman of TRL, whereas the training in Kenya was carried out by Byron Anangwe of RCMRD and Robin Workman of TRL. Photographs from the trainings in Uganda and Zambia can be seen in the Interim Trials Report, and from Ghana and Kenya in Annex 6.

In each case the training included the AfCAP partner roads institution plus a local remote sensing institution, which was either a government body, a University department or in the case of Ghana an independent remote sensing organisation. The remote sensing partners were:

- Ghana – Centre for Remote Sensing and Geographic Information Services (CERSGIS)
- Kenya – Department of Resources Surveys and Remote Sensing (DRSRS)
- Uganda – Makerere University, Department of Geomatics and Land Management
- Zambia – National Remote Sensing Centre (NRSC)

Training manuals and powerpoint presentations were produced for each country and have been handed over to the countries for future use. Each training course lasted for 3 days and included a half-day field trip.

In addition, each country has produced a local guideline which is used to calibrate the system for the particular types of roads and conditions in each country. The participants were shown how to do this in the training and then produced the guideline for each country shortly afterwards, before the assessments started.

RCMRD attended the Uganda training, in order to experience how it was delivered and to prepare for the Kenya training, which they conducted themselves. They were engaged as a local subcontractor to test if the training could be carried out sustainably from a supplier within the region.

Training assessment questionnaires were completed anonymously by all of the participants and a training assessment report can be seen in Annex 7. Overall the feedback was good. It should be

remembered that the training included two very different institutions, a roads institution and a remote sensing institution. Much of the first day and a half was focused on how to use QGIS in the context of the project, whereas the remainder of the training was focused on image interpretation and road details, so the two different institutions will have had quite different perceptions of the training.

**Issues with training:**

- Before the training started it was recommended that the maximum number of participants should be between 6 and 8 people. However, for the training in Zambia and Uganda 12 people attended, in Ghana there were 10 and Kenya had 7. Whilst it was good to see such interest in the project, it made it difficult for the trainers to give enough individual attention to the participants, with the danger that some would fall behind. Much of the first day was used to set up the QGIS software using spatialite files to prepare drop-down boxes, which would be used to determine the attributes of the road. This made the first day quite challenging in terms of ensuring everyone was up to speed and fully understood the process.
- There were some common issues, such as electricity shortages and start delays caused by traffic, but these were not significant in affecting the training negatively.
- In the majority of cases the participants were able to provide a laptop with QGIS installed. Where this was not the case, the trainers were able to assist the participants to set up the software quite quickly. In Kenya RCMRD were able to loan laptops to those who did not have them.
- In general the training was well attended, with most people attending for the full period. Less than 15% of the participants did not attend for the full duration of the course.
- Due to the fact that the participants were from different institutions, the level of QGIS knowledge varied quite significantly. This was especially evident on the first day, where the remote sensing specialists found it quite easy, and the roads specialists found it harder. Where possible the roads institutions had provided basic training in QGIS to their staff in advance of the training, but this was not possible in all cases.

Most of the issues listed above are common for locally arranged courses and should be expected when carrying out training. However, probably the most important aspect that can be controlled is the number of participants. If more than 8 participants are present then an additional trainer should be employed, as it is essential that all participants fully understand the process and how to set up QGIS for road condition assessment. From the training feedback it is also advisable to hold the course over a longer period, or add one or two days at a later date to check and refresh the participant's skills. Detailed recommendations for training will be included in the final guideline.

**4.6.2 Data analysis:**

In this section the data from each individual country will be analysed.

**Ghana:**

Ghana was the only country to use a three level condition assessment system, as mentioned before. It was assumed before the assessments started that it would be easier to assess roads using this system, as opposed to a four or five level system. In addition Ghana was the only country with significant lengths of paved rural road. It was assumed it would be more difficult to assess the condition of paved roads from satellite imagery due to the lack of contrast in the surface and the fact that paved roads have fixed pavement widths, as width was one of the main visible factors that indicate condition.

In total 57.983 km of unpaved roads were assessed, as opposed to 29.306 km of paved roads. There was also a trial carried out using archive imagery, which was just over two years old. This was

undertaken in order to test the feasibility of using archive imagery, which is cheaper than tasked imagery. SAR imagery was also procured for a small area in Ghana, in order to check whether it is a viable option for assessing road condition, as it is not affected by cloud cover.

The headline results for Ghana for the correlation of assessment against ground truthing in percentage, are represented by the graph in Figure 1, for both unpaved and paved roads.

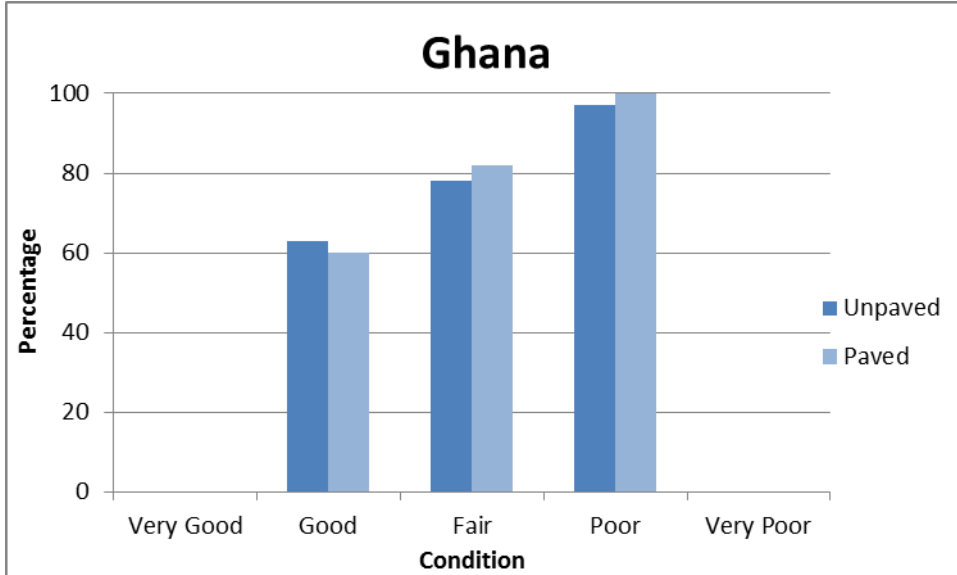


Figure 1

It is worth noting that for unpaved roads the length of good condition road was less than 2.5 km, with fair and poor making up the remaining 55 km. Hence the overall correlation of 87%, as can be seen in Table 1 below. The results for both unpaved and paved are very consistent.

**Unpaved assessment:**

This assessment was carried out on the unpaved roads, using both the 2014 and the 2017 imagery.

UNPAVED Assessment			Misclassified as;				
	Ground truthing (km)	Corresponding Satellite assessment (km)		Good	Fair	Poor	Unknown
Good	2.441	1.547			0.158	0.736	0
Fair	28.026	21.979				6.047	0
Poor	27.516	26.65			0.866		0
	<b>57.983</b>	<b>50.176</b>					

Correlation			Percentage of correctness
Good	2.441	1.547	63%
Fair	28.026	21.979	78%
Poor	27.516	26.65	97%
	<b>57.983</b>	<b>50.176</b>	<b>87%</b>

Misclassified as more than one level out:  
0.736 1.27% > 1 level out

Table 1

From Table 1 it can be seen that the overall level of correlation between the ground truthing and the satellite assessment is quite good, 87%, compared to previous results in Nigeria which showed 64%. However, there are a number of reasons that can be attributed to this:

- There are only three levels of condition, as opposed to five in Nigeria, so it is logical that the allocation of condition is easier and therefore more accurate.

- There are very few roads in the 'Good' category at 2.441 km, so most of the decisions the assessors had to make were between fair and poor condition.

It can be seen that the level of roads that were misclassified by more than one level, i.e. classified as good instead of poor, or vice versa, is only 1.27%. This is less important for a three level assessment, but does indicate a reasonable level of confidence.

These results are also represented in the graph shown in Figure 2, which shows the length of ground truthing and the length of assessed road where there was correlation.

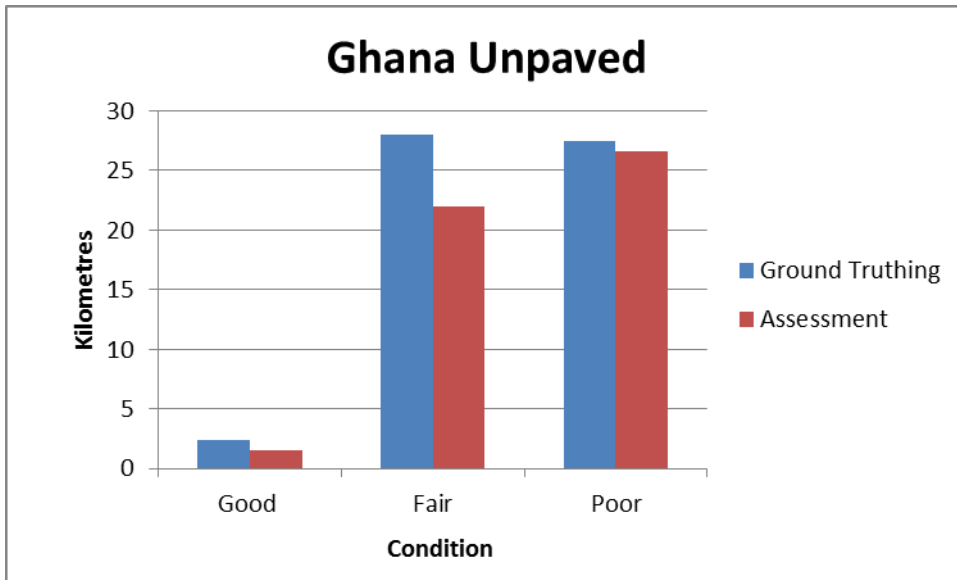


Figure 2

**Paved Assessment:**

This assessment was also carried out using both the 2014 and the 2017 imagery, and the overall correlation for paved roads in terms of percentage can be seen in the graph in Figure 1.

PAVED Assessment			Misclassified as;				
	Ground truthing (km)	Corresponding Satellite assessment (km)	Good	Fair	Poor	Unknown	
Good	4.527	2.716		1.693	0.118		0
Fair	22.934	18.918	3.467		0.549		0
Poor	1.845	1.845					0
	<b>29.306</b>	<b>23.479</b>					

Correlation			Percentage of correctness
Good	4.527	2.716	60%
Fair	22.934	18.918	82%
Poor	1.845	1.845	100%
	<b>29.306</b>	<b>23.479</b>	<b>80%</b>

Misclassified as more than one level out:  
0.118 0.40% > 1 level out

Table 2

From Table 2 it can be seen that the paved road assessment is also good, but not as accurate as the unpaved assessment. This was expected due to the features that can be seen on each surface type, with less visible features available for paved roads. For paved roads the width is generally not variable due to lined side drains and fixed pavement widths, and the edges do not vary as much as unpaved roads. However, in some cases it is possible to use the white lines and how worn they are as an indicator. There is, however, a remarkable consistency between the unpaved and paved surfaces, with poor showing very high correlation, and reducing to fair and good. However, the

range of roads in each condition is not even, with the majority being in fair condition, and only a total of less than 6.5 km being good and poor.

The graph of the ground truthing against the assessment can be seen in Figure 3. The most significant feature of this graph is how much road has been ground truthed and assessed as fair condition.

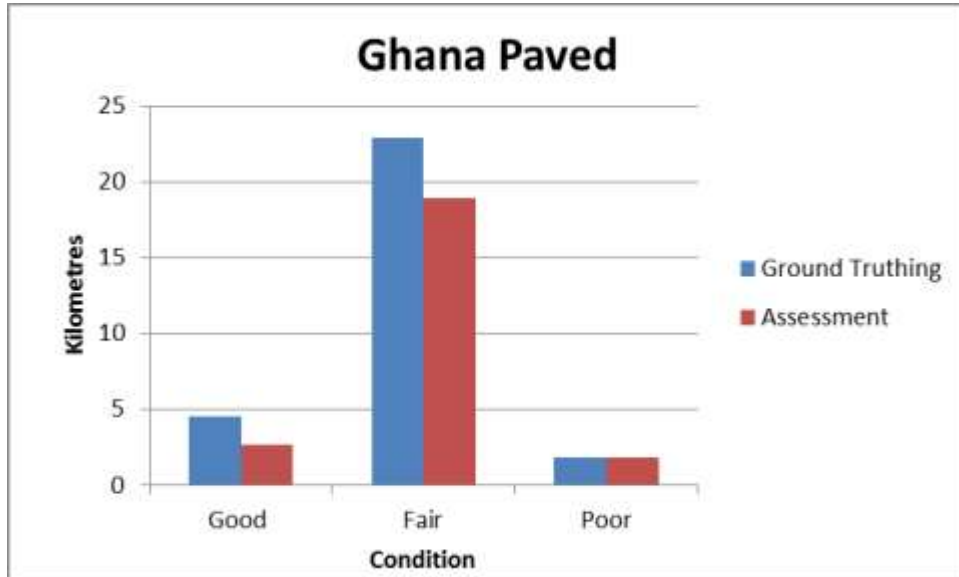


Figure 3

Also the percentage of misclassification that was more than one level out is very low at 0.4%.

Auditing showed no errors in the compilation of the data or in the condition assessment, so the results were not revised. The results for Ghana were also tested for the differences between the two imagery dates of 2014 and 2017. Unsurprisingly the results for 2017 were more accurate as at least one road has been rehabilitated in the intervening period.

#### Kenya:

Kenya used a five level assessment system, although it was based on a paved road assessment system as unpaved condition surveys are not regularly carried out. The graph in Figure 4 below shows the results from the Kenya assessment. Again it should be noted that the good category only contained 4.318 km of road, significantly less than the other categories.

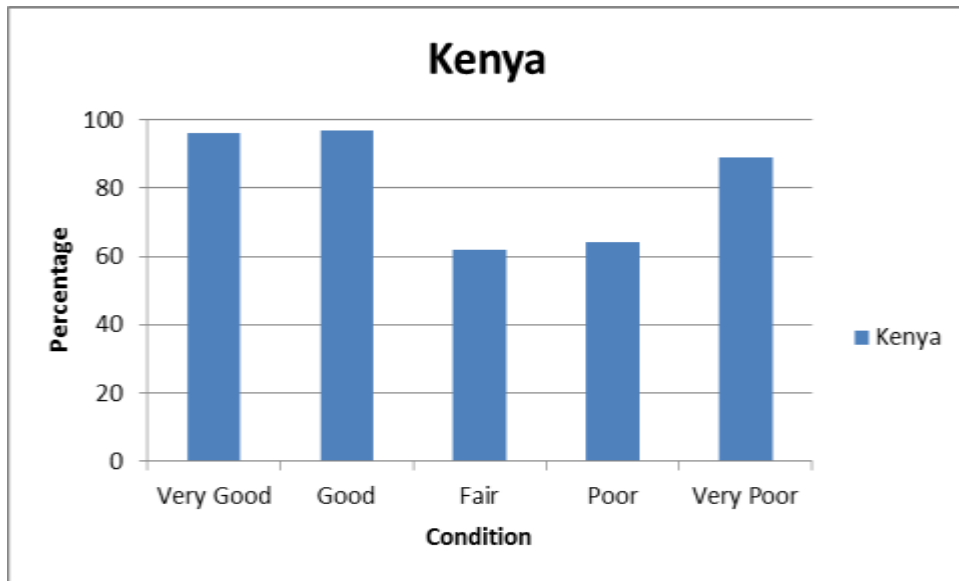


Figure 4

**Unpaved assessment:**

All of the roads in Kenya are unpaved. The only paved road in the area is the main highway from Nairobi to the Ethiopia border, which doesn't fall into the category of a rural low volume road.

Assessment			Misclassified as;					
	Ground truthing (km)	Corresponding Satellite assessment (km)	V.Good	Good	Fair	Poor	V.Poor	Unknown
V Good	36.432	35.13		1.302				
Good	4.318	4.202	0.116					
Fair	13.479	8.377				4.004	1.098	
Poor	10.983	7.07			0.95		2.963	
V Poor	12.67	11.271				1.399		
	<b>77.882</b>	<b>66.05</b>						

Correlation			Percentage of correctness
V Good	36.432	35.13	96%
Good	4.318	4.202	97%
Fair	13.479	8.377	62%
Poor	10.983	7.07	64%
V Poor	12.67	11.271	89%
	<b>77.882</b>	<b>66.05</b>	<b>85%</b>

Misclassified as more than one level out:  
1.098 1.41% > 1 level out

Table 3

The overall correlation results for Kenya also look very good, especially considering that a five level condition assessment system was used. The correlation in the good and very good categories is very accurate, with results in the high 90's. However, it should be noted that one road had recently been rehabilitated, which made it very easy to assess; this road constitutes the entire very good category. It was a gravel road that was regravelled, so the surface appeared on the satellite image as very consistent in colour and shading. The side drains were also reshaped, which meant that the road width and edges were also very consistent. These are the main factors that are used to determine road condition from satellite imagery, so it is logical that a newly rehabilitated road would be consistently assessed as very good. The results for fair and poor are 62% and 64% respectively, which is more in line with other results for a five level condition assessment system.

The graph below in Figure 5 shows the ground truthing against the assessment.

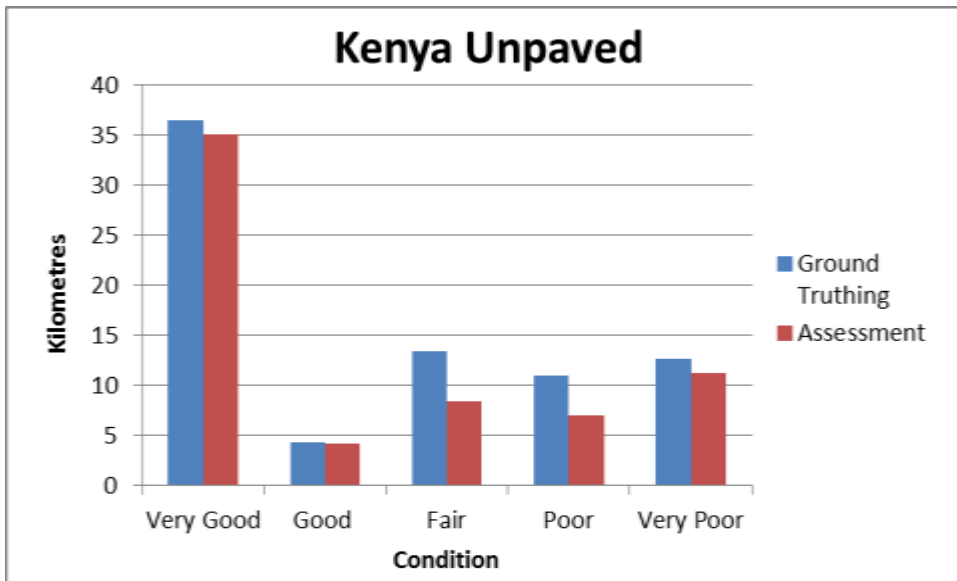


Figure 5

Perhaps a more relevant assessment would be to look at the results for fair, poor and very poor, which are more in line with the results that would be expected, between 60% and 80%

The level of misclassification more than one level out was also good at 1.41%, the main issue being a section of fair road that was assessed as very poor.

**Uganda:**

Uganda also used a five level assessment. A total of 145.745 km of road were ground truthed. The graph in Figure 6 represents the assessment results for Uganda, noting that the very good condition category only contains 3.878 km of road, out of a total of 145.745 km.

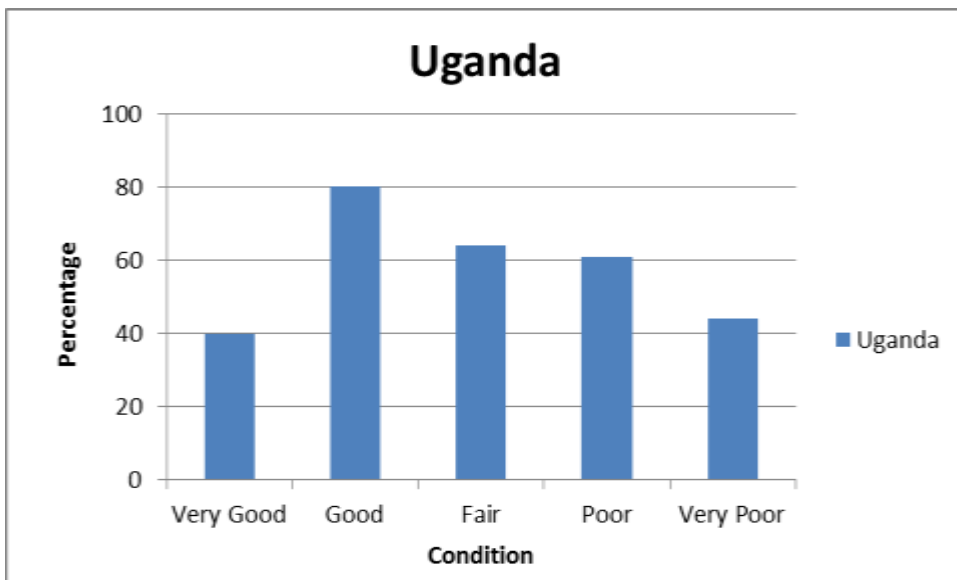


Figure 6

**Unpaved assessment:**

All of the roads that were ground truthed in Uganda were unpaved. There was a paved road in the AoI which is the main road from Kampala to the north of the country, but this does not fall into the

category of a rural low volume road and was therefore omitted. There was a mixture of earth and gravel roads, and generally it was possible to tell the difference from the imagery.

In Uganda the original assessment carried out by the team showed quite poor correlation. The results were generally between 33% and 74%, with an overall average of 43%. This is less than was expected, so checks were carried out on the processes used. During the training a draft guideline was built up to demonstrate how to carry out the assessments, based on general assessments of the roads that could be seen on the imagery. The full guideline could not be finalised at that time because the ground truthing had not been fully analysed. Instructions were left with the team to revise the guideline, based on the fully analysed ground truthing, but this was ultimately not done and the draft guideline was used to assess the road condition. This is clearly not ideal and is reflected in the results achieved.

Following the completion of the ground truthing analysis and a further visit by the Team Leader to Uganda, the guideline was revised and a further assessment was carried out using a different assessor. This was audited and no errors were found in the compilation or analysis of the data, so no further revisions were made.

The final assessment can be seen in Table 4

Assessment			Misclassified as;					
	Ground truthing (km)	Corresponding Satellite assessment (km)	V.Good	Good	Fair	Poor	V.Poor	Unknown
V Good	3.878	1.54		2.338				0
Good	29.036	22.128			3.831	1.34	0.279	1.458
Fair	17.739	9.79				3.917	1.705	2.327
Poor	78.893	42.237			9.488		17.101	10.067
V Poor	16.199	6.345			2.903	5.273		1.678
	<b>145.745</b>	<b>82.04</b>						

Correlation			Percentage of correctness
V Good	3.878	1.54	40%
Good	27.578	22.128	80%
Fair	15.412	9.79	64%
Poor	68.826	42.237	61%
V Poor	14.521	6.345	44%
	<b>130.215</b>	<b>82.04</b>	<b>63%</b>

Misclassified as more than one level out:  
6.227 4.27% > 1 level out

Table 4

The results in Table 4 above show an overall correlation between the ground truthing and the satellite assessment of 63%, which is on a par with the Nigeria research at 64%. As mentioned earlier there was some cloud cover on the Uganda image, which obscured some sections of road. These sections have been entered in the 'Unknown' column and have been excluded from the final analysis. The roads under cloud cover therefore had no bearing on the final results as they were ignored in the analysis.

It can be noted that the very good and very poor conditions were not assessed as accurately as the other levels. The correlation for fair assessments has reduced from the original, whereas those for good and poor have increased, which would suggest that the revised guideline has helped the assessor in clarifying the conditions of the majority of roads that were in that group (111.816 km out of 130.215 km). The very good level is small at only 3.878 km, so no real conclusions can be drawn from this result. The majority of roads were ground truthed as poor, at more than 50%, which showed a correlation level of 61%, again in line with the Nigeria results.

A possible reason for the variety of results and the lower levels of correlation than Kenya is the fact that the area had a much higher level of vegetation compared to the desert in Kenya, plus more

minor roads were included in the study. This made it harder to define the road edges and widths, which are key elements in the interpretation of the imagery. In Ghana there were only three condition levels, so a lower correlation would be expected in comparison, even given that Ghana has high levels of vegetation as well.

The graph below in Figure 7 represents the ground truthing against the assessment. It shows quite clearly that the majority of roads are in poor condition.

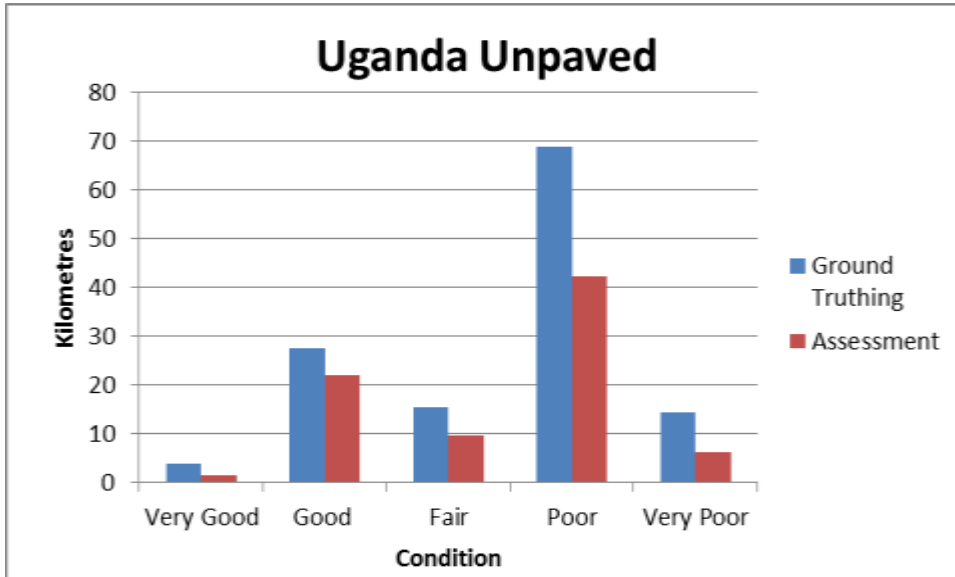


Figure 7

The level of roads that were misclassified at more than one level out was 4.27%. These misclassifications were spread across the range of conditions, which suggests that this was quite a difficult environment in which to assess roads.

**Zambia:**

For Zambia the initial overall assessment showed that 59% of the satellite assessment correlated with the ground truthing. However, as discussed before the ground truthing was carried out on the basis of the GEM project survey methodology with one condition for each 5 km section of road. The satellite assessment changed whenever a change in the surface condition was visible, but without noting very short sections of road less than 250 m.

When the audit was carried out it was found that there appeared to be an error in the assessment for one of the roads. Road U13 was shown as green (good) on the ground truthing, whereas on the ground truthing spreadsheet it was shown as poor. This was assumed to be a straightforward mistake in assigning the correct condition to the correct road in QGIS, so the ground truthing was adjusted in QGIS and the correlation re-assessed. This demonstrates the importance of checking the information and how easily it can be misrepresented in the software. This is a potential weak point in the system and will be addressed in the final methodology.

The graph in Figure 8 shows the assessment results for Zambia. It is essential to note that although the very good category shows 100%, there were no ground truthed roads in this category and no roads were misclassified as very good.

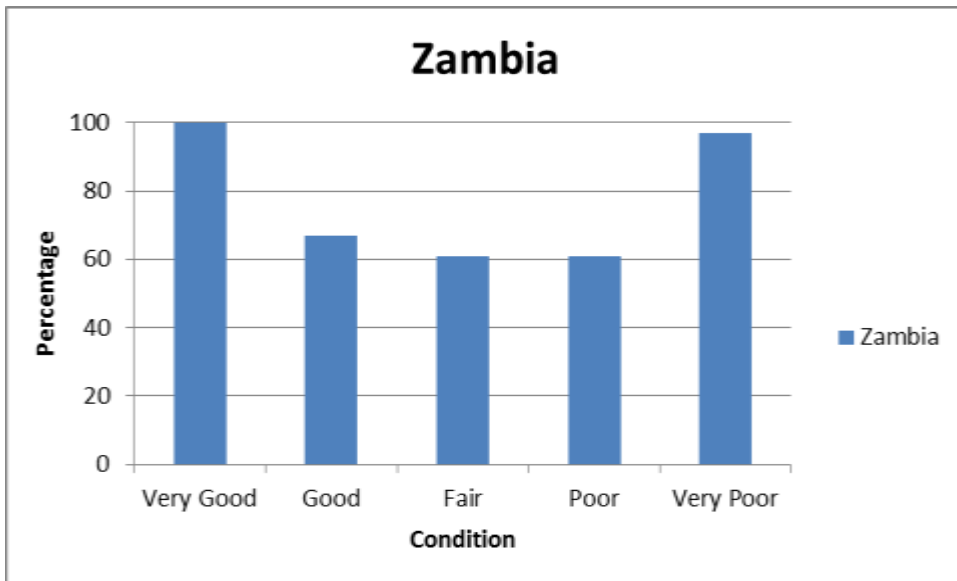


Figure 8

The revised assessment for Zambia can be seen in Table 5.

From Table 5 it can be seen that the overall revised assessment is now 69%. It should be noted that no roads were ground truthed as very good, which effectively makes it a four level assessment, although it would still have been possible for the assessors to assign very good to a road. It could be argued that this correlation is 100%, as no roads were misclassified as very good and the assessment agrees with the ground truthing.

Because the ground truthing was based on condition assessments for each 5 km of road, and the satellite assessments are continuous, it was decided to check if the results would change if the satellite assessment was made on the same basis as the ground truthing, i.e. every 5 km. The result was that the correlation would have been 81.2% if the same methodology was used, as opposed to 69% as per Table 5.

Assessment			Misclassified as;					
	Ground truthing (km)	Corresponding Satellite assessment (km)	V.Good	Good	Fair	Poor	V.Poor	Unknown
V Good	0	0						
Good	10.191	6.829			1.139	2.223		
Fair	23.153	14.087		6.835		2.231		
Poor	8.973	5.514			3.459			
V Poor	10.402	10.129				0.273		
	52.719	36.559						

Correlation			Percentage of correctness
V Good	0.00	0.00	100%
Good	10.191	6.829	67%
Fair	23.153	14.087	61%
Poor	8.973	5.514	61%
V Poor	10.402	10.129	97%
	52.72	36.56	69%

Misclassified as more than one level out:  
2.223 4.22% > 1 level out

Table 5

However, assessing the road by satellite every 5 km is a less accurate result than assessing as per the methodology. So essentially, the result would be to employ a less accurate system in order to match the ground truthing more accurately. If the system is able to assess condition more accurately using the current methodology, this should be retained.

The very poor roads achieved almost 100% correlation. The three roads that were ground truthed as very poor were all local roads, which effectively receive no maintenance and are under the responsibility of the local authorities. In this context it is not so surprising that these roads were assessed accurately. The other categories from good to poor were actually very consistent in the correlation they showed, between 61% and 67%.

The graph below in Figure 9 represents the ground truthing against the assessment. It shows that the majority of roads are in fair condition, with no very good roads.

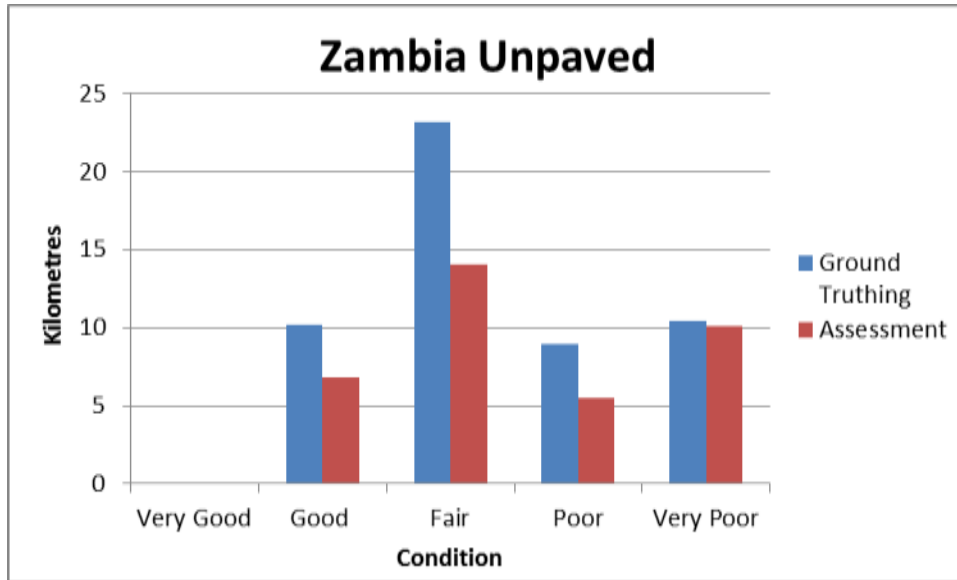


Figure 9

The percentage of roads that were misclassified as more than one level out is 4.22%, consistent with the other partner countries.

#### 4.6.3 Combined analysis:

In order to compare the results of the assessments they have been translated into graphs. The graph in Figure 10 shows all of the results, including the Ghana results which only used three levels of condition assessment.

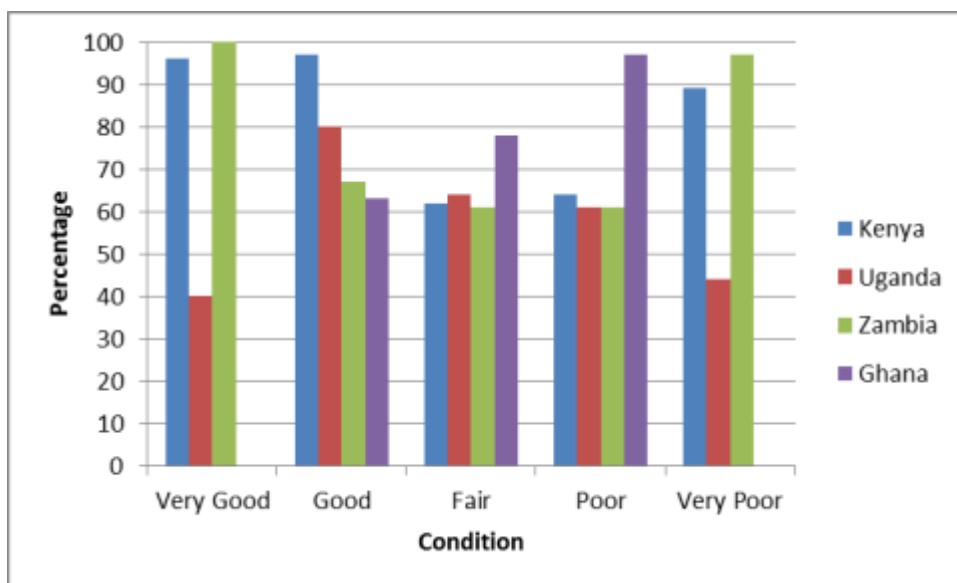


Figure 10

Already it can be seen that the results for very good and very poor are more variable. The low results from Uganda in these categories seem to be at odds to the other results, which all show a high correlation for the extreme ends of the condition scale. The next graph shows the results for all countries, except for Ghana, which used a three scale system. It could be argued that the Ghana results are not valid to show on a five scale graph, as the good and poor would certainly overlap into the very good and very poor, and the distribution between good, fair and poor would also be different. Therefore the next graph in Figure 11 shows only Kenya, Uganda and Zambia.

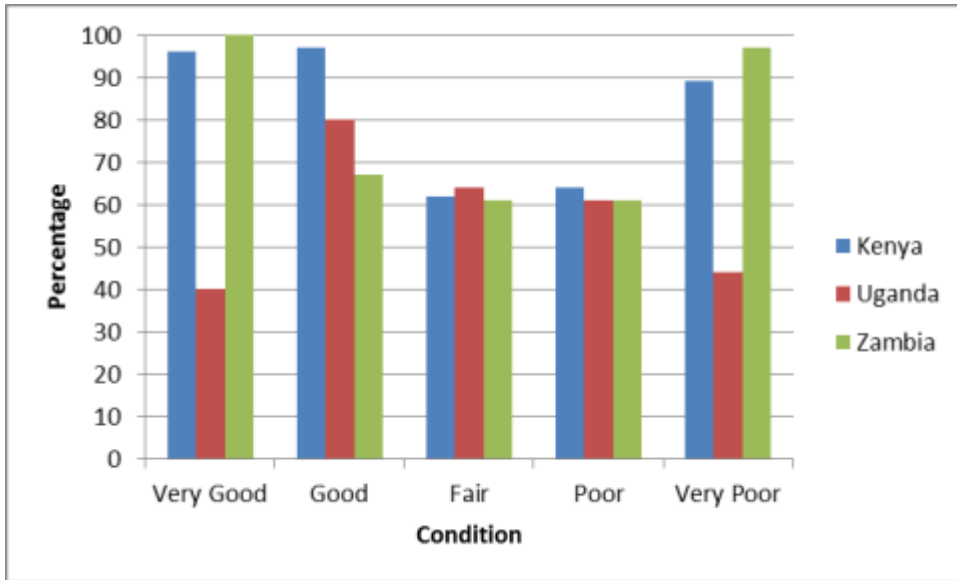


Figure 11

From this it can be seen that the poor and fair assessments are very consistent. However, there were some assessments that included very short sections of road, which distort the appearance of the graph because of the methodology for ground truthing in most countries, which dictates that a minimum length of road should be assigned the same condition, i.e. 0.5 km, 1.0 km or 5.0 km. If the sections of road that constitute less than 10% of the overall assessment for each country are removed, the graph appears as shown in Fig 12. The figure for very poor in Uganda is also a low percentage at 11%, so if this were removed the graph would show a tendency for the assessments to be more reliable at the extremes of very good and very poor.

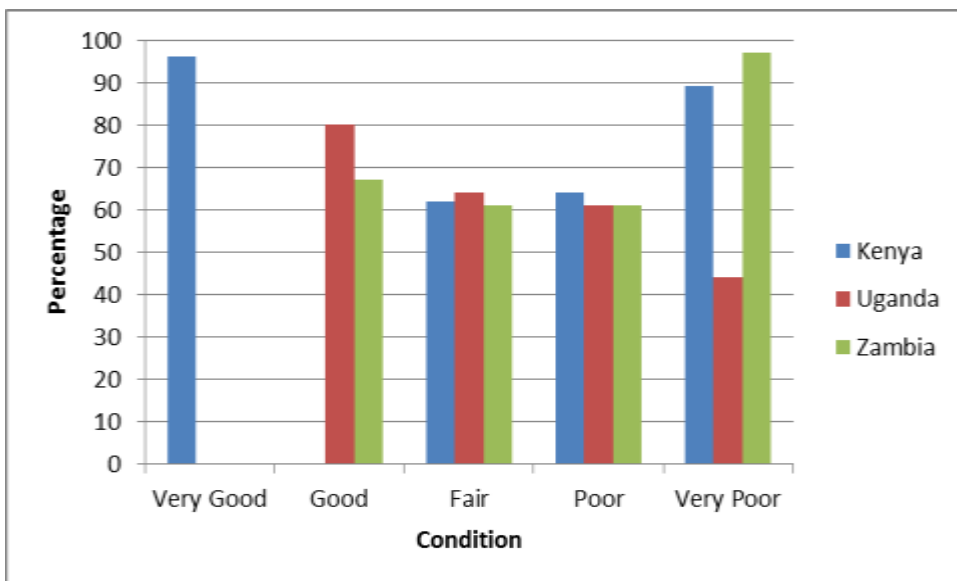


Figure 12

If this is indeed the case, it is necessary to look into the causes. Most of the ground truthing assessments for very poor identify roads that are essentially failed and need rehabilitation. Given the visual indicators that are used to assess from the satellite imagery, such as varying width, winding wheel tracking and surface irregularity, very poor roads should be easy to identify. Similarly, very good is only really assigned to newly constructed or rehabilitated roads, where there will be straight edges, consistent width and regular surface texture. Again, these should be relatively easy to identify, but are likely to be less common.

### Geographical/climatic analysis

The environment in each country can be described as follows:

- Ghana: Tropical, high vegetation, flat
- Kenya: Desert, very low vegetation, flat
- Uganda: Savanna medium rainfall, medium vegetation, rolling
- Zambia: Savanna dry with low rainfall, medium to low vegetation, rolling

In terms of the imagery procured and how it appears visually, the Kenyan imagery is more similar to the Zambian, and the Ghanaian is more similar to the Ugandan. This is helpful in trying to understand some of the reasons for the more diverse results.

Generally in the dry areas such as Kenya and Zambia, the edges of the road are clearer and not obscured by vegetation, which makes it easier to judge the width. The variation in road width and the clarity of the road edge were significant factors in identifying road condition. It is also easier to identify drainage, as the watercourses are much clearer than with a densely vegetated image.



Figure 13

When the graphs above in Figure 13 are viewed again together, it can be seen that there is some pattern to the percentage of matching assessment, with the very good and very poor seemingly easier to identify. In terms of road maintenance, it is probably most important to identify the poor and very poor condition roads, as these are the ones that will require interventions most urgently. The clear identification of road width and edge definition could have helped in this identification.

It is not possible to compare Ghana and Uganda directly as they used different levels of condition assessment, but the accuracy of the assessments for very good and very poor are certainly less than for Kenya and Zambia.

#### 4.6.4 Cost effectiveness

The costs for condition assessment by satellite imagery were analysed using the approximate costs provided by each country for the various activities involved, see Table 6. It has been assumed that

the ground truthing costs are a good approximation for the normal condition assessment surveys, as in each country the existing system of condition assessment was used to carry out the ground truthing. In most cases the ground truthing was undertaken as a stand-alone exercise, so it would probably be slightly more expensive than if it were carried out as part of a larger survey.

For the satellite assessment costs the training has not been included, as this would be a one-off cost. However, the process of calibration has been included and was estimated at up to 10% of the network, which has been estimated as the maximum that would be necessary for the first year of operation.

So in summary the cost estimates (full breakdown is shown in Annex 4) included:

**Traditional visual survey condition assessment:**

- Staff wages to travel to site, carry out surveys and analyse results
- T&S costs to stay overnight, including accommodation and living allowance
- Vehicle and fuel, plus driver
- Any equipment used, such as GPS or roughness measurement

**Satellite assessment:**

- Cost of the imagery
- Cost of the calibration, based on traditional survey costs
- Staff wages to assess the imagery and produce results

Two figures are shown for the satellite imagery costs; the first is using the actual costs of the imagery as supplied by Airbus DS with all relevant discounts applied, and the second is using the headline costs without any discounts. It can be seen that there is a large difference in some cases between the project costs and the headline costs. In most cases the assessment by satellite from the project is only slightly more expensive than the traditional driven surveys, but in order to make the system cost effective it would be necessary to negotiate good discounts for the procurement of such imagery. Experience suggests that this should be possible in most cases.

The cost also depends on the density of roads per km<sup>2</sup> of imagery. Areas with high road density are more cost effective. This is demonstrated by Uganda, where the road density in the table is much higher than the other countries. This reinforces the principle mentioned earlier of planning the imagery acquisition carefully so as to not procure any areas without roads.

In terms of assessment time, the following was observed:

**Visual surveys:**

- Uganda carried out 145 km in 5 days = 29 km per day
- Zambia carried out 53 km in 2 days = 26.5 km per day
- Kenya carried out 78 km in 2 days = 39 km per day (not including 2 days travelling to site)
- Ghana carried out 86 km in 3 days = 28.6 km

All surveys except for Kenya were within 1.5 hours drive from the road department headquarters. It is likely that surveys in the other countries would have achieved better coverage if the teams had stayed overnight in the area, thus reducing travelling time.

**Satellite assessments:** These were carried out at a rate of between 50 km and 80 km per day. It is expected that this will increase with practice, possibly up to 150 km per day. It is also of course possible to assign many people to the assessment and thus increase the overall length of road

assessed per day. This is only limited to the number of people that can be trained, although consistency of assessment could become an issue with a subjective system such as this.

The full cost analysis can be seen in Annex 4.

Country Details	Network Details	Satellite assessment per km this project	Satellite assessment per km headline prices	Traditional condition assessment per km
		£	£	£
<b>Ghana</b>				
Length of road km	37.562			
Square area km <sup>2</sup>	153	<b>22.65</b>	<b>67.12</b>	<b>21.30</b>
Road Density km/km <sup>2</sup>	0.25			
Imagery cost £	590.75			
<b>Kenya</b>				
Length of road km	77.882			
Square area km <sup>2</sup>	288	<b>30.56</b>	<b>58.40</b>	<b>21.40</b>
Road Density km/km <sup>2</sup>	0.27			
Imagery cost £	2088			
<b>Uganda</b>				
Length of road km	145.715			
Square area km <sup>2</sup>	187	<b>10.26</b>	<b>23.49</b>	<b>9.22</b>
Road Density km/km <sup>2</sup>	0.78			
Imagery cost £	836.46			
<b>Zambia</b>				
Length of road km	52.719			
Square area km <sup>2</sup>	119	<b>30.62</b>	<b>40.24</b>	<b>30.00</b>
Road Density km/km <sup>2</sup>	0.44			
Imagery cost £	1251.52			

Table 6

#### 4.6.5 Alternative research options:

The following technologies were tested as part of the trials and will feature in the final methodology if they were found to be feasible for road condition assessment.

- **Downsampling:** One of the objectives of using VHR satellite imagery was to see if it is possible to use lower resolution imagery, which would be cheaper to procure and would also be more readily available as archive imagery, which is even cheaper again. In Uganda the 1.0m and 1.5m imagery of the same area was checked to see if it could be used for condition assessment. In order to do this Airbus DS has downsampled the 0.5m resolution Pleiades imagery to approximately 1.0m and 1.5m resolution. It is important to use the same imagery as the condition will be the same, the only difference will be the clarity of the image.
- **SAR imagery:** In Ghana a scene of SAR imagery was procured in order to test the feasibility of using this type of imagery for road condition assessment. The SAR imagery is only panchromatic and tends to be very grainy, so it does not readily represent a visual image of the earth. The consequence of this is that roads may not be as immediately obvious as they would be on a visual image. It takes some skill and practice to be able to interpret a SAR image.

Some comparisons were made between the SAR image and the Pleiades VHR image in Ghana; these can be seen in Annex 8. The shadings/colours (black and white) in SAR represent the density of the object that reflects the radar waves. So less dense objects appear lighter and more dense objects appear darker. In a densely forested country such as Ghana this means that the dense road surfaces show up quite well against the lighter density of the surrounding vegetation, so the roads are quite visible. This, however, is unlikely to be the case in for example a desert area, where the surrounding materials are exposed and are likely to be of a similar density to the road itself.

Also, when assessing the condition of the road on a SAR image there is no more detail visible than there is on a visual image. Therefore, given the much higher cost of SAR imagery, the fact that it can see through cloud cover is unlikely to make it technically viable and cost effective.

- **Change detection:** Change detection is basically an automated way to identify the differences between two visual images of different dates. Airbus DS have been developing this technology for land areas, but it has never been applied to roads before.

This process was not part of our original proposal. Following discussions with Airbus DS and some local partners it was decided to make a small trial to see if it would be possible and useful for roads assessment. The trial was carried out in Ghana where there are two Pleiades images that overlap, one from 2014 and one from 2017. This provided an ideal testing bed for the technology. The images in Annex 1 show the initial results of this algorithm and, although it does not give great detail at the moment, it does provide evidence that this would be worth pursuing in the future. The potential uses could be:

- Monitoring road projects to see what progress has been made
- Assessing the network quickly to see where the major changes in roads have taken place

#### *4.6.6 Additional Issues with satellite condition assessment methodology:*

The potential issues and barriers to replicating this system sustainably using local resources are shown in the Interim Trials Report. The current methodology was therefore designed to test the feasibility and cost effectiveness of the system in a real environment where the resources and skills of the local staff were used with minimal support from the consultant. These issues will be taken into account when revising the methodology, in order to make it more sustainable and consistent for every situation.

Additional issues that have been encountered are:

- Cleanliness of a road. One example was found where a quarry or construction site had led to mud or dirt being carried onto a paved road, giving it the appearance for a short section of an unpaved road. In this case it was quite obvious what had happened, but for larger sites this may not be the case.
- Vegetation. In Ghana one of the paved roads had the appearance that the shoulders were deteriorating, but on further investigation this proved to be where the vegetation had overgrown the shoulders and was recently cut back. This exposed the shoulders as a different colour, but gave the appearance of gravel shoulders. When the rains come this will most likely leave a more consistent appearance across both the road surface and the shoulder.
- In two cases a road has been rehabilitated between the ground truthing and the imagery acquisition. For the training area in Kenya one road was ground truthed, and was shown to be in a poor to very poor condition. However, two or three days later a grader was used to

rehabilitate the surface and side drains. The satellite imagery was procured the following week. So even though there was only two weeks between the ground truthing and the imagery procurement, the surface appeared to be significantly different.

The second case was in Ghana, where the archive imagery from 2014 was used to test the feasibility of using archive imagery. One road was shown as good on the ground truthing as carried out in December 2016, but on the image from 2014 it was assessed as poor. On further investigation the road was found to have been rehabilitated in the intervening period. This is to be expected for archive imagery and demonstrates that the most accurate results will be gained when the imagery and the ground truthing are taken as closely together as possible.

The final methodology will take account of these issues and make recommendations as to how these can be overcome, avoided or managed.

#### **4.6.7 RAMS**

The data and information from the ground truthing and satellite condition assessment was difficult to manipulate and assess without a GIS based database. Part of the Nigeria study was to include the information in a Road Asset Management System (RAMS), which was very successful. Although it was not possible to include the use of a RAMS in the trials phase of this project, the consideration of linking with a RAMS is very relevant to the future use of this system and has been considered. The RAMS used in Nigeria was the TRL product 'iROADS', which is GIS based and made the analysis and use of the data much easier. Most RAMS that are in operation are now GIS based, which is essential for analysing this type of data.

A potential issue with this aspect is that some countries do not have a RAMS, which can be quite expensive to procure and implement. Also, some countries that do have a RAMS, struggle to maintain it, keep the data current and utilise it to its full potential. The ideal platform for this system is to incorporate it within a fully operational and sustainable RAMS, but it is recognised that this may be the exception, rather than the norm. There may be some additional setup or programming that can be carried out within QGIS that could make the management and operation of the system more user friendly and effective, but this would be the subject of further investigation, most likely by a software expert.

Looking forwards, a new satellite image basemap called 'One Atlas' was launched by in late 2016 that covers the entire earth with professional grade imagery, with all areas at a minimum of 1.5 m resolution and urban areas at 0.5 m resolution, the website is <http://www.intelligence-airbusds.com/one-atlas/>. This basemap is updated at least yearly and is available online 24 hours a day. This overcomes the two main issues with free maps, such as Google and Bing, where the resolution is variable and the age of the imagery can be several years. Although the 0.5m resolution is not yet available in rural areas, this is exactly the type of development that would make the satellite condition assessment system more widely feasible and able to compete logistically and economically with traditional methods. Although exact costs are not available yet, it is expected to be cheaper to use than procuring imagery on a yearly basis. If this type of resource is extended to 0.5 m resolution on a wider scale in rural areas, as it would be expected to over time, it would enable the system to provide the level of cost effective inputs into road asset management that could make it accessible to almost any roads organisation.

## **5 Methodology**

The methodology followed was to carry out manual assessments of the road condition in all four countries. As mentioned in the Interim Trials Report this is a similar methodology to that used in the Nigeria research, but with some important differences, focusing on the principle of sustainability and using local resources to carry out the activities, as well as partnering the roads authority in each country with a local remote sensing organisation. This tests the system under local conditions and increases the confidence in the outputs that are produced.

The training courses undertaken to train the local staff in QGIS and image interpretation for road condition will be an integral part of the methodology contained in the next deliverable. Feedback from the training courses will be used to revise and improve the training materials, which will also be included as part of the final guideline. Detailed feedback on the training can be seen in Annex 7.

All of the relevant high-tech solutions will be taken into account in the methodology. It is expected that a range of technologies working together will provide the ultimate solution for network assessment. The full methodology will be produced in the next deliverable, which is the 'Guideline for the use of appropriate high-tech solutions for rural road network inventory and road condition assessment'.

## **6 Local resources used**

All of the countries who participated in the project were required to provide capital resources locally, as counterpart commitment to the project. As mentioned before, some countries found it difficult to commit resources at short notice because there was not enough lead-in time to include the costs in their annual budgets. Regardless, all countries did manage to make some contribution, with most able to fund the ground truthing, training and assessment activities.

## **7 Programme**

The programme remains the same as in the most recent progress report.

## **8 Conclusions**

There are a number of conclusions that can be drawn from the trials and from initial investigations of high-tech solutions:

- Although it was not possible to trial any of the other high-tech solutions, there are some that are relevant and warrant further investigation. These would be appropriate for inclusion in the final guideline and will be explored further at the T2 conference workshop to determine how they can be utilised appropriately in practice. Amongst those technologies that have the most potential to be used in the final methodology are social media apps, UAVs, back analysis, spectral reflectance and the use of DEMs, with a possible use for climate change.
- The condition assessment by satellite imagery was trialled in a real situation with minimal direct input from the consultants in the practical aspects. A number of issues were encountered that are related to problems which often arise in LIC implementation, such as funding barriers, efficiency and logistical issues, and others as mentioned throughout this report. Despite these issues, the results were comparable to the Nigeria research, which was carried out under project conditions using advanced equipment and with adequate direct funding. Also, the assessments in Nigeria were carried out by Airbus DS staff in the UK. This

fact suggests a high level of confidence that the results could be replicated by countries independently.

- Local remote sensing partners were included in the project, in order to provide the expertise in mapping, image interpretation and GIS capabilities. This partnership worked well and provided some robustness to the process.
- During the condition analysis ground truthing the use of DashCams and IRI smartphone apps was trialled. The DashCams were found to be very effective for providing a permanent record of the road condition at the time of assessment, which could be used to check and audit the ground truthing. The videos were also very useful in identifying any anomalies on the satellite image that could not be readily identified. In the final system only a small proportion of the road network will be ground truthed, so this technology has its main benefit in being able to build up a reference document of typical imagery anomalies. The RoadLab IRI smartphone app was also trialled. Although it was found to be less accurate for the lower condition unpaved roads, it was still useful to provide a relative comparison of road roughness.
- The training carried out was effective. Feedback suggests that it could be one or two days longer, with additional practicals and exercises, but was sufficient to enable the participants to assess the road condition effectively. The Kenyan training was carried out by RCMRD, with support from TRL, but the results were comparable to the other countries, suggesting that local training by RCMRD or a similar organisation would be feasible in the future.
- Mapping was produced from the roads digitised on the VHR imagery. This mapping has proven to be accurate, with a few cases where lines did not match exactly, but this was probably due to the digitisers taking a little less care over the process. Mapping was produced in QGIS and can be overlaid on a number of background images to suit its use. The mapping will be a permanent, accurate representation of the road network that can be edited and updated as necessary in the future.
- The system employed used the existing condition assessment system in each country as a basis for the ground truthing assessment. Hence a five level system was used in Kenya, Uganda and Zambia, whereas a three level system was used in Ghana. This has tested whether the system can be calibrated for use in a range of environments, as well as providing results that can be compared to previous years on a similar basis.
- The exercise to check the accuracy of the satellite assessment was carried out using the same manual process as in Nigeria, so can be compared on a similar basis. As mentioned earlier the Nigeria project was under project conditions with project funding, whereas this project relied on local funding to carry out the ground truthing and assessments, with the consultants providing some input into the training and other support activities. In this respect it would have been reasonable to experience a lower accuracy of assessment. However this was not the case. This can be attributed to the methodology used and in particular the detailed guidelines that were produced following the ground truthing (see Annex 9 for an example). This gave the assessors clear guidance on how to assess the road condition. Detailed guidelines such as this were not produced in the Nigeria study.
- The system by its nature is quite subjective. The detailed assessment guideline that was produced for each country has reduced this subjectivity to some extent, but the manual system will always rely on human judgement, as do the visual ground truthing assessments that each country undertook. It is believed that there is scope to develop an automated

system for condition assessment from satellite imagery, and this is indeed being trialled in Tanzania. If found to be feasible this would make the system less subjective.

- The results of the assessments show an overall correlation of 73.66% for unpaved roads from a total of 318.8 km that were ground truthed (Total of unpaved and paved was 342.1 km). This is in comparison to 64% from 31.5 km of road in the Nigeria study. The current study is more than ten times the size for unpaved roads, and also included 29.306 km of paved roads for Ghana. However, this needs to be qualified by the fact that:
  - The Ghana study only used three levels of condition assessment, so showed a higher accuracy, which will have increased the overall correlation accuracy.
  - The Kenya study included a newly rehabilitated road, which was consistently assessed as very good, again improving the overall accuracy of the assessment.

Without these anomalies the overall assessment correlation would be down to 66.6% from 224.4 km of unpaved road.

- The overall correlation from paved roads in Ghana was 80%, from a total of 29.306 km. It should be remembered that this was a three condition level assessment, so is expected to be more accurate than a five level assessment. In comparison the overall unpaved road assessment in Ghana was 87%. It was expected that unpaved roads would return higher results, because the width of the road can be used to assess, whereas for paved roads this is usually fixed to the paved surface, often with constructed side drains, so the assessment has to rely purely on the surface colour/texture which is often less variable for paved roads. It is assumed that a five level assessment for paved roads would be even harder to assess, although for main roads it may be possible to use the road markings as a factor as well.
- It should be remembered that the staff carrying out the assessments only had three days training, and very little practice before they undertook the assessments. If this was their main activity and they had more experience and practice it is likely that they could achieve higher correlation results. Often short term projects are not taken as seriously as the main activity of a person's job, because they are not judged on the results. It could be argued that if a person were assigned to this job full time and judged on their results, the outputs would be more accurate.
- The use of freely available existing imagery was considered for condition assessment, such as Google earth and OpenStreetMaps. The main problem with these sources is the variability of the imagery quality, plus the date of acquisition. For maximum accuracy in establishing the calibration the imagery should be acquired as close to the date of ground truthing as possible, certainly within the same season, and within a month or two if possible. This reduces the possibility of changes in condition through the environment and minimises the risk of changes in condition due to rehabilitation or maintenance. Once the calibration is established, the assessment should be carried out as soon as possible afterwards, to ensure the assessment is accurate.
- The data and information was difficult to manipulate and assess without a database. Most RAMS that are in operation are now GIS based, which is ideal for analysing this type of data. Incorporating the information into a database, such as the one used in Tanzania, would make the system much more user friendly and would give the user a much larger range of options when processing the data. For example the GIS database should be able to locate structures or defects on a linear as well as on a geo-referenced basis, which is useful as most countries still use chainage to locate their road assets.

- Provision of a database, RAMS, or other type of management system would enhance the utility and user friendliness of the satellite assessment system. Although it provides relevant inputs into an asset management system, including accurate mapping and road lengths, its functionality would be enhanced if it could be incorporated into such a management system that is GIS based. This was trialled to some extent in Nigeria, and there is a possibility that an additional trial will be undertaken in Tanzania in association with the RMAS being developed there. Ultimately, however, the system needs to be flexible enough to link with a range of different databases and asset management systems, because there are many different types already established around the world and it is not justifiable to change the RAMS to accommodate the satellite assessment system.
- Assessment of road condition from satellite imagery is possible, but how useful this is will depend on the accuracy and level of confidence that can be gained and whether this fits to the accuracy required by each country. It is assumed in most countries that visual assessments are 100% accurate, but there are varying amounts of subjectivity involved in all condition assessments for unpaved roads as they do not generally warrant the application of expensive equipment. Some spot checks were made on the ground truthing in this project, using the DashCam videos, and most were found to be accurate, but there was some doubt that would suggest they are not 100%. The resolution of the imagery available is also likely to improve, as it has done consistently over the past few years, which should increase the accuracy and level of confidence in the results.
- Cost is also an important factor. In order to be feasible the assessment by satellite imagery needs to be cost effective. Given the figures shown in Annex 4, the system is more expensive than carrying out traditional driven surveys. The main costs are in procuring the satellite imagery, but there are ways to reduce this expenditure by planning the acquisitions carefully and not procuring areas without roads, as well as by negotiating the cost of imagery when large areas are to be procured. Additionally, as with many high-tech solutions, the cost is likely to come down in the near future as many more satellites are launched and competition increases. The cost effectiveness of the system is therefore likely to be more feasible in the medium to long term, rather than the short term.
- In comparison to traditional condition assessment systems, the satellite assessment system is faster and is logistically less onerous. For example one person can assess the satellite imagery for condition at a rate of about 75 km per day, whereas the traditional systems used in this project collected data on about 30 km per day, using a team of 2 or 3 people, a driver, vehicle and equipment. The big difference on cost is the imagery itself.
- Satellite imagery is starting to be made available on a reference basis, where the user does not own the imagery, but has access to it for limited periods. This would make regular condition assessments more feasible and cost effective, although the user would probably want to procure imagery at certain intervals as well.
- Environmentally the satellite assessment system does have an advantage, as it does not rely on having to drive every road, with the consequent use of fossil fuels. The manpower inputs are also less. Most of the work can be carried out in the office environment, without the need to travel.
- There are potential uses for some of these technologies in climate change resilience; most notable the change detection and back analysis. The imagery itself can also be useful in combination with the DEMs to work out catchment areas and waterways that are likely to affect the road network.

- The system is capable of providing appropriate, cost effective support to an asset management system. However, it may not be the best solution for every situation, so a careful assessment process needs to be carried out by the user to determine if the system meets their requirements in terms of the information collected and its quality, against the cost to collect the information. The main advantages of the system are that it provides a permanent record of the assessments, it allows accurate maps to be produced, it is auditable and it is less environmentally damaging. It is more appropriate for areas with lower levels of vegetation and longer dry seasons, it is more accurate with less condition levels and it can be carried out more quickly with less logistic input. The disadvantages are that VHR satellite imagery is still relatively expensive; it is still quite subjective and will require additional skills and experience within the roads organisation. It is less effective for areas with very high vegetation levels and long wet seasons, and tends to be less accurate for systems with five condition levels.

## 9 Recommendations

The main recommendations that can be made from these trials are summarised below:

- The final guideline will include recommendations for the appropriate use of high-tech solutions, combined with the methodology for condition assessment by satellite imagery. It is recommended that a holistic approach is adopted, which includes appropriate combinations of the different high-tech options. The solutions that were found to be most appropriate are:
  - Dashboard Cameras, for use in ground truthing
  - Smartphone apps for measuring an approximation of IRI, more relevant for paved roads and good condition unpaved roads
  - UAVs for specific uses where highly detailed images are required, such as bridge inspection or profiling of a road by photogrammetry or LIDAR
  - Back analysis for various uses, including to identify an appropriate frequency for road condition surveys
  - Social Media has the potential to inform road authorities if issues, but the authority has to be prepared to act on the feedback
  - Specific uses for Big Data were not identified in the trials, but this should not be discounted as a solution
  - There are a number of internet and computer applications that could be useful in establishing knowledge on the road network, for example the use of different data formats in the Philippines to produce maps; so this option should be further explored when appropriate
- The possibility of automated condition assessment from satellite imagery is further explored, possibly in association with the Tanzania study initiated by DFID. This is a logical next step for the system and DFID Tanzania has shown initiative in exploring this possibility, both projects would benefit greatly from cooperation.
- Further investigation into the use of roughness apps and roughness measuring equipment is carried out, possibly in association with MTRD in Kenya, who have initiated this research. This project has shown how variable the traditional condition assessment systems are between countries, especially for unpaved roads, so any standardisation that can be applied

would be welcome. Even established IRI scales vary, so research in this area would be useful to provide some clarity.

- DashCams are promoted for calibration of the system. It is also recommended that liaison is established with the manufacturers to develop the camera for specific use on unpaved and rural roads in LICs. Some of the partner countries are interested to procure these items for their traditional condition assessments.
- The training duration is extended and practical exercises are increased as part of the training.
- The system remains focused on using the existing condition assessment system in each country. However, where a roads authority can be flexible with this requirement, a three level system should be recommended in terms of achieving a higher quality of assessment.
- Local remote sensing partners should be identified to work with road authorities in the future. Until the local road authorities achieve a higher capacity in GIS and mapping activities, this should be included as part of the final guideline.
- As the system matures a reference document should be built up that identifies typical anomalies and areas on a satellite image that are not readily identifiable.
- Condition assessment by satellite imagery should be concentrated on unpaved roads, as there are more identifiable visual factors that can be used to determine the condition. For paved roads the images could be used to identify condition using spectral reflectance, but further research would be required in this area.
- The system should be incorporated into a GIS based RAMS, which will make the analysis and manipulation of data much easier. This is desirable for the practical and efficient use of the system, but the drawback could be the cost of such a database. Most countries already have some sort of a GIS based database, but as shown in this project they are often not fully operational.
- Where the system is used, the imagery acquisition should be carefully planned to avoid procuring unnecessary imagery that has no roads. In addition the roads authority should enter into negotiations with the imagery provider to get the best possible deal.
- The use of DEMS and satellite imagery should be further explored for its potential in providing information on climate change and resilience. This could be carried out under the AfCAP climate resilience project.
- The system has most benefits for remote, inaccessible and conflict restricted areas. If further trials are planned, it is recommended that it is trialled in a mountainous area with a high density of roads. This was not possible in Africa, but may be possible in some areas of Asia.
- There should be a further project to roll out the system on a larger scale, which would further test the cost effectiveness and usefulness of the results. Tanzania is a potential partner for this option, but it would also be possible in Ghana and Uganda. Uganda have already applied for government funding to acquire more imagery in order to use the system for the remote northern areas of the country where knowledge of the network is limited and access is difficult. The roll-out would be questionable in Zambia and Kenya because funding may be limited, but this should be confirmed in consultation with the countries themselves.

## **Annex 1 Change detection algorithm example**

### Pleiades Change Detection Tests

2014



2017



Change has been restricted to the road extent, there is significant change on buildings and vegetation that has been filtered out.

Algorithm has been run on an 8 metre grid, further tests required at a higher resolution to detect more subtle changes and ignore edge effects caused by vegetation.

2014










2017


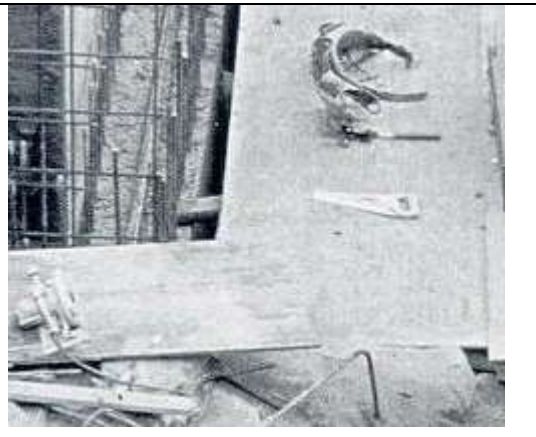


Change has been detected due to widening of road, further tests required on roads where no change is expected.

## Annex 2 National Imagery Interpretability Rating Scale (NIIRS)

<p><b>NIIRS 1 Criteria</b></p> <ul style="list-style-type: none"><li>• Distinguish between major land use classes (e.g., urban, agricultural, forest, water, barren).</li><li>• Detect a medium-sized port facility.</li><li>• Distinguish between runways and taxiways at a large airfield.</li><li>• Identify large area drainage patterns by type (e.g., dendritic, trellis, radial)</li></ul>	
<p><b>NIIRS 2 Criteria</b></p> <ul style="list-style-type: none"><li>• Identify large (i.e., greater than 160 acre) centre-pivot irrigated fields during the growing season.</li><li>• Detect large buildings (e.g., hospitals, factories).</li><li>• Identify road patterns, like clover leaves, on major highway systems.</li><li>• Detect ice-breaker tracks.</li><li>• Detect the wake from a large (e.g., greater than 300') ship</li></ul>	
<p><b>NIIRS 3 Criteria</b></p> <ul style="list-style-type: none"><li>• Detect large area (i.e., larger than 160 acres) contour ploughing.</li><li>• Detect individual houses in residential neighbourhoods.</li><li>• Detect trains or strings of standard rolling stock on railroad tracks (not individual cars).</li><li>• Identify inland waterways navigable by barges.</li><li>• Distinguish between natural forest stands and orchards.</li></ul>	

<p><b>NIIRS 4 Criteria</b></p> <ul style="list-style-type: none"> <li>• Identify farm buildings as barns, silos, or residences.</li> <li>• Count unoccupied railroad tracks along right-of-way or in a railroad yard.</li> <li>• Detect basketball court, tennis court, volleyball court in urban areas.</li> <li>• Identify individual tracks, rail pairs, control towers, switching points in rail yards.</li> <li>• Detect jeep trails through grassland.</li> </ul>	
<p><b>NIIRS 5 Criteria</b></p> <ul style="list-style-type: none"> <li>• Identify Christmas tree plantations.</li> <li>• Identify individual rail cars by type (e.g., gondola, flat, box) and locomotives by type (e.g., steam, diesel).</li> <li>• Detect open bay doors of vehicle storage buildings. Identify tents (larger than two person) at established recreational camping areas.</li> <li>• Distinguish between stands of coniferous and deciduous trees during leaf-off condition.</li> <li>• Detect large animals (e.g., elephants, rhinoceros, giraffes) in grasslands.</li> </ul>	
<p><b>NIIRS 6 Criteria</b></p> <ul style="list-style-type: none"> <li>• Detect narcotics intercropping based on texture.</li> <li>• Distinguish between row (e.g., corn, soybean) crops and small grain (e.g., wheat, oats) crops.</li> <li>• Identify automobiles as sedans or station wagons.</li> <li>• Identify individual telephone/electric poles in residential neighbourhoods.</li> <li>• Detect foot trails through barren areas.</li> </ul>	
<p><b>NIIRS 7 Criteria</b></p> <ul style="list-style-type: none"> <li>• Identify individual mature cotton plants in a known cotton field.</li> <li>• Identify individual railroad ties.</li> <li>• Detect individual steps on a stairway.</li> <li>• Detect stumps and rocks in forest clearings and meadows.</li> </ul>	

<p><b>NIIRS 8 Criteria</b></p> <ul style="list-style-type: none"><li>• Count individual baby pigs.</li><li>• Identify a USGS benchmark set in a paved surface.</li><li>• Identify grill detailing and/or the license plate on a passenger/truck type vehicle.</li><li>• Identify individual pine seedlings.</li><li>• Identify individual water lilies on a pond.</li><li>• Identify windshield wipers on a vehicle.</li></ul>	
<p><b>NIIRS 9 Criteria</b></p> <ul style="list-style-type: none"><li>• Identify individual grain heads on small grain (e.g., wheat, oats, barley).</li><li>• Identify individual barbs on a barbed wire fence.</li><li>• Detect individual spikes in railroad ties.</li><li>• Identify individual bunches of pine needles.</li><li>• Identify an ear tag on large game animals (e.g., deer, elk, moose).</li></ul>	

### Annex 3 Anomalies shown in both DashCam and Satellite

#### Pile of chippings beside road

DashCam



Satellite



**Lined side drain**

DashCam



Satellite



**Grass growing on road**

DashCam



Satellite



**Sand beside road**

DashCam



## Annex 4 Cost comparison tables

	Road details	Cost of training facilities	Road Density km/km <sup>2</sup>	Imagery cost per km road	Cost of satellite ass'ment	Cost of ass'ment per km	Cost of calibration per km	Satellite ass'ment per km this project	Satellite ass'ment per km this project headline prices	Cost of ground truthing	Cost of ground truthing per km	Cost of analysing ground truthing per km	Cost of traditional ass'ment per km	
		£		£	£	£	£	£	£	£	£	£	£	
<b>Ghana</b>														
Length of road	37.562	1,805.00	0.25	15.73	180.00	4.79	2.13	<b>22.65</b>	<b>67.12</b>	780.00	20.77	20.00	0.53	<b>21.30</b>
Square area	153													
Imagery cost	590.75													
<b>Kenya</b>														
Length of road	77.882	1,375.00	0.27	26.81	125.20	1.61	2.14	<b>30.56</b>	<b>58.40</b>	1,629.36	20.92	37.56	0.48	<b>21.40</b>
Square area	288													
Imagery cost	2088													
<b>Uganda</b>														
Length of road	145.72	1,133.33	0.78	5.74	524.44	3.60	0.92	<b>10.26</b>	<b>23.49</b>	1,167.82	8.01	175.56	1.20	<b>9.22</b>
Square area	187													
Imagery cost	836.46													
<b>Zambia</b>														
Length of road	52.719	1,090.91	0.44	23.74	204.55	3.88	3.00	<b>30.62</b>	<b>40.24</b>	1,527.27	28.97	54.55	1.03	<b>30.00</b>
Square area	119													
Imagery cost	1251.5													

## **Annex 5 GPS accuracy for DashCams and RoadLab**

3-10m accuracy of the GPS tracks

DashCam



RoadLab



## **Annex 6 Training photographs from Ghana and Kenya**

### **Ghana Training:**



### **Ghana field trip**



**Kenya training**





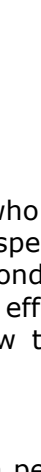
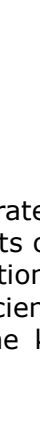
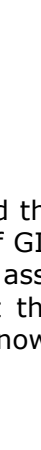
**Kenya field trip**



## Annex 7 Training Assessment report

### Training Report

#### Question 1: How much have you learned from this course?

Course No.	Title of Course	Q: How much have you learned from this course?					Score
		Nothing  A Lot					
		1	2	3	4	5	
1	Zambia Training						3.8
2	Uganda Training						4.3
3	Ghana Training						4.0
4	Kenya Training						4.1

#### Comments accompanying Answer 1:

The trainees were asked to comment on why they selected that particular rating, based on what they chose. They were given a choice on a sliding scale from 1 (Nothing) to 5 (a lot). For example the answers were divided into three groups, those who chose rating 4 or 5, those who chose 2 or 3 and those who chose 1. In this way the answers are more aligned to the actual ratings given. A summary of the comments is shown below for each country in turn:

#### Zambia:

- **Rating 4-5:**

The Zambian trainees who rated their learning as 4 or 5 commented mainly on learning QGIS and the various aspects of GIS software, and on the technical road-related aspects of the course such as condition assessment and categorisation. One particular comment noted how simple and efficient the process of condition monitoring was. Again there were comments on how the knowledge gained could be applied in a wider range of subjects.

- **Rating 2-3:**

The only comment from people who rated their learning as 2 or 3 noted that the trainer presented too quickly in some cases. It can be assumed that this comment came from an RDA staff member, as the trainers noted that the GIS specialists on the course coped very well with the speed of the training and often finished well before the next session was due.

- **Rating 1:**

No one rated the training as 1.

#### Uganda:

- **Rating 4-5:**

The comments for Uganda also appear to be related to the level of expertise the trainees had in QGIS in particular. Many commented that they learnt a lot about the software and digitising, which can be assumed are from the RDA staff. On the other hand some commented that they learned more about the technology and how to analyse road condition, which can be assumed to have come from the NRSC staff. One encouraging aspect was that trainees commented on how much they learned and how they had become aware of wider possibilities for using the software. Specific comments included that a longer duration of training would have been better. Given that some trainees were familiar with QGIS and some were very new to it, all seemed to cope well and the comments did not indicate that anyone was dissatisfied.

- **Rating 2-3:**

Only two people who gave a rating of 2 or 3 provided comments, one commented that they managed with QGIS but missed some of the training sessions, and one other felt they needed more introduction to the first principles of GIS in general.

- **Rating 1:**

No one rated the training as 1.

## Ghana

- **Rating 4-5:**

Again the main learning here was in QGIS, with the participants who replied linking it to their daily work. This demonstrates that QGIS is quite easy to learn and can be a useful tool for road engineers.

- **Rating 2-3:**

The only comment

The feedback from this question was quite diverse, with one person reporting that their knowledge of GIS and road data processing had increased, whilst another did not understand the software and suggested more time for tutorials.

- **Rating 1:**

No one rated the training as 1.

## Kenya

- **Rating 4-5:**

Most comments related to new users of QGIS, so they learned a lot using a new software. One commented on the appropriate use of cost effective assessment using apps, which is a new concept for them.

- **Rating 2-3:**

The only comment under this heading was regarding previous knowledge of QGIS, where the participant already had some knowledge so consequently gained less new knowledge.

- **Rating 1:**

No one rated the training as 1.

**Question 2: What part/s of this course will be most useful for you in your work?**

**Zambia:**

For Zambia the most common response was 'how to determine road condition'. Two trainees reported that everything was useful, but image analysis and interpretation were also singled out as being important.

**Uganda:**

A number of trainees responded that everything was useful, and that they had learned something new. Some of the specific aspects that were identified as being useful were digitising, condition assessment, image interpretation, working with spatialite files, layer and vector processing, showing field results on image files and the field visit.

**Ghana:**

Most of the Ghana feedback focused on QGIS and image interpretation, and how it can be used to facilitate the condition assessment. There was also feedback on how useful the DEM analysis of basins and channels was to locate drainage structures.

**Kenya:**

The feedback here was focused on QGIS, image processing and interpretation. There were specific comments on how it is used to identify poor areas of road and monitor road condition.

**Question 3: What part/s of this course will be least useful for you in your work?**

**Zambia:**

Zambia was also very positive in responding to this question, with the only comment being that GIS was the least useful aspect as there are many different GIS softwares used in their office. It is assumed that this comment was from an NRSC staff member as very few RDA staff use GIS software.

**Uganda:**

The Ugandan trainees were overall very positive about the course and the only thing that was identified as being 'least' useful was the site visit (by only one respondent). Most trainees responded that everything was useful. One trainee commented that it will be difficult to place new features that appear after the image is taken, but this seems to be a general comment on the process rather than responding to this particular question.

**Ghana:**

There were few comments, but the categorisation of road conditions and identification of drainage structures were mentioned, presumably from the CERSGIS participants.

**Kenya:**

In Kenya one person mentioned that Google maps would not be useful, plus the image processing and DEMS were also mentioned here.

**Question 4: Are there any subjects you feel should be included (added)?**

**Zambia:**

In Zambia there was also one comment that a general introduction to GIS was required. Here the NRSC provided basic training before the specialist training was carried out, which seems to have been quite effective given that most trainees seem to have coped with QGIS quite well. Other comments were related to extracting images from the AoI and analysing data from the field, plus presentation of results, which would have to come when all the process and analysis is complete. There was one comment on how vegetation and tree roots affect road condition, which is quite specific and probably

stems from one particular road in Lusaka where the surface is particularly damaged by tree roots.

**Uganda:**

There were two comments from Uganda that more information on basic QGIS should be added, which is assumed to have come from UNRA staff. Some basic QGIS instruction was given to UNRA staff who needed it before the training took place, but there were also some last-minute attendees who did not receive this instruction, hence this comment. There were also some interesting responses suggesting that the software could be used of monitoring water quality or crop rotation, and linking the video to create street view, which it is presumed is suggesting a link to Google Street-View. Automated classification is also suggested, as is the possibility of including visual condition information from the physical surveys. This is an interesting suggestion as it may be possible to link some of the ground truthing observations to the final condition assessment if it is incorporated into an asset management program. An additional question asked about the compatibility of QGIS with other GIS software; whilst most GIS programmes are fairly interchangeable in terms of file types and information, this would have to be dealt with on a case by case basis.

**Ghana:**

In Ghana there was a suggestion that ArcGIS should be used, instead of QGIS. This is because most remote sensing specialists already use ArcGIS, but this would require licenses which are expensive, especially for people who are not using it full time. One suggested network analysis for QGIS, and the extraction of contours and spot heights from the DEMs, which could be useful in more detailed assessments. LIDAR interpretation was also mentioned, but this would be pointless unless the roads department starts to use LIDAR. A final suggestion was to use attribute querying using SQL; this would be very useful for the image interpretation, but would probably be too advanced for most of the roads participants at the present time.

**Kenya:**

The Kenyan participants did not suggest any new subjects, but did suggest that there should be more practical exercises and demonstrations, and more on the application of remote sensing to roads.

**Question 5: Are there any subjects you feel should be omitted (left out)?**

**Zambia:**

No subjects were recommended for exclusion.

**Uganda:**

No subjects were recommended for exclusion.

**Ghana:**

No subjects were recommended for exclusion.

**Kenya:**

No subjects were recommended for exclusion.

**Summary of Question 6**

Question 6 was split into three main areas, which give an overall rating for the course/s. The first part deals with how 'useful' the course was, the second deals with how 'interesting' the course was, whilst the third asks if the course was too basic or too complicated.

**1.1.1 Question 6a: How do you rate the course overall? 'Not Useful' to 'Useful'?**

These questions are important in determining how well the course was delivered and how much the participants were able to apply it to their jobs. For this scale '1' is Not Useful and '5' is Useful, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the course overall?					Score
		Not Useful  Useful					
		1	2	3	4	5	
1	Zambia Training						4.8
2	Uganda Training						4.6
3	Ghana Training						4.3
4	Kenya Training						4.6

The results for this question are remarkably consistent. The participants clearly found all aspects of the course to be useful for their present work or future tasks. This result confirms that the course content was appropriate in teaching the participants the knowledge and skills they need to carry out their work effectively.

**1.1.2 Question 6b: How do you rate the course overall? 'Not Interesting' to 'Very Interesting'?**

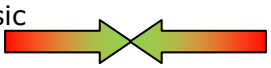


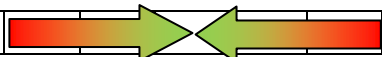

For this scale '1' is Not Interesting and '5' is a Very Interesting, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the course overall?					Score
		Not Interesting  Very Interesting					
		1	2	3	4	5	
1	Zambia Training						4.6
2	Uganda Training						4.7
3	Ghana Training						3.6
4	Kenya Training						4.0

This question deals with the issue of the course being 'interesting'. The course scored well in all countries, although Ghana was slightly lower, perhaps due to the higher proportion of remote sensing participants who attended. They could possibly find the focus on QGIS less interesting if they are already familiar with it.

**Question 6c: How do you rate the course overall? 'Too Basic' to 'Too Complicated'?**

For this scale '1' is Basic and '5' is Complicated, with a sliding scale in between. Hence, out of a possible 5 marks the ideal answer would be 3.0, which would be a good balance between being too basic or too complicated.

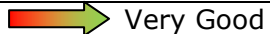


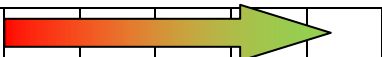

Course No.	Title of Course	Q: How do you rate the course overall?					Score
		Basic  Complicated					
		1	2	3	4	5	
1	Zambia Training						3.5
2	Uganda Training						3.3
3	Ghana Training						3.0
4	Kenya Training						3.1

All of the courses are within 0.5 of the half-way mark of 3.0, with a slight bias towards the course being too complicated. However, this is very consistent and there were no participants who failed to complete the course, which suggests an appropriate level of content and that the course was pitched at the correct level.

**Summary of Question 7 - Summary of Training Facilities**

Question 7a: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Room Facilities

For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Room Facilities?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Zambia Training						3.3
2	Uganda Training						4.5
3	Ghana Training						4.2
4	Kenya Training						4.6

This question relates to the room and the training facilities provided. The highest scoring was Kenya, which is the only course that was held at a dedicated training facility, so this was clearly reflected in the scoring. In Zambia there were constant issues with electricity supply, which probably reflects the low score there.

**1.1.3 Question 7b: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Food/Refreshments**

For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Food/Refreshments?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Zambia Training						2.8
2	Uganda Training						4.6
3	Ghana Training						3.4
4	Kenya Training						4.0

The requirements for lunch and refreshments were not specified as part of the course, so each country provided a different set up, which is reflected in the range of the scoring. Quality of refreshments provided can make a difference to the motivation of staff attending the course, and if these are provided on site, it prevents delays and disruptions when people have to leave site to find lunch, etc.

**1.1.4 Question 7c: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Comfort of Seating**

For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.



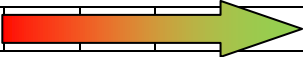


Course No.	Title of Course	Q: How do you rate the Comfort of Seating?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Zambia Training						3.7
2	Uganda Training						4.1
3	Ghana Training						4.0
4	Kenya Training						4.1

The feedback on comfort of seating is quite consistent, with the scores being perfectly acceptable for a short training of this nature.

There are potential health and safety issues if participants are asked to use uncomfortable or inappropriate seating. Many people develop back problems for this very reason, and although this is unlikely on a short-term course the participant will be able to concentrate more and learn more if s/he is comfortably seated and able to view the presentations easily.

**Question 7d: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Convenience / Location?**

For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Convenience/Location?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Zambia Training						3.4
2	Uganda Training						3.9
3	Ghana Training						4.1
4	Kenya Training						4.0

The assessment of the convenience of the location is also fairly consistent. Participants have based their answers on the proximity to their home, so unless the venue is in a very remote location, it is likely to attract consistent scores.

**Question 8: Further comments**

Final comments provided from the participants in each country are shown below:

**Zambia:**

- More trainers were required, depending on number of trainees. When the training was panned it was recommended that between 6 and 8 trainees should attend the training, because if there were more, then the trainer would not be able to follow-up individually with all of the participants. In total 11 trainees attended the training, so it is not surprising that this comment was made as the ratio of trainers to trainees was effectively too low.
- One trainer may not be able to attend all trainees. This is a similar comment to that above, resulting from the high class size.
- More practice is needed. This is also a pertinent comment as the trainees will need practice to stay familiar with the software. It is assumed that this comment is referring to more practice within the training period, which would mean that the training would need to be extended.
- Very informative with brilliant instructors who did their best to help understanding.

- Enjoyed training and look forward to using the skills gained, hopefully if difficulties arise we can get help. Again, remote assistance was offered to the trainees should they encounter any problems.

#### **Uganda:**

- The comment that overall the training was good/very good was mentioned several times.
- Some commented that learning the software had been useful
- There was a comment that automatic classification should be used to identify the area of interest. It is not clear exactly what this is referring to, but it is assumed that the feedback is referring to the selection of networks where satellite assessment of road condition could be used.
- Field practical data should be added
- There was a comment that the lecturing was quiet, so as not to disturb other workers. This is referring to the fact that the training had to be held in an open office due to the recent move of UNRA to new offices and the untimely strike at Makerere University, where the training was originally supposed to be held. A closed training room would have been better.
- Not all staff had laptops so some had to share. The training is much more effective if all trainees have their own laptops. A number of UNRA staff were invited to attend when it became clear that Makerere University staff would not be able to attend, and not all of the UNRA staff has access to a laptop.
- Feedback and follow-up should be done for a given period. This is a valuable suggestion because it is very easy to forget aspects of a training if the software is not used regularly. Reinforcement of training is important and the trainers offered to support the trainees in the subsequent months if they encountered any problems in using the software.

#### **Ghana:**

- There was a comment that there should be a slight introduction into QGIS software before the course is carried out. This was actually recommended by the trainers in advance of the training and in most cases was carried out, but clearly not all participants were included.
- Another comment was that extra days were needed to do more analysis. This would suggest that a follow-up session or monitoring could be useful.
- In Ghana SAR was tested as a potential option for condition assessment, and one participant noted that they were looking forward to exploring SAR data and the role it plays in the assignment.
- General comments included that the training was interactive and informing, but that the participants need more practical use of QGIS

#### **Kenya:**

- In Kenya there were some comments that the period of learning was too short and 'a lot of training is necessary to fully understand'. This is consistent with comments from other countries and probably applies more to the roads participants who are not familiar with QGIS. It would probably be beneficial if the participants who have no knowledge of QGIS were to attend a formal training course in advance of the training in order to ensure that they are up to speed with the software,
- There was also a comment to increase number of facilitators and time for practicals, which again suggests that people need more time to become familiar with QGIS.

- An additional comment suggested that 'for maximum concentration and hence achievement, it should be carried on outside our working stations'. As the Kenya training was carried on outside the working stations of MTRD and DRSSRS, it is assumed that this is reinforcing that decision.
- There was a final comment that it was a 'Good course'.

## **Analysis**

This section of the report covers the analysis of the participant's feedback, the feedback from the trainers and general issues.

## **The Trainers**

### ***Trainers***

The trainers were:

- **Zambia** – Ned Chisholm, Robin Workman
- **Uganda** - Ned Chisholm, Robin Workman, Byron Anangwe
- **Ghana** - Ned Chisholm, Robin Workman
- **Kenya** – Byron Anangwe, Robin Workman

### ***Trainer's feedback***

The trainers fed back that in general the participants were of a high standard and had been well educated to degree level. Given that the trainees were from different backgrounds and qualifications, they interacted well and were able to support each other, especially in the use of the QGIS software.

There were some negative comments from the trainers on various aspects of the training:

- The training venues and facilities were adequate, but suffered from minor issues such as electricity failures.
- Participants were sometimes late arriving and returning from breaks, and some left the training early. However, this was not a significant issue during the training.
- Some participants who were not proficient in QGIS were not able to have introductory training beforehand, as was recommended. In some cases this made it harder for the trainers to carry out the basic QGIS tasks and maintain all participants at the same level.

### ***Resources***

Some feedback from the participants suggested that the training could be longer, with more exercises and practicals. Some also suggested more trainers, which is not surprising given that the maximum number of participants was exceeded in three of the four courses.

## **The Participants**

### ***Level of Participants***

Most of the participants have little or no practical experience in QGIS, although some of the remote sensing experts were proficient in other GIS applications, which are similar.

### ***Attendance***

The courses were designed to be delivered to between 6 and 8 participants. The attendance varied throughout the courses, with attendance of 12, 12, 10 and 7. Although it was good to see high attendance rates, the trainers did struggle to give everyone the individual support they required.

### ***Staff Motivation***

In general the motivation of staff to attend the courses in full and on time was good. Where possible courses were held away from the workplace in order to avoid distractions, but where this was not the case, minor disruption was inevitable.

## **The Course**

### ***Course Content***

Overall there were few comments on the content of the courses. The feedback indicated that overall the participants were happy with the content, learned a lot and found the training useful for their work.

In the course feedback there were no significant areas where the participants requested additional course content or different subjects, so it can be assumed that the participants were generally happy with the subject matter. It can therefore be concluded that the contents of the course is sound and appropriate to build the capacity of both roads and remote sensing institutions to carry out condition assessment.

### ***Practicals:***

There were some comments that more practical exercises should be included. This is a valid concern, especially for those who are not so proficient in QGIS. However, this would require an extension of the course duration, so it is something that could be considered for future courses.

### ***Field Trips:***

The field trips were recognised as an important aspect of the training, especially for those who do not have a roads background. They were very useful in demonstrating various aspects of the training, for the image interpretation and drainage identification.

### ***Timing and Duration***

Most comments on the course duration suggested extending the course, possibly to four or five days long. This would be possible, but it could be beneficial to have a break in between to allow the participants to practice in the workplace. For example, an initial three days, then a break of a week or two, followed by an additional one or two days.

## **Location**

Overall the location of the courses seemed to be appropriate, although it will always be convenient for some and less convenient for others.

## **Conclusions**

In conclusion, the courses were completed satisfactorily and provided the participants with the necessary skills to carry out road condition assessment using GIS. The participants clearly learned a lot from the course and were generally happy with how they were delivered.

The content of the courses were found to be appropriate and no significant areas were identified that need to be added to the programme. Some minor adjustments were suggested, such as including more practicals and exercises, and the duration could be one or two days longer in order to ensure that everyone has a full grasp of QGIS.

The course run by RCMRD received very similar reviews to the courses run by Airbus DS, which suggests that RCMRD is an appropriate partner to deliver the course. In addition RCMRD has good training facilities and is able to hire laptops, as well as install the relevant software for the participants. It has very good links to all countries in the region and is well set up for this type of training.

The full training materials have been provided to the participants. This includes a manual and a PowerPoint presentation. The participants also have a copy of the satellite imagery, although it should be noted that the local roads institution remains the end user and is therefore the owner of the images.

## **Recommendations**

In terms of the training course it is recommended that:

- The recommended number of participants should be adhered to, or additional trainers should be assigned to assist.
- The course remains flexible and reacts to feedback from participants and any changes in the software, in order to improve the content and delivery.
- The course duration is extended by one or two days to include more time for the participants to become familiar with the software, and to add practical examples and exercises.
- The course contents are included in the methodology for assessing road condition from satellite imagery.

**Template of 'End of Course' Assessment Forms**

# Training Course Questionnaire

## End-of-Course form

**Course:** .....

**Location:** .....

**Question 1:** How much have you learned from this course?

Nothing

1	2	3	4	5
---	---	---	---	---

A lot

If your answer was 4 or 5, why do you think this?

If your answer was 2 or 3, why do you think this?

If your answer was 1, why do you think this?

**Question 2:** What part/s of this course will be **most** useful for you in your work?

**Question 3:** What part/s of this course will be **least** useful for you in your work?

**Question 4:** Are there any subjects you feel should be **included** (added)?

**Question 5:** Are there any subjects you feel should be **omitted** (left out)?

**Question 6:** How do you rate this course overall?

Not useful	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Very useful
1	2	3	4	5			
Not interesting	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Very interesting
1	2	3	4	5			
Too basic	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Too complicated
1	2	3	4	5			

**Question 7:** How do you rate the facilities of the course:

Room / facilities?

Poor	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Very good
1	2	3	4	5			

Food / refreshments?

Poor	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Very good
1	2	3	4	5			

Comfort of seating?

Poor	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Very good
1	2	3	4	5			

Convenience / location?

Poor	<table border="1"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr></table>	1	2	3	4	5	Very good
1	2	3	4	5			

**Question 8:** Please add here any further comments you may have:

(continue overleaf or on an additional page if necessary)

<b>Zambia Training - Attendees</b>					
No.	Name	Designation	Organisation	email	Telephone
1	Victor Miti	Engineer - Planning	RDA	victormiti@gmail.com vmiti@roads.gov.zm	0977722365 0966722365
2	Chipulu Chilumba	Intern	NRSC	Chilumbachipulu@gmail.com	0976528184
3	Teza Chila	GIS expert - Planning	RDA	Echila@roads.gov.zm	0963251147
4	Mutimba Kawisha	Intern	NRSC	mutimbakawisha@gmail.com	0962204077 0974138858
5	Presley Chilonda	Principal Engineer	RDA	pchilonda@roads.gov.zm	0978949956
6	Mukwena Dipuo	Intern	NRSC	pipuomukwena@gmail.com	0978619201
7	Michael Katongo Phiri	Technical GIS	NRSC	mikaphi@yahoo.com	0977563762
8	Lusekelo Kasunga	Technical IP	NRSC	k.lusekelo@gmail.com	0979342430
9	Phillimon Goma	Principal Engineer	RDA	philgoms@yahoo.com	0977039801
10	Alice Chipasula	Engineer - Planning	RDA	achipasula@roads.gov.zm	0977435318
11	Misozi J. Banda	Technical Assistant IP	NRSC	misozijooma@yahoo.com	0971980881 0978234719

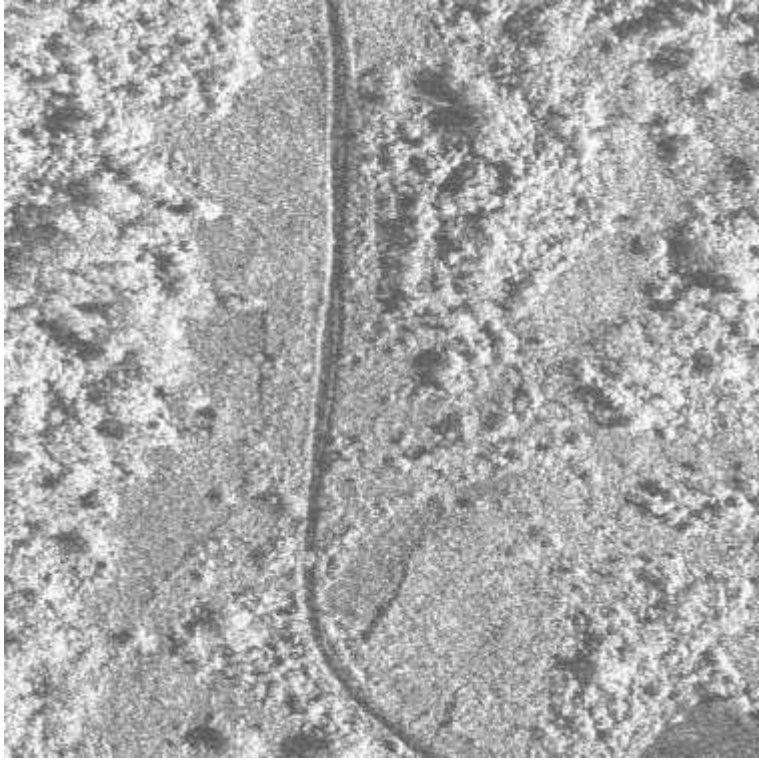
<b>Uganda Training - Attendees</b>					
No.	Name	Designation	Organisation	email	Telephone
1	Ingrid Martha Kintu	Student	Makerere Uni.	ingridmartha72@gmail.com	0701260850
2	Florence Kyalisiima	Student	Makerere Uni.	florencekyarisiima@gmail.com	0752097675
3	Christine Mutesi	Planning	UNRA	christineadyeeli@gmail.com	0782748173
4	Immaculate Katutsi		UNRA	Immaculate.katutsi@unra.go.ug	0785938304
5	Gidah Nabatanzi		UNRA	Gidah.nabatanzi@unra.go.ug	0777842732
6	Chris Byaruhanga		UNRA	Chris.byaruhanga@unra.go.ug	0701836373
7	Rodgers Mugume		UNRA	Rodgers.mugume@unra.go.ug	0706515760
8	Francis Asaba		UNRA	Francis.asaba@unra.go.ug	0782604092
9	Michael Akol		UNRA	Michael.akol@unra.go.ug	0772644841
10	Doreen Wafula		UNRA	Doreen.wafula@unra.go.ug	0706520383
11	David Vule		UNRA	Dominic.vule@unra.go.ug	0777282184
12	Jude Waidha		UNRA	Jude.waidha@unra.go.ug	0777518660

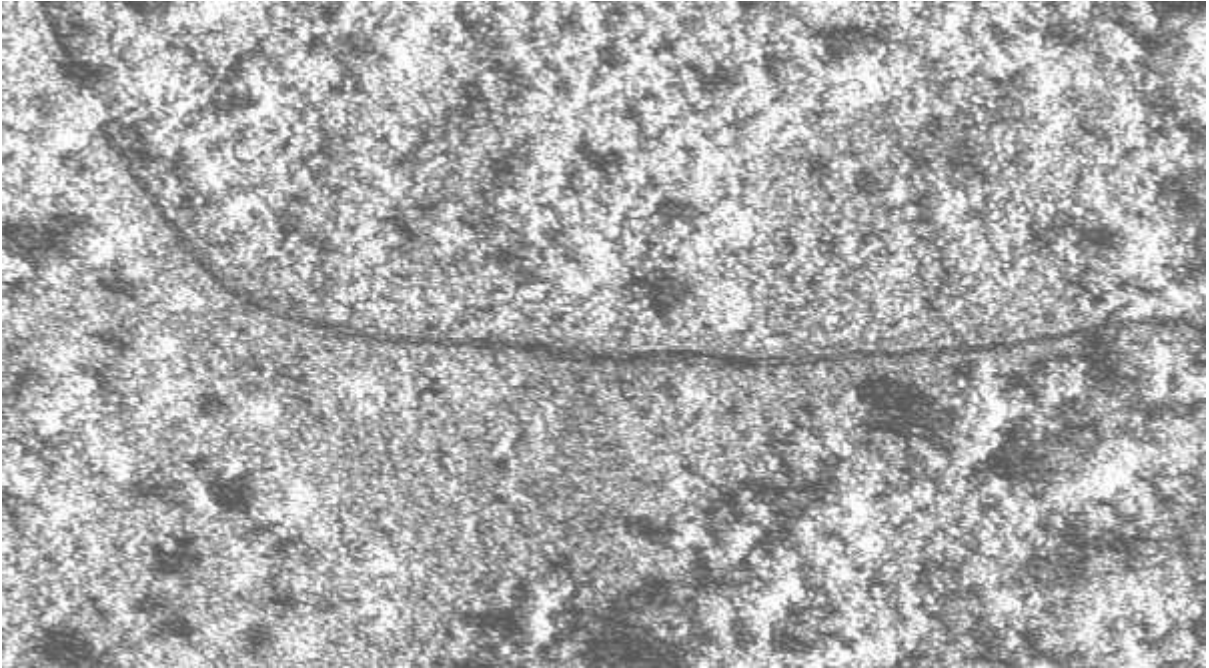
<b>Ghana Training - Attendees</b>					
No.	Name	Designation	Organisation	email	Telephone
1	Kenneth Buaba Buekson		Dpt. Of Urban rds	Knexx91@gmail.com	0266678500
2	Richmond Ankrah	IT/GIS Administrator	DFR	yoomaccy@gmail.com	0264755258
3	Edmond M Balika	Assistant Engineer	MRH	balikaem@gmail.com	0246738954
4	George Lutterodt	Tech Engineer	MRH	Luttori039@gmail.com	0548087120
5	Barbera A Abubaka	Assistant App Spec.	CERSGIS	bashgrad@gmail.com	0241740180
6	George Owusu	Senior GIS specialist	CERSGIS	georgeseny@gmail.com	0243053574
7	Benedict Martey	GIS/data analyst	CERSGIS	benedictmartey@yahoo.com	0240667945
8	Stella Ofori-Ampofo	RS application spec.	CERSGIS	ellaampy@gmail.com	0265068457
9	Juliet Wirekoa Amponsah	Env. Engineer	DFR	Wireko2007@yahoo.com	0549964480
10	Elikem Adanu	GIS/data analyst	CERSGIS	Eadanu2009@yahoo.com	0209184153
11					
12					

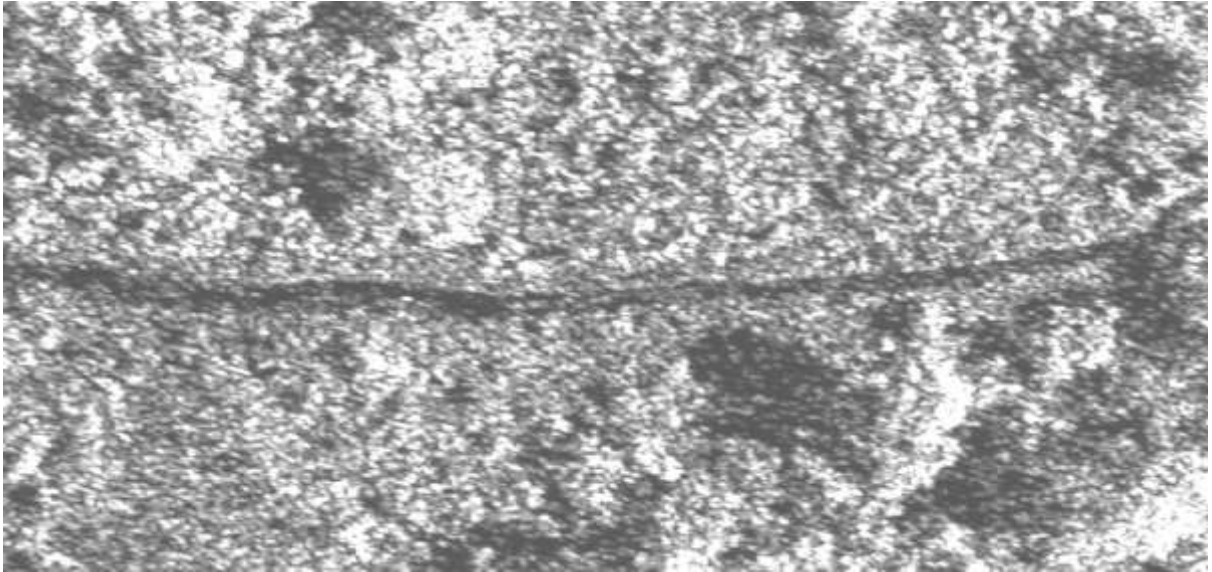
<b>Kenya Training - Attendees</b>					
No.	Name	Designation	Organisation	email	Telephone
1	Reuben R Njomo	Lab Technician	MTRD	reronfo@gmail.com	0721802467
2	Joseph Gatimu	Technologist	MTRD	Mgatimu2@gmail.com	0721281068
3	Hezron Otero	CNRS	DRSRS	nyaegao@yahoo.com	0726529195
4	Julius Kioko	SGA	DRSRS	jkiosh@yahoo.com	0700467533
5	Esther E Amimo	Engineer A4T	MTRD	emmyamimo@gmail.com	0720360624
6	Eunice Juma	Geo-info officer	DRSRS	euninede@gmail.com	0721633572
7	Antony Gathungu	Technician	MTRD	toshtsonga@gmail.com	0721909560
8					
9					
10					
11					
12					

## **Annex 8 SAR trials**

SAR image 2017







## Annex 9 Assessment/calibration guideline for Uganda

### UNPAVED ROADS - 2016 Pleiades Imagery

The satellite assessment methodology will need to be calibrated. Each country has different road condition parameters, environments and processes. The methodology will need to be calibrated to fit with the prevailing system, which involves a process of calibration. This guideline explains the calibration process and includes a guideline for assessing the condition of roads in Uganda.

The first step is to identify a small number of roads or road sections that can be used for calibration. Ideally these roads should cover the full range of conditions, from 'Very Good' to 'Very Poor', and that are typically found in the area being assessed. If condition assessments are already available, these can be used, so long as they are accurate and in line with national practice and regulations. If no conditions are available then surveys will need to be carried out to establish the ground truthing.

Figure A

When the ground truthing information has been collected, it is necessary to create a

Very Good	Good	Fair	Poor	Very Poor	Unknown
Dark Green	Light Green	Yellow	Amber	Red	Blue

condition map of the roads surveyed for ground truthing and selected for calibration. This is achieved by digitising the roads with condition, showing the colours assigned to condition, as shown in Figure A. This range of conditions should then act as a guide to the assessment of condition by satellite imagery.

When the map has been completed for the sample roads, as shown in Figure B, note the features of each condition that are common and can be identified easily from a satellite image. A guideline can then be built up that will assist the assessor in determining the condition of the roads from the satellite imagery.

The simplest way to do this is to take three or four screen-shots of the road for each condition, and provide explanations as to what the assessor needs to look for. Wherever possible this guide should use measurable indicators, such as variation in the width of the road. The manual system of assessment is fairly subjective, so any information that can reduce that subjectivity is welcome.



Figure B




## **Elements of Image Interpretation**

The principles of image interpretation fall into the following categories:

- Location
- Size
- Shape
- Shadow
- Tone and colour
- Texture
- Pattern
- Height and depth
- Site/situation/association

The criteria for assessing road condition are based on the following features that are visible on the satellite imagery:

- **Edges of road:** The edges of the road can indicate the road condition, depending on whether they are clear, broken, faint, etc. If the edges are straight and well defined it suggests that there are drainage channels alongside the road, and that drivers are not driving over the shoulder to avoid poor or damaged areas. If the edges of the road are broken, unclear or difficult to define, it suggests that the drainage is not functioning properly and the road is not well maintained.
- **Width of road:** The width of the road and how much it varies can be a good indicator of the condition of an unpaved road. On unpaved roads drivers tend to drive over the shoulders to avoid poor areas and potholes, which has the effect of widening the road. This is more prevalent in arid areas where there is no vegetation to prevent drivers leaving the road, but it also happens in lightly vegetated and savanna areas.
- **Surface:** A certain amount of detail can be seen on the surface of the road. Different colours, textures, patterns and shading can be identified from the imagery. If the surface is uniform, with consistent colour and shading, it suggests that the road is in good condition. However, if differing colours and shading can be seen it suggests that the condition is not so good.
- **Wheel tracks:** On gravel or earth roads it is often possible to see wheeltracks of vehicles. Generally, if the wheeltracks are straight it suggests that vehicles are travelling in a straight line at a reasonable speed and there are no defects to avoid. However, if wheeltracks are winding or irregular it suggests that drivers are driving to avoid damaged areas on the road such as potholes or soft spots. The more the wheeltracks vary, the more likely it is that the road is in poor condition.

Description	Example
<p><b>Very good (Dark Green):</b></p> <p>Some very slight differences in surface colour and texture can be seen, but generally very even.</p> <p>Negligible variation in width.</p> <p>Edge of road consistent and straight.</p> <p>See Figures 1.1 to 1.3.</p> <p>Condition can be relative for earth and gravel roads. If the surface can be determined, the condition of earth roads can be shown as good when the width and edges vary.</p> <p>For unpaved roads this category will normally apply to recently constructed or rehabilitated roads, as the condition often changes during the first wet season.</p> <p>For U roads Figs. 1.1 to 1.3</p>	<p><b>Figure 1.1</b></p>  <p><b>Figure 1.2</b></p>  <p><b>Figure 1.3</b></p> 

**Good (Green):**

Some slight differences in surface colour and texture can be seen.  
Slight variation in width, up to 10%.  
Edge of road slightly broken and varies slightly.

See Figures 2.1 to 2.6.

Condition can be relative for earth and gravel roads. If the surface can be determined, the condition of earth roads can be shown as good when some surface irregularities can be seen, as in fig. 2.4

For C/D roads Figs. 2.1 to 2.3

**Figure 2.1**



**Figure 2.2**



**Figure 2.3**



For U roads Figs. 2.4 to 2.6

**Figure 2.4**



**Figure 2.5**



**Figure 2.6**



**Fair (Yellow):**

Different shading and colours visible on road surface, but not dramatic.

Width varies slightly by 10% to 20% and edges appear more broken, although maintain a relatively straight appearance.

Where wheel tracking is visible, it tends to be straight, indicating that vehicles are travelling quickly with no obstacles to avoid.

See figures 3.1 to 3.9.

For C/D roads Figs. 3.1 to 3.3

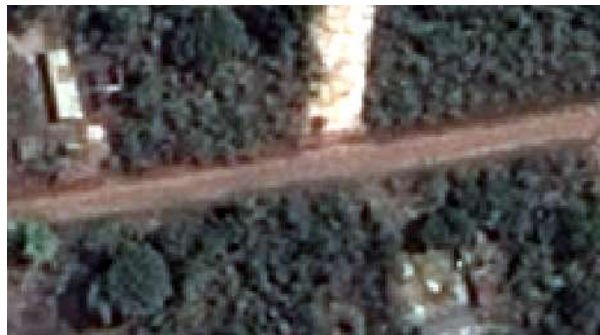
**Figure 3.1**



**Figure 3.2**



**Figure 3.3**



**Figure 3.4**



**Figure 3.5**



**Figure 3.6**



For U roads Figs. 3.7 to 3.9

**Figure 3.7**



**Figure 3.8**



**Figure 3.9**



**Poor (Orange):**



Significant variation in the colour and shading of the surface.

Width variable by 20% to 30%.

Edges of road not clear, variable and often not straight or broken

Some wheel tracking visible, winding to avoid defects.

See Figures 4.1 to 4.9.

For C/D roads Figs. 4.1 to 4.8

**Figure 4.1**



**Figure 4.2**



**Figure 4.3**



Figure 4.4



Figure 4.5



Figure 4.6



**Figure 4.7**



**Figure 4.8**



For U-Roads Fig. 4.9

**Figure 4.9**



**Very Poor (Red):**



Significant variation in the colour and shading of the surface.

Width variable by more than 30%.

Edges of road broken or indistinguishable from surrounding road

Wheel tracking visible, very winding to avoid defects.

See Figures 5.1 to 5.5.

For C/D Roads Figs. 5.1 to 5.4

Note: These roads can be very narrow so details of the surface may be difficult to see.

**Figure 5.1**



**Figure 5.2**



**Figure 5.3**



For U-Roads see Fig. 5.5

**Figure 5.4**



**Figure 5.5**



## Annex 10: Progress towards ReCAP logframe outputs

Intervention Logic	Indicator	Next Milestone Target Date (from Inception Report)	Next Milestone Target (from Inception Report)	Comment. (Risks, challenges, will Targets be achieved, and on time?)	Achievement <sup>1</sup>	
<p>Outcome: Sustained increase in evidence base for more cost effective and reliable low volume rural road and transport services, promoted and influencing policy and practice in Africa and Asia</p>	<p>1. SUSTAINABILITY: Partner Government and other financiers co-funding research with ReCAP. Contributions in kind (K) and Core Contributions (C)</p>	March 2017	All countries on board but Kenya unable to commit sufficient resources.	Kenya has lack of funds, AFCAP agreed to supplement training costs,	This reporting period	4 countries committed
					Cumulative to date	As above
	<p>2. Concrete examples of change (applied or formally adopted), influenced by ReCAP research that will be allied to #km of road in focus countries.</p>	Too early to identify change	March 2017, ground truthing should be complete	Ground truthing is still delayed in Kenya, local resource arrangement is a challenge, despite funding being confirmed.	This reporting period	Some countries have allocated resources
					Cumulative to date	As above
	<p>3. Number of citations in academic articles of ReCAP peer reviewed articles and/or working papers, conference papers etc.</p>	Not due until end of project			This reporting period	None
					Cumulative to date	None

<sup>1</sup> Evidence to be attached to the report submission.

Intervention Logic	Indicator	Next Milestone Target Date (from Inception Report)	Next Milestone Target (from Inception Report)	Comment. (Risks, challenges, will Targets be achieved, and on time?)	Achievement <sup>1</sup>	
<p>Output 1: RESEARCH and UPTAKE: Generation, validation and updating of evidence for effective policies and practices to achieve safe, all-season, climate-resilient, equitable and affordable LVRR and transport services in African and Asian countries.</p> <p>(Low Volume Rural Roads : LVRR / TS – Transport Services)</p>	<p>1.1 LVRR: Number of peer reviewed papers generated from ReCAP supported or related LVRR research projects made available in open access format.</p>	<p>May 2017</p>	<p>May 2017</p>		<p>This reporting period</p>	<p>None</p>
					<p>Cumulative to date</p>	<p>None</p>
	<p>1.2. TS: Number of peer reviewed papers generated from ReCAP supported or related LVRR research projects made available in open access format.</p>	<p>May 2017</p>	<p>May 2017</p>		<p>This reporting period</p>	<p>None</p>
					<p>Cumulative to date</p>	

Intervention Logic	Indicator	Next Milestone Target Date (from Inception Report)	Next Milestone Target (from Inception Report)	Comment. (Risks, challenges, will Targets be achieved, and on time?)	Achievement <sup>1</sup>	
	<p>1.3 Engineering Research: National policies, manuals, guidelines and/or research outputs that have been fully incorporated into Government/Ministerial requirements, specifications and recommended good practice as a result of ReCAP engineering research (including climate change adaptation and AfCAP and SEACAP adaptations).</p> <p>To include introduction of new policies and modification to existing policies.</p>	May 2017	May 2017	Guidelines will be complete by May 2017, but it will take a lot longer for them to be incorporated into government policy.	This reporting period	None
					Cumulative to date	None
	<p>1.4 TRANSPORT SERVICES Research: National policies, regulations and/or practices for rural transport services</p>	May 2017	May 2017	This depends on what high-tech solutions are taken forwards by the countries. Even after the research it will take time to	This reporting period	None

Intervention Logic	Indicator	Next Milestone Target Date (from Inception Report)	Next Milestone Target (from Inception Report)	Comment. (Risks, challenges, will Targets be achieved, and on time?)	Achievement <sup>1</sup>	
	<p>modified or introduced as a result of ReCAP research (including road safety and gender and AFCAP and SEACAP research )</p> <p>To include introduction of new policies and modification to existing policies.</p>			incorporate into government policy	Cumulative to date	None
	<p>1.6. LVRR and TS information generated for dissemination, and disseminated, that is not peer reviewed. Total to include research papers, final research reports, workshop reports, manuals and guidelines.</p> <p>CHECK IF THIS IS TO BE PART OF Service Provider Reporting</p>	Trial report due in Feb/March 2017	March 2017		This reporting period	All ground truthing done except for Kenya, Training done in 2 countries, analysis complete in 1.
					Cumulative to date	As above

Intervention Logic	Indicator	Next Milestone Target Date (from Inception Report)	Next Milestone Target (from Inception Report)	Comment. (Risks, challenges, will Targets be achieved, and on time?)	Achievement <sup>1</sup>	
Output 2: CAPACITY BUILDING: The building of sustainable capacity to carry out research on low volume rural roads, and rural transport services in African and Asian countries.	2.1. African / Asian experts or institutions taking lead roles in ReCAP Research Projects.	May 2016	March 2017	Local partners have been brought in, but funding an issue for some.	This reporting period	Other institutions have been brought in to partner the local team, either Universities or Remote Sensing Centres. They will play a key role in the project.
					Cumulative to date	
	2.3. Research projects with female researcher inputs at senior technical level.	October 2016	March 2017	Involvement of women is dependent on availability, but Uganda have shown good initiative in identifying women in senior roles.	This reporting period	In Uganda four of the team of six are women and three will play a senior technical role. In Zambia there is one woman on the team, but not in a lead role. Ghana team is yet to be determined. Kenya have not yet done ground truthing.
					Cumulative to date	As above
Output 3: KNOWLEDGE: Generated evidence base of LVRR and transport services knowledge is widely disseminated and easily accessible by policy makers and practitioners (including education and training	3.2. ReCAP generated knowledge presented and discussed at high level international development debates and conferences	April 2017	May 2017	If project is delayed the T2 conference may be missed, but planning to host a workshop,	This reporting period	None
					Cumulative to date	None
	3.3.ReCAP generated	April 2017	Held		This reporting period	None

Intervention Logic	Indicator	Next Milestone Target Date (from Inception Report)	Next Milestone Target (from Inception Report)	Comment. (Risks, challenges, will Targets be achieved, and on time?)	Achievement <sup>1</sup>	
institutions).	knowledge disseminated through significant workshops and dedicated training, virtually or physically, that are rated by participants as effective..		workshop at ICTA conference in October 2016		Cumulative to date	None

## **Annex 11: Participant Data**

### **Capacity Building Recipients**

The recipients are shown in Annex 7, the training report. The final pages show a full list of the participants.

<b>Name</b>	<b>Position</b>	<b>Organisation</b>	<b>Gender</b>	<b>Contact details</b>

## Annex 12: Partner Contribution

Partner countries have compiled their expenditure on resources to this project, as shown below:

### Ghana:

No.	Item	Days/No.	Rate	Total GHS	Comments
1	<b>Staff time</b>				
2	<b>Roads Authority</b>				
3	Scoping Visits	6	100	600	
4	Ground truthing	10	100	1,000	
5	Training	15	100	1,500	
6	Digitisation and assessment	12	100	1,200	
7	Other			0	
8	<b>Remote sensing partner</b>				
9	Training	15	100	1,500	
10	Digitisation and assessment	8	100	800	
11	Other				
	<b>Sub-total</b>			<b>6,600</b>	Total Staff Costs
12	<b>Ground truthing</b>				
13	<b>Staff costs</b>				
14	Per Diems/Acco	4	200	800	
15	Per Diems/Acco (driver)	2	150	300	
16	Other			0	
17	<b>Vehicles (hire + fuel)</b>				
18	Scoping Visit	1	900	900	
19	Ground Truthing	2	900	1,800	
20	Training field trip	1	600	600	
21	Data collection			0	
22	<b>Equipment purchase or hire</b>				
23	GPS			0	
24	Software apps			0	
25	Other			0	
	<b>Sub-total</b>			<b>4,400</b>	Total Ground Truthing Costs
26	<b>Training</b>				
27	Room hire (incl. multimedia)	7	1,000	7,000	7 days room hire, assumed cost (no charge)
28	Lunches and refreshments	9	225	2,025	Avg 9 people for 6 days
29	Equipment hire			0	
30	Software			0	
31	Other			0	
	<b>Sub-total</b>			<b>9,025</b>	Total Training Costs
32	<b>Other</b>				
33	??			0	
34	??			0	
35	??			0	
36	??			0	
37	??			0	
	<b>Sub-total</b>			<b>0</b>	Total 'Other' costs
	<b>TOTAL</b>			<b>20,025</b>	Ghana Cedi
				<b>4,005</b>	UK £ Pounds approximately

**Kenya:**

No.	Item	Days/No.	Rate	Total KSh	Comments
1	<b>Staff time</b>				
2	<b>Roads Authority</b>				
3	Scoping Visit	6	3,130	18,780	
4	Ground truthing	9	3,130	28,170	
5	Training	16	3,130	50,080	
6	Digitisation and assessment	3	3,130	9,390	
7	Other			0	
8	<b>Remote sensing partner</b>				
9	Training	9	3,130	28,170	
10	Digitisation and assessment	2	3,130	6,260	
11	Other				
	<b>Sub-total</b>			<b>140,850</b>	Total Staff Costs
12	<b>Ground truthing</b>				
13	<b>Staff costs</b>				
14	Per Diems	9	6,500	58,500	
15	Accommodation	9	3,000	27,000	
16	Other			0	
17	<b>Vehicles (hire + fuel)</b>				
18	Ground Truthing	3	30,000	90,000	
19	Training field trip	1	30,000	30,000	
20	Other			0	
21	<b>Equipment purchase or hire</b>				
22	GPS			0	
23	Software apps			0	
24	Other			0	
	<b>Sub-total</b>			<b>205,500</b>	Total Ground Truthing Costs
25	<b>Training</b>				
26	Room hire			0	
27	Lunches and refreshments			0	
28	Equipment hire			0	
29	Software			0	
30	Other			0	
	<b>Sub-total</b>			<b>0</b>	Total Training Costs
31	<b>Other</b>				
32	??			0	
33	??			0	
34	??			0	
35	??			0	
36	??			0	
	<b>Sub-total</b>			<b>0</b>	Total 'Other' costs
	<b>TOTAL</b>			<b>346,350</b>	Kenya Shillings
				<b>2,771</b>	UK£ approximately

**Uganda:**

No.	Item	Days/No.	Rate UGSh	Total	Comments
1	<b>Staff time</b>				
2	<b>Roads Authority</b>				
3	Scoping Visit	1	395,000.00	395,000.00	
4	Ground truthing	3	700,000.00	2,100,000.00	
5	Training	3	910,000.00	2,730,000.00	
6	Digitisation and assessment	62	390,000.00	24,180,000.00	
7	Other			-	
8	<b>Remote sensing partner</b>				
9	Training	6	100,000.00	600,000.00	Makerere Uni students
10	Digitisation and assessment	8	100,000.00	800,000.00	Makerere Uni students
11	Other				
	<b>Sub-total</b>			<b>30,805,000.00</b>	Total Staff Costs
12	<b>Ground truthing</b>				
13	<b>Staff costs</b>				
14	Per Diems (inclusive of accomodation)	3	268,400.00	805,200.00	
15	Other			-	
16	<b>Vehicles (hire + fuel)</b>				
17	Scoping Visit	1	700,000.00	700,000.00	
18	Ground truthing	3	700,000.00	2,100,000.00	
19	Training field trip	1	700,000.00	700,000.00	
20	Other			-	
21	<b>Equipment purchase or hire</b>				
22	GPS	3	50,000.00	150,000.00	
23	Software apps	1	100,000.00	100,000.00	
24	Other			-	
	<b>Sub-total</b>			<b>4,555,200.00</b>	Total Ground Truthing Costs
25	<b>Training</b>				
26	Room hire	3	250,000.00	750,000.00	
27	Lunches and refreshments	3	1,400,000.00	4,200,000.00	
28	Equipment hire	3	50,000.00	150,000.00	
29	Software			-	
30	Other			-	
	<b>Sub-total</b>			<b>5,100,000.00</b>	Total Training Costs
31	<b>Other</b>				
32	??			-	
33	??			-	
34	??			-	
35	??			-	
36	??			-	
	<b>Sub-total</b>			-	Total 'Other' costs
	<b>TOTAL</b>			<b>40,460,200.00</b>	
				<b>8,991.16</b>	Total £ pounds approximately

## Zambia:

No.	Item	Days/No.	Rate ZMW	Total	Comments
1	<b>Staff time</b>				
2	<b>Roads Authority</b>				
3	Scoping Visit	6	600	3,600	
4	Ground truthing	4	600	2,400	
5	Training	4	900	3,600	
6	Digitisation and assessment	3	300	900	
7	Other			0	
8	<b>Remote sensing partner</b>				
9	Training	4	450	1,800	Assumed cost, rates not available
10	Digitisation and assessment	3	450	1,350	Assumed cost, rates not available
11	Other	2	450	900	Assumed cost, rates not available
	<b>Sub-total</b>			<b>14,550</b>	Total Staff Costs
12	<b>Ground truthing</b>				
13	<b>Staff costs</b>				
14	Per Diems (missing lunch)	4	600	2,400	
15	Accommodation			0	
16	Other			0	
17	<b>Vehicles (hire + fuel)</b>				
18	Scoping Visit (fuel)	1	6,807	6,807	
19	Training field trip	1	600	600	
20	Ground truthing	2	6,000	12,000	
21	<b>Equipment purchase or hire</b>				
22	GPS			0	
23	Software apps			0	
24	Other			0	
	<b>Sub-total</b>			<b>21,807</b>	Total Ground Truthing Costs
25	<b>Training</b>				
26	Room hire	3	2,000	6,000	Not charged, assumed 1000/day
27	Lunches and refreshments	3	1,500	4,500	
28	Equipment hire	3	500	1,500	Not charged, assumed 500/day
29	Software			0	
30	Other			0	
	<b>Sub-total</b>			<b>12,000</b>	Total Training Costs
31	<b>Other</b>				
32	??			0	
33	??			0	
34	??			0	
35	??			0	
36	??			0	
	<b>Sub-total</b>			<b>0</b>	Total 'Other' costs
	<b>TOTAL</b>			<b>48,357</b>	
				<b>4,396</b>	Total UK£ pounds approximately