NPO: 2017/035104/08

Journal of Geography Education in Africa (JoGEA)

Journal of the Southern African Geography Teachers' Association - sagta.org.za

Geomorphology from 'on high': The use of drones/ UAV technology in teaching soil erosion

L. Riddle, T. Hill and B. Gijsbertsen

Discipline of Geography, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal (Pietermaritzburg Campus), South Africa

L. Riddle: lyndonriddle@gmail.com, https://orcid.org/0000-0003-0881-1791;
T. Hill: hillt@ukzn.ac.za, https://orcid.org/0000-0001-7015-6906;
B. Gijsbertsen: gijsbertsen@ukzn.ac.za

DOI number: https://doi.org/10.46622/jogea.v4i1.3806

Abstract

Unmanned Aerial Vehicles (UAV) are increasingly being utilised in scientific research endeavours and considered for field-based experiential education. UAVs are making it safer and less complex for a researcher to conduct scientific studies in a cheaper and faster manner compared to contemporary methods. In this study, a UAV was used to determine how effective the onboard camera's resolution would compare to aerial imagery and how this can be utilised in the educational field. The UAV was flown at various heights above the ground imaging a Pixel Density Reference Chart (PDRC), to determine the most appropriate height to obtain the highest quality image. At a height of 100 m above ground level, the on-board 4k camera provides pixels, which each cover a ground area of 5 cm x 5 cm. At this height, the onboard camera covers a total ground area of approximately 30 000 m^2*. With the ability to monitor erosional landforms and the capability to duplicate the image position for comparing images over time, UAVs can be critical spatial tools in illustrating landform features. The UAV can be a critical tool for an educator, to assist in teaching and improving students' knowledge of the processes behind soil erosion, image capturing, geo referencing and GIS.*

Keywords: Unmanned Aerial Vehicles; Education; 3-Dimensional Mapping; Gully Erosion; Erosion Mapping

Introduction

Advancements in remote sensing technology have improved our ability to map, observe, quantify and understand soil erosion processes (Glendell, 2007). This is most evident in the use of aerial and satellite images for mapping and investigating the progression of landscapes (Gonzáles & Rodriguez, 2017). Furthermore, remote sensing has assisted in determining landscape and land-use change, allowing us to understand and interpret changes of the past, which in turn could elicit present processes and predict future changes with more certainty. In developing remote sensing technology, autonomous/unmanned vehicles (UV) are increasingly playing a critical role. This is evident in scientific research, particularly in regions that are inaccessible and due to their relative ease of acquisition, setting up, piloting and capturing data (Gonzáles & Rodriguez, 2017). UVs are split into their relative medium in which they travel; Unmanned Aerial Vehicles (UAV) operate in the air, Unmanned Ground Vehicles (UGV) on the ground, vehicles that can float and travel on water are Unmanned Surface Vehicles (USV) and vehicles with the ability to travel below the surface of the water are known as Unmanned Underwater Vehicles (UUV).

The process of geomorphological research is to constantly view and record the changes of landforms (Toth et al., 2016). This has been improved through the use of aerial imagery from manned craft and satellite images, however, these methods are time-consuming, costly and of a relatively low resolution. They are however able to capture a large area. UAVs have the ability to obtain images at a reduced cost and at a shorter image acquisition time period and can carry and transport a myriad of payloads dependent on the researcher's requirements. UAVs can acquire aerial photographs under high cloud cover conditions by flying below the clouds and obtaining uninterrupted imagery. This is the case in humid regions where cloud cover is persistent and may negatively affect the images from a manned craft or satellite image (Kah & Wich, 2012). However, many UAVs do not have the ability to fly in rain or high winds, whereas manned crafts are dependent on the pilots' abilities.

Mapping and monitoring *in situ* soil erosion has limitations due to the inaccessibility of sites, for example, steep slopes, gullies, and unstable soils. We argue that a UAV allows the researcher improved access to observe and map a study site without these limitations. In addition, little experience is required to pilot the UAV and if damaged or lost they can be replaced, unlike a manned vehicle. The UAV used for this research can transmit a live video feed to the remote control which is saved to the remote device, saving video footage to the UAV itself. In an event of the UAV becoming lost or unable to be retrieved, the video data would still be saved to the remote device. The ability to input pre-determined flight paths allows one to re-fly the same route over time, which will allow for a time-lapse record of the erosional and depositional features of the study sites. The aim of this paper is to demonstrate the capability and applicability of UAVs to observe, record and teach for a better understanding of erosional and depositional processes.

Unmanned Aerial Vehicles

UAV technology continues to advance, from the first remote control fixed-wing plane to the more stable, technologically advanced quadcopters of today. The fixed-wing has been and still is, used due to its relative ease of use, although image quality is low, as fixed-wing planes cannot remain in a stationary aerial position and must fly parallel to the ground surface. Thus, they are affected by turbulence which alters image quality due to vibration. Many of the UAV take the form of a 4-propeller arrangement in a 'X' shape with the propellers at the end on each arm (quadcopter), they are electric and have an independent motor driving each propeller. This configuration allows for stable flight, which is ideal for stable imagery. Many UAVs are fitted with a motorised gimbal, which is an independent hardware attachment that links a camera to a vehicle. This allows for the independent movement of a vehicle while the camera remains stationary. A 3-axis gimbal allows for movement along 3 separate axes and is a mechanical device with 3 motors on each axis which keeps a payload stable and isolated from the aerial vehicle.

Payloads for a UAV are dependent on lifting capacity and many small UAVs have cameras, which are designed specifically for that UAV. However, market cameras can be placed on a UAV if the camera does not exceed the lifting capacity of the UAV. UAVs can range in price from a few hundred Rand for the entry-level drone with a camera installed, to hundreds of thousands of Rand for the top-of-the-range drone with a high-definition camera and sensors depending on the technology and the camera. As a cautionary note, the lower end drones have short flight times (5 to 8 minutes), compared to the higher end that can have up to a 30-minute flight time. GPS, barometers, and 360-degree sensors have been placed on the high-end UAV to improve the craft stability in flight. Many UAVs are linked to a GPS and can hover on a point without the user/pilot interaction. One of the leading drone brands has installed sensors onboard the UAV facing forwards, upwards and downwards, to help prevent the UAV from flying into surrounding obstacles, making it safer to fly. The sensors will prevent the UAV moving in that direction when it comes too close to an obstacle.

The UAV is able to capture high resolution imagery, that can be used and manipulated to obtain a desired result, incorporating GIS software. The UAV used for this research captures with a 4K RGB sensor. Each image records height of UAV above the ground, GPS location, altitude and angle of the camera. This allows a researcher to capture multiple images and stitch them together in an orthomosaic software such as Pix4D (William et al., 2016).

Soil Erosion

Soil erosion is the movement of soil by an external medium (Daba et al, 2003), be it water, wind or biological. Erosion occurs in sequential stages where overland flow or sheet wash occurs and gulley erosion can be considered the most advanced stage. Sheet erosion occurs when the ground is saturated, or the infiltration rate is not enough to allow rain fall to infiltrate into the soil and the excess water flows over the land as sheet wash. This sheet wash will develop a depression in the soil where the water will concentrate and erosion will occur at an accelerated rate (Keesstra et al, 2016). The rill formations can, over time, develop into a gully system. The mapping of the soil has in the past been undertaken manually, via manned aircrafts or satellites (Zhang et al, 2018). These methods do have the ability to capture large study areas however, the resolution, compared to a UAV, is lower and smaller erosional features (small gullies and rills) may be missed (Gonzalez and Rodriquez, 2017). Satellites images are easily downloaded on-line and can be free, however they are often out-of-date and at a low resolution. Higher resolution images can be bought, but these are still not at a resolution comparable to a UAV. Manned aircrafts have the ability to obtain a comparable image, however, this process is expensive and out of the reach of most researchers.

The monitoring of soil erosion for the purpose of research and education is critical as soil is an integral component of our ecosystem (Phinzi and Ngetar, 2017). With the use of UAVs, researchers and educators may be able to obtain a better understanding of the processes that control these erosional events.

Methods

We compared an ‘off-the-shelf’ UAV with an onboard 4k camera against recent aerial photography of a researched gulley/soil erosion site (Okhombe Valley, Northern KwaZulu-Natal) to determine the effectiveness, operability and resolution of both remote sensing (UAV and aerial photography) techniques to interpret the site based on resolution, in this case, on-the-ground pixel density. With the use of a Pixel Density Reference Chart (PDRC), which is a reference chart that displays six 10 cm x 10 cm squares that alternate in colour (black and white) to display the highest contrast in colour, to determine the number of pixels in the image relative to each block on the ground (Plate 1, Image E). A pilot study was conducted to determine if the Pixel Density Reference Chart would be seen at various heights (Plate 1). Due to the difficulty in spotting the PDRC at higher heights, the UAV was flown above a white plastic sheet (15 m x 1.5 m) on a sports field, with the PDRC placed on the sheet. This method allowedthe user to identify the PDRC on the plastic sheet and place the UAV directly above the PDRC to capture images with the lowest error or distortion. The UAV was flown at varying heights (25, 50, 75 and 100 m) above the PDRC and images were captured at each height once the UAV was aligned correctly with the PDRC and plastic sheet. The sports field study site was used to prove the validity of the methods, which were then implemented at the study site to determine if the methods would work under field-based conditions and, in particular, for gulley research. The method above was determined to be suitable to capture data in the field, thus the UAV was flown on the Okhombe valley situated in northern KwaZulu-Natal. The images for each height were uploaded to a photo-editing program (Adobe Lightroom

ISSN: 2517- 9861

v5), to observe individual pixels and measure the number of pixels in each block (e.g., 10 pixels per 10 cm x 10 cm block).

Results

The PDRC becomes increasingly difficult to observe with increasing height (Plate 1, Plate 2), however, one can increase magnification on-screen and 'zoom into the image', thus still being able to count the number of pixels per 10 cm x 10 cm block (Plate 1). To improve the resolution, one would need to fly the UAV lower. The PDRC was placed on a white plastic strip measuring 15 m by 1.5 m, with the test pattern on the bottom left corner. The pixel density changed for the pilot study, the initial test with the plastic sheet, and the final test at the study site, which could be an effect of adverse weather conditions, where a slight haze may reduce the effectiveness of the camera to read the highest number of pixels at varying heights (Hodgson et al., 2018). At a height of 50 m, the area of each pixel covered on the ground varied from 5 cm^2 to 2.78 cm^2 (Table 1). From this test, it was determined that when a UAV is flown at a height of 100 m above ground level, each pixel covers an area of 5 cm by 5 cm (25 cm^2).

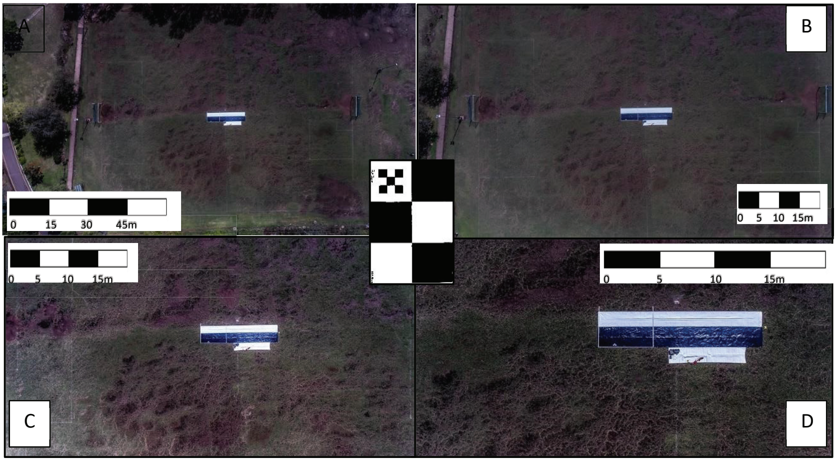

Plate 1: The pilot study on the sports field, displaying images from the UAV at different heights focusing on a test pattern sheet for measuring pixel density, to determine the pixel density of each image at each height. (A) at a height of 100 m, (B) at a height of 75 m, (C) at a height of 50 m, (D) at a height of 25 m and (E) image of the PDRC.

Scale is dependent on the height at which each image is captured and is shown in the corner of each image.

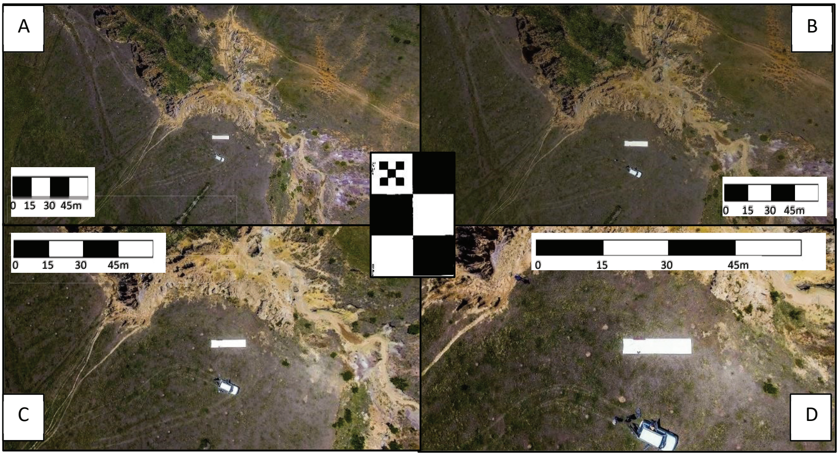

Plate 2: Image from UAV taken at Okhombe Valley, Northern KwaZulu-Natal, showing severe gully erosion. The images were taken at different heights focussing on a test pattern sheet for measuring pixel density. (A) at a height of 100 m, (B) at a height of 75 m, (C) at a height of 50 m, (D) at a height of 25 m and (E) image of the PDRC. Scale is dependent on the height at which each image is captured and is shown in the corner of each image.

Table 1: Size of pixels against area on the ground at various heights

	Pilot	**Test flight with plastic sheet**	**Okhombe**
Height above ground (m)	Area of single pixel (cm^2)	Area of single pixel (cm$^{2)}$	Area of single pixel (cm^2)
10	0.08		
20	0.27		
25		0.83	1
30	1		
40	2		
50	5	2.78	4
60	6.25		
70	8.33		

ISSN: 2517- 9861

	Pilot	**Test flight with plastic sheet**	**Okhombe**
Height above ground (m)	Area of single pixel (cm^2)	Area of single pixel (cm^2)	Area of single pixel (cm$^{2)}$
75		6.25	6.25
80	11.11		
90	16.66		
100	25	11.11	16.66

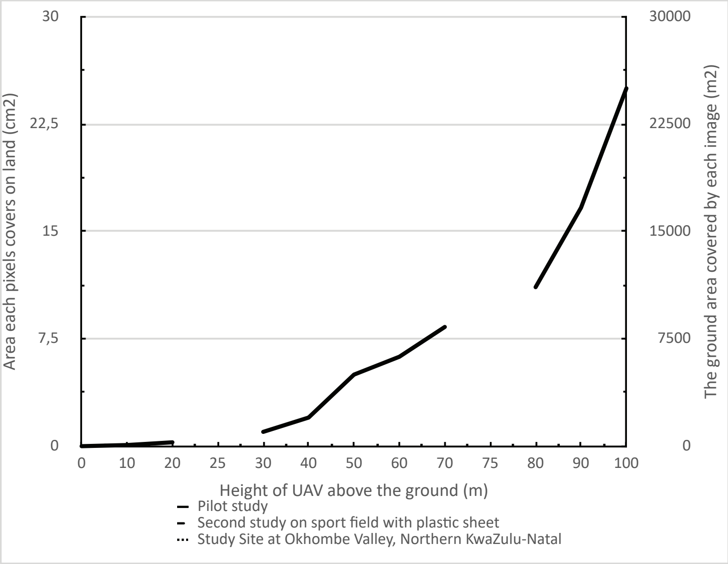

Figure 1: The relationship between pixel density and UAV height.

Discussion

The optimum height at which a UAV with a camera of the same resolution as the camera used in the tests, should fly, would be approximately 50 m above the ground to obtain the highest pixel density on the ground (Table 1). At this height, each pixel covered a ground area of approximately 2.78 cm^2 to 5 cm^2. This would not be the optimum height to fly at all sites as there may be natural or human-made features obstructing flight. One would have to assess the surrounding environment and vegetation to determine a safe height at which the UAV could fly. The 4k resolution will improve if the UAV flies lower, however, there is a compromise as the area covered will decline (Figure 1). This will allow users to obtain an improved image and one can mosaic images together for a high-resolution image. Although these UAV images will be of a high spatial resolution, they lack multi-spectral images (Gonzáles & Rodriguez, 2017). This makes the manipulation of images in any GIS programs difficult as multi-spectral sensors capture images in, and on either side of, the visible light spectrum. These bandwidths are required by GIS programs for the manipulation of images as it allows the GIS user to manipulate the image to view features that are not observed in the visible light spectrum. Multi-spectral image platforms/machinery can be installed onto a UAV if the imagery device has a low enough weight that the UAV will be able to lift. Fan et al., (2017) replaced standard cameras for V-NIR cameras to determine biomass and leaf area index.

Use of UAV in field-based education

As the skills required to fly and collect data with the use of a UAV are generally easy, students can learn how to operate and manage the remote approach to data collecting. The platform does not require a landing area and can be launched and caught by hand, making it more accessible and user-friendly in an outdoor classroom situation. UAVs are providing GIS and Remote Sensing students with the opportunity to create GIS maps from data collected to the final product. Rather than relying of older manned aircraft imagery or satellite imagery, they can capture aerial imagery of their study site and transfer these data into GIS program for analysis and interpretation. This can be accomplished multiple times over shorter periods of time to obtain small time frames of movement/change within the study site.

This provides GIS students with a ‘real-life’ field-based application to understand and be skilled in aerial image capture and uploading onto an appropriate software analysis package. Mapping exercises can be established for students to conduct and collect images of a site using a drone and then interpret (Jordan, 2015). This can be of a site directly adjacent to a teaching facility to which an educator can monitor the flight of the UAV and be able to test the final result. At present, there is a gap between acquiring imagery and the use of that image on computer software. This ‘gap’ is an area of study whereby researchers/ students have, and are taking for granted, the process of how to acquire aerial imagery, and the process needed to geo-reference the image for later manipulations on GIS software. This process is missing, as many GIS images can be downloaded from the internet. The use of UAV may encourage the user to learn the process from imagery on the UAV to the imagery required for remote sensing software (William et al., 2016). This will make the UAV an ideal training tool for students to learn the process of acquiring the image, correcting and processing the image to be uploaded onto computer software, and final visualisation, validation and interpretation of the image to test various attributes needed for the research. The relatively inexpensive set-up will bring the technology closer to schools and universities, where faculties have the option to obtain multiple UAV and parts to assist in the teaching of their students(William et al., 2016).

A 3D scanner can be attached to the UAV to create computer models with user-defined specifications, for example UAVs can be used to map rivers in high definition, and 3-dimensional (3D) mapping of geological or human-made structures (Jordan, 2015), flying along the route of the river processing images with correlated GPS locations. The images can be stitched/mosaiced together to obtain a 3D representation of the river. This process can be conducted on several occasions, which may display changes in patterns of erosional and depositional events of the river. The 3D mapping can be used to accurately map the inside of a gully over a designated time period to monitor the change of the gully shape and display erosional and depositional features. A 3D scanner sensor to attach to a UAV can be expensive and a similar result can be completed with the capture of multiple images of a site and then stitched together in an orthomosaic software (Glendell et al, 2007). These images will require a high degree of image overlap to assist the software in identifying features in the image. This software is able to create 3D renders of a site in a relative short period. These software are available online thus allowing educators to custom fit the best software to their requirements and resources available to them. These software's have the ability to export Digital Elevations Models (DEM) to be later processed on GIS software. This may in the future help researchers to determine areas that may be prone to erosion or determine a method to predict the occurrence of erosion.

A UAV can be constructed to collect hyperspectral and hyperspatial data, with bandwidths from 4 to 5 nm and spatial resolution of 2-5 cm (Lucieer et al., 2014). This allows for the mapping of biochemical and biophysical attributes of vegetation communities, such as composition and health (Lucieer et al., 2014). Micasense Altum is a multi-spectral sensor which uses five different wavelengths to capture images and a thermal infrared sensor (Miller et al, 2020). These sensors, with the use of the orthomosaic software, are able to produce images with the calculation of a Normalized Difference Vegetation Index (NVDI). However, the Micasense Altum sensor can be costly and require a specialised UAV. The idea is to develop this approach to include the agricultural sector to allow for a rapid appraisal technique, which could be deployed to monitor crops over time. Thus, one can undertake a pre-and post-treatment on various crops. Sampling can become a completely autonomous task, removing human error or contamination from soil samples. UAVs have been used for a wide array of wildlife and environmental monitoring applications (Hodgson et al., 2018). The UAV has in the past been used to count livestock and monitor the movement of wildlife, to protect wildlife in the use to monitor for poachers and to reduce stress during times of animal census taking.

As UAV technology advances, so will the capability of the UAV. Longer battery life, autonomous flight (already in existence), improved imagery, and a diversity of images (thermal, infrared) and many more technologies will be installed onboard standard UAVs. Already infrared scanners and thermal imagery can be installed on a UAV for desired projects and outcomes. Autopilot systems (ArduPilot Mega) allow users to plan routes for the UAV to follow without physically controlling the UAV (Kah & Wich, 2012). The user plots a route with the use of ArduPilot Mega of where they would like the UAV to follow. Once the route is accepted by the user, the UAV will follow that route with its onboard GPS and sensor systems. This program will allow the UAV to take off, fly a set route, land back at the take-off point, charge and download recorded data automatically. This makes the monitoring process quicker and user-free.

Technology will allow the use of a UAV in a multitude of applications appropriate to teaching and research within the geographical field. New cell phone applications and programs have been developed which allow the user to demarcate a study area before the flight commences and the UAV will cover the area autonomously at a predetermined height, speed and path. This flight path, height and speed can be saved and later repeated. The application/program allows the user to determine how high the UAV flies and by how much the images overlap. Today's researcher/student in the field will use a digital camera, GPS, smartphone and laptops (William et al., 2016) and one-day UAV will be a standard component in our field kits. A field survey conducted by William et al., (2016) stated that students were interested and were more engaged with the use of technology in the field. The UAV assisted in the observation and mapping of the study site. Due to the UAVs relatively ease of setup and operation, students/researchers were able to conduct fieldwork in shorter time periods and the ability to repeat the methods a number of times. With the use of the UAV, erosional and depositional landforms on the study site were easily depicted, while keeping the students/researchers at a safe distance from the unstable area. Thus, UAVs in the education fields would engage students to contribute and involve themselves in fieldwork and studies. The UAV allows students, schools, and universities that cannot afford to purchase expensive GIS programs and the images (e.g., Quickbird, Ikonos) to use a UAV with the free GIS software to analyse the data at a reduced cost (Kah & Wich, 2012).

Limitations

The primary concern are the natural conditions of operation, technological issues and legislation (Jordan, 2015). Many of the existing UAVs are not waterproof thus flying in rain or inclement weather is not feasible, although water-proof models are under-development and could be in circulation in the near future. These UAVs are capable of transitioning from air to water, by landing on the water and submerging under water whilst in operation. Allowing for a UAV to capture images above the ground and in the water. This could be a vital tool when requiring a digital elevation model of a terrain that consists of both land and water. However, the accuracy of the images and telemetry in the water may not be as accurate as that above the water.

High winds can be an issue due to the drone size and can be blown off-course. This said, the UAVs that have on-board GPS can correct themselves to some extent and keep the UAV on the correct specified position or path, although this does impact energy usage and battery life. The larger the UAV the less of an effect the winds will have and the more stable the UAV can be. This said, these UAV are expensive and can be out of reach of most researcher and educators. Off the self UAVs are light in weight and can weigh as little as 269g. Thus, the researcher or educator would need to monitor weather conditions prior to flight to prevent any negative issues.

At present, a drone licence to fly commercially is required and the process of obtaining the commercial licence is slow and expensive. To date, only 26 Remote Operators Certificate (ROC) and several Remotely Piloted Licence (RPL) have been issued in South Africa (www.caa.co.za). Currently in South Africa, flying a UAV legally for commercial use may be out of range financially for many researchers and educators. Commercial use is classed as any activity that the UAVs is utilised to generate a financial gain. The RPL allows a drone pilot to fly said UAV for a company that possesses a ROC (Matos, 2015; www.prowings.co.za). While the ROC is expensive and takes a minimum of one year to acquire (Schmidt, 2016). The laws are put into place to protect all flying vehicles in the sky, however, the UAV licences are presently perceived as being unrealistic and preventing the use of UAV in areas that may be useful. UAV have been given a negative connotation from some hobbyist misusing or abusing the platform. General public may discourage the use of a UAV in an area which is required by the researcher or educator.

Technology development has limited the use of a UAV in the past, as the UAV is electric and requires battery power to be operated (Jordan, 2015). The battery life of many UAV are approximately 20 to 30min, and this is reduced in low temperature and high winds. The RGB sensor is a limitation as smaller sensors are required with a higher resolution. As the development of sensors and batteries improve, the usefulness of a UAV for multiple applications will increase.

Conclusions

A UAV is a relatively user-friendly tool, which can be purchased from many electronic stores in South Africa, with the ability to capture, observe and map inaccessible sites, to critical or dangerous for either humans or manned aerial vehicles. This said, currently in South Africa, due to the laws and legislation regulating the use of a UAV for commercial gain (i.e., teaching students to use the drone, thus meaning the teacher is being paid) is illegal without the possession of a RPL and ROC, which is expensive and time-consuming. The research has proved that the use of a UAV for research and education can be highly beneficial, however until laws are changed to make the process of acquiring a licence faster and more within budget, UAV in South Africa will be for the elite and larger companies.

From this research, it was seen that the use of a UAV has proved itself to be highly versatile in observing, recording and acquiring a better understanding of erosional and depositional events. At present the UAV for the use of aerial imagery and landform mapping is the better option above that of satellite and manned aircraft imagery systems, due to its versatility, low costs and is relatively simple to operate. The UAV as a spatial tool has the potential to allow researchers and educators a more holistic approach to research, as one will be able to utilise the UAV for data capturing, developing data and later manipulation on GIS to assist in obtaining the desired outcome. The UAV can be a critical tool for education not only for soil erosion studies but for a myriad of field-based courses. The researcher or educator would need to determine how it can utilise and assist in obtaining new or faster perspectives of a site or feature. UAV has the ability to create 3D images of a site or feature which can be manipulated in GIS software or 3D analysis software.

The UAV takes erosion monitoring to the next level by assisting the user in obtaining rapid data pre-, during and post-erosional events. The potential for the UAV to be a standard tool for educators or researchers is high and should be considered. As technology continues to develop and there is a need to ensure that students are acquainted with the latest technologies to ensure skill development and vocational training, the UAV skills set can provide both the latest technological know-how and serve as a case study of spatial skills development. The UAV should be a tool used in schools and universities for educational purposes. The lack of use can be a missed spatial and technological opportunity, both critical skills that we know our students, scholars and staff-alike enjoy 'playing' with!

Acknowledgements

This research is a part of a larger research project (WRC K5/2402/4) which is funded and managed by the Water Research Commission, entitled

‘Assessing the impact of erosion and sediment yield from different land uses in farming and forestry systems and their effect on water resources in selected catchments of South Africa’.

Author Bio’s

Lyndon Riddle, an enthusiastic geomorphologist, currently holds a MSc (UKZN) in coastal erosion and future sediment movement. He has lectured at both the under- and post-graduate level, in the field of earth sciences (University of KwaZulu-Natal). He was lucky enough to teach the senior students at Glenwood High School (Durban, South Africa), while completing his PhD. He has interest in the utilisations of UAV in research hence the PhD topic of implementation of UAV in geomorphological research.

Trevor Hill is trained as a Physical Geographer with a focus on palaeoecology. He is an Academic Leader for Research within the School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, ex co-editor SA Geographical Journal, present Editor of Transactions of the Royal Society of South Africa. His own research interests tend to be rather eclectic, and one could be polite and call it transdisciplinary! His dream is to get back in the lab, avoid admin and count pollen!

Brice Gijsbertsen is the Principal Cartographic Technician for the Discipline of Geography on the Pietermaritzburg Campus of the University of KwaZulu-Natal. His specialties are Geographic Information Systems (GIS) and remote sensing (RS) with specific interests in high precision differential GPS systems, mapping demographics, forestry, and health utilization. He has over 25 years of practical experience in the GIS, RS and computer arenas. He is passionate about renewable energy projects assisting with the design and manufacture of mobile solar powered pollution monitoring trailers.

ISSN: 2517- 9861

References

Adasi, 2014. *Types of Unmanned Systems.* [Online], Available at www.adasi.ae [Accessed 27th June 2018].

Daba, S., Rieger, W. and Strauss, P. (2003) Assessment of Gully Erosion in Eastern Ethiopia Using Photogrammetric Techniques. *Catena*. 50(2-4). Pg 273 – 291.

DJI, 2017. *Phantom 4*. [Online], Available at: www.dji.com. [Accessed 7th May 2017].

Fan, X.; Kawamura, K.; Xuan, T.D.; Yuba, N.; Lim, J.; Yoshitoshi, R.; Minh, T. N.; Kurokawa, Y. and Obitsu, T. (2017). Low-cost visible and near-infrared camera on an unmanned aerial vehicle for assessing the herbage biomass and leaf area index in an Italian ryegrass field. *Japanese Society of Grassland Science*. 64(2). Pg 1 – 6.

Glendell, M.; McShane, G.; Farrow, L.; James, M.R.; Quinton, J.; Anderson, K.; Evans, M.; Benaud, P.; Rawlins, B.; Morgan, D.; Jones, L.; Kirkham, M.; Debell, L.; Quine, T.A.; Lark, M.; Rickson, J. and Brazier, R.E. (2007). Testing the utility of structure from motion photogrammetry reconstructions using small unmanned aerial vehicles and ground photography to estimate the extent of upland soil erosion. *Earth Surface Processes and Landforms*. 42(12). Pg 1860 – 1871.

González, M and Rodriguez, P. (2017). Monitoring Soil Erosion by Raster Images: From Aerial Photographs to Drone Taken Pictures. *European Journal of Geography*. 7(5), Pg 117 – 129

Hodgson, J.; Mott, R.; Baylis, S.; Pham, T.; Wotherspoon, S.; Kilpatrick, A.; Segaran, R.; Reid, I.; Terauds, A. and Koh, L. (2018). Drones Count Wildlife More Accurately and Precisely Than Humans. *Methods in Ecology and Evolution*. (9)5. Pg 1-8.

Jordan, B.R. (2015). A bird's-eye view of geology: The use of microdrones/UAVs in geologic fieldwork and education. *The Geological Society of America Today*. 25(7). Pg 50 – 52.

Kah, L.P. and Wich, S.A. (2012). Dawn of drone ecology: Low-cost autonomous aerial vehicles for conservation. *Tropical Conservation Science*. 5(2). Pg 121 – 132.

Keesstra, S., Pereira, P., Novara, A., Brevik, E., Azorin-Molina, C., Parras-Alcántara, L., Jordán, A., and Cerdà, A. (2016). Effects of Soil Management Techniques on Soil Water Erosion in Apricot Orchards. *Science of the Total Environment*. 551 – 552. Pg 357 – 366.

Lucieer, A.; Malenovshý, Z.; Veness, T. and Wallace, L. (2014). HyperUAS – Imaging spectroscopy from a multirotor unmanned aircraft system. *Journal of Field Robotics*. 31(4). Pg 571 – 590.

Matos, C., 2015. *How to get a drone licence in South Africa*. [Online] Available at: http://www.htxt.co.za/2015/11/26/how-to-get-a-drone-licence-in-south-africa/ [Accessed 7 May 2017].

Miller, I., Schieber, B., De Bey, Z., Benner, E., Ortiz, J., Girdner, J., Patel, P., Coradazzi, D., Henriquez, J. and Forsyth, J (2020) Analyzing Crop Health in Vineyards Through a Multispectral Imaging and Drone System. *System and Informations Engineering Design Symposium*. Charlottesville, VA, USA, 24 April 2020, Pg 1- 5.

Phinzi, K. and Ngetar, N (2017). Mapping Soil Erosion in a Quaternary Catchment in Eastern Cape Using Geographic Information System and Remote Sensing. *South African Journal of Geomatics*. 6 (1). Pg 11 – 29.

ProWings, 2015. *Remote Pilot Licence*. [Online] Available at: http://www.prowings.co.za/remote-pilot-licence/ [Accessed 7 May 2017].

Remotely Piloted Aircraft Systems. *RPAs Operators*. [Online]. Available at: http://www.caa.co.za/pages/rpas/rpas%20operators.aspx .[Accessed 30 June 2018]

Schmidt, M., 2016. *Costly, clunky aviation rules clip our wings say, drone operators.* [Online] Available at: https://www.businesslive.co.za/bd/companies/transport-and-tourism/2016-11-23costly-clunky-aviation-rules-clip-our-wings-say-drone-operators/ [Accessed 7 May 2017].

Smith, K.W. (2015). Drone technology: Benefits, risks and legal considerations. *Seattle Journal of Environmental Law*. 5(1). Pg 291 – 302.

Toth, C.A.; Barkoczi, N.; McIntosh, R.W. and Plasztan, Z.J. (2016). Studying the development of fluvial landforms in the Berettyo-KOROS region using geoinformatics methods. *Landscape and Environment*. 10(3-4). Pg 137 – 144.

William, R.D.; Tooth, S. and Gibson, M. (2016). The sky is the limit: Reconstructing physical geography from an aerial perspective. *Journal of Geography in Higher Education*. 41(1). Pg 134 – 146.

Zhang, Z.; Gerke, M.; Vosselman, G. and Ying Yang M (2018). A Patch-Based Method for the Evaluation of Dense Image Matching Quality. *International Journal of Applied Earth Observation Geoinformation*. 70, Pg 25 – 34.

ISSN: 2517- 9861