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Satellite vs. UAVs Remote Sensing of Arid Ecosystems: A Review with in an Ecological Perspective

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Abstract

Arid rangelands in most countries are currently managed without any clear information of long-term trends of the ecological processes and desertification. Remotely sensed imagery is widely used to detect changes in the vegetation cover in arid ecosystems. However, vegetation of arid lands is a challenge due to the spectral, floral, and topographical characteristics of the landscape. This paper focuses on reviewing the main challenges and limitations of RS satellite imageries in the field of ecology in arid ecosystems, and whether UAVs can resolve such limitations.

Introduction

The management of arid ecological systems is a key component for long-term sustainability and has been recognized globally as arid regions cover 41% of the earth's land surface and contain 38% of the human population [1,2]. Arid ecosystems are dramatically influenced by human activities resulting in desertification and soil compaction leading to losses in ecosystem services [3-5]. Assessing and monitoring arid ecosystems is difficult due to the complexity of the ecological system as several elements including vegetation, animals, soils, and climate are all connected together. However, remote sensing is one of the most powerful technologies in assessing and monitoring the ecological system due to its contribution in providing large amount of data, which helps in answering critical ecological questions [6-8]. Several studies show that remote sensing technology can provide powerful information in the field of ecology by enabling scientists and researchers with decent information to analyze dynamic changes in landscapes [6,9,10], evaluate the distribution of vegetation cover [7,11,12] and monitor landscape degradation [13-15]. Additionally, the integration of RS and GIS was successfully examined in our previous work in Kuwait [16-19], which assisted in:

a) Developing a site history for disturbed locations to determine the major source of disturbance,

b) Selecting reference/or control sites for the restored areas,

c) Monitoring the dynamic changes in vegetation in a war affected area,

d) Evaluating the potential soil loss at the restored location, and

e) Selecting optimum locations for revegetation.

Thus, some limitations were found through the use of satellite imagery when dealing with arid ecosystems [20], but modern RS technologies including low-altitude unmanned aerial vehicles (micro-UAVs) may resolve some of these limitations [21]. Therefore, this paper focuses on reviewing the main challenges and limitations of RS satellite imageries in the field of ecology in arid ecosystems, and whether UAVs can resolve such limitations.

Limitations of RS Satellite Imagery in Arid Landscapes

Even though RS applications using satellite imagery showed a decent amount of useful information, several limitations and challenges were detected when dealing with arid ecosystems. These concerns include the small size and low amount of vegetation cover in arid landscape, which makes it difficult to detect the coverage and specific types of desert species due to the high reflectance of the soil background, variable mixture of green and senescent grasses (shrubs and herbs), and multiple reflectance from open canopies and bright soils [20]. Moreover, common RS vegetation indices and methods are insensitive to detect non-photosynthetic vegetation (NPV) which include dry / dead shrubs, leafless drought deciduous plants, and senescent plants [22]. NPVs are considered the major component of the total desert surface cover, and play an important role in vegetation dynamics in arid ecosystems [23]. They may also be important, especially when studying soil erosion (both wind and water), as they play a critical role in preventing the risk of soil loss [16,23].

Data acquisition for required time periods is also an issue with satellite imageries. There are some restrictions in the availability of satellite imagery data as satellites travel along geosynchronous orbits providing only a partial view of the earth with specific timing which may be an issue for time sensitive applications [24]. This is important for assessing and monitoring vegetation dynamics as arid plants are more distinct and visible in specific seasons. Spectral resolution is also important in identifying and mapping arid ecosystem features. The broad spectral bands of multispectral sensors such as Landsat Thematic Mapper (TM) and SPOT XS as well as medium spatial resolution sensors such as IKONOS greatly reduce their ability to spectrally discriminate between arid ecosystem features that have similar reflectance. However, hyperspectral sensors, with higher spectral and spatial resolutions, have the ability to identify arid ecosystem features in more details than multispectral sensors [17]. Hyperspectral data can provide reliable results for identifying arid ecosystem features as they expand and improve the spectral capability of multispectral sensors thus providing more accurate results for mapping [25]. However, hyperspectral data are not commonly used due to the large expenditures involved in acquiring such information. From previous work it can be seen that the multispectral and hyperspectral sensors showed similar results of vegetation cover depending on the classification method, and the number and types of classes within the landscape. For instance, hyperspectral sensors may differ when mapping more complex areas with multiple classes such as urban areas. However, it may not show significant differences when dealing with the mapping of an open landscape covering a few classes such as vegetation and bare soils [18].

In addition, the capability of satellite remote sensing to identify and map arid ecosystem features can be limited by the accuracy of the geographic location of the target feature and radiometric factors (e.g. atmospheric scattering). The geometric distortion (e.g. platform motion, optical and scanner distortions, and target motion such as the Earth's rotation) can limit the accuracy of the geographic locations [26]. In addition, radiometric effects, such as atmospheric scattering, can influence the amount of radiation reaching the sensors and therefore reduce the accuracy of remotely sensed satellite data. Consequently, geometric and radiometric limitations of sensors should be considered and corrected before processing any imaging analysis.

Low-Altitude Unmanned Aerial Vehicles (micro-UAVs)

With the development of modern RS technologies, most of these challenges and issues could be resolved. In the past few years, rapid increase has been seen in the use of low-altitude unmanned aerial vehicles (micro-UAVs), and LIDAR (Light Detection and Ranging) sensors (including airborne and terrestrial LIDAR) [21]. These technologies can be used in several ecological applications, including detailed ecological studies [27] and biodiversity assessment [21]. One of the major advantages of UAVs is the flexibility of data acquisition for required time periods as well as the low cost for capturing data. This is important in studying ecological systems, and especially vegetation dynamics due to the seasonal dynamics and spectral characteristics of vegetation as desert plants are often more distinct and visible in specific seasons [24,28]. They also provide much higher spatial resolution that ranges from meters to millimeters, which is relevant in assessing several ecological processes [27]. Such methods are also helpful in monitoring and modeling ecological issues, including plant population and communities, soil condition, and plant monitoring, which includes estimations of biodiversity and biomass [21] as LIDAR sensors are able to directly measure the function of height [29].

The image resolution captured by UAVs also depends on the flight altitude and the size of the area covered [30]. The higher the altitude of the UAVs, the larger the area covered. However, covering large area with UAVs will lower the resolution of the imagery, limiting feature identification in the image frame. In addition, the technical camera/sensor specifications (i.e. camera / sensor focal length) can also affect the quality of UAV images. These specifications can validate the capability of the UAVs in vegetation identification in arid ecosystems.

In addition, UAVs require a real-time weather information. For example, the information on wind speed and direction, atmosphere visibility, and cloud coverage can all affect the quality of UAV images. Selecting the optimum flight time can be an advantage of the UAVs. However, the uses of UAVs could be limited in arid ecosystem areas with consistently bad weather conditions.

Can UAVs replace Satellite Imagery?

The question here focuses on whether UAVs imagery can replace satellite imagery. The answer for this question depends on the purpose and scale of the project. Satellite imagery and UAVs imagery differ according to the type of information where each has its own advantages and disadvantages (Table 1). If the project focuses on a large scale, then satellite imagery could be the best option as UAVs are unable to cover large scale landscapes. Figure 1 represents an example showing the differences between UAVs and Landsat 8 imagery (medium resolution imagery) at Al- Abdali agriculture area located in the north of Kuwait. The Landsat imagery covers north portion of the country including Abdali agriculture area in one image which is useful for large scale objectives such as assessing the changes in agriculture area, and detecting the green areas within the agriculture area which is difficult to study using UAVs. The UAV image covered only one farm in the agriculture area with a very high resolution image which was captured using Parrot

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Disco Pro-AG with Sequoia Multispectral camera. 300 images were mosaicked together to cover one farm within the agriculture area with a very high resolution, whereby small species such as the shrubs were easily detected from the UAVs imagery. However, the processing time for the UAVs imagery was long compared with the satellite imagery which was faster. Figure 2 shows another example that compares high resolution Pleiades satellite imagery with UAV (Phantom 4 Pro drone) imagery for Jahra pools nature reserve area, State of Kuwait. The high resolution imagery shows a high level of details (e.g. spectral, shape, context and texture) of the area over a large scale. Whereas, imagery obtained by UAV (Phantom 4 Pro drone) covers a small scale area with higher details of vegetation information (e.g. species type, size, health, etc.) than that of the satellite imagery.

Table 1: UAVs vs. landsat imagery.

Characteristics	UAVs	Satellite Imagery
Spatial resolution	Very high resolution (meters to millimeters)	High and medium resolution
Scale	Suitable for small scale projects	Suitable for large scale projects
Processing time	Long processing time	Short processing time
Images captured	188 image	Lager area is covered with one image
data acquisition	flexibility of data acquisition for required time periods Only future imageries can be captured	restrictions in the availability for specific time periods Availability of images for previous years

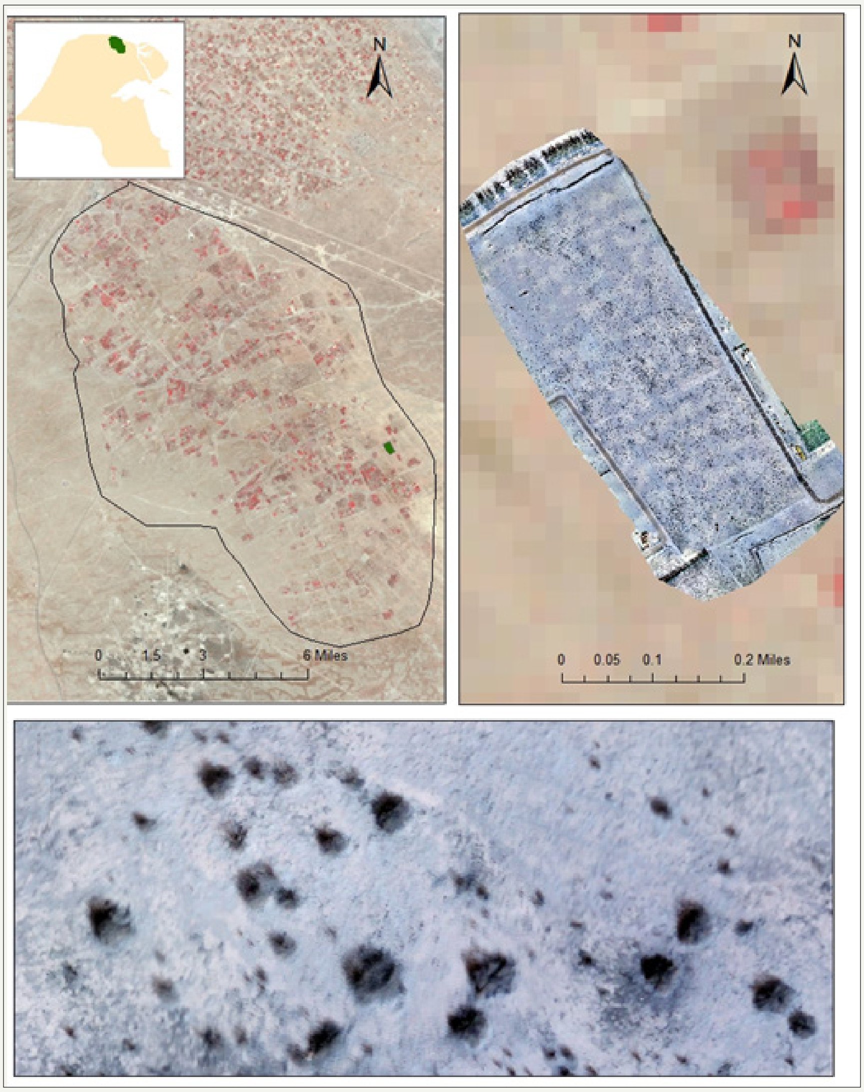

Figure 1: Example of Abdali agriculture area conducting Landsat 8 and UAVs. the location of the agriculture area obtained from Landsat 8 imagery, PAFF farm which covers native desert species, the image was obtained using UAVs, and zoom in to the Arial imagery, shrubs can be easily detected through the imagery.

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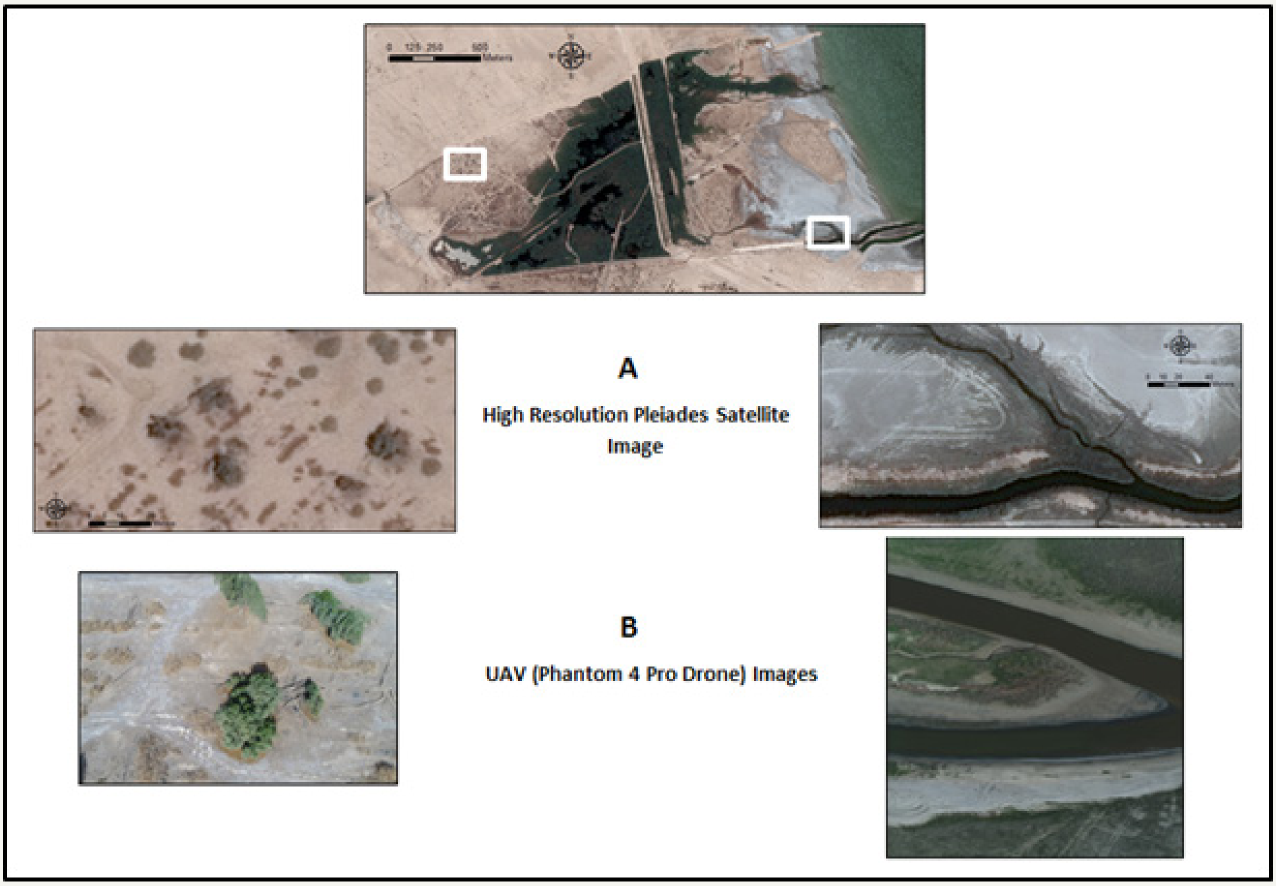

Figure 2: Example of Jahra pools nature reserve area conducting high resolution Pleiades satellite image and UAVs (Phantom 4 Pro Drone).

(A) Vegetation from arid ecosystem area and river side obtained from high resolution Pleiades satellite imagery.

(B) The species type and size of vegetation, and the vegetation cover near the river appear clearly in the image obtained using UAVs (Phantom 4 Pro Drone).

Conclusion

Assessing and monitoring land cover of arid ecosystems is complicated due the small size and low amount of vegetation coverage. RS satellite imageries showed good results in assessing land cover in arid ecosystems, but there are some limitations due to the difficulty of the RS methods and indices in detecting non-photosynthetic vegetation (NPV). However, most of these issues could be resolved by using very high resolution imagery obtained from UAVs, which provide decent information for small scale projects due to the very high spatial resolution. Yet, the fine spatial resolution is not always beneficial, it depends on the scale and purpose of the study. For large scale projects, satellite imageries will be better in detecting the healthy vegetation coverage. UAVs are powerful in monitoring and modeling detailed ecological issues within a small scale, including plant populations and communities, soil condition, and plant monitoring, which also includes estimations of biodiversity and biomass. Nevertheless, we believe that research on the use of UAVs is limited in arid ecosystems. Therefore, more research and experiments are needed in modeling the ecological process in arid ecosystems in order to provide better information for land management decisions.

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