Misan Journal of Engineering Sciences ISSN-E: 2957-4250
Vol. 4, No. 2, June 2025 ISSN: 2957-4242

Utilize Remote Sensing Techniques for Mapping Karez Systems and Their Alignment with Keyline Design for Sustainable Water Management and Topographic Harmony

Zahraa R. Fakher[1]
[1]*Department of Petroleum Engineering, Missan University, Missan, Iraq*
**Corresponding author E-mail:* geologist_2021@uomisan.edu.iq

(Received 9 June, Revised 3 Oct, Accepted 3 Oct)

Abstract: Unmanned Aerial Vehicles (UAVs) have been utilized for almost twenty years primarily in military contexts. Today, they serve as one of the most effective tools for remote sensing, with a wide range of applications.The main justification of this research is applying remote sensing a powerful tool for locating karez systems in eastern Missan. In the same way, analyzing their alignment with keyline design. In turn, offering insights into water harvesting as an ancient water management and its harmony with natural topography. The landscape analysis approach combines GIS technologies, remote sensing, drone surveys, and fieldwork, with a focus on water management and sustainability. The DJI Mini 2 drone was employed to capture high-resolution imagery, effectively covering a significant portion of the study area. Ineddtion to the fieldwork using the drone DJI Mini 2 highlighted the process of determining a very high-resolution scale for mapping, and analysis applying the Ground Sampling Distance. This makes it perfect for identifying karez system distribution and their extensions at flight's height range is 114 to 37 meters. the keyline design principles align with the path of the karez system in the site. This alignment suggests that the karez system was designed in harmony with the natural topography, following the keyline to maximize water efficiency and minimize erosion or water loss. The match between the two indicates a sustainable and intelligent use of the landscape, where the karez system complements the natural water flow patterns identified by keyline design.

Keywords: UAV; Ground Sampling Distance; Remote Sensing; P. A. Yeomans' Design; Karez system; water sustainability

1. Introduction

Unmanned Aerial Vehicles (UAV) have been used for nearly two decades for surveillance purposes related to military offers. Now it's the most effective remote sensing tool with multiple applications. Aerial photography is an example of the oldest remote sensing tool [19]. The scale of the aerial photograph can also be calculated in the case that an object with a known ground size appears in the image. To determine the scale, one way is to locate a feature in the image that has a known size [10]. In this study, drone techniques are utilized to estimate the scale of the aerial photograph through the ground sampling distance (GSD). The GSD is a term commonly used in remote sensing and photogrammetry to describe the spatial resolution or level of detail in an image acquired by a sensor. In simpler terms, it tells us how much area on the Earth's surface is covered by each pixel in the image [17]. The GSD calculation depends on the focal length (f) and sensor properties. This factor may be expressed as [7]:

$$GSD = \frac{Sw * Hg}{Iw * f} \quad (1)$$

where: Sw: Sensor width, H_g: Height of camera above the ground, Iw: image width, and f: focal length.

Generally, the real resolution of an image is assigned based on the measured size of the smallest object that can be identified in the image. The main justifications of this research are: applying remote sensing a powerful tool for locating karez systems. and analyzing their alignment with keyline design, offering insights into water harvesting as an ancient water management and its harmony with natural topography. people designed novel groundwater extraction methods. One of these developed systems is known as a Karez.

DOI: https://doi.org/10.61263/mjes.v4i2.174

It’s It is similar to the P. A. Yeomans' Keyline Design in terms principles and goals, particularly in their focus on sustainable water management and land use optimization [13]. Karez, a historic technical marvel, its termed as subsurface canal.The dimension of karez ranges widely, from 3 to 50 km. The tunnel is 0.5–0.8 m broad and 1.2–1.8 m high. Vertical shafts are spaced 10-20 m apart in the lower levels and 30-70 m apart in the top reaches to allow for ventilation and karez maintenance [9]. Karezes have long been connected with sustainable water usage because to their ability to keep up groundwater levels and avoid loss during drought conditions. Karezes also minimize evaporation and function as drainage systems in arid regions [12], [6]. Drainage using karezes has kept groundwater levels from increasing during heavy precipitation. Karezes assist in restoring water salinity and protect agricultural lands downstream. It’s not only ancient method to get water, but also expressing the economic, social, and culture development. This water management systems exist in several nations worldwide, including Japan, Central Asia, Europe, North Africa, and Central and South America Due to Karez wide spread, it is also known as qanat or kariz, khettara in Morocco, galeria in Mexico, falaj in UAE, and foggara in North Africa [8]. Iran has the world's largest karez network, with 32164 operational units that provide almost 9 billion cubic meters per year. P. A. Yeomans' Keyline Design is a natural land management approach that focuses on harvesting water, preserving soil, and agricultural production by utilizing the land's inherent topography [5]. P. A. Yeomans, an Australian engineer, designed it to regulate water flow and storage by using keypoints (where valley slopes shift from convex to concave) and keylines (contour lines across keypoints) [20]. This landscape classification is the process of dividing land into zones (ridges, valleys, and keylines) to maximize its usage, mixing grazing, farming, and forestry to simulate natural ecosystems. The system increases water efficiency, decreases erosion, and boosts agricultural yield, making it suitable for both dry and rainy areas. Throughout history, civilizations have focused on water supplies. As humans developed permanent communities for agriculture and herding, a consistent source of water became necessary [2].

2. Materials and Methods

2.1 Description of Study Area

Misan Governorate, like other governorates in Iraq, is known for its richness of historical sites, with approximately 602 ancient sites [4]. The Karez site is located in Missan northern portion, approximately 68.7 kilometers from the governorate's center Fig.1. It is located between longitude 32º27' 23.70''N, 32º27' 10.54''N and latitude 47º10'57.83''E, 47º11'22.77''N. It also covers an area of 0.81 km^2 Fig.2.

Fig.1: Karez Site in Missan

Fig.2: 3D Surface of Karez system is study area

2.2. Methodology

This methodology combines geospatial tools, remote sensing, Drone survey, and fieldwork to analyze landscapes, focusing on water management and sustainable design. Here's a concise summary (Fig.3 demonstrates detailed steps):

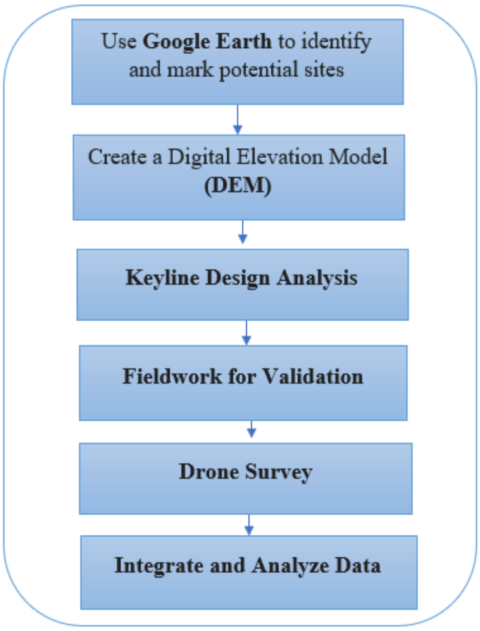


Fig.3: Methodology

3. Results

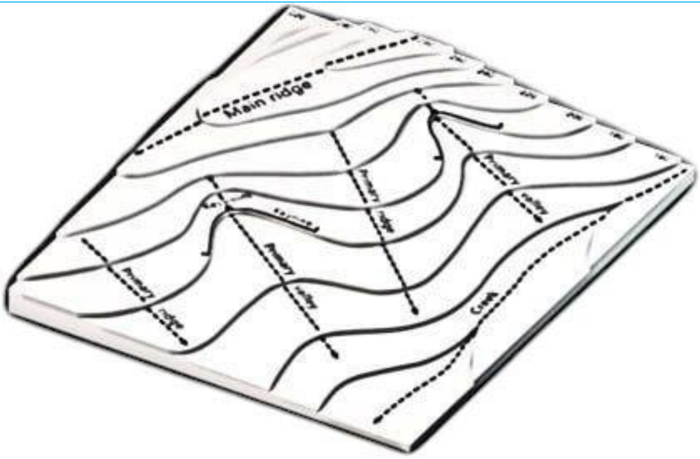
a) **Keyline Design Analysis** / Figs. (4,6) explain Analyzing the topographic map in the site based on keylines design (contour-based ridges and valleys)

Fig.4 P. A. Yeomans' Keyline Design **A.** Ideal design of keyline, **B**. Keyline in study area

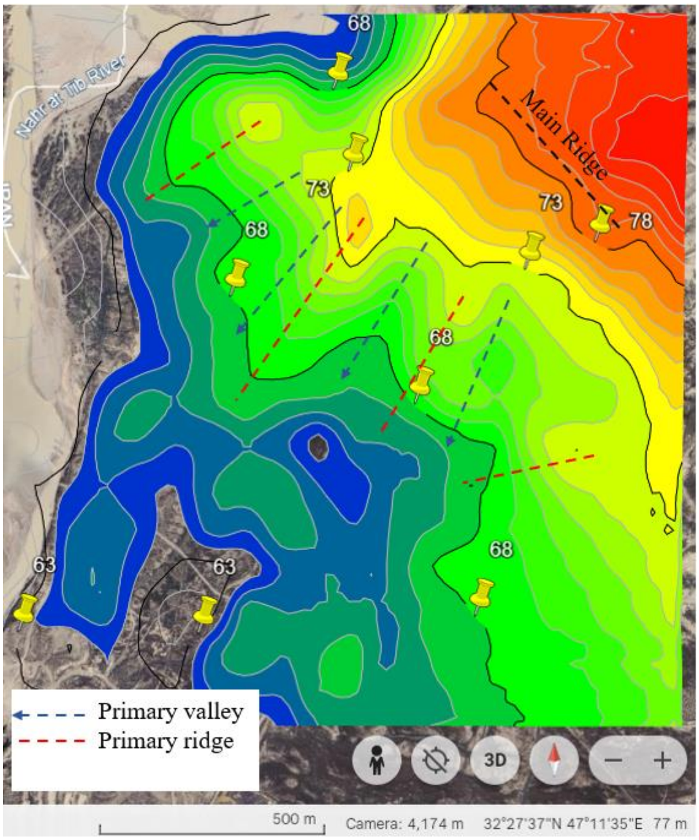
Fig. (4) likely shows how the keyline design align with the path of the karez system in the site. This alignment suggests that the karez system was designed in harmony with the natural topography, following the keyline to maximize water efficiency and minimize erosion or water loss. The match between the two indicates a sustainable and intelligent use of the landscape, where the karez system complements the natural water flow patterns identified by keyline design.

b) **Field work:** The fieldwork was conducted with a focus on two primary objectives:

firstly, collecting detailed information about the karez systems, including their dimensions and structural characteristics. This involved on-site measurements and observations. the Karez sites extending from the northeast of Maysan towards the southwest were surveyed. The dimension of karez ranges widelyabout 3 km. Also, the external diameter of each karez in study area about 32.6m, the internal diameter 11.2m.



a.



b.

Fig.4: P. A. Yeomans' Keyline Design a. Ideal design of keyline, b. Keyline in study area

Second, the fieldwork highlighted the process of determining very high resolution scale applying the Ground Sampling Distance (GSD) [3]. The GSD was critical in defining the resolution and quality of the acquired data. The procedure of selecting very high-resolution scale based on GSD, has been achieved using an object with known dimensions. In addition to the followings:

Global drone GD89 pro: camera: 4K modular camera with battery: 3.7V/1200 mAh [14].Vertical arial photographs at a flat area Table1: show the technical properties of photography.

Table 1.Technical properties of photography

Camera parameters	Values	Image parameters	Values
Flight height	158.305m	Image width	4000 pixels
Sensor hight	24mm	Image height	2250 pixels
Focal length	4mm	GPS	32.212065 46.1231.9
Sensor height	13.2mm		
Sensor width	8mm		

Aero point: the car will be used as “aero point" Fig.5. The car is a Mitsubishi Pajero 2011 with length 4.90m [11]. Table 1 explains a type of parameters involved in this study.
According to technical specification of photography, the GSD can be computed using equation (1):
GSD = $\frac{13.2mm * \ 158305 \text{ mm}}{4000 \ pixel*4mm}$, GDS = 9.89 mm/pixel, GSD= 0.9 cm/pixel. GSD of 0.9 cm means that one pixel in the image represents 0.9 cm on the ground (0.9 * 0.9 = 0.81square cm). Hence, the projection of individual pixels on the earth's surface is not exactly square-shaped. therefore, the estimation of GSD must utilize the biggest and lowest value of both GSDh and GSDw.

$$GSD_h = \frac{Flight\ height*sensor\ height}{Focal\ lenght*Image\ height} \quad \text{(Eq.2)}$$

$$GSD_w = \frac{Flight\ height*sensor\ height}{Focal\ lenght*Image\ width} \quad \text{(Eq.3)}$$

$GSD_h = \frac{158.305mm \ *13.2mm}{4mm \ *4000 \ pixel}$, $GSD_w = \frac{158.305mm*8mm}{4mm \ *2250}$

GSD_h= 0.13 mm/pixel, GSDw= 0.14 mm/ pixel
The accuracy increases with a lower GSD, minimizing the difference between an object measured volume and its actual volume.

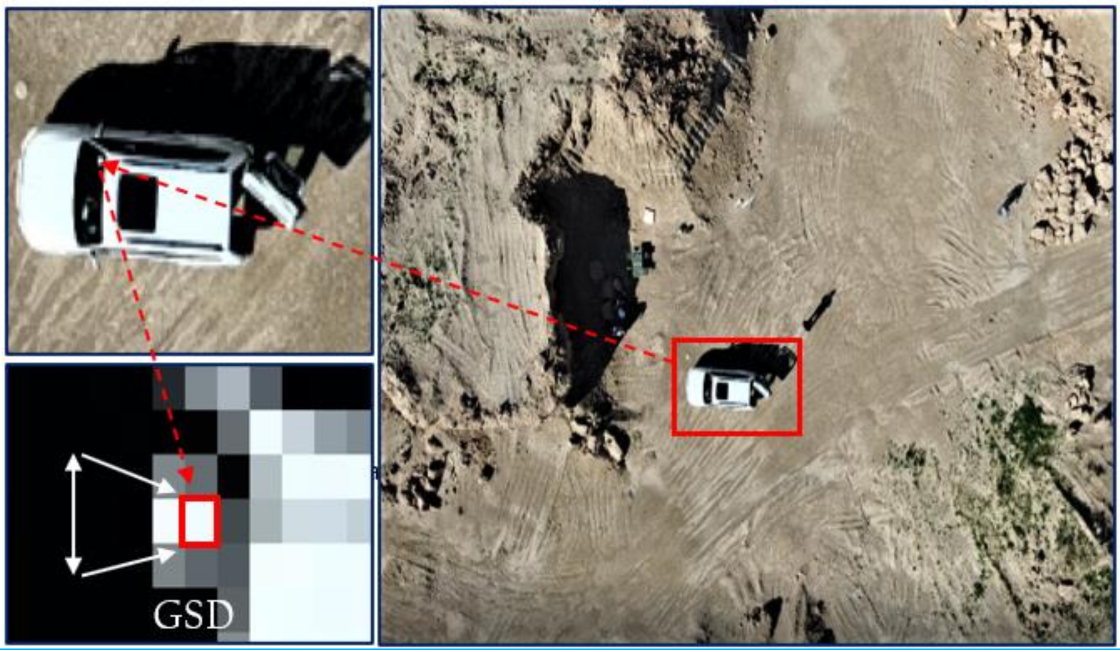


Fig.5: Calculation ground sampling distance

4. Conclusion

A. Concerning karez system and Keyline design, both systems are designed to optimize water use in arid and semi-arid regions, though they employ different methods. Keyline design uses contour-based techniques like swales and dams to capture and distribute surface water, while Karez relies on underground tunnels to extract and transport groundwater [19]. Both systems work with natural topography. Keyline design leverages land contours to manage water flow and reduce erosion, and Karez uses gravity to move water through gently sloping tunnels [10]. By integrating Keyline design's surface water management with Karez's groundwater extraction, these systems could complement each other to enhance water efficiency, recharge aquifers, and improve agricultural resilience in water-scarce environments.

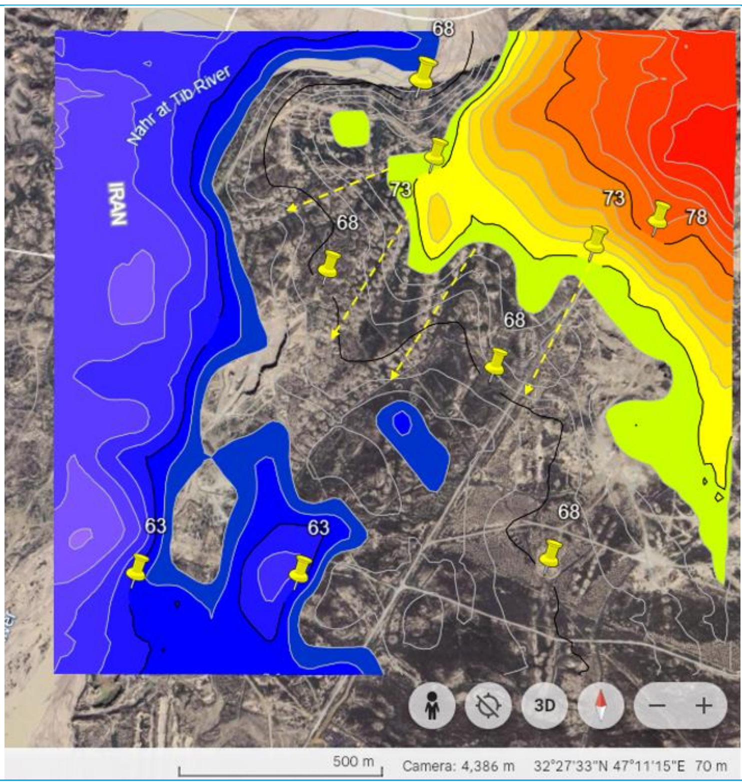


Fig.6: P. A. Yeomans' Keyline Design

B. The distance of the ground sample has an inverse relationship with accuracy. A smaller ground sample distance leads to more detail in an image [16]. This suggests that the camera is much higher quality or that the drone is flying at a low height. After selecting a lens with a specific focal length, a surveyor decides on the flying height for taking pictures. The scale of aerial photography is determined by these two factors (Aber, et al., 2019). A higher GSD score indicates a picture with less spatial resolution and less discernible features. This means that in order to carry water via moderately sloping tubes, the drone needs to be at 81.7 meters above the ground for the current set of sensors to have a resolution of 2 cm/pixel.

c. **Drone Survey:** The DJI Mini 2 was used to capture high-resolution photos, for accurate mapping and analysis. Its advanced GPS and stabilization technology enable exact positioning and smooth flight, even in challenging situations [1]. The DJI Mini 2 successfully covers a large part of the study area. This makes it perfect for identifying karez system distribution and their extensions fig.7. The flight's height range is 114 to 37 meters.

A.

B.

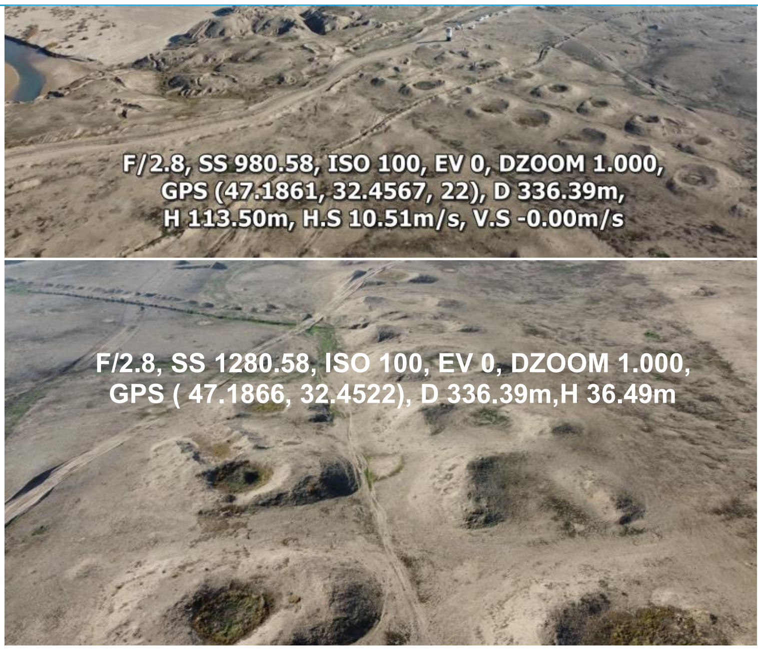


Fig.7: A. B explain Distribution of karez and their extensions

Author Contributions: The authors contributed to all parts of the current study.

Funding: This study received no external funding.

Conflicts of Interest: The authors declare no conflict of interest

References

[1] Aber, J.S., Marzolff, I., Ries, J. & Aber, S.E.W. (2019), "Small-format aerial photography and UAS imagery: Principles, techniques and geoscience applications", Academic Press.

[2] Abudu, S., Sheng, Z., King, J.P. & Ahn, S.R. (2019), "A Karez system's dilemma: A cultural heritage on a shelf or still a viable technique for water resiliency in arid regions", Socio-Environmental Dynamics along the Historical Silk Road, 507-527. doi:10.1007/978-3-030-00728-7_22.

[3] Aero, P. (2018), "What is ground sample distance (GSD) and how does it affect your drone data?", Propeller.

[4] Ali, M. (2024), "History of Iraq based on archaeological sites", The Geography of Iraq, 347-373. doi:10.1007/978-3-031-71356-9_16.

[5] Barnes, D. (2017), "The permaculture earthworks handbook: How to design and build swales, dams,

ponds, and other water harvesting systems”, New Society Publishers.

[6] Center for Sustainable Development and Environment (CENESTA). (2004), “Qanat irrigation systems: An ancient water distribution system allowing specialized and diverse cropping in desert regions of Iran”, CENESTA and FAO.

[7] DeWitt, B.A. & Wolf, P.R. (2000), “Elements of photogrammetry (with applications in GIS)”, McGraw-Hill Higher Education.

[8] Ebrahimi, A., Mehraban, Y., Omidvarborna, H., Vakilinejad, A. & Al-Sayigh, A.R.S. (2021), “Kariz (ancient aqueduct) system: a review on geoengineering and environmental studies”, Environ. Earth Sci., 80(6), 236. doi:10.1007/s12665-021-09522-9.

[9] English, P. (1998), “Qanats and lifeworlds in Iranian plateau villages”, Transformation of Middle Eastern Natural Environment, Bulletin Series, 103.

[10] Fensham, R.J. & Fairfax, R.J. (2002), “Aerial photography for assessing vegetation change: a review of applications and the relevance of findings for Australian vegetation history”, Aust. J. Bot., 50(4), 415-429. doi:10.1071/BT01032.

[11] Fraser, C. (2019), “Motoring: The 2019 Mitsubishi Pajero”, Aust. Med., 31(19), 39.

[12] Hayes-Rich, E., Levy, J., Hayes-Rich, N., Lightfoot, D. & Gauthier, Y. (2023), “Searching for hidden waters: The effectiveness of remote sensing in assessing the distribution and status of a traditional, earthen irrigation system (khettara) in Morocco”, J. Archaeol. Sci. Rep., 51, 104175. doi:10.1016/j.jasrep.2023.104175.

[13] Hill, S.B. (2003), “Yeomans’ Keyline design for sustainable soil, water, agroecosystem and biodiversity conservation: a personal social ecology analysis”, Agriculture for the Australian Environment. Proceedings of the 2002 Fenner Conference, 34-48.

[14] Ivanciu, M. & Alexandru, M. (2020), “Antidrone wireless personal shield”, Bull. Transilv. Univ. Braşov, Ser. I-Eng. Sci., 13(62), 9-14. doi:10.31926/but.ens.2020.13.62.1.8.

[15] Kendouci, M.A., Bendida, A., Khelfaoui, R. & Kharroubi, B. (2013), “The impact of traditional irrigation (Foggara) and modern (drip, pivot) on the resource non-renewable groundwater in the Algerian Sahara”, Energy Procedia, 36, 154-162. doi:10.1016/j.egypro.2013.07.018.

[16] Mesas-Carrascosa, F.J., Notario García, M.D., Meroño de Larriva, J.E. & García-Ferrer, A. (2016), “An analysis of the influence of flight parameters in the generation of unmanned aerial vehicle (UAV) orthomosaicks to survey archaeological areas”, Sensors, 16(11), 1838. doi:10.3390/s16111838.

[17] Mostafaeipour, A. (2010), “Historical background, productivity and technical issues of qanats”, Water Hist., 2, 61-80. doi:10.1007/s12685-010-0018-z.

[18] Schiller, N., Chlosta, M., Schloegel, M., Bars, N., Eisenhofer, T., Scharnowski, T., Domke, F., Schönherr, L. & Holz, T. (2023), “Drone security and the mysterious case of DJI's DroneID”, NDSS.

[19] Wilson, J.P. & Gallant, J.C. (2000), “Terrain analysis: principles and applications”, John Wiley & Sons.

[20] Yeomans, P.A. (1981), “Water for every farm using the keyline plan”, Second Back Row Press.