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Using the Mavic 2 Pro drone for basic water quality assessment

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ABSTRACT

This paper assessed the capability of the Dà-Jiāng Innovations (DJI) Mavic 2 Pro Drone (unmanned aerial vehicle – UAV) for the collection and delivery of river water samples for basic water quality assessments. The primary objective of this paper was to evaluate how this UAV model could help in generating large water quality data sets in the developing world to assist in the design and implementation of water quality monitoring and assessment programs, which are often a challenge due to data paucity and resources. We hypothesized that the traditional approach (portable hand meters) to measuring in-situ water parameters, including pH, dissolved oxygen, electrical conductivity, and turbidity could not yield significant water quality data variations from those collected by the Mavic 2 Pro. The UAV was equipped with a plastic bottle attached to a three-meter rigid thin line for sample collection. Samples were collected at stations 50 m apart over a 300 m river length. The drone captured samples in wind conditions of about 10.1 km/h with ease. About 350 mL of samples were collected per mission. A paired t-test was performed to determine the parameter differences between the two approaches. We conclude that, given similar environmental, physical conditions and pilot experience, Mavic 2 Pro can generate large and much more reliable datasets at faster rates than the traditional approach. The drone also avoided obstacles with ease, a perfect technology for use in rural rivers. However, pilot efficiency and precision, including agitation during flight require further investigations considering their potential parameter influences. Similar future tests should investigate the performance of this drone model and data reliability over a long river course to ascertain its capability and suitability in various conditions in ecological applications.

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Introduction

Freshwater ecosystems continue to be impacted by increasing pollution due to several anthropogenic activities including mining, industrial effluents, poor agricultural practices, and pharmaceutical-related wastes [7,8,14,15]. In middle and low-income countries, pollution scales are usually challenging to quantify due to data paucity owing to lack of technical expertise to collect, unfavorable policies guiding the protection and management of ecosystems, high capital and running costs for data collection. The lack of and inadequate data affect the design and implementation of appropriate ecosystem monitoring programs. In river ecosystem studies, however, understanding the status of water quality is necessary to periodically characterize and identify its variations and trends over time [4]. Monitoring data can be used to implement pollution prevention and remediation strategies and assist in ensuring that compliance is adhered to or not. Despite data challenges, new approaches are needed to generate solutions that address existing problems to meet Sustainable Development Goals and to embrace the 4th Industrial Revolution (4IR). The ability to use artificial intelligence knowledge and techniques in water sampling can be time and cost-saving compared to traditional water collection approaches.

The influx of drone technology on the market provides a great opportunity for their application in various fields, including mining, military and police, the media, health, tourism, disasters, and construction (e.g. for bridge inspections as in [2]). In ecological applications, drones can be a useful and innovative tool to monitor various ecosystems from pollution and effluent discharges and many more. For example, drones have been used to sample water in aquatic environments, despite their criticisms in terms of data reliability and accuracy, legislative limitations, and payload capacity [6]. In some cases, drones have been used to monitor harmful algal blooms, overcoming the shortfalls of the traditional satellite and manned aircraft approaches that experience atmospheric obstructions such as clouds [1]. It is thus evident that with the advancement in technology, drones are used widely as important ecological data collection techniques.

In this study, Mavic 2 Pro drone was used to test its capability for the collection and delivery of river water samples for basic physico-chemical assessments.

Many drone enthusiasts consider this drone model as the "king of the drones in the air" on the consumer market due to its capabilities such as flight duration, stability, obstacle avoidance, and powerful camera specifications. While some authors have corrected its rolling shutter distortion in unmanned aerial vehicle (UAV) photogrammetry [16], others have used it to conduct complex high altitude search and rescue operations successfully [9] and for creating 3D maps [12]. However, basic assessments can be useful to test the applicability of technologies before their complex applications. For example, ecological applications of UAVs are relatively gaining interest worldwide yet in middle and low-income countries, including Malawi, basic water quality assessments such as pH, dissolved oxygen, temperature, salinity, and turbidity measurements are a challenge despite increasing freshwater pollution threats [3, 5, 13]. This in part is due to the expensive equipment of meters or gadgets associated with a lack of technical expertise needed to perform such basic tests.

To our knowledge, therefore, no studies have assessed the capability of the Dà-Jiāng Innovations (DJI) Mavic 2 Pro model for river water sampling aimed at generating water quality data sets, particularly in rural middle and low-income countries. This case demonstrates how UAVs can contribute to the design of water quality monitoring programs and assessments in remote regions. It is against these backgrounds that this study assessed the capability of the Mavic 2 Pro in sampling and delivery of river water for basic water quality assessments. The quality of data generated by both the UAV and the hand-held deployed sensor-probes was also assessed to ascertain the drone's applicability to generate large data sets within the shortest time. The key objective of this study was, therefore, to assess if the Mavic 2 Pro could be deployed to aid in ecological assessments by collecting river water samples. Specifically, the study compared the data variability between the UAV-collected samples and the traditional handheld multi-probe water quality assessment method. The use of drones in generating water quality data would greatly ease human efforts and reduce field costs particularly in middle and low-income countries where finances are usually a conservation issue.

Materials and methods

Description of the unmanned aerial vehicle (Mavic 2 Pro)

Mavic 2 Pro is a quadcopter that is faster, quieter, and can fly a horizontal distance of up to 8 km unobstructed and in line of sight using the Remote Controller with the DJI Go 4 app connected. The drone is equipped with obstacle sensors on all 6 sides with front and back collision avoidance technology, allowing it to fly around obstacles with ease (Fig. 1). The Mavic Pro uses both the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS) so the quadcopter connects to quite a few satellites. The Mavic 2 uses the dual satellite system to assist with precision flying, return to home, obstacle avoidance, waypoints, points of interest, and much more. This was important during sample collection and landing the aircraft to avoid crashes.

Batteries

The Mavic 2 Pro uses a Four-cell lithium-ion polymer DJI intelligent flight battery with a Capacity of 3850 mAh that lasts up to 31 minutes of flight time with no wind at a consistent speed of 25 km/h. In this study, batteries were changed after the collection of every second sample. The idea was to fly the UAV at a relatively constant speed and maneuver.

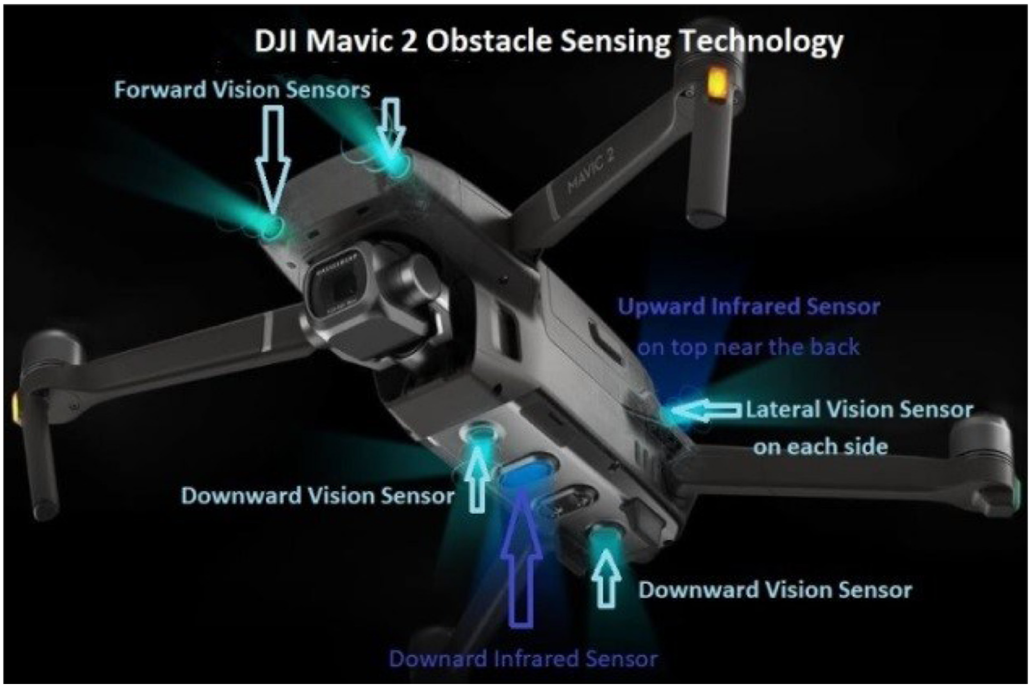


Fig. 1. DJI Mavic 2 Pro showing its obstacle sensing technology (Source: Dronezon.com).

Study area and sampling points (stations)

Luchenza River is located in the Traditional Authority of Chimaliro, Thyolo District in the Southern region of Malawi (Fig. 2). It is situated roughly at a distance of 2.5 km from the Malawi University of Science and Technology (MUST). The area experiences a warm and temperate climate with an average annual rainfall of 1500 mm. The elevation ranges between 634 m and 1216 m above sea level. Luchenza River runs a stretch of about 45 km from Limbe and feeds into the Thuchila river. Agricultural activities (mainly crops and dairy) and a railway line under renovation dominate the area. Natural trees and shrubs dominate the river stretch for canopy in most sections. Nearly all farmers along the river abstract and divert water from Luchenza to irrigate their crops.

A section of the stream was chosen for the flight operations and data sampling due to its proximity to MUST for ease of access. There were eight sampling points labeled as Station A, B, C, D, E, F, G, and H that were selected randomly (Fig. 2). Station A was on the upper stream while H was located downstream. Water quality parameters were measured at an interval of 50 meters apart. The selected sections of the river are dominated by patches of shrubs and trees as a canopy on either side. The durations taken to collect and deliver samples were recorded accordingly.

Sampling design

The unmanned aerial vehicle (UAV) was maintained within the visual line of sight (VLOS) to meet both drone regulations in Malawi and the manufacturer's recommendations. However, the river morphology and surrounding physical structures determined the final sampling approach and process. The study team decided to test the DJI Mavic 2 Pro over a 500 m meandering river stretch. Seven sampling stations of 50 m apart were identified randomly for the in-situ physico-chemical parameter measurements. In the end, samples were limited to within a stretch of 300 m due to the gimbal overload error on the Mavic.

Preparation of sampling bottles and payload capacity

Payload capacity refers to the maximum amount of weight added to the drone in addition to its empty weight. The recommended payload capacity for the DJI Mavic 2 Pro is 907 grams (g) according to the manufacturer's manual. This guided the study team to design a sampling bottle that could collect and hold samples with a payload mass of less than the recommended capacity. The first task involved finding the right sampling bottle. This was done by cutting out the flat top of two empty plastic Coca-Cola bottles of 500 mL each (Fig. 3 (a)). Two holes were on the topsides served as hooks for the rope that was attached to the drone. The total mass of the two empty bottles was 36.9 g. One of the bottles was cut on both the sides and the bottom to allow water to drain out within seconds after sample collection. The bottle contained a rock

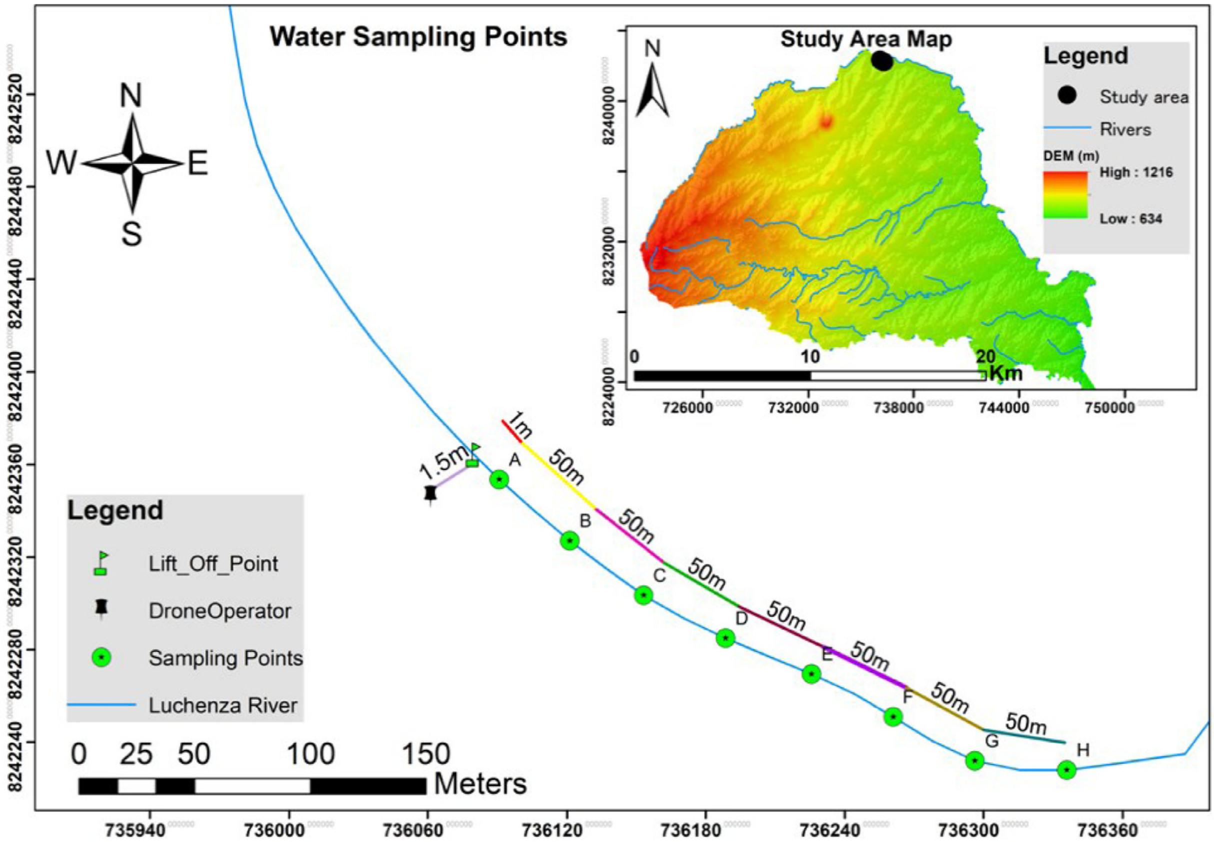


Fig. 2. Map depicting sampling points along the Luchenza River in T/A Chimaliro, Thyolo, Southern Malawi.

that weighed 68.7 g to avoid buoyancy of the actual sampling bottle. Clear sellotape was used to wrap both bottles together by the sides. In the end, the UAV payload capacity after sample collection weighed 431.9 g, nearly half of the recommended payload. The sample volume was about 350 mL after the flight took off and upon delivery and measurement. The volume was enough to conduct physico-chemical measurements with ease.

The length of the sampling line

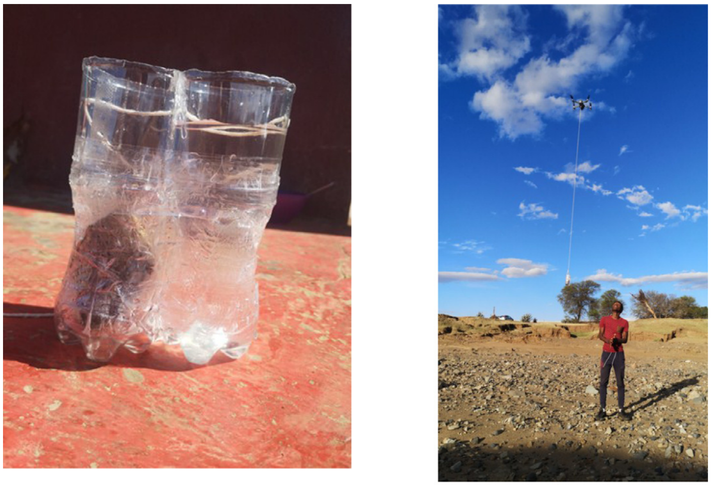
A rope (line) attached to the gannet dropper on the drone was improvised to aid in the sampling process. An appropriate length and thickness of the rope were used to avoid interference with UAV downward sensors. At first, a line of 1 meter attached to the drone was used to collect water samples from a single point. Unfortunately, drone downward sensors were interfered with by the rope after the payload. After a series of trials, a 3-meter rope was attached to the gannet dropper at an appropriate position to attain the center of gravity with the payload. The drone was well-balanced with the relatively easy pilot maneuver. The sampling bottle was attached at the end of the rope (Fig. 3 (b)). The rope was used throughout the sampling process of the study.

Flight altitude and pilot experience

Mavic 2 Pro has a maximum flight altitude of 500 m. For this study, flight altitude was maintained between 18 and 20 m before and after sample collection for consistency purposes. All UAV maneuvers were left in the positioning mode on the remote controller. This allowed the Mavic to stabilize its position throughout the study. The sport mode on the Mavic 2 Pro was not used at any point. After attaining the required altitude, the drone was flown immediately to the starting point (Point A) for measurements of water parameters. At the time of this study, the pilot had a total flight time of 20 hr 05 mins, 102, 691 m flight distance and 154 flight times and 148, 458 experience points.

Measurement of water quality parameters and sampling procedure

A portable AQUAREAD multiprobe meter (Aqua Read Water Monitoring Instruments, UK) model AP-800 was used to measure the parameters under investigation. Physico-chemical parameters including pH, electrical conductivity (EC), dissolved



(a) (b)

Fig. 3. (a) Improvised water sampling bottle attached to the Mavic 2 Pro drone. (b) the rope and sampling bottle attached to the gannet on the Mavic 2 Pro drone.

Fig. 4. The water sampling process using the Mavic 2 Pro drone.

oxygen (DO), temperature, and turbidity were measured in-situ using the portable hand multi-probe meter. After this process, the UAV was dispatched to collect and deliver samples for testing on the river bank (Fig. 4). The UAV samples were measured directly using the same multi-probe meter while the aircraft hovered. The probe was inserted into the sampling bottle for physico-chemical measurements to minimize changes in water chemistry. Samples were discarded afterward without landing the aircraft by a study team member. Deionized water was used to rinse the multi-probe in between sample measurements. The UAV-collected water sample volume measured about 350 ml after collection. The UAV collected one sample per station and a total of eight during the study. There were no replicates per station because the goal was to assess how capable the Mavic 2 would collect samples for further use in ecological assessments.

At station "H", the pilot tested the UAV avoidance system both during sample collection approach and take off. However, the last sample collected from station "H" was discarded due to pilot delays in maneuvering the aircraft to avoid compromising the physico-chemical parameters. All measurements were recorded in a field notebook.

Data analyses

The physico-chemical data were analyzed using a two-sample t-test to ascertain any significant differences in Microsoft Excel (Excel 2016, Microsoft, Redmond, WA, USA) between the two methods. Percent differences were calculated for each water quality parameter to determine how close the measurements were between the UAV-collected samples and the manually collected samples. Alpha level was set at 0.05.

Table 1
Comparisons of the volume and time taken to sample water by various drones (Adapted from [6]).

Drone type	Water volume/per sample	Water sampling times using drone/ flight times	Parameters measured
Custom-built chassis -spring-lidded chambers (no physico-chemical sensors attached)	60 ml	120 mins	Temperature, dissolved oxygen (DO), sulphate & chloride
As above (no physico-chemical sensors attached to drone)	60 ml	20 mins	Temperature, conductivity & chloride
Custom-built metal-free high-density polyethylene sampling bottle (no physico-chemical sensors attached)	250-330 ml	Not provided	Conductivity, pH, chemical concentration. (chloride, sulphate, aluminium, calcium, iron, potassium, magnesium, manganese, sodium, silicon dioxide) & stable isotope ratios
Custom built “thief-style” water sampler with physico-chemical sensors attached to a drone	130 ml	60 mins	DO, temperature, pH, conductivity & chloride
Off-the-shelf Hexarotor- Ascending Technologies Firefly	Not provided	20 mins	
Off-the-shelf Six-rotor LAB645	Not provided	40 mins	pH, electrical conductivity (EC)
Custom-built hexacopter with floatation attachments	Not provided	8 mins	
Fixed-wing drones (no ability to carry sampling apparatus)	Not provided	25 – 75 min	
Transitional drones (no ability to carry sampling apparatus)	Not provided	25 – 90 min	
DJI Mavic 2 Pro (no physico-chemical sensors attached) – **this study**	350 ml	6 mins 45 seconds	DO, pH, EC, temperature, turbidity

Results and discussion

The time duration for sample collection and delivery

The average time variations between collection and delivery of the samples from the river to the measurement station showed that the UAV took approximately 11 seconds for the first sample, 26 seconds for the second, 30 seconds for the third, 60 seconds for the fourth, 53 seconds for the fifth, 57 seconds for the sixth while the seventh sample lasted about 150 seconds. This represents a total of 6 mins and 45 seconds as the total duration of the drone sampling. Thus, on average the UAV collected and delivered water samples for 54 seconds for the 300 m river stretch. However, the collection and delivery of the seventh sample were delayed due to a gimbal error on the UAV. The error displayed on the pilot's remote controller required the pilot to land the aircraft immediately, which could not be possible as the area was not safe due to vegetation cover. Instead, the aircraft hovered for some seconds until the pilot regained control without a crash. This phenomenon demonstrates the importance of pilot experience when using drones for ecological assessments. Although the last sample was discarded due to the delays, the Mavic 2 Pro avoided trees and shrubs in its path easily. This was particularly an important observation as most rivers are characterizes by such features. Previously, helicopters equipped with sensing technologies have managed to avoid obstacles in rural areas at low altitudes [10].

Compared to other drone types used in ecological assessments (Table 1), the Mavic 2 Pro took relatively less time to collect and deliver samples (without comparisons of sample numbers and distance covered). Also, the Mavic 2 Pro is advantageous as it is a foldable, portable, and affordable drone than the use of helicopters in sampling river water. However, other drones such as the Phantom can perform similar tasks. Thus, drones generally provide the potential to fulfill many aspects of biological and physico-chemical sampling to meet large-scale water sampling programs [6]. This study supports the notion that UAVs used in water sampling increase the speed and range at which samples can be collected while reducing effort and cost [11].

On the contrary, the measurements done by the potable handheld multi-probe meter took about 01 hour 45 minutes to cover the 300 m stretch due to riverbank morphology that was characterized by patches of thorny shrubs, vegetable gardens, trees, and reeds.

Water quality data

Whether the Mavic 2 Pro could collect and deliver ecological samples or not was less important than assessing its capability to deliver an “X” amount of load and providing reliable data as fast as possible was important. In this case, the UAV

Table 2
Descriptive statistics for water quality parameters obtained by in-situ measurements and UAV-collected sampling.

Parameter	In-situ Mean	Standard Deviation	UAV-collected sample Mean	Standard Deviation	P-value
pH	8.5	0.1	8.5	0.1	**0.005**
EC (μS/cm)	153.4	3.0	121.7	17.2	**0.002**
DO (mg/L)	4.0	0.9	2.3	0.6	**0.005**
Temperature (°C)	26.2	0.9	26.7	0.8	**0.076**
Turbidity (NTU)	753.7	11.2	754.9	7.1	**0.367**

used in this study collected and delivered water samples for physico-chemical assessments with relative ease. The paired t-test indicated that electrical conductivity (EC) measurements taken for the manually collected samples were significantly higher than those taken for the UAV-collected samples ($N = 7$, $p = 0.002$). The paired t-test also indicated that dissolved oxygen (DO) measurements of the UAV-collected samples were significantly lower than the corresponding manually collected samples ($N = 7$, $p = 0.005$). The percent difference of the EC and DO measurements for the manually collected samples as compared to those for the UAV-collected samples were 20.6% and 38.7%, respectively. Generally, however, mean measured parameter values for the UAV-collected samples were lower than the ones for the portable hand meter. The differences in pH, temperature, and turbidity measurements between the manually collected samples and UAV-collected samples were not statistically significant ($p < 0.05$). The accuracy of the pH, temperature, and turbidity measurements from the manually collected samples, relative to those made from the UAV-collected samples were 99.3%, 96.8%, and 99.2% respectively.

Summary statistics for water quality parameters obtained by manual and UAV-collected sampling are presented in Table 2. For raw data values, see supplementary table.

The measured water quality parameters, from the manually collected samples and UAV-collected samples, for seven different sample stations, showed similar general trends (Fig. 5) with some intra-parameter variability across the five parameters measured. This potentially indicates that the water sampling method and the time delay between sampling times had little impact on the measured water characteristics. Trends in pH, temperature, and DO were relatively similar while EC and turbidity were significantly different.

However, Fig. 5 further indicates a general downward trend in the measured parameters between the sample stations, except for the manually sampled EC and DO measurements (Fig. 5 **(a)** and **(d)**). This could be due to different characteristics of the sample stations arising from activities upstream and downstream. For example, the abstraction and diversion of water for irrigation purposes could deteriorate downstream water quality compared to the upper reaches of the river. This is evident in EC concentration loads at Station A that was higher than that of stations **C** and **G** respectively. Unlike the hand or manually measured parameters, these results suggest that the UAV collected samples had improved and relatively reliable parameters. Another key reason for this finding lies in the time differences between the measurements. The hand measurements meant that the researchers had to walk from Station A, through B to the last Stations G. In doing so, sample accessibility was a challenge, leading to time wastage due to the difficulty of walking through the river bank terrain and topography. On the contrary, the UAV did not encounter such challenges, saving time in the process. Unlike pouring samples into a beaker for parameter measurement, drone-assisted samples were measured directly in their collection bottle upon arrival while the UAV hovered. The idea was to overrule DO changes that could have emanated from sample transfers as some authors have argued [6].

It is well-known that DO levels are directly related to temperature. The findings of this study were not different in the sense that there was a clear observed direct relationship where the manual approach indicated that DO levels were generally high in low temperatures. This was particularly true for stations 4, 5, 6, and 7 (Fig. 5 **c** and **d**). However, the UAV approach nearly showed consistent temperature and DO levels across the stations. On turbidity, it was the UAV approach that generally revealed low levels compared to the hand approach. However, both approaches showed an improvement in the water clarity downstream compared to the initial stations in the upper reaches of the Luchenza river. This could be attributed to relatively minor subsistence agricultural activities that could not greatly influence the water turbidity during the study. Besides, the continuous water flow of the river meant that dilution was occurring at the time of this study.

In contrast to the other parameters, Fig. 5 (b), indicates that the EC measured by the hand-held meter at the sample stations was nearly constant, while the EC measured from the UAV-collected samples might have changed during transit, especially at stations C, E, and F. Such changes could be attributed to pilot experience, agricultural-irrigated wastes, and dilution. Further, unlike the in situ measurements of the parameters using a handheld multiprobe meter that were recorded in the edges of the river, the UAV-collected samples were originated from slightly different points (pools, runs, riffles) across the river course as deemed appropriate by the pilot. After attaining the required horizontal sampling distance, the aircraft was descended, and the camera pointed downward to locate a sampling point. In reality, variations in sampling points arose besides maintaining the UAV's line of visual sight. Other variations could have come from weather conditions or battery life on the UAV. Also, pilot delays in controlling the UAV during turns after sampling were common. These factors could have influenced the obtained water quality data.

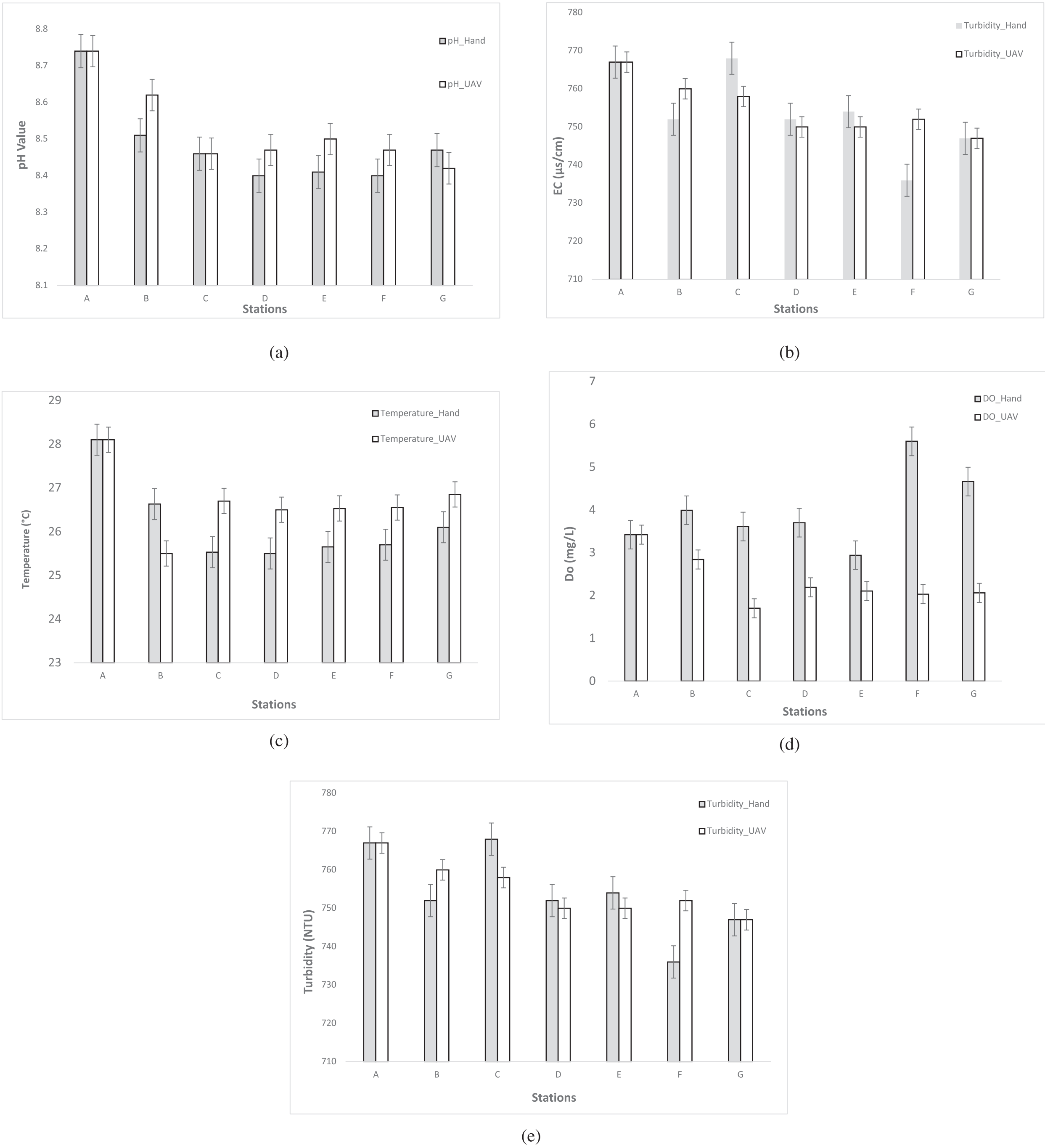


Fig. 5. In situ and UAV-collected sample measurements of water quality parameters at seven sampling stations; **(a)** pH, **(b)** electrical conductivity, **(c)** temperature, **(d)** dissolved oxygen, and **(e)** turbidity.

Conclusion

The present study has demonstrated that the Mavic 2 Pro is capable of the collection and delivery of ecological samples including running river water. It has been shown that the UAV samples were relatively more reliable in terms of quality than those that were collected by the traditional hand-held meter approach. Further, the UAV saved a good amount of time by collecting and delivering samples at a much faster pace that could not be compared to humans walking through the terrain or topography of the river in this study. Given similar environmental and physical conditions as those reported herewith, the Mavic 2 Pro can generate large and much reliable datasets than the traditional approach. This would be useful in developing countries and remote areas where basic water quality data is scarce, inadequate, and inexistent to guide water quality monitoring and management decisions. The findings of the present study demonstrated that it is possible to use the Mavic 2 Pro to collect water samples for basic water quality assessments in low and middle-income countries. We do note, however, that this task was never the manufacturer's intention. We acknowledge that drone technology is still in infancy, and suggest that future UAV studies should focus on sampling in-situ river samples by mounting multi-probe sensors to the aircraft. Furthermore, the Mavic 2 Pro still needs to be tested under different weather conditions such as wind speeds and visibility and with several pilots.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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