# Identifying the Potential Application of Unmanned Aerial Vehicle Technology in Mine Waste Dumps

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*Abstract*

*In recent years, unmanned aerial vehicles (UAV) have been applied in the mining sector for a variety of purposes. This paper discusses the use of UAVs in the management of mine waste dumps based on analyzing scientific publications (January 2010 to May 2023). Three bibliography databases including Scopus, Google Scholar, and Web of Science were used to perform a thorough assessment of the literature. This study provides a comprehensive overview of UAV applications in mine waste dumps including environmental management, terrain surveying and 3D modeling, and safety and risk management. The obtained results of the study hope to give a technical reference, enhancing the understanding of UAV monitoring in mine waste dump.*

**Keywords:** *UAV, drone, mine, mine waste dumps*

## 1. Introduction

The mining industry creates significant amounts of waste. According to Cebada et al. (2016), the waste produced by mining might be solid, slurry, or tailing with the most prevalent types being waste rock, tailings, slag, and tail ends. However, under certain conditions, vegetation and overburden may also be regarded as waste [1]. In mines, one of the main operations is the management of the waste dumps [2]. Mining waste is produced in all phases of mine development and extraction activities as well as technical operations related to enriching and purifying the raw material that was extracted [3]. The literature showed that there were many problems associated with mine dumps that need to be considered such as dump fires, slope stability of dumps, etc. Therefore many different methods were used and remote sensing technology seems to be used most of all. This approach can be applied in evaluating the thermal activities of a coal waste dump to detect and locate the spontaneous heating in coal dumps [4], predicting the settlement of mine waste dump [2], analyzing the stability of a mining waste dump sites [5], recognizing and extracting of a waste dump in mining area [6] studying the process of mine waste dump filling up by vegetation [7], mapping mine waste dumps in a semiarid mine district [8]. In addition, Dev and Goyal (2019) used field survey data combined with software based on Finite Difference Method to assess the waste dump slope stability at iron ore mines [9]. Based on expeditious physico-chemical parameters, Mayara et al. (2017) established the mining waste map and analyzed affected areas [10]. Some other methods were mentioned by many scientists such as geoelectrical methods for investigating mine dumps [11], a combined direct current resistivity and induced polarization approach for mapping the internal composition of a mine waste rock pile [12], geostatistical interpolation based on GIS for mapping heavy metals concentrations of mining waste dump [13], magnetometric resistivity approach for detecting preferential flow paths in mine waste rock dumps [14], geotechnical parameter method for analyzing the slope stability of mine waste dumps [15], integrating infrared thermography and close-range photogrammetry for generating a surface temperature distribution model of a coal-mining waste dump [16], application AUV for dump slope stability analysis [17], etc.

Recently, UAVs are increasingly popular tools for remote sensing applications [18]. UAVs are widely known by numerous names such as drones, unmanned aerial systems (UAS), and remotely piloted vehicles (RPVs). Thanks to recent enhancements in UAVs, this technology has secured an ever-expanding field of application in sectors like agriculture [19], construction [20], disaster management [21], transportation [22], etc. UAVs are crucial instruments in the mining sector as well. Because UAVs can be equipped with various devices such as optical, thermal, magnetic, and natural gamma-ray sensors, they can be utilized for numerous purposes like surveying and mapping [23], mine safety monitoring [24], air quality measuring [25], mine waste dumps [26], etc. There have also been many studies reviewing the application of AUVs in the mining industry. While Park and Choi (2020) reviewed academic publications on the usage of UAVs in the mine sector during three phases: exploration, exploitation, and reclamation [27], Lee and Choi (2016) mentioned the UAV technology trends and their applications in the mining industry. Like Park and Choi (2020), Loots et al. (2022) focused on the application of UAVs in the four phases (exploration, development, exploitation, and reclamation) of mining [28]. To provide information about specifications, UAV types, usage of commercially available UAVs for mine industry, requirement for the design and operation of UAVs in underground mines, Shahmoradi et al. (2020) present a thorough analysis of UAV technology and how it is used in the mining sector [29]. Ren et al. (2019) provide an overview of the various uses for UAVs and some recommendations for further advancing their use in resource development and environmental protection. In order to increase awareness and understanding of UAV uses in surveying and mapping in mine regions, Long et al. (2023) offers a technical reference that provides an overview of current advancements in the use of unmanned aerial vehicles (UAVs) for mapping and assessing surface, underground, and abandoned mines. However, all of them have not mentioned the use of this system for monitoring and man-

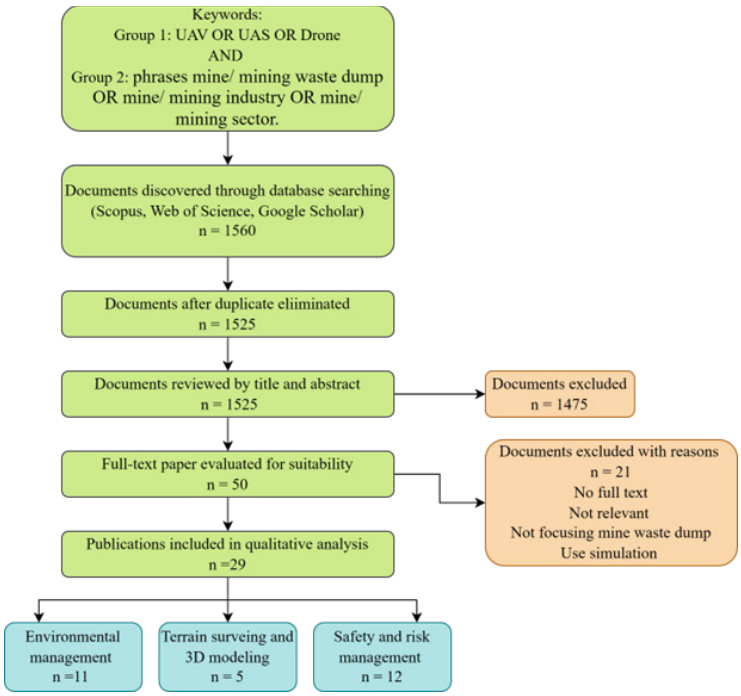



Fig. 1. Study selection process

agement of mine waste dumps. Therefore, this paper aims to perform a review on UAV applications in mine waste dumps to partially fill the aforementioned gap. The authors believe that the paper, one of the first in this field, can assist in advancement of UAV technology and develop them into a tool just as widespread in the field of mine waste dump managing and monitoring.

## 2. Methodology and Data

In this paper, a systematic literature search was carried out to assess scientific works involving UAV applications for mine waste dumps. The study selection process shows in Figure 1.

### *2.1 Eligibility criteria*

The search results can be filtered based on language, year of publication, and subject field. Only reviews and papers in the English language were selected, and the search was restricted to materials published after 2010. Subjects unrelated to UAV application in mine waste dumps were not included in this study. In addition, duplicate papers or articles that concentrated on simulations rather than actual data were also excluded.

### *2.2 Information sources and search*

For this review, relevant publications were identified on Web of Science, Google Scholar, and Scopus by searching the titles, abstracts, or keywords. The search has been carried out from January to May 2023.

The keywords were categorized into two main groups: the first group was involved with tools including the terms UAV, or UAS, or Drone, and the second group was associated with the interest field including phrases mine/ mining waste dump or mine/ mining industry or mine/ mining sector. At that time, the searchers used the "AND" Boolean operator to connect groups of keywords. The obtained results were exported to EndNote. The duplicates were eliminated using this software, and then appropriate research was extracted after a preliminary title and abstract screening. The information from each study was retrieved such as publication year, authors, nation, paper objective, type of UAV and camera, software technique, and critical findings. This data was then put into Microsoft Excel to analyze further.

## 3. Results and discussion

UAVs open up new possibilities for mining engineers, by providing aerial views that are challenging to obtain using traditional methods. Table 1 shows some applications of UAV technology in mine waste dumps. The obtained results indicated that most applications of UAV in mine waste dump focus on the areas of environmental management, terrain surveying and 3D modeling, and safety and risk management.

### *3.1 Environmental management*

According to Wang et al. (2014), waste products from mining are produced in substantial quantities, and as lower-grade ores are used in mining, it is anticipated that the number of waste products will rise in the future [30]. Tailings are one of the waste types created, and they are made up of water, together with coagulants and flocculants as well as solid leftovers after mineral extraction [31]. One of the biggest environmental dangers in mining locations is tailings impoundments. There are many studies to identify the potential of using UAVs to monitor tailings impoundments. Because the use of UAVs as a quick and adaptable data collecting system to create orthomosaics and three-dimensional models has grown in popularity, this system can make it possible to monitor mine waste facilities economically and effectively [32]. In a study of [33], the authors revealed that UAV-assisted tailings impoundment monitoring is accurate enough to support management tasks including volume estimates and surface movement tracking down to the decimeter level. Also related to the tailings impoundments, [34] combined the use

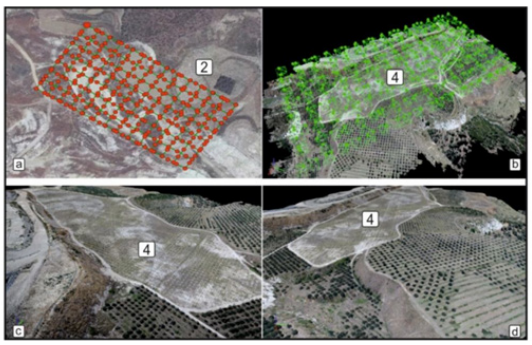


Fig. 2. UAV data on dump site. (a) UAV flight plan; (b) UAV position on Amygdolus Communis plant areas; (c) and (d) Solid models [39]

Fig. 3. Digitisation of the stockpile boundary on the point cloud dataset [48]

of UAV with traditional geochemical and photogrammetric methods to evaluate potential pollution through a categorization of tailings utilizing two hazard indexes, as well as calculate the volume of eroded material and past erosion rates of the abandoned mine tailings impoundments II and III in the town of Nacozari de Garca. According to [35], the tailings reservoir is a dispensable component of the operation of metal mines, and because it typically accumulates waste materials and wastewater, a source of artificial debris flows with high potential energy has been created, increasing the environmental risk. Therefore, they use UAV hyper-spectral imaging and ground-based hyper-spectral data to undertake an extensive aviation-ground disaster and environmental monitoring of the tailings reservoir.

Numerous minerals are exposed to oxidizing conditions throughout the mining process, especially sulfide minerals, which are then broken down by water to produce acidic mine water. Mining-related acid mine drainage (AMD) can contaminate local rivers and lakes and result in severe ecological issues [36]. Compared to traditional methods, UAV technology has benefits regard to security, image accuracy, and real-time imagery. Therefore, many scientists used this approach to study acid mine drainage. In order to identify this environmental phenomenon caused by mining, [36] used a UAV aerial photography system equipped with a Red, Green, Blue (RGB) camera to acquire extremely high-resolution photos of the stone coal mine in China. The images were then classified using support vector machine (SVM), random forest (RF), and U-Net methods, and the distribution of five different types of land cover, including AMD, vegetation, water, roof, and bare land, was identified. Similarly, [37] described the initial findings of an examination into acid mine drainage flows, nearby land, and sulfide-bearing mine tailings dumps in Russia using the integration of geophysical, geochemical data and UAV images. A photogrammetric method of aerial photography was used to record the morphology of the terrain and generate a digital elevation model at the study area.

The dump sites, which are created in the proximity of the mine regions, are frequently bigger than the sites when actual mining is taking place. Thus, rehabilitating waste dumps is a critical and mandatory action [38]. Various research demonstrated the effective usage of UAVs in the rehabilitation processes at the mine waste dumps. [39] produced vegetation index maps of a mining dump site that had been rehabilitated using UAV photogrammetry. These maps were utilized to assess the plant species' adaptation, health, and chance of survival. Figure 1 shows the flight plans for the flights, the position of the UAV on the site, and the solid model of the sites produced from the point cloud. The same goal as [39], [40] used high-resolution UAV visible and near-infrared (NIR) imagery to evaluate the success of vegetation establishment on the SP11 waste rock dump and the abandoned D2808 road stretch in Namibia. In addition, according to [41], monitoring the composition of vegetation species is critical for determining the efficiency of ecological restoration and managing biodiversity after restoration. Therefore, [42] used UAV LiDAR and hyperspectral images to study the structure and composition of the restored vegetation cover in semi-arid mine dumps. The vegetation intensity, height, and echo features were derived from LiDAR data, while the vegetation spectrum, index, and texture features were extracted from hyperspectral image data. In order to green the tailing dump, [43] recognized that the storage area on the investigated surface needs to be arranged, geometrized, weeded, and forested. In this study, a 3D model that is as accurate to reality as possible was produced using a combination of satellite and photogrammetric techniques, and it will be crucial in the process of reforestation of the tailings dump. According to [44], coal-waste dumps are an essential component of the ecology and form the scenery of coal basins. Therefore, they showed an assessment of environmental changes related to land use and alterations in vegetation on self-heating coal waste dumps

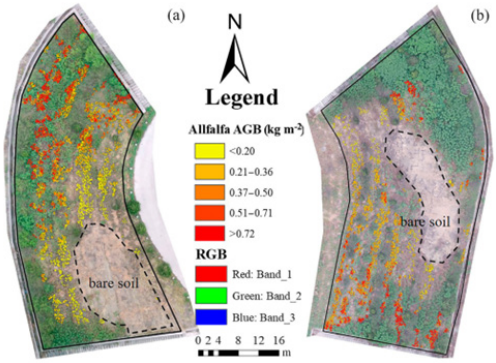



Fig. 4. Alfalfa aboveground biomass estimated results of the study area. (a) and (b) are Areas A and B, respectively. The black dotted polygon is the bare soil area with no vegetation coverage [61]

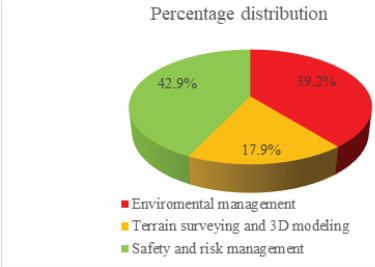



Fig. 5. Percentage distribution and number of publications of UAV applications in mine waste dumps

of various ages using UAV and infrared camera. The obtained findings revealed that when burning coal waste dumps. if the object is not sufficiently protected against the growth of fire, adding vegetation has no effect.

The use of hyperspectral imagery has also proven to be helpful for soil environmental monitoring of mine waste dumps. In the study of [45], the authors integrated UAV hyperspectral imagery with the simulated annealing deep neural network model to predict soil organic matter and available copper in the mine tailings pond of China. 74 samples of soil were taken from the study region, and their available copper (Acu) and soil organic matter (SOM) were calculated. Finally, maps of the distribution of ACu and SOM in the study area were established.

According to [46], the dumping sites, with a considerable volume of peeling material, are barren, with high slopes, untable slopes and soil compaction platforms, complicated material composition, and irregular subsidence. This causes a significant amount of vegetation communities to be destroyed and dramatically increases the possibility of soil erosion. Thus, to determine how much erosion occurs in gullies, [47] collected data using UAV oblique photography and created a thorough 3D model of the gully. The obtained results indicated that it might be simple to acquire the distinctive features of the typical erosion gullies of open-pit mine dumps using UAV-based 3D model and GIS spatial analysis technologies.

### *3.2 Terrain surveying and 3D modeling*

According to [48], the ecology was significantly harmed by the abandonment of the waste in various dump sites during exploitation. Nevertheless, abandoned mounds are still rich in rare earth metals and possibly even valuable metals. These dump locations could create a brand-new potential stockpiles, which might pique the interest of business organizations. Therefore, it is necessary to locate dump sites and determine the bottom and top stockpile surfaces. In order to do this, the authors used UAVs to create a 3D topographic map and a 3D model of waste dumps in Mathiatis, Cyprus. The 3D model of reconstructed waste piles can be utilized to compute their volume and other factors such as the gradient of slopes, that are essential to help determine how much the cost of possible restoration. The boundary line of the stockpile was generated on the point cloud itself as Figure 2. Also for the purpose of generating 3D models, in the study of [49], a precise 3D model of waste dump was produced using a combination of satellite and photogrammetric techniques, and it will play a key role in the effort to green the waste dump of the Ucicani mine. The volumes of deposited waste ore could be calculated using the three-dimensional model, and an overview map of the waste dump area that will be greened up could be made.

The accurate mapping and 3D construction of a mine waste dump play an important role to monitor its stability. Acquisition and monitoring of elevation data is a critical issue in relation to some later reclamation activities in waste dumps, such as vegetation planting, soil covering, and cultivation mode. For change detection and analysis, it is crucial to produce digital surface models (DSMs) quickly [50]. Previous research showed that many parameters have an impact on the accuracy of UAV-based DSMs, including the number and distribution of ground control points (GCP) [51]. Thus, for the purpose of producing precise DSMs from UAS in a coal waste dump, they suggest an enhanced GCP configuration.

To broaden knowledge about the cascading behavior of the run-of-mine material during and after dumping, [52] used UAVs with mounted cameras to create photogrammetric models of dumps. Then, a technique for creating high-fidelity models (HFMs) of dump profiles was developed and studied in order to more thoroughly analyze this phenomenon. The

Tab. 1. Applications of UAV technology in mine waste dumps

| Number | Resources | Year | Application | Objective |
|---|---|---|---|---|
| 1 | [33] | 2017 | Environmental management | Monitoring Tailings Inpoundments |
| 2 | [47] | 2019 | | Analysis of the Development of an Erosion Gully |
| 3 | [34] | 2019 | | assess potential pollution through a classification of tailings |
| 4 | [35] | 2019 | | Study environmental monitoring of the tailings reservoir |
| 5 | [45] | 2023 | | The prediction of organic matter and available copper n the mine tailings pond |
| 6 | [43] | 2022 | | Study the process of afforestation of the tailings dump |
| 7 | [36] | 2023 | | Recognize acid mine drainage |
| 8 | [37] | 2022 | | The investigation of sulfide-bearing mine tailings dumps, as well as the surrounding terrain and acid mine drainage flows |
| 9 | [42] | 2022 | | Study the Structure and Composition of the Restored Vegetation Cover in Semi-Arid Mine Dumps |
| 10 | [40] | 2018 | | Assess the effectiveness of vegetation establishment on the waste rock dump |
| 11 | [44] | 2020 | | Assessment of environmental changes related to land use and alterations in vegetation on self-heating coal waste dumps of various ages |
| 12 | [39] | 2019 | | Study the rehabilitation processes at the mine waste dumps |
| 13 | [48] | 2023 | Terrain surveying and 3D modeling | Create a 3D model |
| 14 | [49] | 2020 | | 3D modelling of the tailings dump |
| 15 | [30] | 2020 | | Modelling a hypothetical tailings dam |
| 16 | [51] | 2020 | | Generate accurate DSMs |
| 17 | [52] | 2022 | | Generate photogrammetric models of dumps |
| 18 | [54] | 2020 | Safety and risk management | Monitoring of deformations at the adjacent dump site |
| 19 | [17] | 2022 | | Analyze the stability of active mine waste dump slope |
| 20 | [56] | 2023 | | Determine particle size distribution |
| 21 | [55] | 2022 | | Analyze particle size distribution |
| 22 | [26] | 2022 | | Warn spontaneous combustion of coal waste dump after reclamation |
| 23 | [63] | 2020 | | Assess the deformation activity of open-pit mine dump site |
| 24 | [58] | 2016 | | Classify the index for self-heating intensity |
| 25 | [60] | 2021 | | Determine influence of water erosion on fire hazards |
| 26 | [57] | 2017 | | Determine particle size distribution |
| 27 | [59] | 2022 | | Investigate the influence of water erosion on fire hazards |
| 28 | [61] | 2022 | | Detect the spontaneous combustion monitoring of coal waste dumps |
| 29 | [62] | 2022 | | Investigate the land degradation and soil erosion at an opencast coal mine dump |

findings indicated that the HFMs developed in this study may be used to calibrate computer models of dumps so that they more closely resemble reality.

In contrast to water-retaining dams, which are typically constructed using concrete, rock, or soil, tailings dams are typically constructed utilizing the tailings themselves to reduce expenses [53]. As a result, operations and emergency management are frequently more difficult due to increased risks of disasters involving dam breaches, debris flows, or overtopping [30]. A model of the run-out flow of tailings dam breach was proposed by using UAVs SfM-photogrammetry and field surveys in China. The findings showed that UAV imagery can generate accurate enough data to assist tailings management activities and monitor yearly surface displacements in the decimeter range [30].

### *3.3 Safety and risk management*

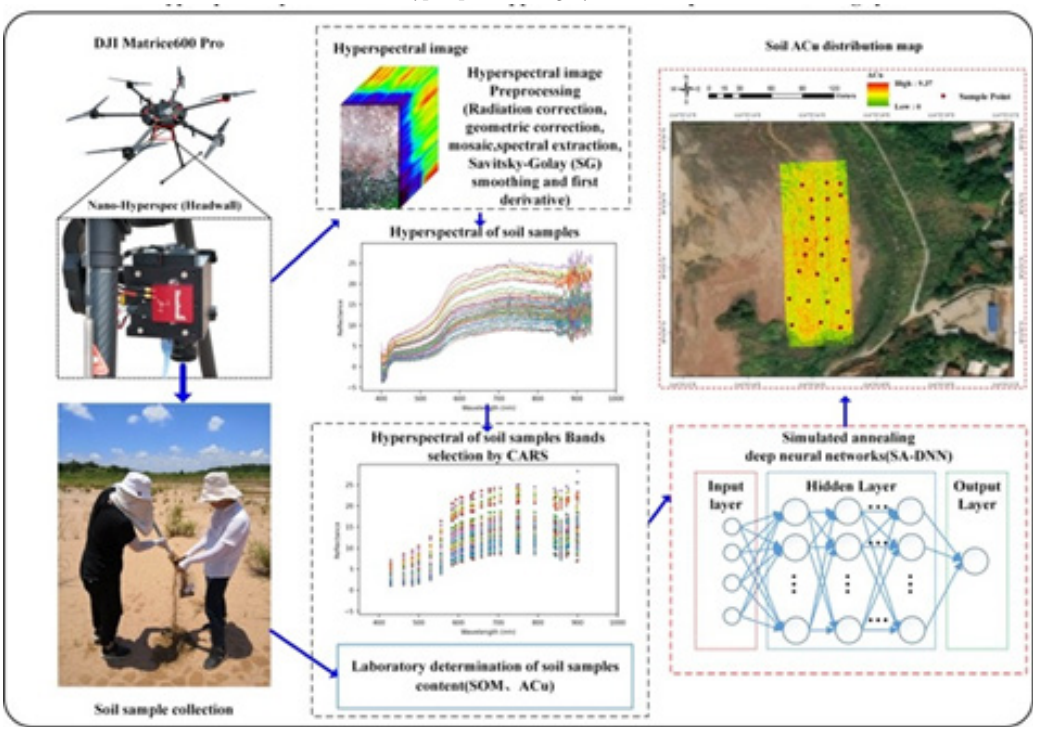
For both security and the continuation of mine production, it is crucial to identify and monitor potential deformations in the benches of dump sites of open-pit mines. [54] used the Global Navigation Satellite System (GNSS) method assisted with UAV technology to monitor and determine the deformation of dump sites of three different open-pit marble mines in Turkey. In this study, the GNSS approach identified the locations of displacements, and UAV photogrammetry investigated the reasons for mobility at the location as well as its areal and volumetric sizes. The obtained results revealed that monitoring of deformations using the combined utilization of UAV photogrammetry and the GNSS approach will enable the effective identification of the primary variables that may contribute, particularly to slope failures, and taking the timely implementation of necessary preventive measures.

During the open-pit mining process, the excavated soil received no economic benefit to the mining sector. These items are categorized as waste which is dumped forming a slope. Mine waste dumps are created quite quickly, therefore these dump slopes are really large. This hurried approach is increasing the risk of disasters on the slopes of dumps. Thus, it is necessary to analyze the stability of mine dump slope and this is a primary subject in geotechnical engineering. [17] analyzed the stability of an operational in-pit mine waste dump using UAV imagery, DGPS survey, and geotechnical samples gathered from the study area. With the aid of UAV photos, 3D modeling, and accurate geometry are retrieved from the active waste dump slope. The findings proved that the UAV's accessibility and image sensor advancements are helpful for building 3D maps and models of the mining regions.

The particle size distribution (PSD) is necessary for assessing the mechanical characteristics of the materials (rock fill) deposited at mine waste dumps, particularly their shear strength. [55] studied the use of UAV photogrammetry to characterize the shear strength in waste dump materials and the impact of PSD on shear strength. The UAV-based map can show the geometric characteristics of the rock fill and waste dump particles. Also to determine PSD, the workflow and the results for PSD evaluation of waste rockfill materials using UAV images were presented in the study of [56]. In addition, PSD is also one key element that governs the flow behavior in ore/rock beds. Because traditional sieve analysis has its limits, [57] used UAV imagery to examine the PSD in ore piles. Analyzing images captured by the camera mounted on a UAV allowed researchers to characterize the PSD of the dump leach pad at the case study mine.

According to [58], after depositing, the mining waste material starts to weather as a result of organic matter oxidation and other processes, which could subsequently result in self-heating. Emissions from dumps have a negative impact on both human and animal life. Due to its negative impact on

Fig. Make a soil available copper distribution map in the mine tailings pond by using that the combination the SA-DNN model and UAV hyperspectral imagery [45]




the environment and human health, it is essential to identify the self-heating process as soon as possible in order to avoid the spread of impacted areas and put out self-combustion zones. In order to do this, in study [58], the authors use Landsat, ASTER, and thermal-infrared camera collection from a drone to generate a classification index for self-heating intensity at coal waste dumps in various areas combining Landsat 4-5 TM, ETM+, and ASTER photographs.

Up utill now, the influence of intense rainfall and water erosion on spontaneously combusting of coal waste dumps has gained no much attention. As a result, the concern arises as to whether heavy rain can cause water erosion of the dump slope, increasing the likelihood of the dump's self-ignition. For this purpose, [59] studied the amount of rainfall, changes in the status of the slope surface, and the thermal operation of the chosen dump. Moreover, the state of mining waste dumps is impacted by precipitation, especially intense rainfall. The influence of rainfall on the erosion of water on a coal waste dump's slopes and its thermal condition presented in the study of [60]. The study's objective was to depict the beginning conditions of the studied dumping ground surfaces and the thermal conditions of particular slopes. With the assist of UAV-based low-altitude aerial photogrammetry, terrestrial laser scanning, observations of temperature and gas concentrations, the occurrence of phenomena like water erosion and thermal activity at the coal waste dump has been determined. As can be seen, spontaneous burning of coal waste dumps is one of the major issues in mining regions. Even after ecological restoration and land reclamation, this danger still occurs. [61] proposed better technology, UAV RGB imagery based on alfalfa aboveground biomass, for monitoring coal waste dumps for spontaneous combustion, which might serve as a guide for early detection and prevention in mining areas. Stepwise linear regression models were used to estimate this plant aboveground biomass together with the vegetation index and texture metrics taken from UAV RGB data. The alfalfa aboveground biomass map of the research area was created based on the model as Figure 3.

A rehabilitated opencast coal mine waste is influenced by erosion caused by wind and water from natural processes after artificial management is discontinued, leading to land deterioration as well as safety incidents. In order to degree and spatial distribution of erosion cracks and the soil erosion and land degradation after 5 years of natural processes, a multi-source data collection approach was used [62]. In this study, a UAV was used to gather the position and intensity of soil erosion as well as high-precision topography parameters and by using field sampling, the topsoil's physical characteristics were discovered. Moreover, [63] insisted that UAV can be a helpful instrument to monitor long-term continuous deformation and soil erosion. Therfore, UAV images were utilized to aid in phase unwrapping, demonstrating the soil erosion and deformation of the open-pit coal mine dump in China. In this study, high-resolution UAV images play an important role to understand the developmet of the waste dump. The elimination of the topographic factor and a time series analyses were processed using the high-resolution DEM (8 cm/pix) generated by UAV, structure from motion, and multi view stereo technologies.

### *3.4 Discussion and recommendation*

From the review, it was determined that several trends helped to categorise current UAV uses in the mine waste dumps, as follow:

(1) Environmental management (eleven papers)
(2) Terrain surveying and 3D modeling (five papers)
(3) Safety and risk management (twelve papers)

Figure 4 displays the percentage distribution of each UAV application related in mine waste dumps together with num-

ber of publications categorized under that application. The obtained results show that there are very few studies on the application of UAVs in mine waste dumps, so this is a new approach that has not received much attention. Published papers focus more on environmental management and safety and risk management. There are only 5 studies with the aim of terrain surveying and 3D modeling, mainly papers used UAV to generate DEM, DSM, 3D models for purposes related to the landscaping, geometry, weeding and afforestation in mine waste dump [49], tailings dam [30], waste material stock-piles [48], mine haul truck dumping process [52]. In addition, publications involved environmental management primarily concentrate on environmental monitoring of the tailings reservoir [33-35, 43, 45], identifying acid mine drainage [36, 37], assessing environment of waste dumps [40, 42, 44]. For safety and risk management in mine waste dumps, UAV application focus mostly on deformation monitoring [54, 63], stability analysis [17], determination of particle size distribution [55-57], detection of spontaneous combustion [26, 58, 61], investigation of soil erosion [59, 60, 62].

Furthermore, the results of the review showed that most of the studies were conducted in recent years and the number increased gradually over the years, from 1 study in 2016 to 10 studies in 2022. Despite the fact that an increase in studies on the use of UAVs to address mine waste dump management indicates a growing trend in the scientific literature, there is a certain delay among researchers in assessing the extensive usage of UAVs in the field of mine waste dump management. Accordingly, the understanding of the potential of UAV for addressing issues with mining waste dumps remain inadequate and needs to be developed. Most studies used digital images, except for spontaneous combustion studies using infrared camera. The SfM technique improves image post-processing and enables the quick creation of any necessary models. Two software programmes that use SfM algorithms to create extremely accurate photogrammetric models were frequently mentioned in the literature including Agisoft Photoscan and Pix4D.

According to [64], UAVs' quick mobility makes multi-view geographical data collection easier. Besides, compared to other remote sensing platforms, a UAV can get closer to a target object. As a result, it is easy to acquire high-resolution images. This closes the gap between present aerial and ground platforms, opening up new possibilities for building high-fidelity 3D models. Furthermore, due to its small form and remote operating abilities, a UAV can gather spatial measurements in an adverse condition that is too risky or inaccessible for other traditional mapping technologies, especially in hazardous or heavy metal contaminated areas such as mining waste dumps. However, managing the enormous number of datasets being collected is a problem that UAV applications frequently face. Thus, the superiority in time efficiency that is an advantage of UAV technology is reduced by the delayed processing of datasets captured by UAVs. In order to overcome this shortcoming, according to [64], it is ideal for all processing steps to be totally automated, requiring no human involvement. Recent developments in artificial intelligence and computer vision technologies may be able to support and give an efficient solution for UAV usage in mining waste dump management. In fact, this technology was used in study of [45] that the combination the simulated annealing deep neural network (SA-DNN) and UAV hyperspectral imagery to make a soil available copper distribution map in the mine tailings pond. The process of using this advanced technology for mapping soil available copper content in the mine tailing pond is shown in Figure 5.

**4. Conclusion**

Although the fact that the scientific community first learned about UAV use in the mining industry more than a decade ago, only in the past six to seven years have there been intensive investigations of the potential of UAV in managing mine waste dump. Based on the analysis of the available literatures as well as findings of current study, it was found that UAV technology has a lot of potential for managing mine waste dumps. Additionally, a list of potential uses for UAVs in mine waste dumps was provided including environmental management, terrain surveying and 3D modeling, and safety and risk management. Many obstacles still exist, though, and they need to be further investigated. In the near future, we may anticipate a continuous rise in research publications related to the usage of UAVs in mine waste dumps.

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