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REAL-TIME MONITORING OF ARTISANAL AND SMALL-SCALE GOLD MINING OPERATIONS USING ANDROID MOBILE GIS APPS AND GPS RECEIVER: FOCUS ON DEM, BOTE AND DIMAKO I MINING SITES (BATOURI GOLD DISTRICT, EASTERN CAMEROON)

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ABSTRACT

The concept of "sustainable mining" is also based on the requirement for rigorous monitoring of mining operations, in order to prevent abuses that can be exerted on the environment or the loss of income that can be recorded by the administrations of the countries owning the mines, either due to non-compliance by mining operators with the clauses of mining permits or because of the complacency of state agents in charge of mines. Android mobile GIS applications (AMGISA) with integrated GPS are a high-precision navigation, control, monitoring and terrestrial positioning system. This portable mapping and localized imaging system allows in real time addition of spatial information on the position of observation points, descriptions in the attribute table, collecting waypoints, tracks and taking geotagged photos, as well as capturing screenshots of said maps or images available on its interface. The interface is very dynamic, facilitating data collection via internet connection and their transfer to another workstation for offline processing version and submission of results to decision-makers. The automatic monitoring tests initiated with this technology in the Batouri gold district in the small mines of Dem, Bote and Dimako I have successfully enabled the control and monitoring of mining operations both in the exploration phase and in the exploitation phase. AMGISA and GPS thus constitute a viable alternative capable of being deployed in mining environments and meeting the requirements related to the control and monitoring of mining operations, especially in open-pit mines and particularly for countries located in forested or rugged or remote regions.

Keywords: Batouri, Artisanal and Small Scale Mining, Mobile GIS, GPS, Applied Geoinformatics.

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INTRODUCTION

In this modern era where the demand for rare and precious metals from the technological industry on which developed countries heavily depend is increasing day by day; in the so-called mining countries that supply these metals, on the other hand, there are scandals and crises linked to the mining sector. In most of these countries, particularly those located in forested or rugged or remote regions; the distance between the mining sites where the project manager operates and the capital where the project owner's institutions and services reside is often very great and difficult to access. On the field, there are often several problems related to the lack of control and rigorous monitoring of mining operations by the national administrative side. The most recurring problems are linked to: (1) anarchic exploitation due to non-compliance with the laws in force (environmental law, mining code) causing severe damage to the environment (soil pollution, water , air, visual pollution, destruction of ecosystems, etc.) and a significant shortfall in revenue for states; (2) non-compliance with the terms of mining titles (research permit, operating license) with the direct corollary of exaggerated extensions of the limits or perimeter of the mining title, authorized exploitation depths and often exploitation instead of research. In view of all these irregularities and their economic, environmental and social consequences; this article proposes an effective and adequate method for real-time monitoring and control of mining activities in the field. It presents the importance of integrating mobile GIS and the GPS receiver, which are two cutting-edge tools in the field of geoinformatics, in the mining sector. Furthermore, to date it is difficult to find works mentioning the role of mobile GIS and GPS in the monitoring of mining projects; however, several roles are assigned to GPS in the field of Geosciences such as environmental impacts and Water Resources (Castello et al., 2016; Schueler et al., 2011), and landslide hazard and risk (Roya Olyazadeh et al., 2017). The article is structured around three salient points: firstly the method of real-time data collection in the field (or station 1) with the android mobile GIS applications (AMGISA) and the GPS receiver (GPSr); secondly the transfer of data in real time to station 2 (offline/online); and finally thirdly the processing of the data at station 1(online/offline) or station 2 (offline/online) in order to submit them to decision-makers either in photographic or cartographic format, with the aim of making informed decisions and corrective measures if necessary.

1. LITERATURE REVIEW

1.1. Physiography of Study Area

The Batouri sector is located in the Adamaoua-Yade Domain (AYD) of the Pan African fold belt in Cameroon (Asaah et al., 2014) and is one of the areas affected by the Central Cameroonian Shear (Tchakounté et al., 2017). The sites of the small scale mining of Dem, Bote and Dimako I are located near the town of Batouri to the East and are aligned along the Mbil and Djengou rivers with a general NE-SW orientation constituting one of the subwatershed of the Kadey in the infrastructure of the

Kambele Shear. The study area stretches between latitudes 4° 20' N and 4° 28' N and longitudes 14° 22' E and 14° 27' E (Fig. 1). Access to mining sites is easily practicable due to a relatively dense road network made up of numerous rural roads opened and maintained, mostly by loggers and mining companies.

Batouri is under the influence of a hot and humid equatorial climate of the classic Guinean type with two rainy seasons, interspersed with two dry seasons (Tsaléfac, 2007). It extends to the forest-savannah boundary; the vegetation is very heterogeneous including a grassy savannah in the North and a lush forest in the South region (Bissegue, 2021). The geomorphological analysis based on the study of the SRTM DEM data with a spatial resolution of 30 m (Bissegue, 2021) showed that; the relief fluctuates between altitudes 600 and 900 m. Topographic variations show that the Batouri sector includes three geomorphological units: an upper surface (altitude > 680m), a lower surface (altitude < 600 m) and a transition zone (600 m < altitude < 680m).

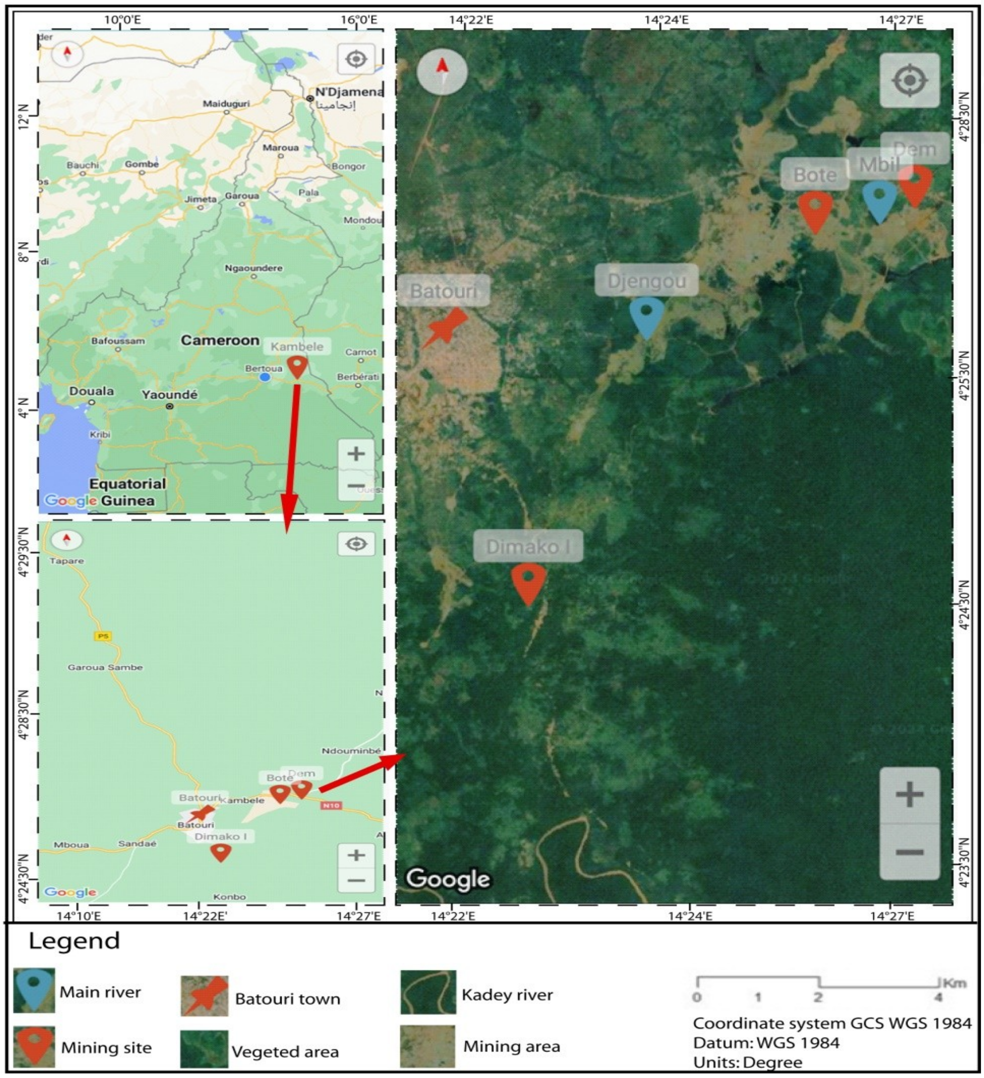

Figure 1. Location map of study area showing Dem, Bote and Dimako I mining sites.

1.2. Mining overview

Exploration by conventional methods and exploitation of Batouri gold remains an ancient activity. Numerous testimonies and stories from residents show that the gold ore deposits from Kambele and surrounding areas, located about 7 km to the East of the town of Batouri was discovered in March 1957 by MBANGO Collette in the Mboscoro stream by making a small well for water (Ntep Gweth, 2013). Several sites of mining activities with the exploitation of gold are located in the study area.

To date, the inventory of mining operations in the area allows, first of all, to identify the presence of several mining companies. Mining is preponderant in the Dem, Bote and Dimako I sites. This exploitation is mainly carried out in the beds, the banks of waterbodies and flats. In watercourses, it is done by dredging or suction and in banks and flats by digging using backhoes or excavators. The opening of mining sites has led to several considerable environmental problems in the operating areas such as water pollution, the destruction and diversions of waterways, deforestation and land degradation (Bissegue, 2021).

1.3. Background and key concepts

According to the functionalities and usages, Mobile Geographic Information Systems (Mobile GIS) extend traditional desktop GIS beyond the offices and allow individuals and organizations to localize, collect, store, visualize and even analyze geospatial data in both field and office environments. GIS have several extra functions in enhancing data performance. It can describe the spatial data on a map, such as the location and shape of geometric objects, and help analyze spatial relationships. It can also store attribute data of map features, and provide the capability to view the distribution network superimposed on different layers (Shin and Feuerborn, 2004). Lastly, GIS can support not only the analysis of features by using the graphical display, but also updating the data (Wei et al., 2010). For instance, about a good definition of Mobile GIS one can dive into more details through those references (Tomlinson 1987, 2007; Goodchild 1992, 2010; Mark, 2003; Egenhofer et al. 2016).

In this section, previous researches concerning field works using mobile GIS are reviewed to give an insight into the background of this study. Generally in geoinformatics, the different techniques for data collection are divided into (i) image interpretation; (ii) semi-automated classification; (iii) automated classification; and (iv) field navigation including total stations, GPS and recently mobile GIS. Data collection includes desk and field studies and involves different activities ranging from low cost to expensive (Soeters and van Westen, 1996). Geospatial information, spatial analysis, and spatial queries are no longer limited to a fixed environment but can be accessed at any place at any time (Shi et al. 2009). This is how many improvements in digital mapping and mobile GIS using geospatial technologies have been revealed in the field of data acquisition for landslide hazard and risk. Free and Open source Software for Geoinformatics has significantly improved the efficient mapping and management of post-disaster and impacted areas around the world (UNEP, 2014; Ushahidi, 2016;

GeoVille, 2016). A mobile GIS application for data collection of cadastral mapping using ESRI and Google Android Software has been developed (Bronder and Persson, 2013).

To end, in the domain of geographic information systems (GIS), advanced mobile information technologies have enabled a variety of novel applications which can help improve positioning and tracking accuracy, efficient field data collection, real-time mapping, ground truth validation, location intelligence and decision support, and so on (Lemmens, 2011; Abdalla, 2016).

2. RESEARCH DESIGN AND METHODOLOGY

2.1. Mobile database and online real-time field data collection

Sites monitoring across mining operations is central to many processes and has always been prevalent amongst exploration and mining operations over the entire course of the project lifecycle. This paper is aimed to provide an operational monitoring method as the project moves through its development phases. Our works focused on three sites whose national and international operators hold operating licenses granted by the State of Cameroon.

Mobile database maintains all the spatial and non-spatial data for mobile GIS applications. The geospatial data used here are essentially primary and come from direct field collection and analysis of cartographic databases available in the Mobile GIS software interface and GPS receiver (GPSr, Tab.1). These data are mainly composed of geotagged photographs, digital maps and Google Earth aerial images. The data thus collected is presented in four digital formats (JPG (.jpg) or PNG (.png) format and KMZ format (.kmz) for the AMGISA data source and GPX format for the GPS receiver). They contain significant information specifically linked to the extension of the perimeter or area of the operations site (size, shape), the precise position of the mining site, the layout and depth of the pits, the phases of mining operations (exploration, exploitation or ore processing) throughout the lifecycle of the mining project. GPS and Google Earth were used for collecting geographical location points of various utility features. The geographic coordinates in latitude and longitude determined by GPS in decimal degrees and surveyed in the global system WGS84/ ellipsoid IAG-GRS80 were arranged in an Excel database with a unique identifier (ID).

When doing field work with GIS technology, two aspects should be considered ; one is visualization (Pundt and Brinkkotter-Runde, 2000), and the other is data acquisition (Poorazizi et al., 2008). Field-based GIS has become the new solution for data visualization and acquisition. The control and monitoring of mining activities as proposed by this article consists of a full-time daily process of data collection, using mobile GIS by android applications (AMGISA) or other handheld GIS devices, GPS and internet connection, their preprocessing and/or their processing then sending in real time to decision-making services. For the convenience of this article, only the data collected during the period from August 29 to 30, 2024 are presented in order to support the approach. From the visualization perspective, the actual mining sites are well displayed on a Mobile GIS-based map (AMGISA) ; this GIS technology is handling geographical and attribute data. With the visualization servers, user gets a better understanding of real world conditions, then views the attributes of area of interest on the digital graphical data displayed accordingly. For data acquisition during field surveys, different field processes have to be completed such as Geotagged photographs recording with both location and attribute and Screenshots of Collector (Fig.2).

Table 1. Database for real-time monitoring of artisanal and small-scale gold mining operations using Android Mobile GIS Apps and GPS receiver.

ID	Data inventory	Source/Description
1	Location	GPS Lat/Long coordinates
2	Date	GPS real-time
3	Type/Format	JPG/PNG/KMZ /GPX
4	Depth	GPS receiver
5	Volume	Measurement
5	Time	GPS real-time
7	Perimeter	GIS calculation
8	Path or track	GPS receiver
9	Polygon/area	GPS receiver
10	Geotagged photographs	Mobile GIS apps
11	Google maps	Mobile GIS-based map
12	Google satellite images	Mobile GIS-based map
13	Google Earth aerial photos	Google Earth pro
14	Photographs	Digital camera

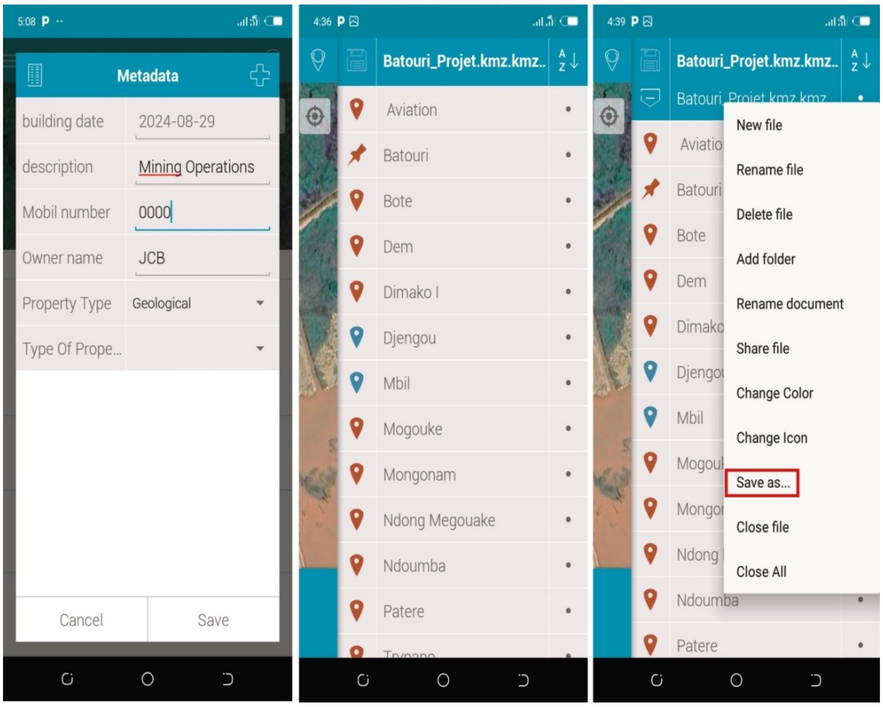

Figure 2. Attribute table editing and field data recording with AMGISA.

2.2. Online real time data pre-processing and transmission

Preprocessing consisted of correcting the position of observation points collected by the AMGISA, deleting unnecessary data and transferring data from mobile device and GPSr to in-office computer effortlessly. The process of correcting the position of a point after data collection is done in three steps: (1) Simple navigation through the application to the location of the point considered, then placement of a new waypoint which modifies the incorrect coordinates and automatically gives the real coordinates of the location, (2) noting the coordinates then deleting the waypoint with false coordinates and, (3) editing the location to be corrected. The corrected points were recorded in Table 2. The method of deletion, verification of the accuracy of the data and recovery of GPS data and their export to the computer is classic. Using a cable, the GPS is connected to the computer ; then using specialized software, the data in GPX format including positions of observation points, lines or tracks (in lines or polygons) of spaces mining operations were converted and saved in shapefile and KML formats.

Online data access for field work needs handheld devices such as laptops, smartphones and tablets. Smartphone was adopted for this work in the field because of its own graphical user interface, touch keyboard, wireless communication capabilities and the ease of having the Android mobile GIS application (AMGISA) online through the Playstore platform with Android as Operating Systems (OS). For data gathering, updating via mobile GIS and transferring to another users (Fig.3), the availability of wireless communication is important. Typical technologies used here it's cellular networks well supported by Android devices and available in the field. 4G is the most commonly cellular network used in Cameroon facilitating online mobile GIS functionalities and making the communication fast and stable. Communication among different devices (e.g. station 1 in the field and station 2 in the office) and data transfer is therefore established by mobile network connection. Online mobile GIS (AMGISA) also enables a real-time data updates and exchanges between centralized map servers and distributed mobile.

Table 2. Correction of observation point coordinates using the GIS Mobile apps (AMGISA).

		Incorrect coordinates		Real coordinates	
ID	Placemark	X(DMS)	Y(DMS)	X(DMS)	Y(DMS)
1	**Dem**	360.000 0.000 0.000	360.000 0.000 0.000	14.000 26.000 30.103E	4.000 27.000 42.738N
2	**Djengou**	360.000 0.000 0.000	360.000 0.000 0.000	14.000 23.000 54.596E	4.000 26.000 14.841N
3	**Dimako I**	360.000 0.000 0.000	360.000 0.000 0.000	14.000 22.000 42.510E	4.000 23.000 22.586N
4	**Mongonam**	360.000 0.000 0.000	360.000 0.000 0.000	14.000 22.000 06.728E	4.000 24.000 52.339N
5	**Pater**	360.000 0.000 0.000	360.000 0.000 0.000	14.000 23.000 14.133E	4.000 25.000 20.370N

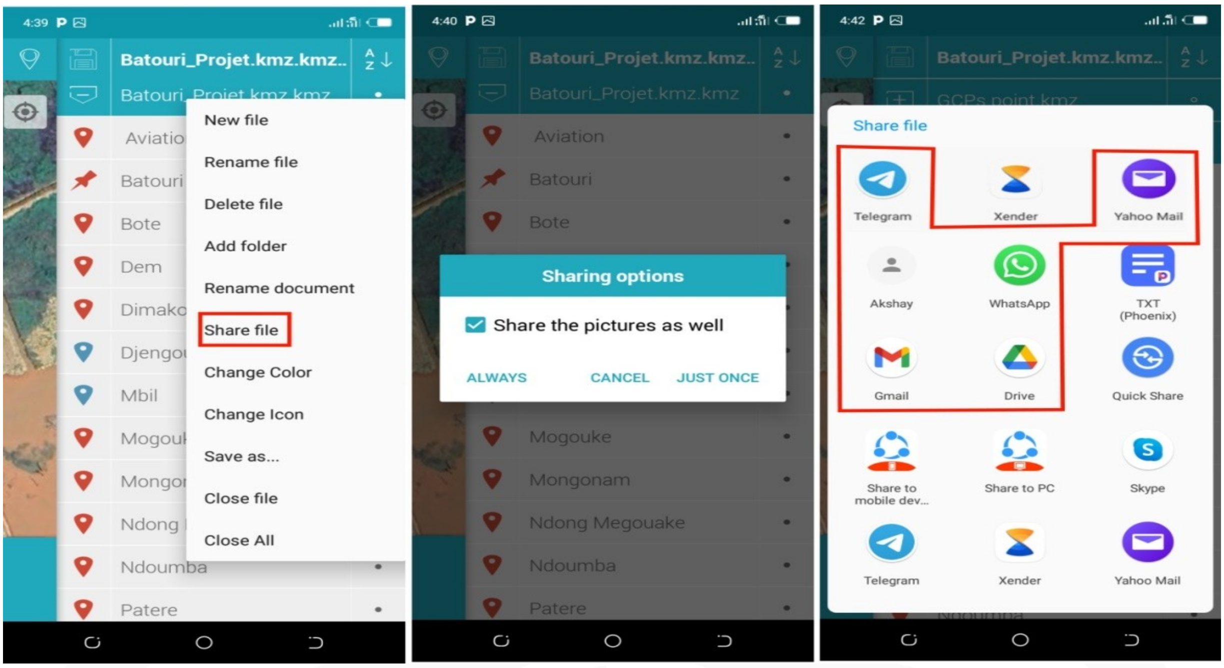

Figure 3. Data transfer process from mobile device to in-office computer effortlessly based on the use of internet and common web apps from the field.

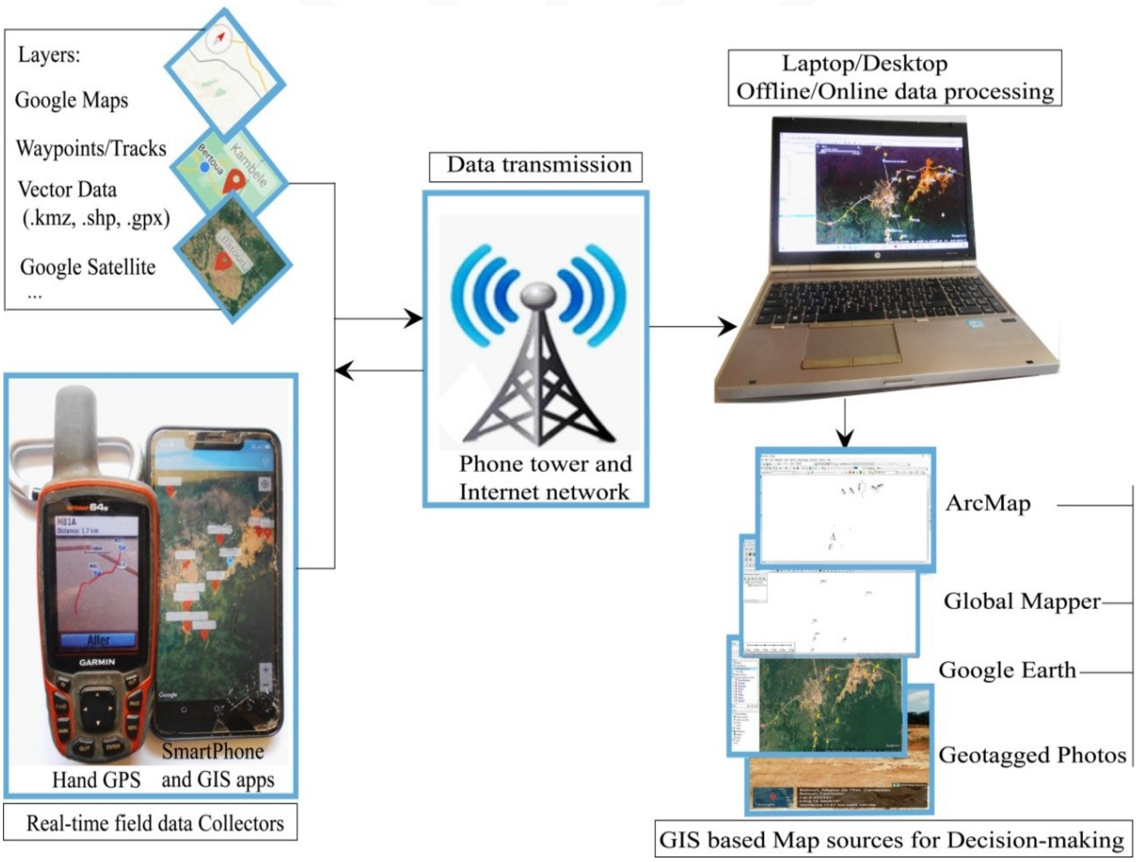

Figure 4. Conceptual workflow of real-Time GPS handed and Mobile GIS Data Acquisition System for gold mining operations monitoring.

2.3. Offline data processing and post-processing

Real-Time Data Collection enables immediate data upload and synchronization with cloud-based GIS systems or data transfer to another users (workstation). Once the fieldwork has been completed for the day, the mobile GIS apps (AMGISA, as indicated in section above) allow to gather field data including GPS coordinates, geotagged photos, basemap and feature attribute information. Then, daily data can be downloaded quickly and effortlessly. Offline mode data processing consists of the data visualization and analysis; this stage (station 2) permits to utilize GIS softwares (such as ArcGIS, Google Earth, Global Mapper, …) to analyze the collected data and create maps, reports, and visualizations to aid decision making. Thereafter, post-processing enables the analysis and interpretation of the collected field data using desktop GIS softwares, creation of informative maps ; helps to perform spatial analysis, and generate reports. The conceptual workflow is briefly described as seen in Figure 4.

3. RESULTS

3.1. Monitoring of Dem Mining open pit

Early mobile GIS and GPS monitoring was conducted in Dem, Bote and Dimako I in order to define the different mining operations carried out in these mining sites and consequently collect accurate data and transfer them in real time for decision-making. Firstly, GPS data is basically point oriented ; whereas GIS data is more complex comprising points (GPS coordinates), lines (tracks) and polygons (areas) and images and Relational Databases. However, the only prerequisite for collecting data is to actually be on the ground; no image data can be collected outside the field. The location of mining sites on the basemap served by the mobile GIS app (AMGISA) interface also allows for taking pictures of the observed points, which generates two types of data, namely maps of mining sites and geotagged photos. Thus, accurate and up-to-date data for the entire mining site can be viewed in the field via the basemaps available on the mobile GIS application interface.

The centered map (Fig.5) presents the mining site of the small Dem mine, this map shows the extent of the activities and allows spatially to appreciate the scale of the exploitation whose observation elements are the perimeter, the position, the type of activity, the equipment used and even the evolution over time. The geotagged images around centered map provide details and precision on the type of activity and its degree. These activities include the stage of the mine opening, stripping of waste rock, transport of mining waste, backfilling and ore deposition among others. The most important thing here is the geographical position of the mine site, its size, nature, extension and depth in accordance with the provisions of the research title.

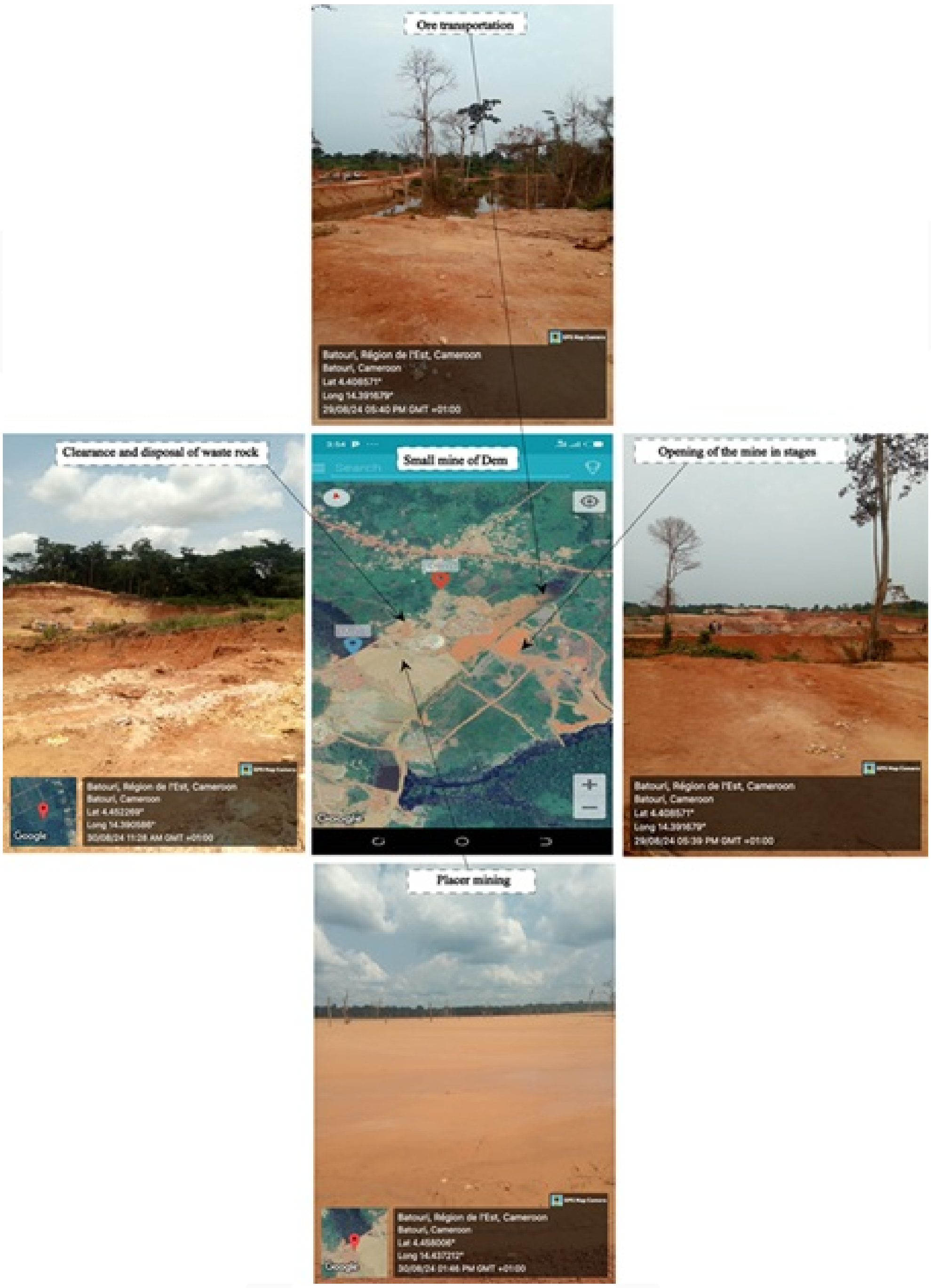

Figure 5. Screenshot of centered Google satellite image of Dem's small open pit mine and geo-tagged photos of operations.

3.2. Monitoring of Bote Mining open pit

An important application of Mobile GIS apps (AMGISA) alone or in combination with GPS is the monitoring of mining and geological operations related to all phases of a mining project such as prospecting, exploration, mine development and exploitation. Data collection tests by mobile GIS applications downloaded from playstore conducted in Dem, Bote and Dimako I demonstrated their interest in being associated with GPS in order to improve the availability of coordinates and, consequently, the accuracy of the data. Comparison with 2D coordinates obtained from an geotagged image at station 1(in field) confirmed a repeatability of less than 0.01 degree, as well as an accuracy of less than 0.01 degree (assuming no movement of the device) with the 3D coordinates taken by the GPS receiver (GPSr). Figure 6 presents the monitoring images of the mining operations at the small Bote mine, carried out using AMGISA and GPSr. Bote is the largest mining site in the study area. The mine consists of several pits, each approximately 1.5 km length and 750 m width, reaching depths of almost 50 m in places. The data collected, mainly consisting of geotagged photos, tracks, and GPS coordinates indicate that the site is located between 14° longitude and 4° latitude. The mining phase is very advanced in terms of the extension of the mine perimeter and the depth that almost reaches the granite bedrock. Activities also include, among others, mine opening, stripping of waste rock, transport of mine waste, backfilling, ore deposition, as well as ore processing and enrichment. Irregular or illegal activities can now be detected through rigorous real-time monitoring using mobile GIS and an internet connection. Appropriate measures can be taken in real time by decision-makers to ensure strict implementation of the clauses of the various contracts or the provisions of the various mining titles awarded to mining companies.

3.3. Monitoring of Dimako I Mining open pit

Android mobile GIS is a portable mapping and imaging system, operating simultaneously in harsh urban and rural environments, and often used for mining in environments where good sky visibility is not guaranteed. It is a positioning/orientation device imposing strict requirements in this regard; the solution to the positioning/orientation problem increasingly relies on the integration of several technologies. Therefore, in this paper as a reminder, a hybrid system based on Android mobile GIS applications (AMGISA) and GPS receiver (GPSr) is used.

The small Dimako mine is in the data collection phase of its opening. The Dimako locality is located in the middle of a dense forest; the installation of a mine in this site is the cause of the loss of a strong forest cover. The GPSr made it possible to collect the coordinates and tracks of the extension of the exploitation perimeter. The mobile GIS interface permitted to access the maps and take precise geotagged photos of the observation points. Mining operations at this stage include the opening of the mine, stripping of waste rock, excavation and transport of mining waste. The image data presented in Figure 7 are thus integrated in offline mode into desktop GIS tools for visualization, analysis, interpretation and creation of maps useful for decision-making.

Figure 6. Screenshot of centered Google satellite image of Bote's small open pit mine and geotagged photos of operations.

Figure 7. Screenshot of centered Google satellite image of Dimako I's small open pit mine and geo-tagged photos of operations.

4. DISCUSSION OF FINDINGS

4.1. Mapping and data assessment for decision-making

Several cartographic and image editing platforms available, such as GIS, make it possible to produce maps and carry out data evaluations, necessary to support the taking of appropriate measures by decision-makers in accordance with the mining and environmental law in force in the host country. Figure 8 presents the field data projected on the Google Earth image basemap, the rapid visualization and evaluation of which allow the extent of activities on the ground to be assessed. The superposition of spatial terrain information on aerial imagery therefore makes it possible to faithfully visualize the reality as it is on the ground and to induce informed decision-making. Thus presented, the online mobile GIS and offline office work aim to reduce the costs and time required for data collection/modification/loading, increase data accuracy, make data for the entire study area visible and complete the mapping of the study area within the time limit for informed daily decision-making.

Researchers in the environmental field are increasingly interested in the use of geolocation and mobile mapping devices such as GPS devices (Zheng et al. 2008, Yue et al. 2014) and mobile phones (Kang et al. 2010, Gao 2015, Xu et al. 2016, Zhao et al. 2016). Thus, the popularization of mining operations monitoring technology and the processing approaches of data collected online or offline by mobile GIS via smartphones will therefore advance informed decision-making and geospatial intelligence based on them.

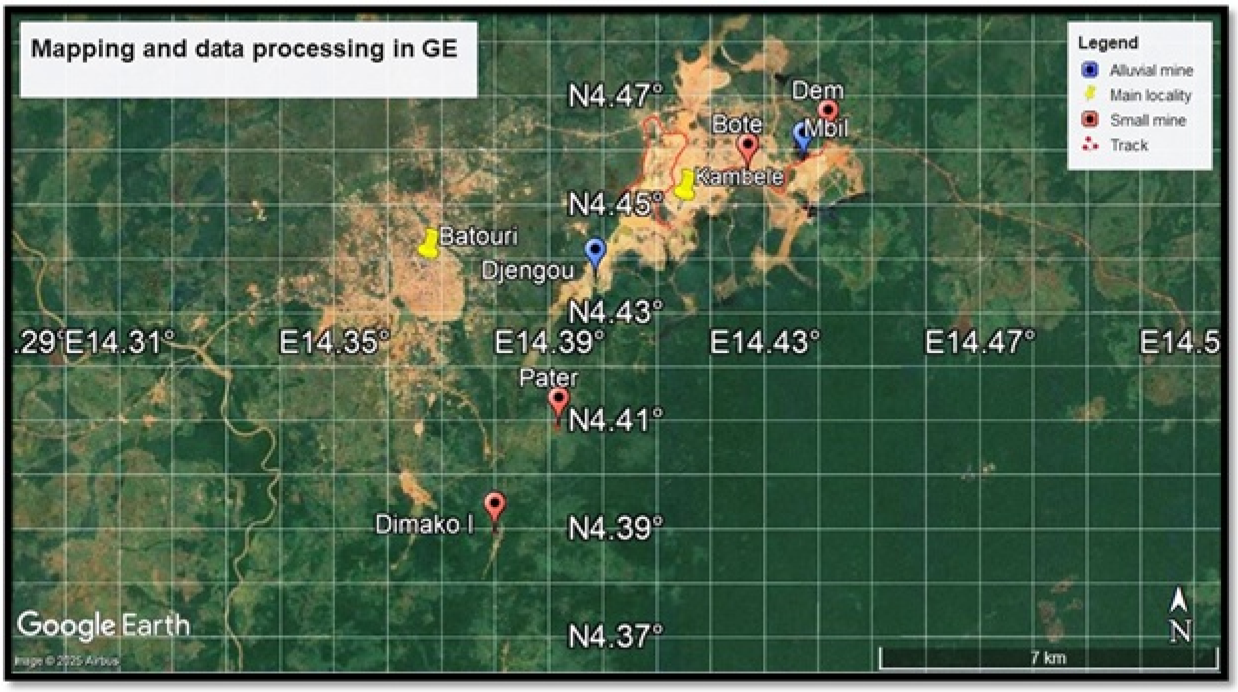

Figure 8. Display and visualization on Google Earth of data including observation points and routes of mining site extensions.

4.2. Map publishing

To publish a map to support informed decision-making, it was first necessary to create a map project in a desktop GIS in offline mode and connect all the data layers. The test map template produced in this example therefore contains several feature layers. The built-up, land-use, waterbody, and road network layers were chosen as background layers. All these layers were used as operational layers for visualization, queries, querying, and editing to better assess the location of the various mining sites and the nature of their operations. Figure 9 presents an overview of the test map, it is important to mention that this map comes from the data collected during the monitoring test using AMGISA in the test area of the Dem, Bote and Dimako I mining sites. Users (mining operators and decision-makers) can identify the symbols of the mining sites, their geographical position, the paths of their extension and their relationship with the environment, as well as several other characteristics can be evaluated. These geospatial data layers on the mining sites thus represented are essentially the reflection of the work carried out by the field agents responsible for monitoring mining activities. The choice of symbology and colors make each element of the map easily readable and identifiable.

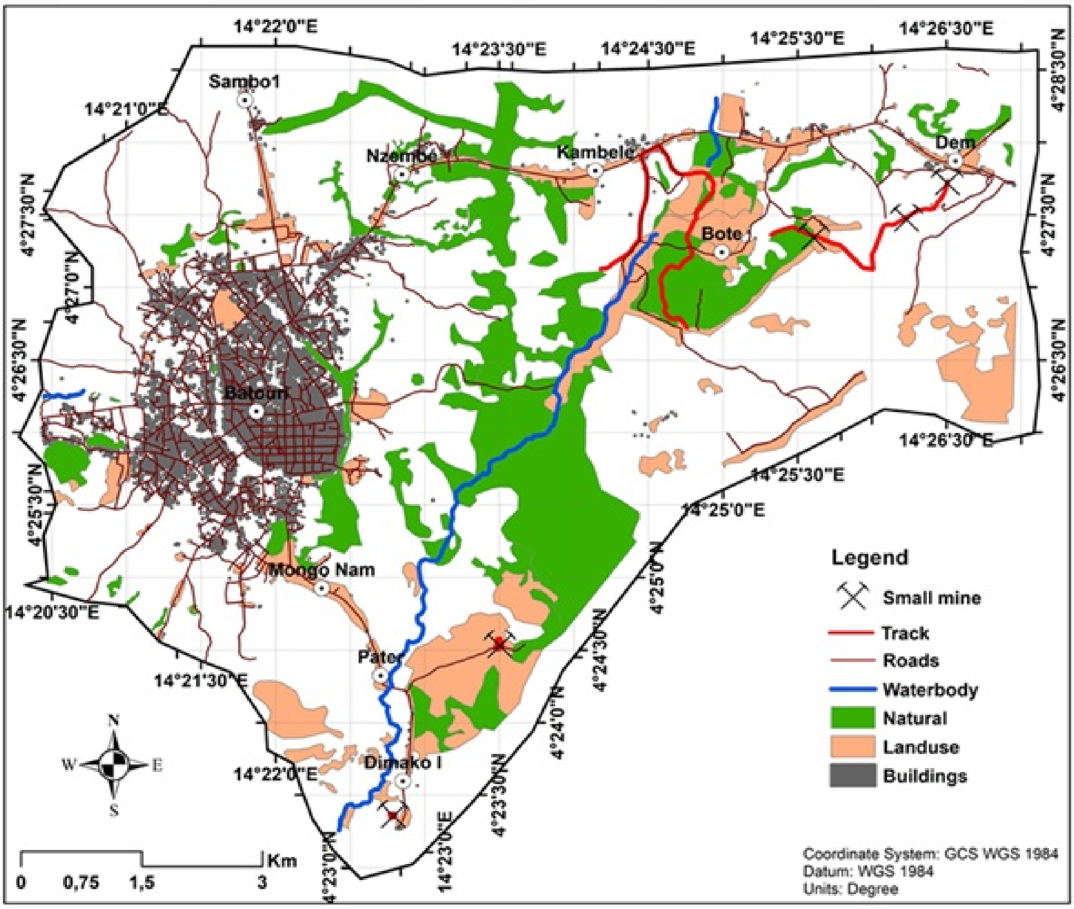

Figure 9. Informed decision support map edited in an offline GIS mode using field data collected by the mobile GIS apps and GPS receiver then plotted on land use-land cover basemap of the study area.

The results of this research have shown how mobile GIS via smartphones have facilitated the tasks of monitoring mining operations and collecting field data. In terms of data access, collecting, querying, and modifying or correcting data on a mobile device and transferring it to another workstation for offline processing and mapping have become possible. From a visualization perspective, they help mining stakeholders visualize the spatial distribution information of mining sites on digital maps. However, this research also has some limitations. To this end, the development of a mobile GIS application for use in the environmental field must address certain challenges, including: i) the limitation of system resources, such as processor speed, memory size, and battery power; ii) the limitation of network connection during field survey; and iii) the size of the screen and keyboard, as well as the interface as indicated by Fu and Sun (2011). As additional practical solutions, it is suggested here to use optimized mobile GIS applications and other alternative devices such as power banks, solar charging systems, internet modems and tablets. Fu and Sun (2010) also pointed out that it is essential to choose a widely used system and mobile device to maximize the acceptance of this application by different target groups (such as mining authorities). Therefore, Android mobile GIS has proven valuable as the main platform in this study, thanks to its free resources, accessible online to all on playstore. From this point of view, Android also helps reduce the costs of controlling and monitoring mining works because it makes it possible to edit data in real time through its graphical interface, as mentioned by Wei et al. (2010).

CONCLUSION

Android mobile GIS applications (AMGISA) are a new type of portable mapping and localized imaging system, capable of providing high-precision positioning coverage when accompanied by the GPS receiver (GPSr). It is therefore a navigation system allowing to locate oneself on the map and to mark the precise position of the observation point and take geotagged photos. This article presents some technical aspects of this technology, summarizes the strengths and describes the various applications of this technology, including its ability to explore spatial information and transmit it in real time to another workstation. GPS data is basically point oriented; whereas GIS data is more complex comprising points, lines, polygons and images and Relational Databases. Extensive tests on the use of the GPSr and AMGISA at the small gold mine of Dem, Bote and Dimako I have confirmed the effectiveness of this hybrid system, essential for monitoring and informed decision-making in the field of mining, particularly for countries located in forested or rugged or remote regions. The applied method is also particularly suitable for critical applications of automatic supervision of mining activities, in regions where sky visibility is restricted either due to the canopy or the high walls of open-pit mines.

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