

استخدام نظم المعلومات الجغرافية لتصنيف حفر الشوارع الحضرية في مدينة الخرطوم - عاصمة السودان

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ملخص:

هدف الدراسة: تهدف الدراسة إلى تصنيف وتحديد المواقع المكانية للحفر في الطرق والشوارع وسط مدينة الخرطوم، عاصمة السودان، الناجمة عن ركود مياه الأمطار الموسمية. **المنهجية:** استخدم تطبيق Survey123 أحد تطبيقات شركة ESRI للاستخدام الحقلية، وجمعت البيانات مكانياً بالاعتماد على النموذج المسبق إعداد من صفحة التطبيق لإنشاء متطلبات البيانات الحقلية ومشاركتها وتحليلها. استخدم جهاز الموبايل (أندرويد) في هذه الدراسة لرصد وتسجيل مواقع الحفر بالشوارع خلال العمل الميداني الذي غطى ثلاثة طرق رئيسة وطريقين فرعيين. استخدمت أداة التحليل الإحصائي المكاني في إصداره ArcGIS 10.4 لتحليل وإنتاج خرائط توزيع الحفر وتصنيفها وتحديد المناطق الأكثر خطراً. تم تصنيف الحفر في ثلاث فئات: الكبيرة والمتوسطة والصغيرة. **النتائج:** وصل إجمالي عدد الحفر إلى 77 حفرة في الشوارع الخمس التي تم مسحها. وبناءً على المقياس المستخدم، تم تصنيف 21 حفرة كبيرة، و36 متوسطة، و20 صغيرة. ظهرت أضرار كبيرة في الشوارع ذات الحركة المرورية الكثيفة؛ حيث أظهرت نتائج تحليل النقاط الساخنة (Hotspot) شارعاً واحداً كان أكثر تأثراً بظهور الحفر وأخطر على الحركة المرورية؛ مما يتطلب إعادة رصف كاملة.

المصطلحات الأساسية: الحفر، الخرطوم، المياه الراكدة، تطبيق المسح Survey123، التحليل الإحصائي، النقاط الساخنة.

Using GIS to Classify Urban Street Potholes in Khartoum City, the Capital of Sudan

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Abstract

Objectives: Specifically, this study aimed to classify and identify the spatial locations of street potholes caused by seasonal rainwater logging in Khartoum, the capital of Sudan. **Methods:** The field data collector Survey123 of ESRI was used, which is an application for collecting data spatially based on the pre-prepared Excel form available on the application website to create, share, and analyze field data requirements. Using an Android mobile device, the study recorded the locations of potholes in three main roads and two bystreets. In ArcGIS 10.4, a spatial statistical analysis tool was used to analyze and produce maps of pothole occurrences, as well as to classify and identify high-risk areas. A total of 77 pothole events were recorded, based on their size that was classified into three categories: large, medium, and small. **Results:** According to the scale used, there were 21 large, 36 medium and 20 small potholes on the five streets surveyed. The most severe potholes occurred in heavy traffic streets. A hotspot analysis showed that there was one street that was seriously affected by potholes, which is considered a high risk and requires complete rehabilitation.

Keywords: Potholes, Spatial Locations, Khartoum, Water Logging, Survey123, Hotspots

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1. Introduction

The problem of potholes and cracks, which is becoming very serious for roads around the world, is causing considerable vehicle damage (Wu et al., 2020). The most important concern within the current urban environment is safety, so long as there is no street distress (potholes). The construction specifications and monitoring systems are among the most effective means of tackling street risks. One pothole can cause severe injuries or even death to tens of thousands of people. Consequently, planners will increasingly rely on spatial analysis to address urban problems; city streets and roads information management systems incorporating GIS techniques are among the most widely employed applications of GIS in transport infrastructures. Management of the road transport network, which is the dominant mode of transport in Africa, plays a big role in the development of the nation (Kayondo-Ndandiko & Togboa, 2011). Inspection of streets and roads is a recurring requirement in urban areas, as well as new spatial analysis techniques. The overall condition of streets and roads in urban centers is a key issue and a top safety priority, as many streets are exposed to severe damages on a seasonal basis that remain undetected for years.

Street and road damage monitoring has become a significant task in terms of safety, mitigation, preparation, and controlling estimates. To meet the immediate and practical needs of maintaining roads, GIS and RS spatial analysis techniques can be used. As identified by ALFAR (2016), fourteen factors have the greatest influence on pavement maintenance decision-making. In this study, the Road Condition Indicator (RCI), the Type of Deterioration, the Observed Deterioration Rate, and the available budget were the most related ones. Geo-databases are critical to street and safety monitoring, as they facilitate rapid and easy operations and plan implementation. A major cause of potholes and cracks in the streets is the failure to meet engineers' specifications, such as the mix of materials used for pavement, the compacting of the base layer, and asphalt quality used. The rainy season is the time when old pits become wider and deeper, while new potholes and cracks appear annually.

Over the city of Khartoum, urban streets and roads have been destructed because of rainwater collected in the low-lying streets of Khartoum, which will become one of the most significant factors. The annual occurrence of potholes and cracks on the streets of the study area

poses a lengthy problem, aggravated by the presence of water, which damages the surfaces of the streets. Most of the rain that affects paved street quality occurs between July and September. Potholes can be effectively monitored and mapped by utilizing the latest methods of data analysis and street maintenance management. Our focus in this paper is on determining spatial information from the street pothole location assessments, mapping the sites where potholes occur, and showing the condition of the potholes using a size scale as an attribute describing the magnitude of the problem.

2. Problem identification

As a result of climatic events such as heavy rains and cyclical changes in temperature, road distress such as cracks, potholes, and settlement of sub-grade are increasing (Yadav et al., 2019). The study area does not have the worst street damage over Khartoum City because it has been chosen to carry out this study, but because of its unique spatial location in the city center, and because it is considered ideal in terms of its landscapes and infrastructure. Drivers are told to avoid some streets in the inner parts of the city because they present a risk to them. The chronic problem of surface anomalies (potholes) in Khartoum continues to cause main traffic interruption in the city. Pothole spatial extent is in arterial, sub arterial, and intersection streets. In addition to seasonal flooding, heavy traffic, engineering specifications, and aging streets, there are numerous factors that may cause street damage; in the study area, rainstorm events are the dominant factor responsible for the condition of potholes. Several streets seem like depressions where water accumulates for weeks. Streets constructed incorrectly erode more rapidly as the amount of seasonal rain increases. There is a risk associated with damage to most street types that ranges from high risk to low risk. Potholes of all kinds adversely affected the street quality and efficiency in Khartoum. By the end of every rainy season, the street conditions in the city of Khartoum are worse than they were in the previous year, and more damages are added each year to aggravate the existing problems.

3. Related previous studies

There are considerable numbers of studies concerning GIS application in transportation, traffic, and streets and roads maintenance. Many studies about road and street damages thematically, methodologically, and chronologically are added in the literatures from different disciplines.

The studies that support this paper are those that use different techniques and methods for determining and assessing the street surface damage confined to pothole distresses. Mednis et al. (2011), published a scientific paper about road line pothole detection using android smart phone with accelerators as a promising approach for pothole data collection. Venkatesh et al. (2014), conceptually proposed an intelligent system to detect, avoid, and maintain potholes on roads using Graph thematic approach as a system that can identify the potholes immediately. In 2014, Fendi et al., published scientific research about using GIS database for road surface monitoring; they used this approach to detect any distress such as cracks and potholes on paved and unpaved road surfaces. Van Geem et al. (2016) studied road surface distress detection using sensors on vehicles (SENSOVO) with wheel acerbating and ToF data collection, by a fleet of ordinary vehicles. In 2017, Bhatt et al., published a paper about intelligent pothole detection and road condition assessment; they developed a system to detect pothole and assess road condition in real-time. In 2018, Pan et al., studied asphalt pavement potholes and cracks detection using unmanned aerial vehicle multispectral imagery. They used such proposed system to distinguish between the normal pavement and pavement damages such as cracks and potholes. In their paper, Nguyen et al. (2019) applied “Response- based methods to measure road surface irregularity, which was a state-of-the-art review in which machine-learning techniques and data driven methods were used internally with promising results. Baek & Chung (2020) wrote about the pothole classification model using Edge Detection in road image; for potholes detection, they used object detection algorithm. Also, in 2020, Wu et al., applied an automated mobile learning approach for road pothole detection using smart phone sensor data; they proposed an automated pothole detection system deriving the built-in vibration data in a city using smart phone with mobile application. The use of remote sensing techniques offers new potential for pavement managers to assess large areas (Schnebele et al. 2015).

Previous local studies applied some GIS and RS techniques but lacked the new innovative and effective tools such as mobile field-based applications. This showed limitations in analysis and monitoring of urban transportation related problems. Due to this progressing of the road and street potholes phenomenon, the introduction of new mobile GIS applications gives new trends in field survey to collect instance

information. Tracing these limitations of applying the new GIS-based field methods in related institutions and academic studies in Sudan, this paper can participate in solving real data collection problems and add new knowledge about modern field data collection mobile applications.

4. Study area

Khartoum locality consists of eight administrative units located at the confluence of the White Nile and the Blue Nile, between longitudes ($32^{\circ} 27' 18'' - 32^{\circ} 40' 35''$ East) and latitudes ($15^{\circ} 11' 58'' - 15^{\circ} 38' 26''$ North) fig. (1). The selected area for this paper is part of Khartoum city, which lies in the core and is characterized by high traffic operations. The city's population of cars is increasing, but related services like street repairing and maintenance are not. Khartoum city is characterized by an increasingly crowded traffic situation which is a serious traffic problem. The latest estimations of Khartoum Traffic Office's report (2019) suggest that the east administrative unit of Khartoum has about 25.000 cars; in this area, the streets have sustained severe and chronic damages for an extended period without being repaired. This paper discusses street damages regarding potholes that vary in their size, shape, and depth. Sample streets consist of three main streets and two bystreets that connected the south and north portions of the neighborhood.

5. Research importance

Modern societies often lack basic infrastructures that would otherwise ensure a free and harmonious flow of information, making it impossible to provide a guarantee for development. As a result, a system containing all the necessary data is required to determine the condition of infrastructure environmental parameters (Nasioula, 2010). It is essential to gather information and identify properties before scheduling and planning; therefore, inventory and timely processing of information are crucial in supporting local and national authorities in monitoring street problems.

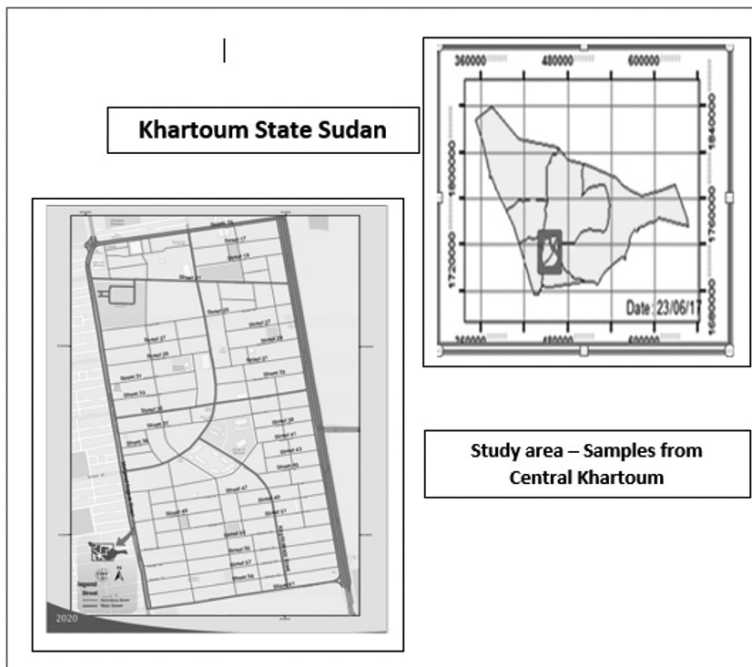
6. Methodology

Monitoring streets is essential to support the speed of maintenances. In part of urban Khartoum, pothole events are analyzed using a variety of analytical methods. In the analysis of pothole occurrence data, spatial statistics are selectively applied to Hotspot analysis. Based on the spatial distribution, areas with concentrated clusters were identified. Using

pothole sizes as key, the final output visualizes the distribution of potholes. Accordingly, the methodology of this paper is outlined as follows: gathering data, exploring it, analyzing it, creating a spatial map, determining the hotspot areas, and interpreting the results. Data checking in the field is a way to correct readings or measurements that might be missed or deviated when collecting data for the first time. Correcting errors is achieved by checking collected information. A checklist was prepared to make sure that Spatio-temporal field data collected by Survey123 was corrected for errors. Validation of error correction is done using external GPS. To provide proper error correction mechanisms for the Survey123 application results, we prepared a checklist to ensure that spatial field data collected was re-corrected.

Fig (1).

Study Area Central Khartoum City – Sudan 2020



6.1 Pothole data collection

To analyze street and road problems and their geographical extent, data collection is a prerequisite. In this paper, the most important data is to find out where the major potholes are. Data was collected from five

streets in central Khartoum city and was categorized into large, medium, and small potholes based on a (1.5+8), (1-2), and (0.5-1) meter scale, respectively (Table 1). To define the inter class specifications, each class was divided into three subclasses. The triple interclass scale for large potholes is (1.5-4.5), (4.8-8) and (8.5+8) meters, the medial class is (1.00-1.25), (1.25-1.50) and (1.50-1.50) meters, and subclasses of the small scale are (0 - 0.50), (0.50 - 0.75), and (0.75 - 1.00). All streets are designed the same and traffic conditions are the same, which is incorrect pavement.

Conducting a field investigation is important to give most up-to-date information about potholes in Khartoum. A field data collection method includes selecting a street, selecting an application for gathering data, and measuring with tape. Data Collection took place in October 2020. As a mobile application for collecting real-time data, ESRI’s Survey123 software collection was used. The application provided efficient methods for storing data and converting it into the shape file format necessary to use with ArcGIS. In addition to spatial data, non-spatial information was gathered from base maps and field observations, such as street name, shape, and condition.

Table 1.

Field Potholes Scale Characteristics

Pothole categories	Description
Small	Potholes that have no effects on traffic
Medium	Potholes that have significant impacts on traffic
Large	Potholes that have significant impacts on traffic

6.2 Analysis methods

Geospatial information technologies can be used to develop new strategies based on information about transportation deterioration (Casas Avellaneda & Lopez-Parra, 2016). Utilizing GIS to monitor street conditions and detect early repairs can help reduce repair budgets, as they deal with a few potholes that are in the present rather than a huge number that would be unknown for years. With real-time survey applications such as Survey123, GIS spatial techniques are extensively used. In ArcMap 10.4, the collected points representing potholes were converted into a

shape file. Using the Hot Spot tool, we analyzed the mode of occurrences, as well as the general concentration that affects traffic conditions.

7. Analysis and discussion:

7.1 Analyzing the location and categorization of the potholes:

A sample of Khartoum's streets was surveyed and mapped as part of this study, which aims at mapping and analyzing pothole spatial distributions. A total of five streets in this area were categorized as pothole occurrence zones. These streets stretch from south to north, crossing high-quality buildings including the embassy of the Kingdom of Saudi Arabia. Khartoum city suffers from several chronic uncivilized issues, including the presence of potholes. Based on field measurements and observation data, street damage (pothole occurrence) maps were created. During the field survey, potholes were measured and observed using ESRI's application Survey123, one of the most effective and potential applications.

After the heavy rain in September 2020, the potholes determined from the field trips ranged from 0.50 to 8 meters. A statistical analysis revealed that the potholes appeared in square and circular shapes and were generally 2.1 meters' size on average. The potholes ranged from the smallest (0.5 meter) to the largest (+8 meter). In this assessment, the street was found to be in more distress than originally thought and it posed a serious traffic risk. Daily, potholes became deeper and wider due to heavy traffic, which increased their size and depth.

7.1.1 Large size potholes

Figure (2.a) shows that this type of pothole is found in congested streets with high traffic levels. Statistically, their size measure ranges between two and eight meters. Based on the presence and distribution of potholes in the streets, we found that such type of pothole tends to occur at the edges of streets and midways, which are particularly hazardous and prone to accidents as drivers attempt to avoid them.

7.1.2 Medium size potholes

Figure (2.b) shows that this type of pothole was also distributed in streets that were congested with high traffic. The statistical analysis showed that their size measured between 1 and 2 meters in diameter. As with the large potholes in the street, the presence of these pothole types is

also noted at the street edges, with an abnormally high concentration in the middle.

7.1.3 Small size potholes

Potholes of this type showed the early stages of pothole formation as they grow with the seasonal logging of storm water and the intensity of driving, and their size ranges between 0.5 and 1 meter. Their distribution extent varies across the study area (Fig 2.c). In addition to large and medium-sized potholes, small potholes are present at the edges of the streets with significant new occurrences at the center. Since it is easy to drive over it, there is no risk involved, but intensive driving eventually causes it to enlarge into a medium-sized crater.

There is an observable difference between the surface of the street and the road from a material or engineering perspective. A serious strategy, therefore, needs to be planned on the occurrence of street damages in Khartoum city regarding its frequency, distribution, and expected risk. Based on the scale used for measuring pothole size, Table (2) presents a statistical account of the pothole subclasses.

Table 2.

The Statistical Account of Potholes

Category	Inter Category Scale (m)	No. of Potholes	Category Total	%
Small	0.00 --- 0.50	11	20	26.0
	0.50 --- 0.75	7		
	0.75 --- 1.00	2		
Medium	1.00 --- 1.25	21	36	46.8
	1.25 --- 1.50	13		
	1.50 --- 2.00	2		
Large	2.00 --- 4.50	15	21	27.2
	4.50 --- 8.00	4		
	8 +	2		
Total			77	100%

7.2 Assessing the geometrical feature of the potholes

Various geometric patterns are found in the street potholes data. Using specific site conditions and size as well as field observation and drawing sketches, geometric spatial information was analyzed. The scales were further divided into three classes for more detailed sizing descriptions. Figures (3.a) and (3.b) illustrate some examples of a pothole in nature.

7.3 Hotspots analysis

By virtue of the development of GIS-based spatial statistics, researchers have been able to measure and evaluate road and street distress of hotspot sites. Since 2008, hotspot analysis has become widely used in a wide variety of disciplines to identify spatial phenomena based on their occurrence of clusters. The term Hotspot refers to a spatial analysis and mapping technique that uses points in a map to indicate the extent of a site. Hotspot results identify statistically significant locations. A potential method for determining locations of high concentration events or objects can be used in service and DSS. Pothole hotspot analysis has been implemented differently, with the purpose of identifying risk and street distress zones. Service and event hotspots have high clustering levels. Specifically, this study examined spatial areas with significant occurrences of potholes. Based on the number of occurrences, each type of pothole has a percentage, which is 27.3%, 26%, and 46.7% for large, medium, and small potholes respectively. Fig (4) shows the result of the hotspot pothole analysis processed using ArcMap 10.4. An internal street in the study area is the main pothole hotspot. On the map, the red color represents pothole hotspots that appear to represent 17.54 % of all potholes.

Figures (2.a), (2.b) and (2.c).
Potholes Occurrence Categories

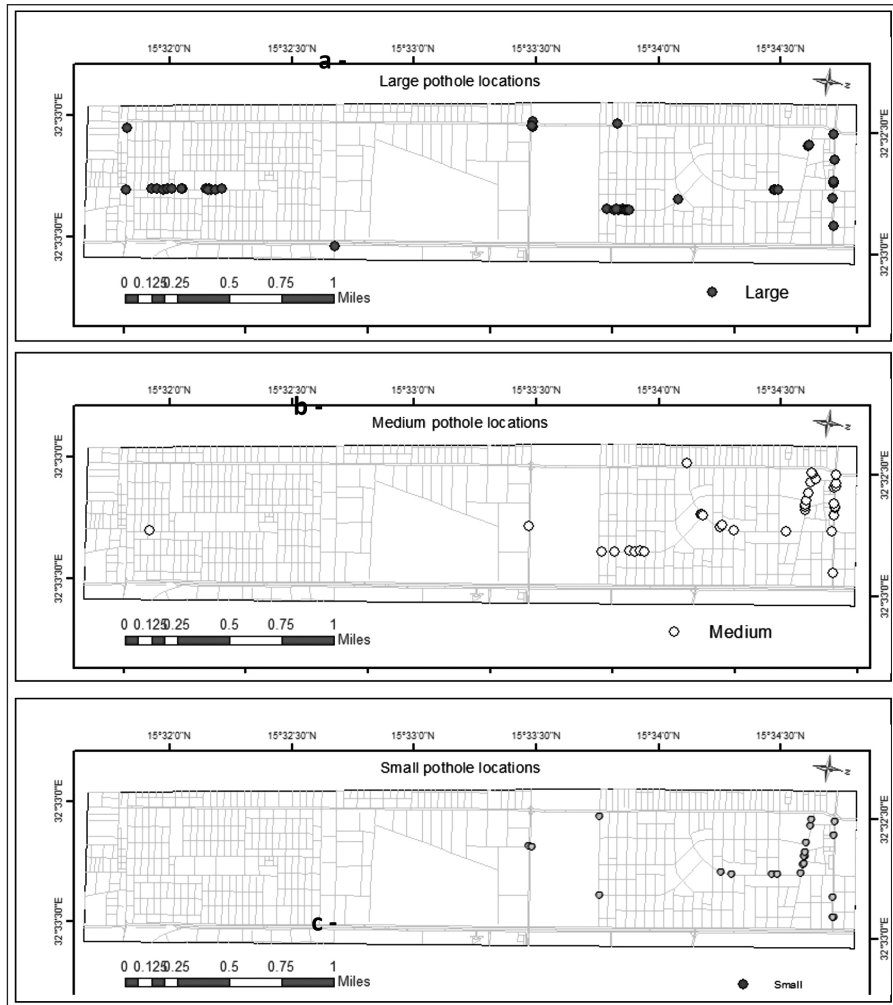


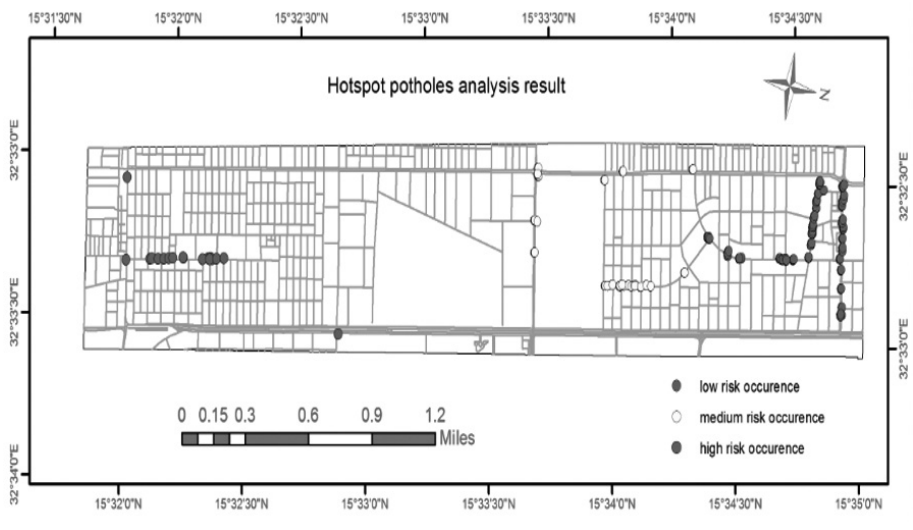
Fig (3)

a. geometrical shape of the potholes b. potholes occurrence at mid of the street



Fig (4).

Potholes Hotspot Analysis



8. General remarks on the analysis

- Based on the general image of the problem, we can state that Khartoum city is a street pothole-adapted city that creates traffic problems as drivers complain that their vehicles are daily exposed to some kind of repair requirements.

- Findings revealed rather ineffective management of streets and roads in the study area. There were more cases assessed to be the worst in their occurrences.

- According to official documents, there is no crash and street damage relational database that helps for more analytical views.

- Strategy and planning concerning street maintenance are totally neglected and sometimes municipal labor refilled these potholes randomly.

- Only low streets traffic pressure is of less pothole occurrences. In most cases, street repairing, and maintenances depend on the municipal capabilities based on their engineering personnel, logistic capacity and rehabilitation budget that always constitute the main constrains all over the city.

- Field surveys help to classify the condition of the streets using binary evaluation approach either in a good or bad condition.

- In fact, increasing the potentiality of monitoring frequent potholes and cracks occurrences on streets, would be in favor of the most optimal street repair and rehabilitation.

9. Conclusion

The analysis and determination of potholes and cracks on city streets (road distress) using spatial statistics techniques is a much needed topic in urban infrastructure development. Geographic Information Systems (GIS) and spatial statistical analysis (SSA) are crucial to many areas of geographical research (Software & Tools, 2000). Statistical analysis based on spatial statistics helps identify and display data in clustering patterns. Potholes are coded according to their longitude and latitude coordinates using hotspots. This study proves that a more comprehensive study is urgently necessary, one that considers all Khartoum's streets as well as its geographic location. Thus, the paper's main objective is to serve as a starting point for more detailed and high-quality studies related to street distress assessment on a state-level.

A chronic occurrence of potholes on Khartoum's streets is becoming more frequent, and a daily increase of potholes is expected to worsen the already bad conditions. In this study, the possibility of using GIS to track the condition and maintenance of streets and roads was demonstrated. We intend to help and support authorities to quickly implement street-

rehabilitation projects, as well as to carry out repair or rehabilitation operations based on current information. Although the spatial extent of this paper is limited to only five streets, it is a standard way to begin more optimal work by expanding the area to include more pothole-prone streets that will produce positive results for DSS. The field measurements and observation data are used to create street damage (pothole) maps. A pothole can be as small as 0.50 meters or as large as eight meters. According to the analysis, potholes are generally found in square and circle geometric shapes on the streets surveyed with an average 2.1 meters. Potholes can be classed as small (0.5-0.75) meters, medium (1 to 4) meters, or large (+8) meters.

Recommendations:

1 - From this study, many recommendations have been suggested for further research. More attention should be focused on assessing damage events at the water-logged streets.

2 - Monitoring urban streets for quick repairing should be considered as the priority to keep streets in a good condition ensuring high safety level. As the techniques and methods for pothole determination have integrating functions, it is better to perform a project that involves experts from different disciplines such as geographers, surveyors, and engineers.

3 - There are many more reliable techniques and methods that can be used on the potholes and cracks detection in urban streets. For more detailed and wide coverage, drone remote sensing has been applied and recommended on the detection of the pavement distress. Such a technique has recently helped in solving monitoring burden for municipalities; it is less time-consuming, cost-reducing, and labor-intensity easing (Petkova, 2016).

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