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Mapping Waste-disposal Sites Using SPOT Remote Sensor Data: Riyadh Case

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Abstract. Four SPOT multispectral subscenes at scale of 1/100000 (spatial resolution 20 m) and covering the City of Riyadh and surroundings were used to map waste-disposal sites on the outskirts of this rapidly expanding city. Digital image processing techniques, using Earth Resources Data Analysis System (ERDAS) software, were employed for this purpose. The results showed that digitally processed remote sensor data could be valuable source of information for inventory and monitoring of waste-disposal sites and their effects on the urban and suburban environment. Further, the results could well serve as valuable input layer for a more sophisticated geographic information system (GIS) of the city.

Introduction

Airborne and satellite remote sensing is now a mature technology with many benefits. Multispectral image processing of such data provides information about chemical composition of the earth surface with better spatial context than non-imaging sensors can generally provide. Thus remote sensing offers opportunities for aerial extrapolation of point measurements made in the field resulting in an increase in the area for which information can be gleaned from a given set of point measurements. Nowadays, once remote sensing data are collected, multispectral and spatial image processing can typically be completed on a personal computer in less time than field measurements and sample collections.

In particular, remote sensing mapping techniques can aid in evaluation of temporal changes in land use within and near hazardous waste and sanitary landfills [1, 2]. The effects of landfill leachate contamination, for example, are also detectable with remote sensing techniques. Thus, by mapping and monitoring waste sites in large cities such as Riyadh, many benefits are gained: First, environmental engineers will have another source of information to consider which increases the possibility of making the right decision in their environmental issues. Second, suitable sites for future use can be determined based on more sound basis. Third, urban expansion towards such sites could be accurately monitored thus preventing evolution of further environmental problems. Fourth, in this era of information technology, waste site maps could well contribute towards the creation of useful and efficient layer of city or county GIS.

Some Experiences Gained With Waste-Disposal Site Surveys

Indeed, many publications have appeared in the literature addressing the role remote sensing can play in the inventorying and assessment of waste-disposal sites. As examples, Barnaba *et al.* [1], investigated the use of aerial photographs in county inventories of waste disposal sites. For this purpose, multidate historic aerial photographs were used in conjunction with field surveys to analyze, detect and categorize hundreds of previously unidentified waste sites for remedial actions. The procedure adopted comprised presurvey work, acquisition of aerial photography, development of appropriate classification system to be used in the inventorying process, survey of public information, airphoto analysis and georeferencing, site prioritization, and finally, implementation of a monitoring program (see [1] for more details). The technique was described as "effective" in performing comprehensive inventories of waste disposal sites over county-size areas.

Lyon [2] reported results of an investigation concerned with the use of a number of data sources, namely old maps, aerial photographs, other remote sensor data and advanced evaluation techniques to better identify and inventory soil, hydrologic and site vegetative states which are believed to be positive indicators of hazardous waste sites. Measurements on these data sources were conducted to establish both the changes in size and characteristics of landfills over time. Siting, monitoring, closure and rehabilitation of abandoned hazardous waste sites were reported to have been possible through use of these data.

On the more advanced side, use of digital photogrammetric methods is proving to be of advantage in assessing solid waste landfills and hazardous waste sites. Vincent [3], for example, carried out detailed topographic mapping by high resolution digital photogrammetric methods to yield high resolution digital terrain models (DTM). These were used as input to surface run-off models to predict where contamination from solid waste and toxic landfills was most likely to occur and where depressions on the landfill may collect and concentrate runoff. Also, two DTM's collected at different dates on a site could be used as input to cut-and-fill estimate software for accurate computation of

volumetric changes in landfills due to continued in-filling or to land subsidence. Visible simulation software could also be used in conjunction with DTM's to produce simulated perspective views of landfill from any user-selected positions.

Use of multispectral remote sensor data and digital image processing revealed that it is possible to map solid waste landfills (specially those aspects related to ferric and ferrous oxides that are by-products of low-temperature geochemical processes caused by contaminants in wastes), and vegetation stress (e.g. chlorosis) which could be indirect indicators of liquid and gaseous waste leaks [4].

Active radar and thermal infrared (TIR) remote sensor systems had also been used to map buried waste disposal sites and potentially hazardous and nonhazardous fluid leak plumes. On this respect, Weil *et al.* [5], state that these sensors could be used to investigate and map tens of acres per day for the purpose of locating waste sites when used in a combined format comprising rapid survey techniques and manual data analysis. Case studies from West Coast Air Force Base in California (U.S.A.) to locate 89 suspected underground storage tank locations, and from New Mexico, where a 33-year old buried waste site was successfully located and characterized using radar and TIR sensors, showed that these nonconventional sensors could also contribute positively to mapping waste-disposal sites.

The role of non-metric small format camera photography (the so-called low-cost mapping system) in surveying waste sites was described by Warner [6]. Photographs taken with a hand-held standard 35 mm camera were enlarged using a commercial color laser-scan electronic copier. Stereoscopic and monoscopic measurements were made on the enlarged photos using a low-cost tablet digitizer and ordinary photogrammetric procedures. In one of the three waste site surveys conducted by Warner [6], the surface areas of five filtration lagoons (which were newly constructed at the base of a rural waste site) were measured. The absolute accuracy requirement was believed to be in the order of $\pm$ 2m. Control points on the site were digitized from a 1/5000 scale map, with 5m contour interval. Coordinate accuracies of $\sigma_x = \pm 2.3\,\text{m}$ and $\sigma_y = \pm 2.1\,\text{m}$ were obtained which were believed to be very much close to the required figure of accuracy, thus demonstrating the effectiveness of low-cost non-metric photogrammetry in mapping waste sites.

Waste-Disposal in Riyadh

Riyadh, the capital of Saudi Arabia, has a population of more than 3 million [7] increasing at a rate of about 7.1% annually [8, 9]. The city has abundant refuses that must be managed and controlled daily. About 400 trucks are involved in the process of carrying different wastes to the landfills situated outside the outskirts of the city. Each truck empties its contents about five times daily. According to the General Clearing Department of

Riyadh Municipality (CDRM) [10], at each landfill, heavy machines spread and compress the wastes to a thickness of 2.5 m. The wastes are then covered with a layer of selected soil to about 0.5 m thickness. The percentages of the materials of the landfill are shown on Table 1. Sources of these waste materials are farms, houses, companies, streets, hospitals, workshops, factories and construction sites. With time, the area and height of the landfill will increase, thus necessitating landfill closure and occupation of another

Table 1. Types and percentages of input materials to landfills (10)

Type of Materials	Percentage
Foods	34%
Papers	28%
Metals	16%
Wood	10%
Plastic	2%
Glass	2%
Rubber	1%
Textiles	1%
Others	6%
Total	100%

site. Obviously, as years drag on, careful measures must be taken to protect the environment from the adverse effects these landfills are likely to have on it.

As far as liquid waste is concerned, about 18,750,000 liters/day of water accumulating in the city is collected and pumped into an open area (pit). Like its solid counterpart, liquid waste can cause serious damage to the environment and consequently water pits must be carefully selected and monitored.

The CDRM stresses that there is real need to monitor these sites. There are four of these in Riyadh shown on Table 2, three are landfills and one is a pit. The contents of Table 2 ought to be somewhat alarming to urban management authorities of the City, specially as regards the closeness of the landfills to urban areas. One of the landfills of Table 2 is believed to be inactive. CDRM did not confirm or deny possible existence of other inactive waste sites which might be close to or within residential, industrial or commercial areas of the city. Therefore the aim of this experiment is to attempt to inventory

Table 2. Known landfills and pit in Riyadh City and related information (10)

Waste	Location	Input (10^6/yr)	Area	Height	Status
Landfill	Al-Solay	Solid	N.A.	19 m	Inactive (close to urban)
Landfill	Al-Solay	Solid (1.5 ton)	1.5 km^2	11 m	Active
Landfill	Okadh	Solid (0.8 ton)	1.0 km^2	13 m	Active half a day (close to urban)
Pit	Al-Solay	Water 7000 l	N.A	N.A.	Active

Data Used and Procedure

The data used in this experiment consists of four 1995 SPOT multispectral subscenes (spatial resolution 20 m) at a scale of 1/100000. The four subscenes cover the city of Riyadh and surroundings from Alnatheem in the east to Dariyah in the west and from Al-Haer in the south to King Khalid International Airport in the north. Originally, the data was provided to the authors in the form of computer-compatible tapes (CCT) by the Saudi Remote Sensing Center of King Abdulaziz City for Science and Technology (KACST) in Riyadh. Later on, the data was digitally processed using the Earth Resources Data Analysis System (ERDAS) owned by the Surveying Engineering Program of the Civil Engineering Department, King Saud University.

The use of the multispectral bands of SPOT despite the inherent lower resolution (20 m as opposed to only 10 m for the panchromatic mode) stems from the fact that these bands proved useful in many occasions for the inventory and mapping of waste disposal sites (see e.g. [2], [3]).

The method of approach therefore consists of using digital image processing techniques in order to map and verify the existence of different kinds of waste-disposal sites using ground truth samples as input to a supervised classification algorithm in the ERDAS image processing software. The procedure goes along the following lines:

(i) image preprocessing;
(ii) image enhancements;
(iii) initial statistics extraction; and
(iv) image classification

The first stage consists of image restoration which deals with geometric corrections (e.g. skew effects, erroneous platform velocity, effects of earth rotation etc) and radiometric corrections (e.g. detector response error and atmospheric effects). Those corrections were carried out in the KACST laboratories.

Image enhancement techniques are applied to digital data to improve sharpness and contrast of imagery, usually for human visual analysis. Although, there are several methods for image enhancement (e.g. contrast stretching, spatial filtering, image ratioing, histogram equalization etc), in this study only spatial filtering is used, the decision on this aspect being based on experience gained in this study and elsewhere [11]. Several filters (Kernel sizes) were attempted and the most appropriate ones were utilized.

Once the digital remote sensor data is extracted from the computer-compatible tape and enhanced, it is customary (and often necessary) to calculate some fundamental univariate and multivariate statistics for the given area. This normally involves computing the minimum and maximum digital value for each band of imagery, the mean value, the

standard deviation, the variance-covariance matrix and frequencies of brightness values in each channel (to produce histograms). Such statistics provide information necessary for band selection, displaying and analyzing remote sensor data.

Classification of the digital image data was performed using the supervised classification algorithm of the ERDAS software. The spectral characteristics of the known waste disposal sites (and other land cover types) were used to "train" the computer for eventual land cover mapping of the remainder of the image.

Results, Analysis and Conclusions

The results of the experiment are produced as enhancement maps and classification maps. For the first type, the spatial filters found to give best pictorial results (i.e. best discerning capability of waste disposal sites) were 3×3 low pass filter and 5×5 high pass filter (c.g. Fig. 1 and Fig. 2 respectively). The 3×3 filter seems to demonstrate the urban features while the 5×5 filter seems to show the landfill sites more clearly than others.

The results of the classification showed six waste-disposal sites in Riyadh all of which lie in the south-eastern part of the city (shown as sites S_1 to S_6 on enhancement image on Fig. 1 and classification image of Fig. 3). S_1, S_3 and S_5 are active landfills while S_2 is inactive. S_4 is an active dumping pit in Al-Solay area and S_6 is an active car junk in Al-Haer. Subsequent field verification confirmed these findings.

On Fig.1, it can be noted that urban expansions (up to 1995) are close to all six waste disposal sites which raises an alarm to urban planners and managers in the city in order to take appropriate measures toward preventing possible hazardous effects of these sites on residential areas close to them. The extent of this problem would have been somewhat more difficult to visualize or apprehend without the use of remote sensor data as conducted in this experiment.

If we take active landfill S_1 in Al-Solay and pit S_4 (Fig. 2) as examples and their image is then classified (Fig. 4), the following facts are revealed:

(i) the lead-colored soil around the waste disposal site seems to have lost its physical characteristics because of acids flowing in from the landfill.

(ii) the contaminated running water from dumping pit S_4 towards urban areas seems to have slight effect on the roads closer to it. This is apparent from the slightly different tones of these roads as contrasted to the tones of roads in the inner side of the city.

(iii) although not quite evident from the GISmap of Fig. 2, the fact that oxidized air

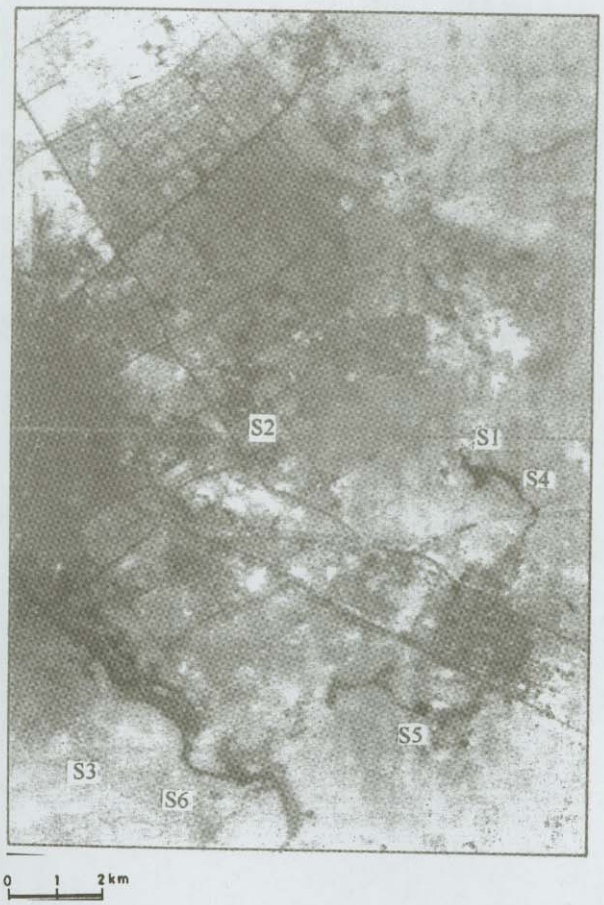

Fig 1. Enhanced SPOT image showing locations of landfills in Riyadh as well as urban expansions as of 1995.

Fig 2. Enhanced SPOT image showing the locations of active landfill (S1) and pit (S4) in Al-Solay district as of 1995.

Fig. 3. The GISmap of the image presented in figure 1. All sites of landfills as well as urban expansions are shown.

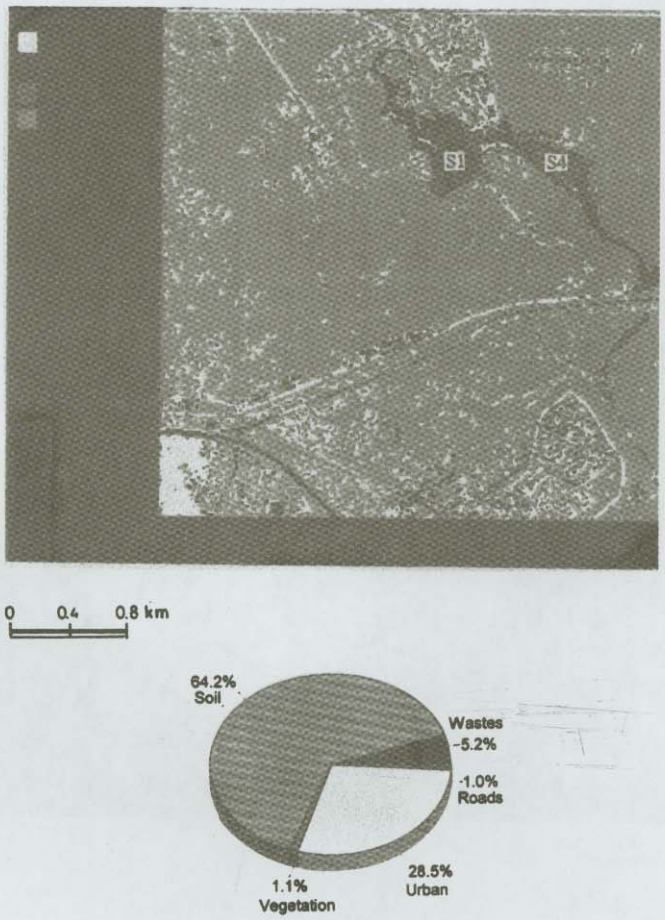

Fig. 4. GISmap showing landfill S1, pit S4, type and percentage of classes.

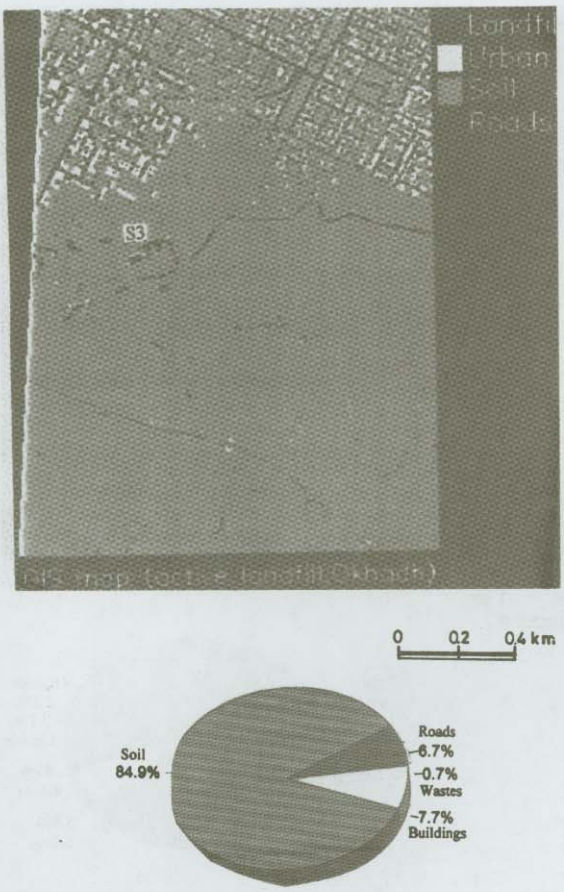

Fig. 5. GISmap showing site S3 in Okhadh, type and percentage of classes.

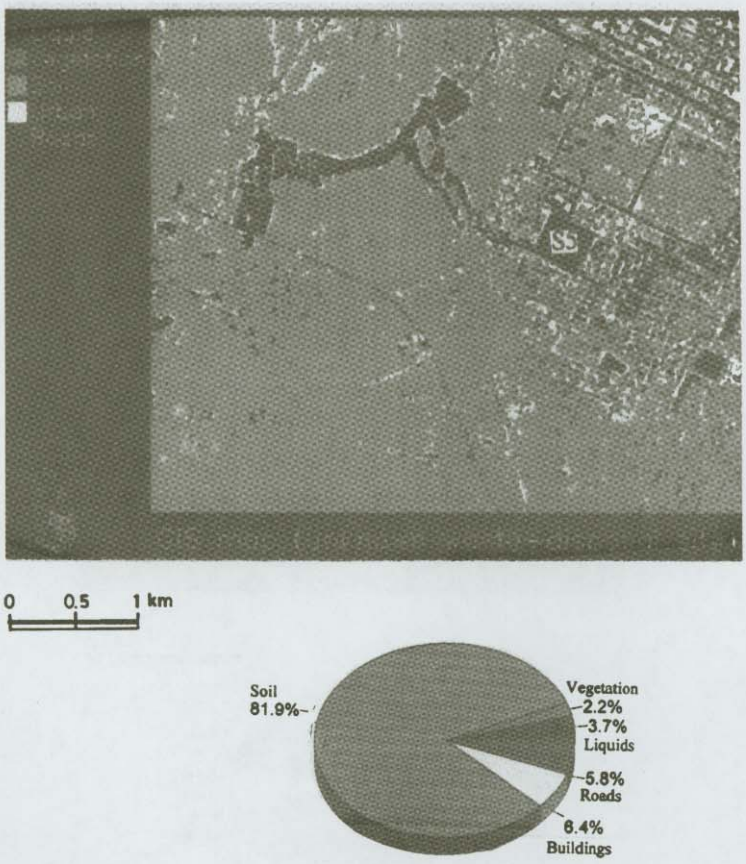

Fig. 6. GISmap showing unknown landfill S5, type and percentage of classes.

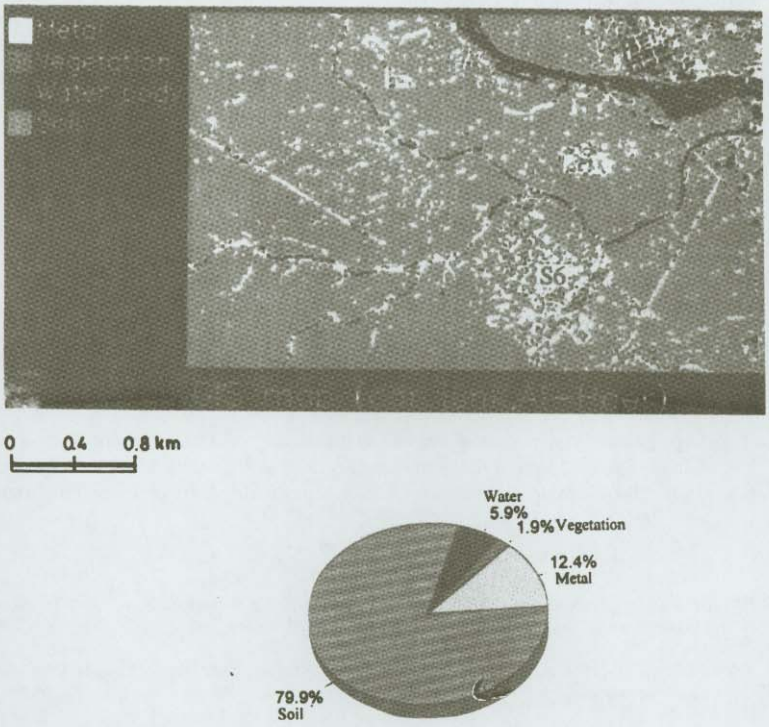

Fig. 7. GISmap showing car junk site S6 in Al-Haer, type and percentage of each class in the cene.

emitted by wastes on S_1 and S_4 will no doubt pollute the air around the site rendering the area difficult to live in.

It might be beneficial to present percentage of materials found around each of waste disposal sites S_1, S_3, S_5 and S_6. These are shown in Figs. 4, 5, 6 and 7 together with the corresponding GISmap of each site. The figures and the maps could be documented for the purpose of monitoring the development of these sites in the future. Further, such results could be used to augment and strengthen the urban GIS for efficient monitoring of the various resources of the city.

In conclusion therefore, it can be mentioned that use of SPOT multispectral imagery in conjunction with digital image processing techniques could be viable tool for the inventory of waste disposal sites. This is an important conclusion for a city like Riyadh where population growth stands at 7% increase annually which necessitates the development of a continuous monitoring program of this phenomenon and its impact on human life and infrastructure of the society. Contrasted with the effort- and time-intensive ground survey work, remote sensing can prove to be a cost-effective method for solving complicated and dynamic environmental problems such as waste-disposal site mapping and inventorying. The authors therefore appeal to relevant authorities in Riyadh (and other major cities in the region) to consider exploiting the undoubted benefits of this technology in their respective works.

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ترسيم مواقع النفايات باستعمال معلومات لاقط الاستشعار من بعد الفرنسي (سبوت): حالة من الرياض

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ملخص البحث. يهدف هذا البحث إلى دراسة مواقع النفايات في مدينة الرياض وتوضيحها على الخرائط بطريقة مغايرة للمسح الأرضي المضني الذي عادةً ما يقتصر على مكان المسح المقصود دون النظر إلى الأماكن المجاورة التي قد تتأثر سلباً أو إيجاباً بهذه المواقع ولو على المدى البعيد. استعملت في هذه الدراسة أربع صور (أو مرئيات) متعددة الأطياف من اللاقط الفرنسي (سبوت) ذات مقياس قدره 1:100000 وذات تباين مكاني قدره ٢٠م. واستخدم أيضاً نظام ERDAS في معالجة هذه الصور الأربع التي تغطي في مجموعها مدينة الرياض وما حولها (المساحة المعنية بالدراسة). وجدت الدراسة أن صور اللاقط الفرنسي مصدر ثمين وذو فعالية عالية - إذا ما عولجت معالجة مناسبة - في متابعة التغيير الحاصل في مواقع النفايات وذلك لإمكانية توقيع المعلومات المتعلقة بمكانها وحجمها وحالتها على الخرائط مباشرةً، ولإمكانية المسح الدوري والرصد المعلوماتي المستمر. كما أوضحت الدراسة إمكانية تحديد بعض المشاكل البيئية الآنية والمتوقعة في المدينة. لذا فإن إضافة مثل هذه النتائج إلى نظام معلومات جغرافي(GIS) لمدينة الرياض من شأنه أن يزيد في كفاءة هذا النظام، ويُيسر سبل جمع المعلومات الضرورية، وطرق الحل المناسبة لما ينجم من عقبات.