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Application of geographic information systems methodology to injury surveillance in Uganda

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ABSTRACT

Injury is a major international public health concern internationally, contributing to population morbidity and mortality and related social and economic costs. While several national injury survey initiatives have been conducted in Uganda in the past, none have explicitly incorporated geographical aspects of injury. Injury surveillance should include location data, with a view to ultimately understanding and explaining the geography of injury risk and prevalence. This paper documents a GIS method developed for a national injury surveillance pilot study in Uganda, Africa. The study's primary goal was to assess the feasibility of using GIS in injury surveillance in Uganda. A trauma registry form was designed and used to capture spatial and non-spatial (socio-economic status of injured persons, injury type/cause) factors of injury events. The trauma registry was piloted for 30 days at two referral hospitals (Mulago and Mubende) in Central Uganda. Spatial patterns of injury pilot data were studied by injury source, and socio-demographic characteristics. The study demonstrated the utility of GIS for injury surveillance and analysis in the Ugandan context. The addition of GIS-based surveillance and mapping capacity may become an important approach to treating the prevalence of different types of injury in Uganda, over the longer term.

Keywords: Geographic information systems, injury surveillance, spatial analysis.

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ABBREVIATIONS: CNIS, Canadian Network for International Surgery; **GIS,** geographic information systems; **GPS,** global positioning system; **ICCU,** injury control centre – Uganda; **IFAD,** International Fund for Agricultural Development; **MDGs,** millennium development goals; **NFA,** National Forestry Authority; **NGO,** non-governmental organisation; **NSDI,** National Spatial Data Infrastructure; **UBOS,** Uganda Bureau of Statistics, **USD,** United States Dollars; **WHO,** World Health Organization.

INTRODUCTION

Injury is one of the leading causes of death and disability worldwide. The World Health Organization (WHO) indicates that injuries are a threat to health in every country of the world and account for 9% of global mortality (WHO - http://www.who.int/topics/injuries/en/). This implies that injuries are responsible for more deaths than HIV/AIDS, tuberculosis and malaria combined (Oxford Martin School, 2013). Mock et al. (2004) observe that injury is one of the leading causes of death in working-aged adults and children in almost every country in the world. Sommers (2006) agrees and observes that injuries are increasing making injury a serious threat to public health and to future generations in all countries around the globe, whether high, middle or low income.

In Uganda injuries are a major public health concern that requires urgent attention. For example, the country's annual injury mortality rate for rural and urban settings is 92/100,000 and 217/100,000 respectively (Kobusingye et al., 2001). Injury surveillance data from the Injury Control Centre-Uganda (ICCU), collected between January and

June 2010, across 10 hospitals suggest that 44% of injuries were caused by road traffic accidents followed by falls (19%), cuts/stabs (13%), bites (6%), and another 18% by undetermined causes (Injury Control Centre – Uganda, 2010). Although for each injury type there are often preventive measures that may reduce the likelihood and severity, limited awareness of the magnitude of the injury problem and geographical patterns of injury, especially in developing countries obstructs injury prevention and control (World Health Organisation, 2008).

Beyond the global prevalence of injury, it is important, from a monitoring and prevention perspective, to recognize that injuries are not always random events occurring within a geographical area. For example, specific demographic and socio-economic factors such as population density, neighbourhood social and economic structure, unemployment, sex, age, and poverty have been associated with increased risk of various types of injury (Lascala et al., 2000; Williams et al., 2003; Yiannakoulias et al., 2003; Cusimano et al., 2007). In addition, environmental factors and site-specific factors like weather conditions, terrain, landuse, neighbourhood design, and environmental change (Stevenson et al., 1995; World Health Organization, 2008; Cinnamon and Schuurman, 2010) are also important drivers of injury and are determinants of geographical patterns of injury.

Therefore, understanding the environmental and social determinants of injury requires acquisition of detailed information on geographic patterns of injury. These data, along with adequate and necessary institutional supports, that is, to develop necessary policy and resource acquisition, can be used to inform injury surveillance, monitoring, prevention, and control. Whereas Ijsselmuiden et al. (2008) argue that the use of information technologies is one of the priorities for global health research, injury surveillance in developing countries has mainly focused on measuring injury prevalence, monitoring injury trends over time, identifying and prioritizing research issues, and planning for and evaluating prevention and intervention efforts (Cinnamon and Schuurman, 2010; Injury Control Centre – Uganda, 2010).

While within geographic disciplines numerous attempts have been made to convey, spatially, that injury patterns can be investigated and mapped (Bell and Schuurman, 2010), previous injury surveillances in many developing countries have largely been descriptive, rarely taking into account spatial aspects and regional differences in injury occurrence. In Uganda spatial aspects of injury have never been integrated in injury surveillance. Although the Injury Control Centre – Uganda (ICCU) has engaged in hospital based injury surveillance in Uganda since 1996, and ICCU data have been used for policy-making and for designing and implementing interventions, the spatial patterning of injury has largely been ignored. Spatial qualities of the social and environmental determinants of injury have not been thoroughly studied, and the selection of hospitals for inclusion in survey work has not controlled for the underlying geography of population(s) at risk. Findings from previous injury work in Uganda do not illuminate spatial patterns of injury occurrence, it remains unclear as to which areas (regionally and otherwise), and segments of the population are vulnerable to injury risks.

Since descriptive epidemiology typically involves the examination of person, place and time in the occurrence of disease or injury, it is clear that geographical issues (distribution and patterns of injury) should be taken into account in injury surveillance in Uganda. Prior to the current study, ICCU conducted a needs assessment to identify areas needing improvement with regard to Ugandan injury surveillance. The needs assessment suggested the use of GIS, as a tool to assist with explicitly incorporating space into the study and surveillance of injury.

Geographical information systems

GIS describes a group of computer tools and methods designed to collect, manage, store, analyze and integrate spatial and non-spatial data to help describe the world around us (Robinson, 2000; Schuurman, 2004). These data may be mapped for visualization purposes and their locational relationships analyzed using tools from the field of spatial statistics (Moldofsky et al., 2008). In addition, GIS makes use of digital mapping technology to provide options for decisions and several software packages have been developed for data transformation (Chang and Wang, 1997).

The theoretical consideration in this study is that injury surveillance is spatial information intensive activity and hence the use of GIS can provide numerous tools and methods to enhance injury prevention and control. For example, GIS allows the creation of maps for specific uses that may assist in understanding how spatial processes (social and physical) converge to expose individuals to different types of injury. These processes may include the effects of rural or urban environments, socio-economic conditions, access to health centres as well as planning or zoning policies among others. In particular, GIS allows researchers to integrate spatial and non spatial data which yields important knowledge about social and structural processes (Bell and Schuurman, 2010). In the field of health for example, GIS has been used by epidemiologists to investigate associations between environmental exposures to, and the spatial distribution of, infectious diseases (Jarup, 2004; Nuckols et al., 2004).

Presently, GIS can offer more sophisticated and extensive database management and display capabilities, and is much more user-friendly (Malczewski, 2004). Availability of affordable geo-data has also increased promoting greater numbers of alternative scenarios analysis and simulations. However, although GIS research in health and healthcare has primarily relied on government supported databases of vital statistics to visualize mortality and morbidity (Moldofsky et al., 2008), in Uganda many of these vital statistics are not readily available and no injury surveillance study in the country has involved GIS.

Uganda country profile

Uganda is a landlocked country located in East Africa across the equator. The total area is 241,038 sq km, of which a third is covered by fresh water bodies and wetlands (Government of Uganda, 2013). Twenty six percent of the land is arable, 17.5% is forest, and 56.5% is for other uses including pasture. The country is largely fertile, well-watered with many lakes and rivers. The most significant water features include River Nile, the longest river in Africa with its source at Lake Victoria, which is also the largest lake in Africa.

Uganda's population, estimated at about 35.6 million (http://www.heritage.org/index/pdf/2014/countries/uganda .pdf), has an annual growth of 3.2% and a fertility rate of 6.7, which are among the highest in the world (Government of Uganda, 2010a; Population Reference Bureau, 2011). At this growth rate, Uganda's population is projected to be 54.1 million in 2025 and 105.6 million in 2050 (Government of Uganda, 2010c). In terms of distribution and structure, Uganda's population is 85% rural, 51% female, is relatively young with more than 50% below 15 years of age (60% below 18 years of age), and the dependence ratio is among the highest in the world (Government of Uganda, 2010a). Population dynamics, structure and uneven distribution have been identified as a major challenge to health care provision in Uganda.

In terms of political geography, Uganda is divided of 111 Districts and one City Authority, the Kampala Capital City Authority (KCCA), as the main political or government units. Each district or authority is further divided into counties and or municipalities which in turn are divided into sub-counties or divisions. Each subcounty/division is divided into parishes and a parish is made up of villages. Uganda's Local Government Act of 1997 (Government of Uganda, 1997) established a decentralized local governance system establishing district and sub-county councils as planning authorities.

Economically, Uganda is classified by the United Nations as one of the Least Developed Countries characterized by low per capita income, feeble human capital and a high degree of economic vulnerability (Government of Uganda, 2010a). The country's per capita income is USD 560 (Government of Uganda, 2013). However, over the years Uganda's economy has experienced varying growth rates. The average rate of growth of Gross Domestic Product (GDP) in fiscal years 2008 and 2009 were 8.7 and 7.1%, respectively (Government of Uganda, 2010b). At 48%, the service sector is the largest contributor to GDP (GoU, 2010c). Uganda has substantial natural resources, but agriculture and fishing employ over 80% of the workforce.The manufacturing and agriculture sectors each contribute 23% of the GDP. Uganda is also Africa's second-leading producer of coffee, which accounted for about 23% of the country's exports in 2007-2008 and 17.9% in 2009.

Although, like other Sub-Saharan African countries, Uganda faces challenges in ensuring health care to its population, the country has made significant progress in improving the health of its population. For example, life expectancy increased from 45 years in 2003 to 52 years in 2008; HIV prevalence reduced from 30% in the 1980s to 6-7% in 2008, and polio and guinea worm were eradicated Nevertheless, malaria is still remains a challenge and is responsible for more illness and more death than any other single disease in Uganda (Government of Uganda, 2010b). The MDG report for Uganda states that health care service delivery in Uganda is hampered by many factors, including among others: human capacity constraints; inadequate distribution of health centres, equipment and supplies; a dysfunctional referral system; and poor basic infrastructure. In particular, the constraints are particularly pronounced in rural areas (Government of Uganda, 2010a). These foregoing constraints also affect injury prevention and control.

Purpose and objectives

The purpose of this paper is to describe a recent injury surveillance pilot study conducted in Uganda to address the geographical limitations of prior surveillance initiatives in the country. The paper documents a GIS method developed for a national injury surveillance pilot study. Essential in this work was the development of capacity *in situ* for the application of GIS to injury epidemiology in Uganda. Conceptual discourse and empirical evidence from the international literature was used to help make the case for embedding geography more centrally into the Ugandan injury surveillance exercise (McLafferty, 2003; Jurup, 2004; Nuckols et al., 2004; Moldofsky et al., 2008; Schuurman et al., 2008).

Among the goals of the pilot study was development and testing of the efficacy of a new trauma registry form. Hence the pilot study was largely organized around development and deployment of the trauma registry. Specifically, the study was intended to: (i) assess the efficacy of a newly developed trauma registry form in supporting epidemiological analysis; (ii) assess the feasibility of the spatio-temporal mapping of injuries recorded in the pilot in explaining geographical patterns of injury; (iii) ascertain the possibility of using the trauma

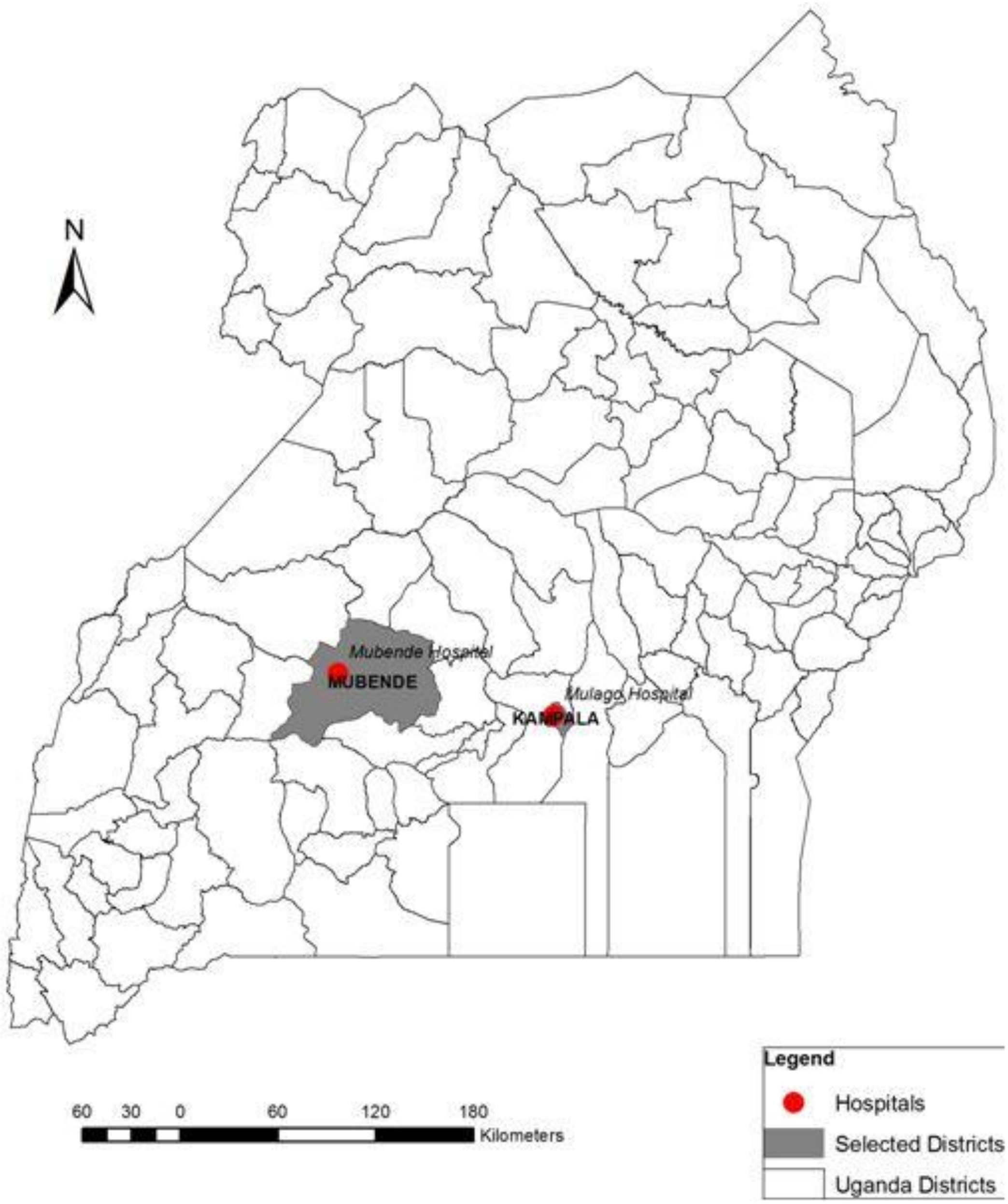

Figure 1. Study hospitals in Uganda.

registry form, and analytical capacity developed in the pilot, in a national trauma surveillance system; and, (iv) reflecting upon lessons learned, develop a spatial sampling methodology for selecting hospital for a broader national injury surveillance program.

The paper addresses methodological issues and other non-material issues that arose during the pilot study. The study was designed and implemented to begin the analytical process of understanding injury incidence across space, (regional differences for example) in Uganda, with a longer-term goal of developing a national GIS-based surveillance system and stimulating researchers and practitioners in the region, and internationally, to use GIS in injury analysis and prevention.

The study area

The pilot study was conducted using data from the trauma units of two hospitals, Mubende regional referral hospital and the Mulago national referral hospital. In this study, a referral hospital refers to a hospital that receives patient referrals from lower levels of health care and centres. Both hospitals are located in Central Uganda (Figure 1) but are distinct with regard to situation and services.

Mulago hospital is located in Uganda's capital city of Kampala and Mubende is situated within a more rural setting. It was important to pilot the surveillance instruments within these different contexts, with a view to ensuring that injury data could be collected in places differentiable in terms of resource constraints and serving different populations.

MATERIALS AND METHODS

Based on ICCU's past work in hospital based injury surveillance, Mulago and Mubende referral hospitals were purposively sampled for the pilot study. The trauma units of the two hospitals were used in data collection. A trauma registry form was then developed and deployed as the main instrument for data collection (a copy of the trauma registry form is provided as Annex 1). GIS tools and methods were used in capturing, visualising, analyzing and integrating spatial and non-spatial data on injuries.

Organizationally, the pilot study consisted of two primary phases. Phase I involved development of the trauma registry form for injury data capture, and development of digital geographical capacity – acquisition and preparation of the map data and attribute data, sourced from various institutional settings, and organized into a GIS database. Phase II involved injury data collection, data entry, and preliminary analysis. Figure 1 presents a procedure chart with a more detailed description of each phase.

GIS database development

The GIS database developed for the pilot study contained spatial and attribute data to support the mapping aspects of the study (Figure 2). The GIS database also became the repository for spatial information collected through the trauma registry form. The GIS software used in this work was ArcGIS version 9.3. The process of data acquisition and processing for the creation of a GIS database involved:

(i) Collection of data, identification of possible inaccuracies, inconsistencies and gaps in the obtained data;
(ii) Verification of data, alignment of projections, and checks as part of quality control;
(iii) Digitization and modelling to create the required GIS maps.

Specifically, the development of a GIS database involved the following activities:

1. Acquisition and preparation of base maps including administrative units/boundaries of Uganda. This was necessary for mapping where the injuries occurred.
2. Preparation and classification of the road network. The road network was necessary for determining accessibility to hospitals and nature of transport used to transport injured persons.
3. Acquisitions of the land cover map from which drainage, forests and protected areas map were digitized. These layers were necessary to indicate population distribution and accessibility to hospitals.
4. Acquisition of population data and preparation of population maps. Population data was used to examine the relationship between injury occurrence and demographic factors. In addition, injury surveillance took into account population density, distribution, by age and sex.
5. Preparation and classification of a health facilities map, with hospitals classified as government (referral and district), Non Governmental Organization (NGO) and private owned.
6. Preparation of an income group map, which shows polygon features having attribute of income groups based on the district poverty levels.

Design of a trauma registry form

A pilot trauma registry form was developed, to include spatial aspects of injury and was then pretested in the trauma units at Mulago hospital. The form was developed in a collaborative manner involving the research team, ICCU epidemiologist, GIS specialist, and the heads of the trauma units of the pilot hospitals. The form was designed to capture socio-demographic characteristics of injured patients, injury event data, and the cause and type of injury; and this was intended to collect adequate data from which the social and environmental determinants of injury could be established.

To enable appreciation and understanding of the patterns of injury, the trauma registry form was designed to capture the location of injuries, taking into account Uganda's political geography. To that end, the trauma registry form was designed to capture injury events coded to the district, sub-county and parish levels where possible. The intention was to capture the where, when, whom and how aspects of injury. The trauma registry form was limited to two pages in order to minimize the burden on the administrator and respondents.

Pilot study execution

The main element of the pilot study was a 30-day injury data capture exercise, 1 to 30 November 2011, implemented in the trauma units of Mubende and Mulago hospitals. The study population consisted of all injured persons treated at the trauma units during the period. Simultaneously we endeavored to develop a spatial database that would facilitate the collection, entry, analysis and visualization of spatial and non-spatial injury data. Patient socio-economic and demographic details, injury type and injury mechanism, and injury location were collected using the trauma registry form.

Injury location was recorded at the sub-county level and not the parish level as was earlier envisioned because enumerated parish names did not match names in the geo-database. However, the details captured in the form facilitated the study of the social and environmental determinants of different types of trauma experienced by registered patients. The data collected by trauma registry forms was entered into Microsoft Excel and then exported into EpiData for analysis. Simultaneously, data were also entered into ArcGIS 9.3 for spatial analysis and visualization.

RESULTS

There were a total of 534 injury cases recorded in the 30-day pilot study, 428 at Mulago hospital (80%) and 106 at Mubende hospital (20%). The divergence in the number of injuries recorded at the two hospitals can be attributed to the fact Mulago is a national referral hospital within Kampala city where there is high population density unlike Mubende, which is in a small town, surrounded by a sparsely populated rural area. The injury data recorded at the two hospitals were aggregated to district counts by type and sub-population. Crude injury rates were analyzed on the basis of socio-economic characteristics

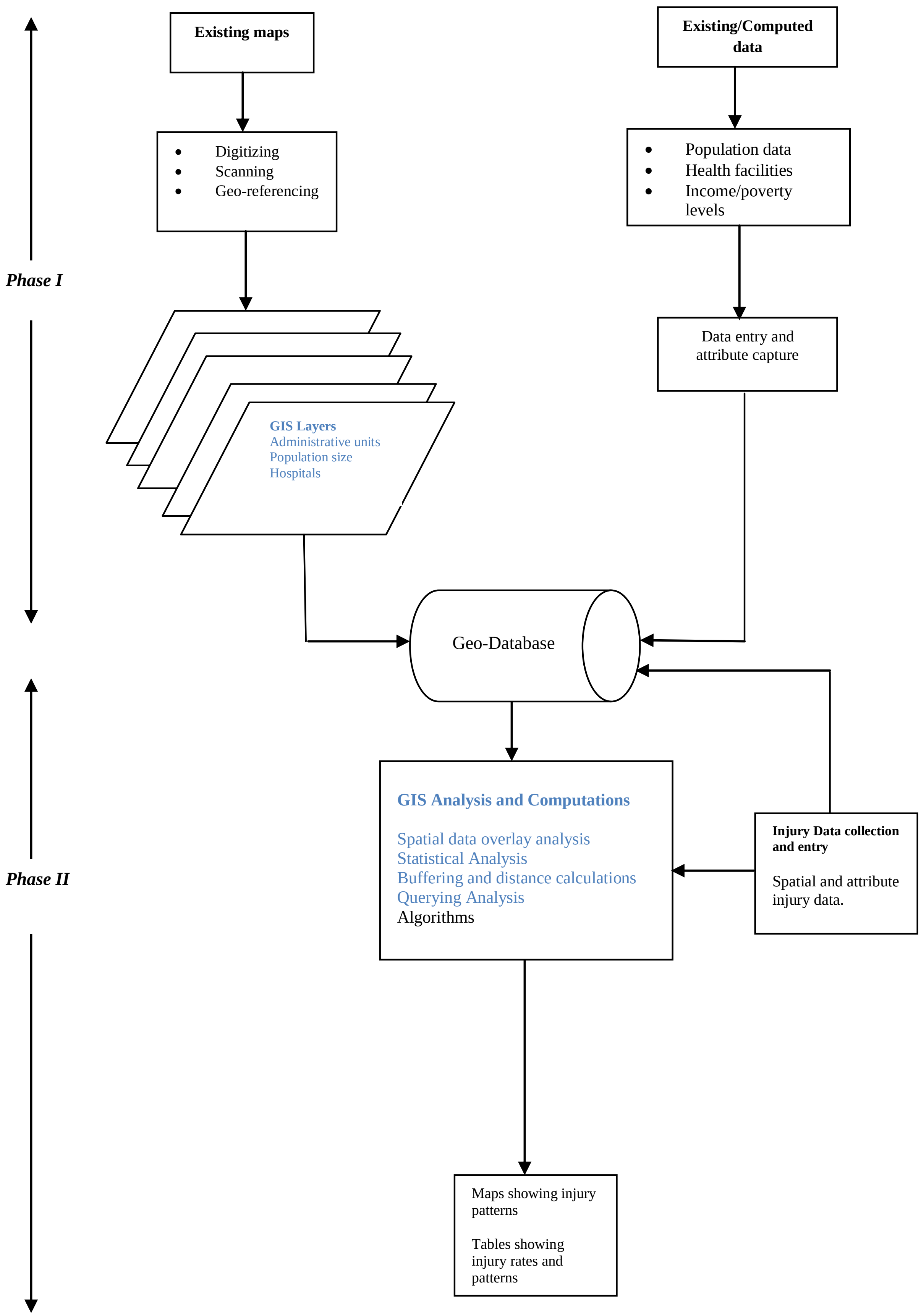

Figure 2. Schematic diagram of a GIS model for injury surveillance pilot study.

Table 1. Socio-demographic characteristics of the injured patients.

Variable	Percentage response (n = 534)
Sex	
Female	35
Male	65
Age (years)	
< 1	1.3
1-14	22.1
15-24	23.6
25-44	45.7
45-64	6.3
65+	1.0
Marital status	
Married	43.6
Single (including children < 15 years old)	53.2
Widowed	1.7
Divorced/Separated	1.5
Unstated	24.0
Income (monthly per household)	
Very Poor < USD 40	49.8
Poor USD 40 - 200	47.2
Middle income - USD 200 - 400	2.6
High income - monthly income USD > 400	0.4

of injured persons (age, sex and income status), injury location (by district of injury) and injury mechanism(s) or type of injury (traffic, bites, burns, assault, and falls).

Socio-demographic characteristics of the injured persons

The socio-demographic characteristics of injured patients (respondents) are presented in Table 1.

Most injured persons self-identified as male (65%) and 35% were female. We hypothesize that the dominance of male patients may be because many households in Uganda have a division of labour, where women are engaged more often in unpaid household work, or unpaid work in informal economies and – as a result, may be less exposed to dominant major causes of injury such as injury from road traffic accidents. Studies by the World Bank (Ellis et al., 2006) and International Fund for Agricultural Development - IFAD (IFAD, 2000) reported that in Uganda men tend to dominate the more remunerative formal activities while women are more engaged in household subsistence responsibility that is largely informal; and that 72% of all employed women and 90% of all rural women work in agriculture (IFAD, 2000) most of which is for subsistence. These gendered labour practices influence the geographical distribution activities with women engaged in rural agrarian activities, which may produce gender differences in the degree of exposure to the risk of certain types of injury.

Injured persons were usually married (44%), 29% were single, two percent were divorced or separated, and one percent was widowed. Marital status was unreported in 24% of cases, most of whom were children below 15 years of age. As for age, the used a United Nations age classification (United Nations, 1982) to classify injuries in broad population-age groups. The majority of injured persons were middle-aged adults 25 to 44 (46%), followed by youth or young adults aged 15 to 24 years (24%). Children aged 1 to 14 years made up 22% of cases while older adults aged 45 to 64 years made up 6% of the cases. The infants aged below one year and older persons aged 65 years and above accounted for only one percent of the injuries each.

To analyse injuries by income status, injured persons were stratified by monthly monetary income into three classes: (i) low socioeconomic status or poor with a monthly household income of less than one ‘minimum’ wage (the monthly wage paid by public service at the time of the study - UGS: 200,000 or US$ 100); (ii) median socioeconomic status with a monthly household income between one and four times the ‘minimum’ wage (up to

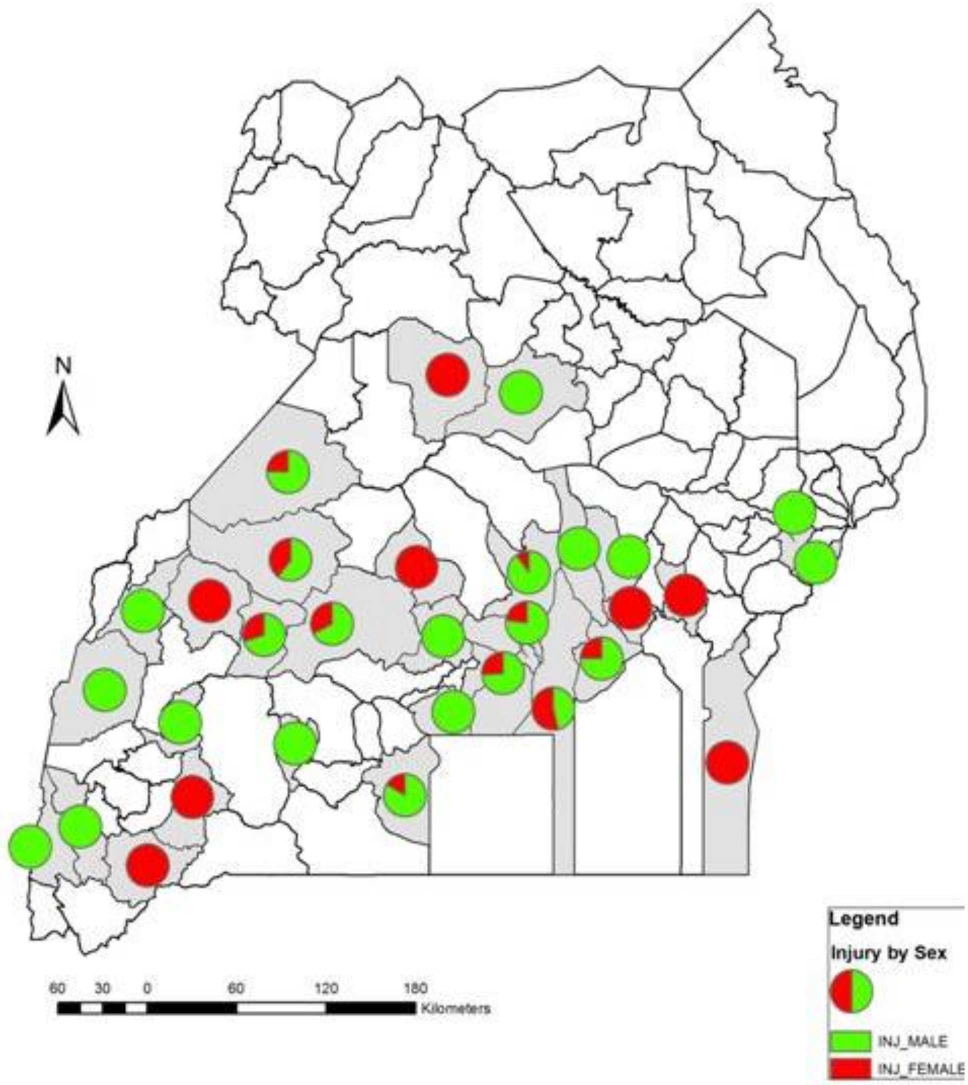

Figure 3. Injury by sex.

UGS 800,000 or US$ 400); and, (iii) high socioeconomic status with monthly household income above four times the 'minimum' wage (above UGS 800,000 or US$ 400). Basing on this classification, 82% of the injured were very poor living in households with a monthly income below UGS 200,000 (USD 100), 17% were in the middle income group in households with a monthly income of UGS 200,000 – 800,000 (USD 100 to 400). Only one percent of the injured persons were in the high income group or in households with monthly income above UGS 800,000 (USD 400). Overall, most injured persons were male between the ages of 25-64 years old, and with a monthly income classified as poor or very poor.

By exploring the place of injury of patients treated for injuries at Mulago and Mubende hospitals, some socio-economic variables, age, sex, income status, population size were identified as potential spatial drivers and explanatory factors for the spatial distribution of injury (Table 1 and Figures 3 to 7). In both Kampala and Mubende Districts males had a higher injury prevalence rate than females. In Kampala the injury prevalence rate for males was 431.1 per 100,000 males, and 117.2 per 100,000 persons for females. In Mubende, the injury prevalence rate for males was 144.2 per 100,000 males, 77.8 per 100,000 persons for females. For children below 15 years, the specific injury prevalence rate was 114.9 per 100,000 children in Kampala and 76.7 per 100,000 children in Mubende. Injury prevalence in Kampala and Mubende districts shows a strong correlation to population distribution. Kampala has a population of 1,659,600 and with injury cases n = 277 as compared to Mubende with a population of 579,200 with an injury cases n = 98. Therefore, the injuries in Mubende are more dispersed because it is a rural area and those in Kampala are much more concentrated because it is an urban area.

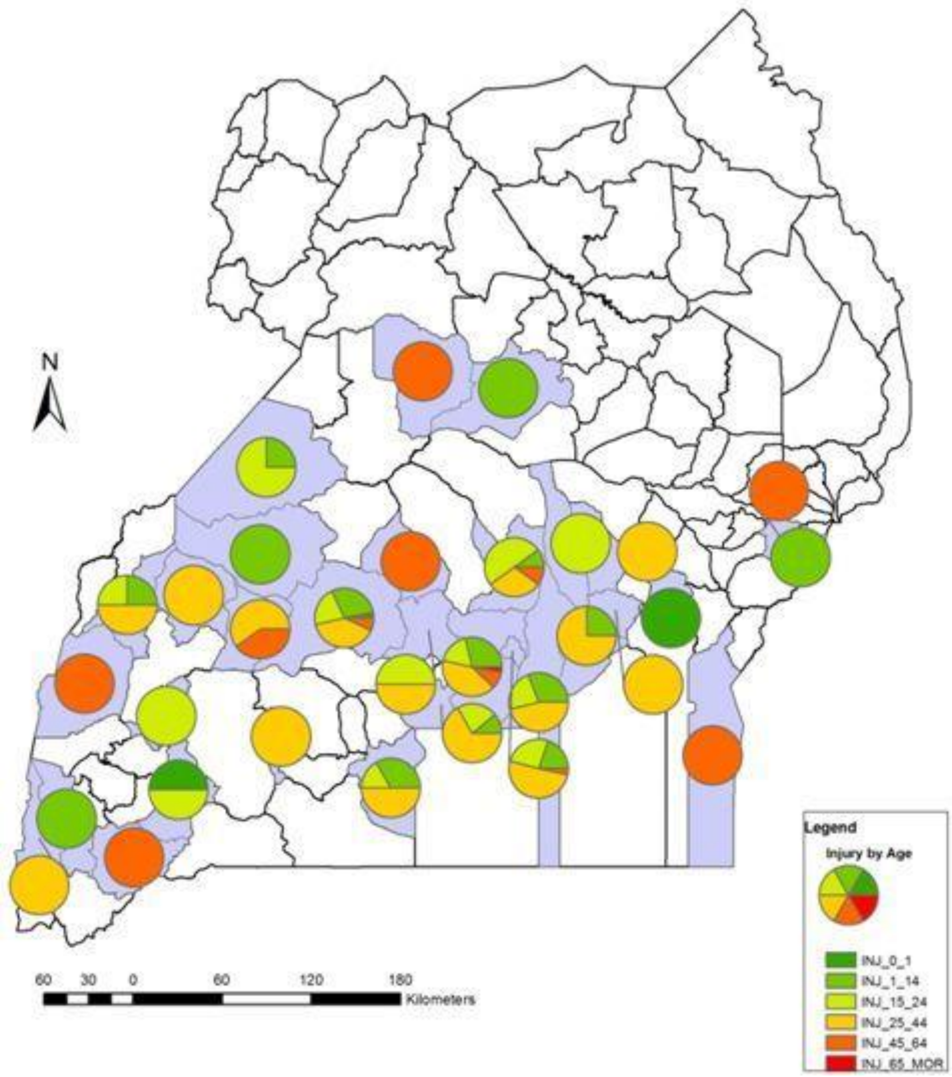

Figure 4. Injury by age.

Injury location

Injuries recorded within the trauma registry were distributed across 31 districts (Figures 8 and 9). Sub-county and parish mapping was not possible. Even after using detailed sub-county maps more than a third (n = 182; 34%) of the injuries could not be properly located on sub-county maps. Consequently injury mapping was only done at the district level. Out of the 534 injuries recorded, Kampala district had the highest number of injuries (51.9%), followed by Mubende (18.4%), Wakiso (13.7%) and other districts (16%). This implies an annual crude injury rate of 266.4 per 100,000 people in Kampala, 118.8 per 100,000 people in Mubende, 59.6 per 100,000 people in Wakiso and 4.9 per 100,000 people in other districts in the country. The lower injury rate in other districts is attributed to the fact that, the hospitals in which this pilot study was conducted was not near to these districts.

It is expected that injury rates are more accurate for Kampala and Mubende districts because the two hospitals Mulago hospital and Mubende hospital are located in Kampala and Mubende districts respectively. The explanation is that an injured person is first taken to the nearest medical facility/hospital. For example, 79.4% the injury cases recorded at Mulago hospital had occurred in the Kampala and Wakiso districts, which are within a distance of 50 km from Mulago hospital.

Eleven percent of the injuries recorded at Mulago hospital that occurred in other districts were all referral cases. Mulago hospital is a national referral hospital and receives referred cases from across the country. Ninety two percent of the injuries recorded at Mubende hospital occurred in Mubende District, and only eight percent occurred in the surrounding district, at a distance equal or greater than 50 km from the hospital. This implies that distance, and transport mode likely play an important role

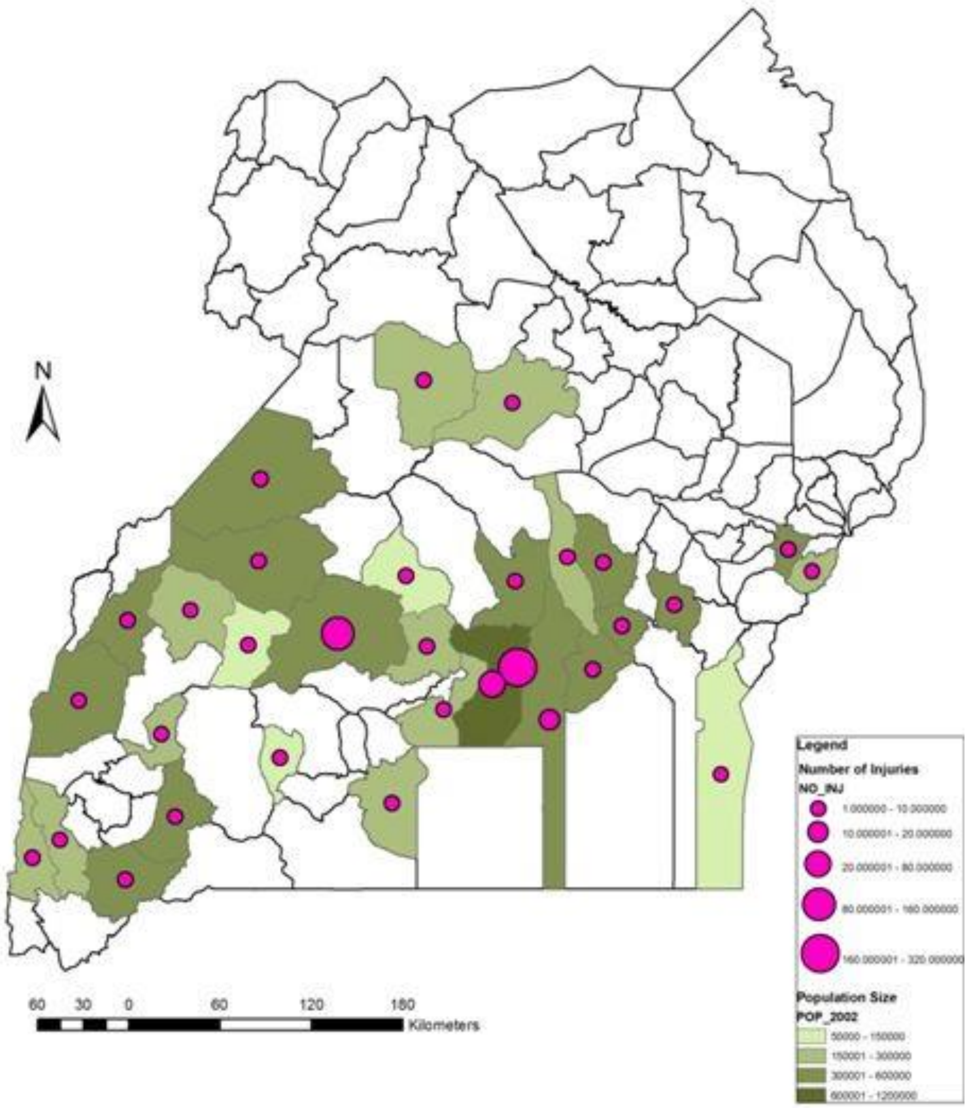

Figure 5. Overlay of population and injury cases.

in determining the health facility to which trauma cases are first taken for treatment.

A comparison of the injury rates in Kampala and Mubende Districts, where the majority (70%) of injuries occurred, indicates that, as expected, urban areas have greater injury prevalence as compared with rural areas. This is based on the fact that Kampala District is an urban area while Mubende District is largely rural. Since Kampala had an injury incidence rate of 266.4 per 100,000, and that Mubende was 118.8 per 100,000 people, it implies that urban areas have a higher injury prevalence rate as compared to rural areas. These data distribution was consistent with the results cited in Kobusingye et al. (2001) that the country's annual injury rate for rural and urban settings is 92/100,000 and 217/100,000 people respectively. However the study results need to be taken cautiously given that data for this pilot study was collected over a limited time period and used as a proxy for the annual injury rate, which does not take into account injury variations over the whole year period (Figures 3 and 4).

Injury type and cause

The trauma registry collected data on the type and cause of injury. Road traffic accidents were the major injury cause, accounting for 46.7% followed by bites (28%), and assault (17%). Road traffic injuries were expectedly concentrated within Kampala, followed by Mubende (21%), Wakiso (18%) and other districts 22%. With respect to dog bites, 54% occurred in Kampala, 21% in Wakiso, 10% in Mubende and others 15%. For assault cases, 54% occurred in Kampala, 17% in Mubende, 17%

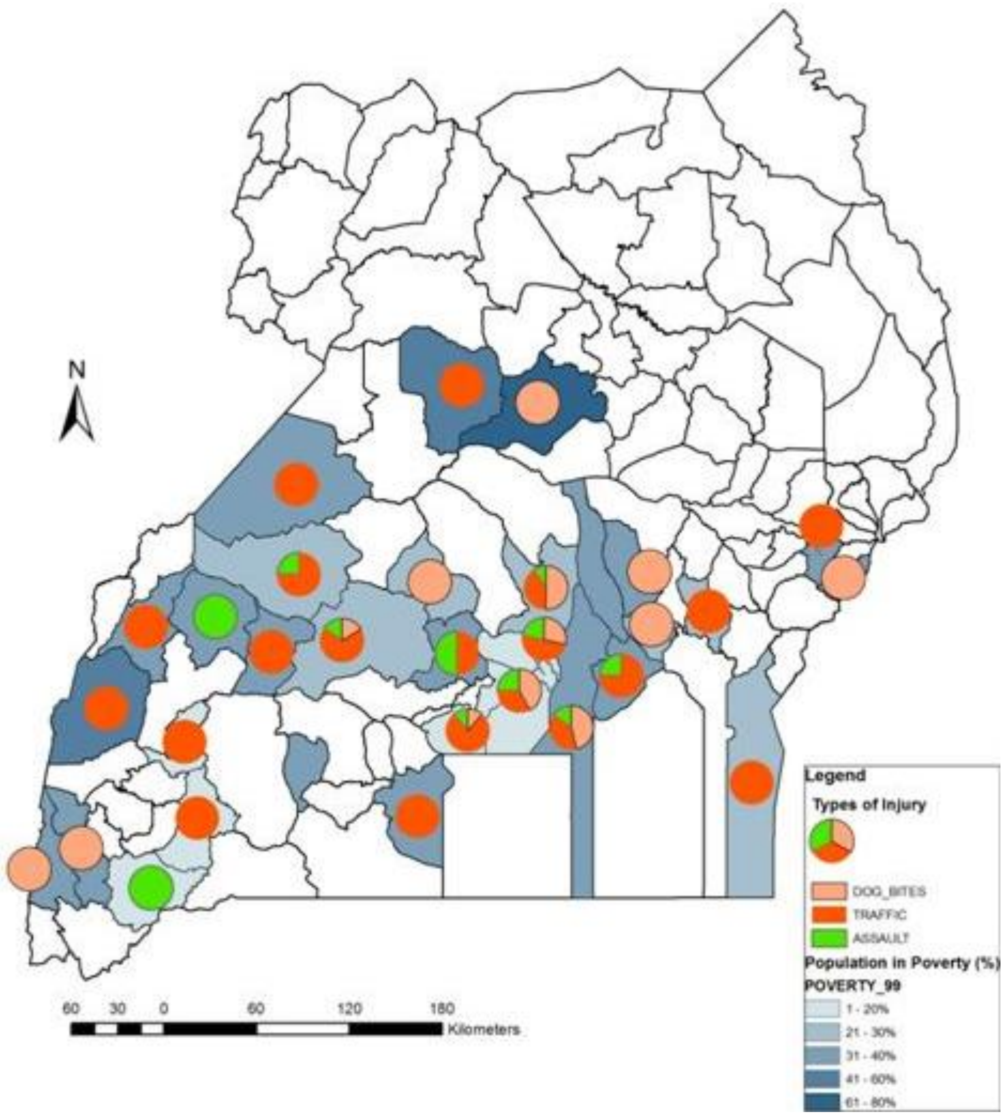

Figure 6. Overlay of population (%) in poverty and injury.

in Wakiso and others 13% (Figures 5 to 7).

DISCUSSION

As noted in the introduction, the earlier, the study's primary goal was to assess the feasibility of using GIS in injury surveillance in Uganda.

This pilot study represents the first stage in the development of a GIS based injury surveillance and trauma registry that could be used for epidemiological analyses and administrative purposes across Uganda. The study mainly focused on spatial data acquisition, preparation and analysis, and the capturing of spatial and non-spatial injury data.

The development of the GIS database faced certain limitations, particularly with regard to acquisition of specific types of data, and data incompatibilities. First, Uganda has not fully developed a National Spatial Data Infrastructure (NSDI). Consequently, the spatial data used in this study were derived from various sources including: Uganda Bureau of Statistics (UBOS), National Forestry Authority (NFA), and from various researchers. These data had considerable geographical incompatibilities related to scale, time, and geographical coverage. It was therefore necessary to combine data derived from large-scale sources with that derived from small-scale sources. This data migration from one GIS environment to another produced inconsistencies and variations. As a result the data required geo-referencing, re-projection, interpretation, re-classification and semantic translation. In some cases, it required re-digitizing. For example the data sets from UBOS and those from NFA were in different coordinate systems and

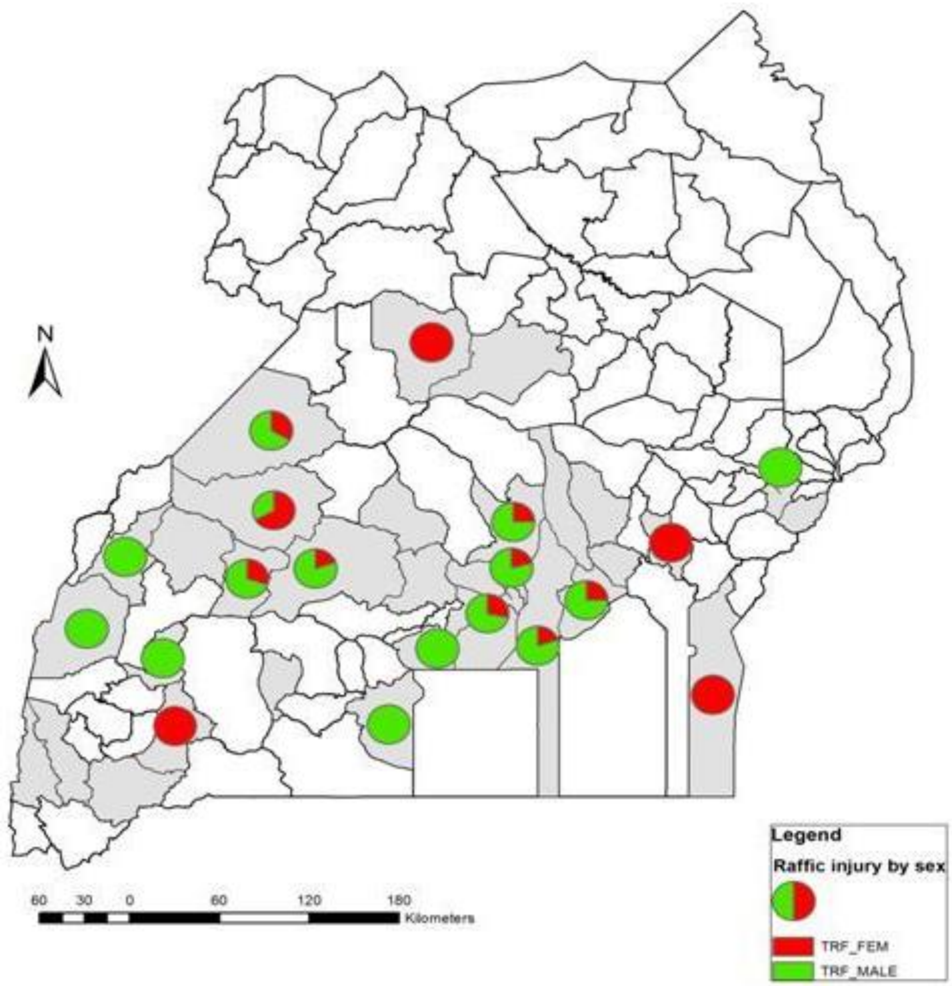

Figure 7. Traffic injury by sex.

needed re-projection.

The parallel entry of data into EpiData and Arc GIS 9.3, however, proved a challenge in data integration because of separate analysts. Parallel data emerged because it was first time GIS was being used in injury surveillance at ICCU and some stakeholders had not yet been convinced that GIS software could be a useful tool for data analysis. This represented a noteworthy moment of tension in the work, between a study team convinced of the efficacy of GIS – or more appropriately – spatial epidemiology supported by GIS and others who were less convinced in part because they had never used GIS or seen it used before.

As expected, the injury maps for Kampala and Mubende Districts show a strong correlation between injury events and overall population distribution. Kampala, which had the highest number of recorded injuries, is urban with high population concentrations and Mubende District, which recorded a low number of injuries, is largely rural with a low population. Uganda Bureau of Statistics - UBOS (UBOS, 2011) estimated Kampala's population as 1,659,600 (population density of 9,429.6 persons per sq. km) as compared to Mubende's population of 579,200 (population density of 124.7 persons per sq.km). Given that Kampala and Mubende recorded injury cases n = 277 and n = 98 respectively, we deduce that population density and demographic distribution could be associated with injuries related to traffic injuries. For example, 42% of the injuries that occurred in Kampala were traffic related, of which 63% involved motorcycles, the dominant mode of transportation among the poor. In Mubende district, traffic injury accounted for 52% of the injury cases in the district and all injuries occurred in Mubende town with none occurring in the rural part of the district. Moreover, all traffic injury cases in Mubende were pedestrians. In both districts, the majority of traffic injury cases were aged 14-65 with 88% in Kampala and 66% in Mubende. A gendered analysis of injury by cause indicates that in all top four injury causes, were more prevalent in males as compared to females. For traffic injuries, 77% of the injured were male, only 23% were females. The findings

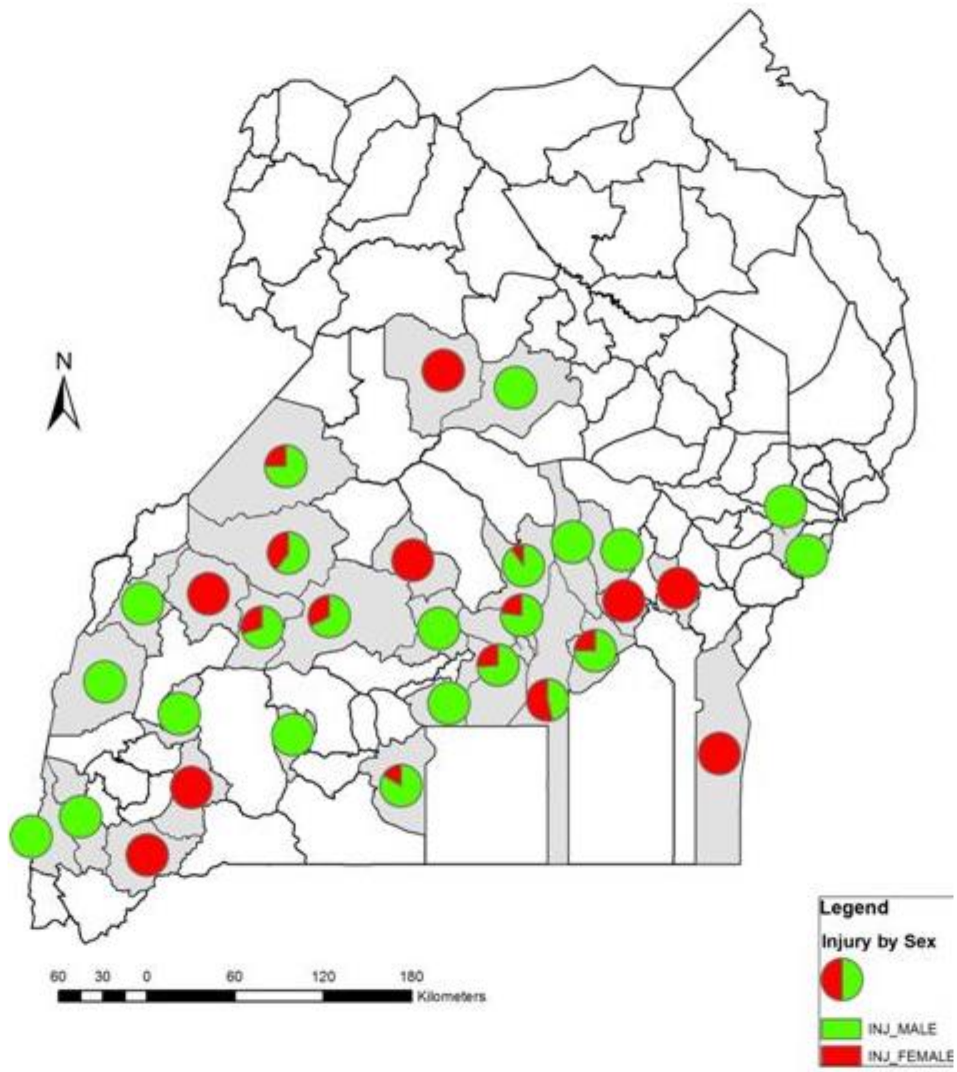

Figure 8. Districts in which injuries occurred.

on dog bite injuries indicate that 65% of the injuries were male and 35% female. For assault related injuries, still males were more (75%) as compared to females (25%).

The GIS methodology described in this study has great potential, it can work but with some challenges in Uganda. A major conceptual challenge of integration of GIS in injury surveillance is the limited appreciation about the capabilities and potential benefits (Ayorekire and Twinomuhangi, 2012). If awareness can be created, and the appropriate/necessary resources organized (e.g., personnel, software), GIS can be easily adopted in injury surveillance and other types of epidemiological surveillance in Uganda. With the increasing use of Internet, open software and web technologies, including GRASS and ILWIS, injury mapping could be conducted at a cost lower than what is involved in using proprietary software. An obvious potential limitation, that may differentiate the Ugandan case from, for example, a similar exercise conducted in North America, is that proprietary GIS technologies come at a high financial cost (this cost is a barrier to adoption) and in many cases require an internet connection, or high-bandwidth wireless services.

It is important to recognise that although GIS is an important tool in analysing spatial patterns of injury and can also show associations of national and community-based data with injury data, it is only a tool for analysis and visualisation and in itself; GIS cannot infer causality of injury. One challenge with visualization technologies is a potential to over emphasize what is visualized because of the perceived reality. This could lead to erroneous mapping in GIS by users unfamiliar or not skilled with geospatial or epidemiological concepts, which could lead to inappropriate decision making. The challenge of organizing the personnel/expertise for GIS based injury surveillance involves adequate training and putting in place appropriate hardware and GIS software, which can be a costly endeavor. However, and in the right hands,

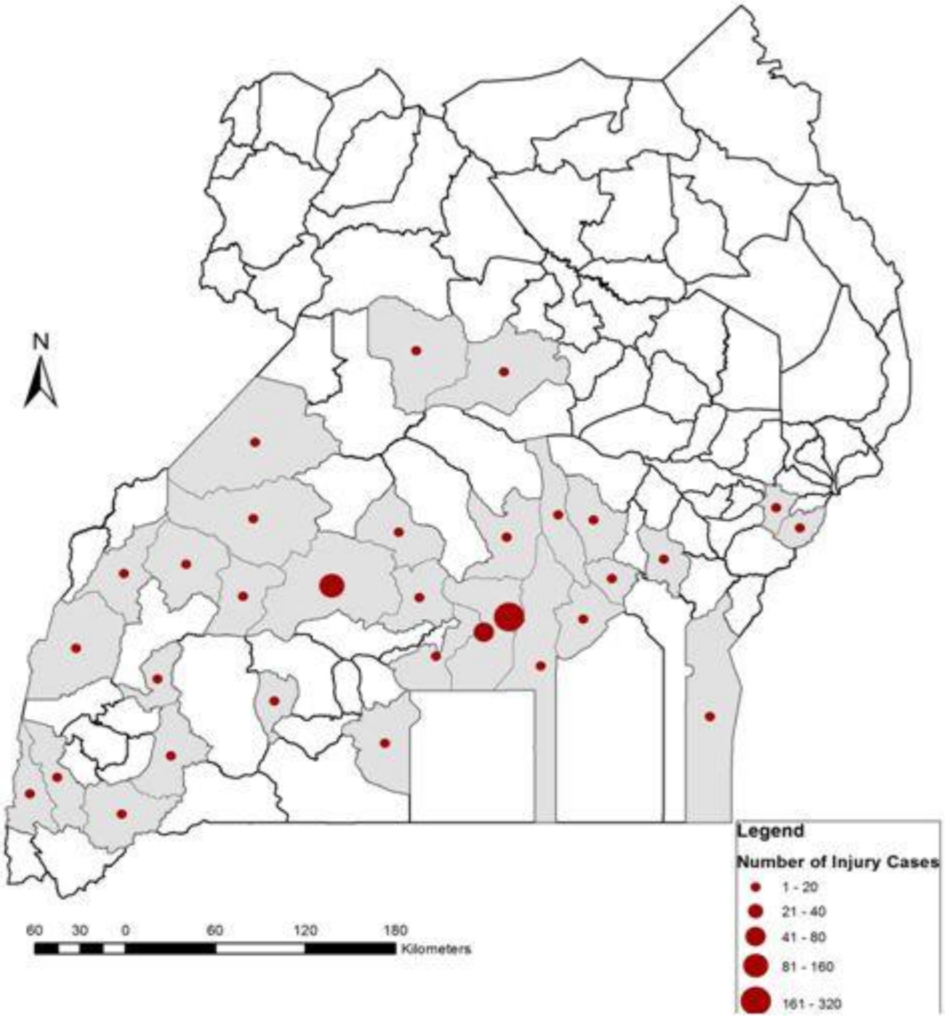

Figure 9. Number of injury cases by district.

GIS can inform the interpretation of causal relationships in many ways. GIS can provide a rational basis for causality; it can be used to assess dose–response effects and changes over time and risk exposure, and can also be used to study the effects of public health interventions.

Lessons learned and future work

GIS theory and tools are clearly beneficial to injury surveillance and control, and could benefit from more intensive uptake of the Geographical Information Science (Cisimano et al., 2007; Schuurman et al., 2008). In Uganda, the use of GIS in health services planning is gaining momentum after a comprehensive survey of health units and development of a national health services geo-database. There is increasing recognition by health practitioners that geospatial analysis techniques and information can aid planning, decision-making and delivery of health services (Lwasa, 2007). At the School of Public Health, Makerere University (associated with Mulago hospital) many researchers are increasingly adopting GIS in their work and more especially in mapping disease epidemics like malaria and cholera outbreaks. By the end of this pilot study the staff at ICCU was appreciative of the potential of GIS for, at the very least, visualizing geographical patterns of injury.

Through the pilot we identified key methodological concerns (both material and non-material in nature) and challenges that can inform the ongoing development of a national surveillance strategy in Uganda, a strategy that could also support future epidemiological study of injury there. First is the extent to which scale can influence the interpretation of results. As many community-based interventions require information at the community-level to design, implement and evaluate prevention strategies, data robustness at the scale of interest determines the ability of GIS methods to inform prevention. Given that Uganda has not fully developed a NSDI, the spatial data used here were derived from various sources and required geo-referencing, re-projection, interpretation, re-classification, and semantic translation. Demographic data acquired from UBOS was not up to date and was therefore, not directly comparable to the incidence data. For example, the last national census was conducted in 2002; recent demographic data were not available. This was compounded by changes in the political geography through the splitting of the local government geographic units (districts) over time. For example, while in 2002 Uganda had 80 districts, as of June 2010 the number of districts had increased to 111 and one Capital City authority resulting from district splitting. However, available population and demographic data for the districts were from the 2002 population census.

Spatial data on administrative is available up to parish level and mapping up to village level is not yet completed. This issue of scale produces uncertainty particularly with regard to representing injury location at the finest grain possible. Accuracy of injury location provided by incidence data from the trauma registry form could not be matched to a specific village. Even where parishes were recorded, mismatches occurred between parish names in the database and the names recorded on the trauma form. Parish names obtained from injury patients differed from those in the geo-database and the data collectors had not been provided with lists of parishes to cross-reference with the correct parish names. Consequently, meaningful mapping of injury location could only be developed at the sub county level. To help attenuate uncertainty in future work, data collectors can be provided a list of all administrative units so that they can cross check the correct units when filling the trauma registry forms. In addition GPS receivers could be used to capture some specific places of injury, following, for example, identification of injury hot spots at a more aggregate scale. Collection and aggregation of data by geographical units such as districts, as was the case in this study, may not provide enough detail for intervention at the community or individual level. For example, in the case of traffic injuries some major roads often make up the boundaries of the areas. There are also linearly oriented settlements along roads especially in trading centres and this is where traffic injuries may cluster. This factor needs to be taken into consideration in future epidemiological work using registry data.

Problems with data collection included patient or data collector omission of information. Most of the missing or incomplete data was on place of injury, place of residence, and income status. Some patients did not disclose information if the injury was related to a crime or, particularly if injuries related to assault, gunshots, or burns. In other instances, the number of admissions, particularly at the Mulago national referral hospital, overwhelmed data collectors and in some cases the trauma registry forms at this hospital were not fully completed.

As already mentioned, we employed geographic aggregation of injury occurrences by districts and in some cases sub-counties. However, when undertaking spatial analysis, the issue of ecological fallacy arises. Ecological fallacy is a situation where analysis is based on units that may be arbitrary in size and shape and internally heterogeneous. Cusimano et al. (2007) suggests that ecological fallacy is present whenever assumptions that are based solely on group characteristics are made about people in a group. For instance, when associating a particular area as high risk for a particular injury or when socioeconomic characteristics with injury risk factors (for instance, low income or neighbourhood), it cannot be assumed that people living in the areas are directly represented by the general characteristics of those areas. Also, the characteristics of a particular area can change on the basis of scale, a phenomenon known as the modifiable areal unit problem, as a result of variance in an area (Openshaw, 1984). In the main national injury surveillance, we intend to address the ecological fallacy problem by calculating injury incidences by first determining the population at risk of a particular injury rather than just aggregating the injuries in a particular area.

Having a small numbers problem, particularly for denominator data used for rate calculations, is also a challenge. For example, handling small values or zero values in injury occurrences raised issues regarding rate calculation and representativeness of data. For example, being a national referral hospital, Mulago receives referrals of every nature including injuries. Almost all injuries that occurred in districts in distances more than 100 km from Mulago hospital were most likely referral cases. Similarly, Mubende hospital is a regional referral hospital receiving regional referral cases. However when interpreting data, one could come to a conclusion that some districts have few or no injuries which is not the case. Zeros also cause problems for some spatial statistical methods, where contiguity of *non-zero* data units is a requirement (Moldofsky et al., 2008; Colantonio et al., 2011). To correct this, the trauma registry form should indicate referral cases, so that they can easily be distinguished from other injury cases.

A suitable next step could be to conduct a more thorough user-test of the tools and protocols developed, in order to assess the suitability of GIS for local capabilities and to ensure the end result is sustainable taking into account resource utilization and acquiring commitments for ongoing participation. The trauma registry form needs to be improved to remove redundant questions, and data collectors could benefit from more training to enhance their ability to capture location data to the parish level. The current form and data collectors could be used to capture data only up to sub-county level and this was due to inadequate training of data collectors. In subsequent phases, attention will be focused on ensuring that the system can be expanded to include other hospitals. This will require - along with other considerations – developing a standard injury coding typology.

Although the focus of the pilot study was on the potential applicability of GIS tools in injury surveillance in Uganda, the ultimate goal is to identify the spatial patterns as well as the environmental and social correlates of injury in Uganda. Once a GIS database is operationalized, one that addresses many of the concerns raised in this paper, a future study will identify high incident injury locations, the populations at risk and will examine the social and environmental characteristics in order to identify injury risk factors. This will require obtaining higher-resolution spatial data on injury location which could possibly be obtained by querying the patient or the person who brought the injured person to hospital, followed by a post-hoc confirmation of the geography of reported injury, for certain cases, using Global Positioning System (GPS) technology.

Conclusion

In this study, we used GIS to depict the geographic patterns of injuries recorded in a pilot on two hospitals in Central Uganda. The results from the pilot study indicate that GIS technologies have a potential to contribute to injury surveillance and other public health surveillance in Uganda. The methodology described in this paper could be transferred to other settings and adapted to local capabilities for organizations that wish to engage in injury surveillance. This study examined the potential and limitations of using GIS technology in injury surveillance in Uganda. The study illustrates that the use of GIS and spatial analysis can be an important addition to the study of injuries in Uganda, both for the geographical representation of injury occurrence and identification of the potential social and environmental determinants of injury, particularly those determinants that are intrinsically spatial. The advantages of using GIS in an injury epidemiology setting, that have been identified elsewhere (Bell and Schuurman, 2010; Colantonio et al., 2011; Cusimano et al., 2007; Schuurman et al., 2008) and also appear to offer benefit in this Ugandan case. For example, there are inherent advantages of GIS in its ability to integrate spatial and non-spatial data, display data in a way that can be easily interpreted and analyzed. In addition GIS is able to combine multiple data sources, with a view to identifying spatial patterns of injury incidence and potential causes. The spatial qualities of representing injury data also add value to the sharing of injury data to multiple stakeholders in ways that are efficient and may contribute to policy, planning and decision making. In the Ugandan case, mapping injuries at community level could assist communities to recognize their increased risk of particular injuries, thereby increasing interest in local prevention efforts. Outcomes from this study suggest that there is important for using GIS in moving from the pilot stage of this work toward development of a national injury surveillance program.

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Annex 1: Trauma registry form

Fill in the gaps left and tick the correct answer(s)

Hospital code		Hospital outpatient No.						Hospital inpatient No.						

1. Gender	M	F		2. Age					3. Tribe…………………………….	Patient's name…………………

4. Occupation	5. Marital status	6. Residence	7. Monthly income	8. Mode of arrival
1). Peasant farmer 2). Commercial Farmer 3). Public/Civil servant 4). Transport - Driver/conductor 5). Small business owner 6). Large business owner 7). Casual labourer 8). Child/Pupil/Student 9). Combatant 10). Unemployed 12). Others (Specify)	1). Single 2). Married 3). Widowed 4). Divorced/Separated 5). Unknown	Sub-county …………… District ………………	1). Below 250,000 4). Above 1,000,000	1). Foot 2). Bicycle 3). Motorcycle 4). Ambulance 5). Police car 6). Car (Personal/hired) 6). Others (specify) …………………….

9. Patient escorted by	10. Blood pressure on admission (Systolic)	11. Respiratory rate on admission	12. Neurological status	13. Number of serious injuries	14. Palpable pulse
1). Police 2). Friend 3). Family member 4). Stranger 5). Ambulance attendant 6). None	1). Undetectable 2). 1 – 49 3). 50 – 89 4). >89	1). < 9 2). >30 3). 10 – 29	1). Unresponsive 2). Responds to painful stimuli 3). Responds to verbal stimuli 4). Alert	1). >1 serious injury 2). 1 serious injury 3). None	1). Radial 2). Femoral 3). Carotid 4). Undetectable

15. Place where injury occurred	16. Activity at time of injury	17. Location of injury (Administrative unit)
1). Home 2). Farm 3). Industry 4). Construction site 4).Sports/recreational area 5). Road/street 6). Bar/Pub 7). Commercial place (market/shop etc) 8). School/Education institution 9). River/lake/pool 10). Unknown 11). Other	1). Work 2). Travelling 3). Sports/playing 4). Education 5). Recreation/Leisure 6). Unknown 7). Other (specify) ………………	Parish …………………………………………… Sub-county: ……………………………….. District: ……………………………………………

18. Intent	19. Cause *(If intentional)*	20. Time Sequences:	21. Alcohol use at time of injury
1). Unintentional 2). Intentional 3).Undetermined	1). Self-inflicted 2). Assault 3). War/insurrection	Injury Date: __/__/__ Time: __am/pm DD / MM/ YY Pt. Arrival Date:__/___/___ Time: __am/pm DD / MM / YY Medical Attention Date: ___/___/___Time: __ __am/pm DD/MM/YY	1). Suspected/confirmed 2). Nil 3). Unknown

22. Body area with serious injuries *(Can tick more than 1)*	**23. Nature of injury** *(Tick and specify)*
1). Head 2). Neck 3). Chest 4). Spinal cord injury 5). Abdomen/pelvis/perineum 6). Bony pelvis & extremities	1). Fracture 2). Burns 3). Sprain, strain or dislocation 4). Concussion/coma 5).Cuts, bites or open wound 6). Bruise or superficial injury 7). Organ system injury 8). Unknown

24. Injury cause	**Road traffic injury**			
	25. Road user	**26. Counterpart**	**27. Seat belt use at injury time** *(if road user 1 or 2)*	**28. Helmet use at injury time** *(if road user 3,4,5 or 6)*
1). Road traffic injury 2). Fall 3). Stab/cut 4). Poisoning 5). Chocking/hanging 6). Drowning 7). Gun shot 8). Blunt force 9). Animal/human/snake bite 10). Sexual assault 11). Landmine/bomb blast 12). Electricity 13). Burns	1). Motor vehicle Driver 2). Motor vehicle Passenger 3). Motorcyclist 4). Motorcycle Passenger 5). Bicyclist 6). Bicycle passenger 7). Pedestrian	1). Motor vehicle 2). Motorcycle 3). Bicycle 4). Pedestrian 5). Stationary object 6). No secondary counterpart	1). Yes 2). No 3). Unknown	1). Yes 2). No 3). Unknown

BURNS				
29. Burn agent	**30. Mother's/ care taker's education level (if child/baby)**	**31. Average day time the mother spends with child**	**32. Is a victim a daughter/son of house head?**	**33. Monthly income of the mother/caretaker**
1). Flame/smoke 2). Hot fluid 3). Chemical 4). Hot surface 5). Other …………	1). None 2). Primary 4). Secondary/certificate 5) Post- secondary	… hours	1). Yes 2). No	1). Below 100,000 2). 100,000 to 490,000 3). 500,000 to 1,000,000 4). Above 1,000,000

GENDER–BASED VIOLENCE					
34. Gender based related injury?	**35. Perpetrator /victim relationship**	**36. Gender of perpetrator**	**37. Is the victim in a polygamous marriage?**	**38. Monthly income of the perpetrator**	**39. Precipitating factors**
1). Yes 2). No	1). Spouse/ partner 2). Parent /step parent 3). Other relatives 4). Friends 5). Others………	1). Male 2). Female	1). Yes 2). No	1). Below 100,000 2). 100,000 to 490,000 3). 500,000 to 1 ,000,000 4). Above 1,000,000	1). Conflict 2). Physical illness 3). Financial issues 4). Death in family 5). Sexual assault 6). Other………..

40. Patient disposition	**41. Status at 2 weeks**	**Form filled by ……………………………………………** **Date completed…………………………………………** **Supervisor's signature…………………………………**
1). Treated and sent home 2). Admitted - IP No. ………………… 3). Died in casualty department 4). Referred 5). Dead On Arrival	1). Discharged 2). Died 3). Still in hospital 4). Run away 5). Referred to another health facility	