ORIGINAL ARTICLE

QGIS Application for Spatial and Temporal Visualisation of Data for Food Safety Audits in Malaysia

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ABSTRACT

Introduction: Advancement in digital technology opens new doors for food safety auditors when it comes to performing food safety audits. Surge of Covid cases since year 2020 has seen an unprecedented switch to remote auditing by the Food Safety and Quality Programme under the arm of Ministry of Health in Malaysia. **Methods:** This paper presents the use of QGIS, an open-source cross-platform for geographic information system (GIS) to store, manage and visualise 2 types of data, i.e. real time data collected via a mobile device using QField, an open-source mobile application and also fixed data retrieved from existing database. New data from obtained from field sampling and surveillance presents updated information for food safety auditing and enforcement purposes. A total of 4972 datasets were obtained from the Ministry of Health's Food Safety and Quality Division database on food factories from all 13 states and 3 federal territories in Malaysia. These datasets were transformed and stored into QGIS point layer for performing data classification analysis on clustering of HACCP, GMP and MeSTI certifications. **Results:** The Penang state has the most HACCP certified companies in fish and fish product category, Selangor is the highest for confectionery industry and Sabah for food services. The general output of mobile GIS provides a big picture of distribution of food safety certifications in Malaysia while more specific adoption of QField can assist in effective field work planning for enforcement officers and auditors leading to cost calculation via information on location, distance and time. **Conclusion:** QGIS application for spatial and temporal visualisation of data benefits the food safety auditing in Malaysia

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INTRODUCTION

The use of Geographic Information System (GIS) has shown great effectiveness in responding to the recent widespread of pandemic Covid-19 globally (1). GIS has played critical and important roles not only in understanding spatial clustering and transmission of the coronavirus but also draw up development of protocols for vaccines distributions and connections to businesses (2,3). In the past, GIS has also proved to be an efficient tool in various other applications (4–6). GIS was used as a tool in mapping the transmission of antimicrobial resistance (AMR) sources into clusters and its spread in the livestock environment, landfills, and waste (7).

Due to mobility restrictions during the pandemic and pressure of continuous food production supply, stakeholders in the food industry have heighten food safety management systems (8,9). In food auditing, the existing style and approach of field work for food safety certifications needs revision and upgrading as the existing manual pen and paper recording method is not feasible for reasons of safety, mobility, versatility and efficiency. Along the advancement of digital technology in blockchain, IoT and big data, mobile phones has become a very convenient tool for collecting and recording data at field work for digital applications and visualization purpose (10–12). Mobile GIS provides real-time data collection and update. It extends the traditional indoor GIS manipulation to outdoor work which enables GIS accessibility at any location, and allowing field personnel to collect, store, edit, manipulate, analyze and display spatial data in an easy, inexpensive, and effective way.

An example of such data collection on mobile phones at field work, the EpiCollect, was used for epidemiology

mapping and visualisation (13). In food safety practices, (14,15) have used mobile phones as a standardised data collector to assess food safety practices of market food handlers efficiently through their hand-washing behaviours. The mobile GIS can be efficiently utilised for health inspection and enable risk tracking through identification of critical food safety violations thus help auditors during food establishment inspection (16,17). Darcey & Quinlan (16) have used GIS to track violations of food safety in retails based on socioeconomic status and demographic characteristics of population as a proxy to track risk for foodborne illness. GIS has also gained much importance in food safety through applications in food production monitoring, transportation and even in some governmental policy planning (18).

The aim of this research was to develop a robust data visualisation method for versatile handling of food safety sampling and database using GIS mapping to enable robust analysis. Quick and accurate visualisation on status of food safety certifications in Malaysia will assist on-site auditing and decisions making for the health department at a state level. QField, a versatile and unique plugin tool was used for field data collection while OGIS, the latest advancement in GIS which has a desktop option, mobile, and web component for spatial and temporal data analysis was used for data visualisation. The QGIS tools could aid error prevention as part of decision-making tool in research and innovation (19) on food safety surveillance for community food safety, biological, chemical and physical hazard monitoring, and even food poisoning outbreak surveillance (5,20,21). This GIS mapping of food safety certifications with choropleth that depicts actual boundaries of districts and states has advantage over the cartograms which often give confusion due to boundaries distortion problems (22) Ultimately, this study is hoped to provide a well-mapped-out mobile GIS platform that could aid enforcement officers in making strategic plans, decisions and quicken procedures of regulatory enforcement efficiently.

MATERIALS AND METHODS

Study design
The mobile GIS-based application was customised to visualise the status of food safety certifications in Malaysia in terms of food product cluster and category distribution via two workflows. The first workflow was synchronisation of QField with Quantum Geographical Information System (QGIS, LTR 3.16) desktop and the second workflow was transformation of food safety certifications from datasets extracted from existing database into GIS visualisation for spatial analysis. QField was used as a tool for real-time data collection from field sampling and surveillance for food safety auditing via a mobile phone while QGIS was the platform used for spatial and temporal analysis.

QField synchronization with QGIS
Figure 1 shows the three stages on synchronisation of mobile QGIS at the mobile device (QField) with QGIS desktop for field data collection. Stage 1 is the pre-processing, detailing the GeoPackage layer creation steps for field data collection with QField. Stage 2 is QField sampling, on steps for data collection with QField, during food safety auditing and sampling. Stage 3 is the processing, where QGIS visualisation and analysis were performed on collected data.
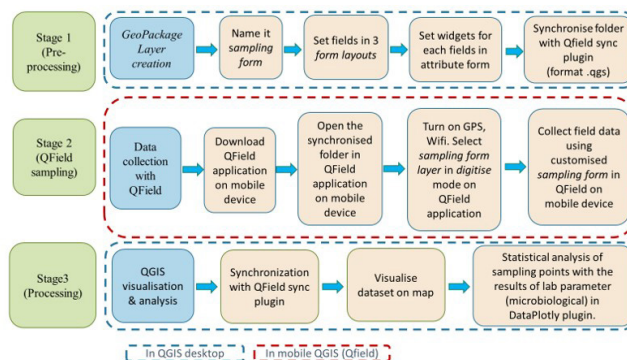

Figure 1: The workflow with three stages on synchronisation of QField with QGIS desktop for field data collection using mobile GIS-based application.

In the pre-processing stage, a new Geopackage layer was created, and named the sampling form. The layer was used for customising fields and assigning the type of data, either as integer, text or date and time. The fields were further customised with widgets from the drop-down designer feature in the layer properties' attribute form. Before setting the widgets, the fields were grouped into 3 tabs in the form layout, i.e. Company Profile, Sampling Information and Built Environment of the food processing factory to contain the fields with various widgets customised for display on QField as listed in Table I.

For the display selection, value map widget was chosen for the display of QField information where it comes with combo box. The combo box was applied to the Company Profile details such as certification with answer options of HACCP, GMP, MeSTI) / none for food safety management system (FSMS); council for local councils licenses, fosim for food premises registration under MOH, and SSM for registration of company which were either valid, expired or none; year est for the year of establishment <1960, >1960, >1990, >2010, >2020); worker for number of workers (<5, >5, >75, >200); and annual return for yearly return of the company (<RM300k, >RM300k, >RM15mil, >RM50mil). For Sampling Information, cleaning frequency was (daily / weekly / monthly / yearly), surface material was (stainless steel, plastic, wood, glass, concrete, tiles, aluminum, cement, epoxy, paper, metal, others), surface condition was (dry, wet, porous, flaked paint, rusty, others), and zone was (1,2,3 or 4).

Table I: Widgets selection for QField display in the 3 tabs of company profile, sampling information and built environment with field type name and answer option

Tab	Answer Option	Field Type Name	Widgets Usage
Company Profile			
certification	HACCP, GMP, MeSTI / none	Text (string)	Value map
region	Putrajaya, Labuan, Perlis, Kuala Lumpur, Terengganu, Kelantan Negeri Sembilan, Melaka, Sarawak, Pahang, Sabah, Perak, Kedah, Penang, Johor, Selangor	Text (string)	Value map
council	valid, expired, none	Text (string)	Value map
fosim	valid, expired, none	Text (string)	Value map
SSM	valid, expired, none	Text (string)	Value map
year est	<1960, >1960, >1990, >2010, >2020	Integer	Value map
worker	<5, >5, >75, >200	Integer	Value map
market	export / domestic	Text (string)	Checkbox
annual return	<RM300k, >RM300k, >RM15mil, >RM50mil	Integer	Value map
Sampling Information			
id	Sample's identification number	Integer (64 bit)	Text edit
label	Sample's name	Text (string)	Text edit (multiline)
sample type	checked state; environment swab / unchecked state: food sample	Text (string)	Checkbox
cleaning frequency	daily / weekly / monthly / yearly	Text (string)	Value map
surface material	stainless steel, plastic, wood, glass, concrete, tiles, aluminum, cement, epoxy, paper, metal, others	Text (string)	Value map
surface condition	dry, wet, porous, flaked paint, rusty, others	Text (string)	Value map
zone	1,2,3,4	Text (string)	Value map
sample photo	Image (relative path)	Text (string)	Attachment
date sampling	$now (date expression)	Date	Date / Time
Built Environment			
temperature (C)	Min: -100, max: 400 °C	Integer	Range - slider
brightness (lux)	Min: 0, max: 1200	Integer	Range - dial
humidity	Min: 0, max: 100	Integer	Range - dial
audit pjkm score	Min: 0, max: 108	Integer	Range - slider
audit infra score	Min: 0, max: 20	Integer	Range - slider
date audit	$now (date expression)	Date	Date / Time
ncr findings	Description for non-compliance	Text (string)	Text edit (multiline)

The checkbox widget was selected for Company Profile's market of the food product i.e. export or domestic, and Sampling Information's sample type, where the checked and unchecked state will be displayed as true or false setting. Text edit widget was picked for Sampling Information's id (identification number), label for sample's name, and the ncr findings for the non-conformances report with editable and multiline enabled for inserting long notes. Range widget was preferred for built environment's temperature (°C) (min: -100°C, max: 400°C), brightness (lux) (min: 0, max: 1200), humidity (min: 0%, max: 100%), audit pjkm score (min: 0, max: 20) for infrastructure compliance with Food Hygiene Regulations 2009 and audit infra score (min: 0, max: 108) for FSMS documentations and records availability during food safety auditing. The range widget type was either slider or dial based on display's preference. Date / Time widget was nominated for sampling information's date sampling and built environment's date audit with added expression of $now, to enable exact date and time insertion in QField. The attachment widget was set in relative path, image in integrated document viewer.

For the Action List of the layer's properties, a new action was added by selecting type as open and in the Action Text, the field layer's name, sample photo was inserted as the expression. This allows sampling photo to be taken in QField, using mobile devices' camera. Finally, the QField sync plugin synchronisation was performed by selecting Package for QField, with Google Map selected as the base map set in the project's configuration, then the project was saved in qgs format, in a traceable directory's folder. in a traceable directory's folder. The folder synchronised from stage 1 was transferred and saved to the mobile device's internal storage.

In stage 2 of QField sampling, QField application was downloaded on an Android version of a mobile device using Google Play platform. Then, the synchronised folder saved on the mobile device was opened with the downloaded QField application. The mobile device's Global Positioning System (GPS) was turned on. Then, sampling layer was selected in digitize mode on the QField application. Field data during food safety auditing was collected using the customised sampling

form in QFleld on mobile device.

In stage 3 for processing, QGIS visualisation and analysis were performed. The collected fields data from food factory were the inputs for QGIS desktop upon auditors completing the on-site audit. The dataset was then synced again in QGIS desktop with QField sync plugin. The new dataset was visualised on QGIS map and further processed in DataPlotly plugin for statistical analysis. In addition, if laboratory results were available in Excel®, the results were also added in QGIS desktop as a text delimited layer. The results could be analysed as 2D histogram, pie chart, bar, box, contour, polar, scatter, violin plot and ternary plot.

The GeoPackage layer of sampling form was only seen as one coordinate point from one factory which is autodetected during field sampling when the mobile phone receives its position by the GPS. With many points sampled from various factories in a single layer, information gathered is then used for visualisation and further temporal and spatial analysis of a populated map in transforming the dataset into meaningful message. Information collected from workflow 1 can also be saved as Comma Separated Value (CSV) file in the form of a QGIS database, stored as text delimited file and exported into Excel® format for further applications. Selected data from specific field, e.g. Company Profile's certification and region (state) can be used further for spatial and temporal visualisation following steps at stage 3 or to build a QGIS database as described in workflow 2 of Figure 2.

Figure 2: The workflow of transformation of dataset for spatial and temporal visualisation.

Transformation of dataset for spatial and temporal visualisation
Figure 2 shows second workflow on transformation of dataset for spatial and temporal visualisation and analysis in QGIS in three stages. Stage 1 is Cleaning and extracting dataset, stage 2 is Geocoding of dataset's addresses into coordinates and stage 3 is Spatial and temporal visualisation in QGIS desktop. It was based on datasets retrieved from existing database without coordinates thus the geocoding step in stage 2 was required.

In the stage 1 of Cleaning and extracting dataset, a total of 4972 food safety certification open dataset were obtained from the Food Safety and Quality Division (FSQD), Ministry of Health Malaysia at http://fsq.moh.gov.my on 30 Jun 2021. They were in Excel® files. The datasets contain general information on food factories registered under MOH in Malaysia which include the FSMS certification i.e. HACCP (Hazard Analysis Critical Control Point), GMP (Good Manufacturing Practices) and MeSTI (Food Safety is Industry Responsibility). Base maps of Malaysia with 5 types of shapefiles were downloaded from open data source at http://data.humdata, which were dragged from the opened directory to the QGIS layer's panel. Other maps like Google Map, Google Satellite and Google Roads were acquired using XYZ hub connectors, while Dark Matter map was searched from QuickMapServices (QMS). Coordinate Reference System (CRS) in WGS 84 (EPSG:4326) was set in the QGIS project.

The FSMS dataset were cleaned by standardising the font type, size and letterings as they contained irregularities from source and then uploaded as CSV UTF-8 as the new delimited text layer in QGIS. In order to represent the dataset in the visualisation stage, the field values were either extracted manually in Excel® before uploading in QGIS or extracted using GroupStats plugin in QGIS. Table 2 shows the 2 fields of extracted data, the FSMS certifications and regions which then proceed to Stage 3a directly for spatial and temporal visualisation. Dataset without coordinates addresses were uploaded in QGIS to proceed for geocoding in Stage 2 or directly for analysis in Stage 3b.

In Stage 2 of Geocoding dataset's addresses, MMQGIS plugin was installed from the plugin manager. Google Application Programming Interface (API) was obtained from https://console.cloud.google.com/ to be used in MMQGIS. The API was selected and copied for subsequent geocoding. In an opened MMQGIS plugin, the dataset without coordinates from stage 1 in CSV UTF-8 file was uploaded as a new text delimited layer. Then, the address, city, state and country's name were inputted together with the copied API in the MMQGIS plugin. The outputs of the geocoded and non-geocoded addresses were selected and saved in the relative path directory. The geocoded addresses which are coordinate points of the FSMS factories in Malaysia across 16 regions were saved in a geocoded layer. The non-geocoded addresses file was opened and manually geocoded from Google Map and merged with the geocoded addresses to include the HACCP dataset with sample size of 903. Then, dataset was analysed spatially and temporally in stage 3c.

In stage 3 of Spatial and temporal visualization on QGIS, all the 3 paths of datasets, 3a: the main extracted dataset from stage 1, 3b: the unextracted dataset without geometry (no coordinates) from stage 1 and 3c: the
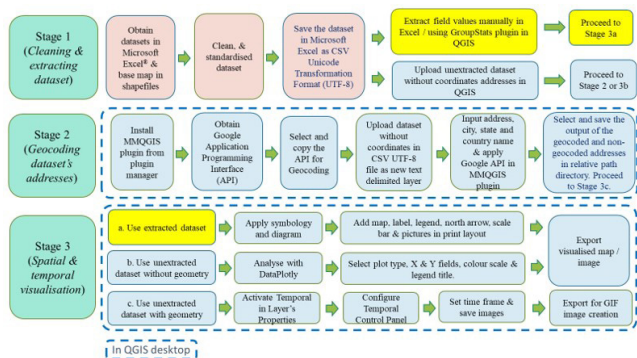
unextracted dataset with geometry (with coordinates) from stage 2 were eventually analysed for a specified visualisation's outputs. For the first path (3a), extracted dataset of FSMS (Table 2) was applied with symbology and diagram from the layer's properties. Graduated symbology was applied using HACCP certifications as value, colour ramp of blues, and 1-2% in the legend format. The dataset was classified into 5 classes based on the equal count or quantile with legends of ascending blues shades from 1-7, 7-24, 24-36, 36-55, and 55-342 to represent number of HACCP certified factories. Similarly, pie chart diagram properties were also inserted on the same map following the 3 types of certifications, HACCP, GMP and MeSTI with colour coding of blue, yellow and pink respectively. Once the settings for the dataset was visualised on the google satellite base map, the map, label, legend, north arrow, scale bar and pictures of 3 certifications' logos, Malaysia's flag and emblem were added in the print layout. Finally, the visualised map was exported as a PNG image file, as shown in Figure 3 in the Results and Discussion section.

For the second path, Stage 3b, unextracted dataset without geometry (no coordinates) was analysed in a plugin installed as DataPlotly. The unextracted dataset was a HACCP dataset. The 2D histogram plot type was chosen and the HACCP layer was selected. The region was assigned as the x-field variable and the product category was assigned as the y-field. The colour scale of the plot was selected from the panel as 'BlueYellowRed' colour ramp with the range from 0 to 45 to represent the number of HACCP certifications. The colour ramp in ascending order from the darkest blue (no certification), yellow (middle range) and to the darkest red representing the highest HACCP certifications (45 certifications) for all 27 product categories across the 16 regions of Malaysia. Legend title was named as Region–Product Category and single plot was selected as the type of plot. The visualised map was then exported as a PNG image file, as shown in Figure 4 in the Results and Discussion section.

For the third path, Stage 3c, 2D animation in temporal analysis with geometry (with coordinates) was used for the unextracted HACCP dataset. The temporal button in layer's properties was activated and single field with date/time configuration was set with the field as 'datecert' and Accumulate features over time was enabled. In the Temporal Controller Panel, the time frame in the format of 'yyyy-MM-dd' from 2012-01-01 to 2021-12-31 was set to animation with a 4-months step. The title label was set by ticking enable title label and inserting the expression as "format_date(@map_start_time, 'yyyy')". Font size was set as 25, pink with a black background on the Dark Matter base map. Then the image was saved in the output directory with calculating from Layer enabled. The saved images were then exported for GIF image creation in ezgif.com as shown in Figure 5 the Results and Discussion section.

RESULTS

Results from visualising datasets of different FSMS
Figure 3 shows the visualised map of FSMS certifications of factories distributed across 16 regions in Malaysia. Selangor and Johor regions both have the darkest blue shade indicating highest density of factories with HACCP certification. Terengganu has the lightest shade indicating least number of factories with HACCP certification. The pie charts in each region shows the proportion of HACCP (light blue), GMP (yellow) and MeSTI (pink) certifications using a different colour segment. In general, MeSTI certification is the highest followed by HACCP and GMP is the last for all regions. By number, MeSTI is the highest because all food manufacturing must comply to Food Hygiene Regulations 2009 (FHR 2009) when acquiring a Food Safety Management System of which MeSTI is the minimum certification. The MOH also provides free services for MeSTI auditing in the effort of encouraging and promoting maintenance of food hygiene and process control. The HACCP certifications are more than the GMP because of the needs of this certification for export markets, where this trend is clearly observed in every region.
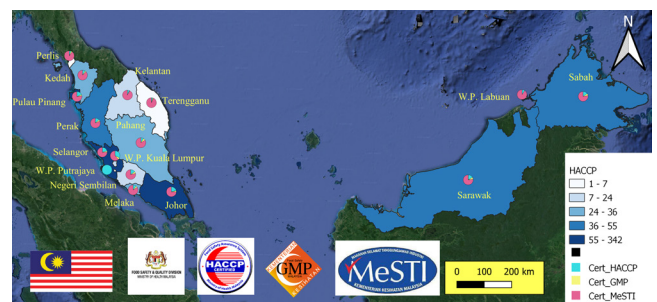

Figure 3: . Distribution of total number of HACCP, GMP and MeSTI certifications in 16 regions of Malaysia.

Results from visualising datasets of product categories
Figure 4 shows the results of HACCP certification by 27 product categories processed in DataPlotly. In terms of product category, food services spans across most regions shown in Sabah, with 19 as the highest HACCP certified food premises as compared to other regions. This was due to most HACCP companies were from the hospital caterings. Scrolling in clock wise manner, the bottom of the plot illustrates the density of colours for the fish and fish product category which weighted most in Penang (26), followed by Selangor (25) and Perak (22). Penang comes top for fish and fish product in terms of number of companies with HACCP certifications to fulfil the importing country's requirement especially from European Union EU) countries. Moving the plot to the left, Selangor contributed the most colours array for product categories with confection (47) comes top, followed by edible fat and edible oil (38), miscellaneous (31) and soft drinks (27). Confection is the staple commodities that is available in ready-to-eat packs, as a quick source of energy with minimal preparation efforts
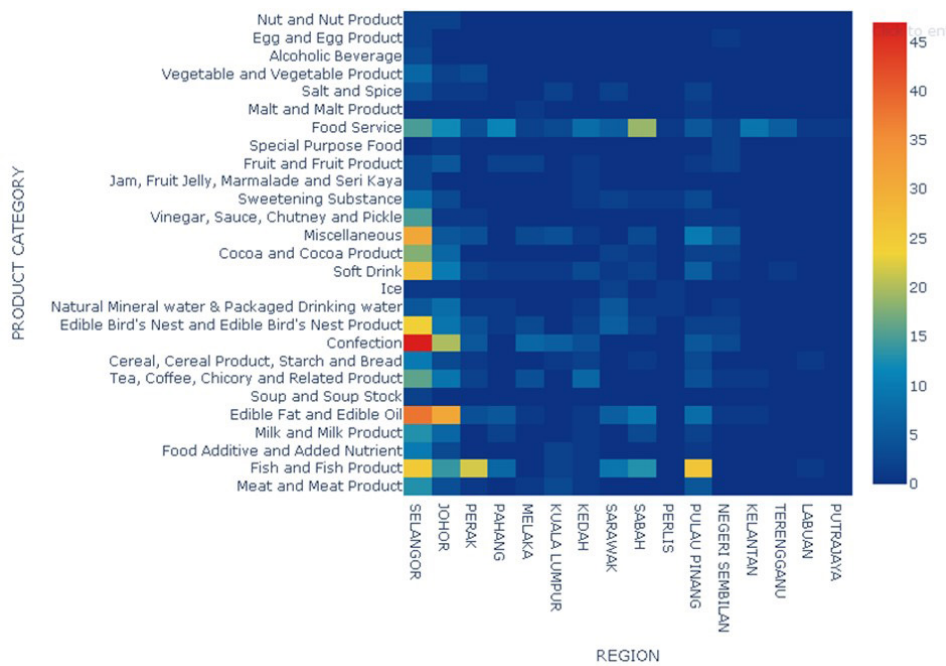
Figure 4: The 2D histogram produced in QGIS DataPlotly plugin, showing the density HACCP certified companies for all 27 product categories across the 16 regions of Malaysia. The density heatmap scale on the right indicate ascending number of certifications from zero (dark blue) to 45 (dark red).

thus suited for the fast-paced life in Selangor. Similar to Selangor, Johor also has highest sectors for edible fat and edible oil (31) and confection (20) and ranked just below Selangor in number. Both Selangor and Johor are the current international cargo hub, where manufacturers have chosen these locations for close proximity to ports and oil palm plantations to produce palm oil products, Malaysia's main export commodity.

Spatial and temporal growth visualisation of HACCP companies

Results from the 2D animation for temporal analysis are shown in Figure 5. The distribution of HACCP certifications acquired by food manufacturing companies from different regions shows Penang region started the earliest acquisition of HACCP certifications in 2012. Malaysia has made HACCP certifications a compulsory requirement for all seafood manufacturing companies for export purposes to EU and other required nations since the export rejection of seafood by EU countries (23–25). The concentration of the points is also seen saturated in Selangor region when over the 9 years, HACCP certification adoption has spread widely. Year 2012 pictured no HACCP companies at the east peninsular of Malaysia, but grew its adoption grew by year 2017 to 2021. The HACCP companies could be seen saturated at city areas, where the main commerce exist and continue to serve in the country's economy growth with food safety awareness.

DISCUSSION

This paper presents the usage of a mobile QGIS application to improve the data collection in the field of food safety auditing and sampling. The usage of this QGIS application on a mobile device enables a
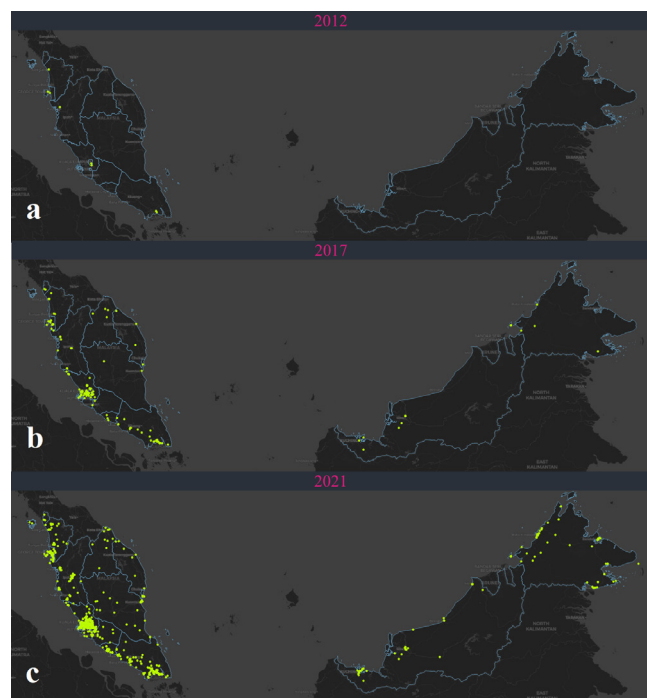

Figure 5: Images extracted from the 30 sets of images for the 1 GIF image of 2D animation distribution of HACCP companies across 16 regions in Malaysia from year 2012 to year 2021 with still images presented for year (a) 2012, (b) 2017 and (c) 2021.

customised sampling form, for the auditors to collect crucial food safety data. Collection of the food safety data could also be used by different auditors from various regions (states). This will improve the standardised effort in building a food safety database of food safety data in the nation.

Presenting the visualisation of two data types, with

the former data collected using a mobile device and the latter using the available dataset could deliver the spatial and temporal data analysis. The analysis of space and time give insight on the crucial food safety hazards among the various food establishments in the country. This empowers the analysis of food safety risk and eventually building the country's competency and role in food safety surveillance.

The limitations in geocoding process through the MMQGIS plugin left 15 set of addresses which were not geocoded. The file was opened in CSV and manual geocoding was done using Google Map coordinates to search from the addresses. The latitude and longitude were merged to the remaining 888 set of addresses geocoded earlier. The issues with the unsuccessful geocoded addresses were due to rural area postal code and confusion of road names with the land area code, description of addresses in terms of stone or kilometres away from a specified road name. Out of the 15 dataset, 7 addresses were from Sabah, 3 from Johor, 2 from Selangor, 1 each from regions of Malacca, Kuala Lumpur, and Kedah. These limitations could be improved by using Python or R language for geocoding.

CONCLUSION

Mobile GIS is a convenient tool for current trends needed in food auditing. This tool complements the food safety auditing and sampling task for competent authorities where it gives an instant reporting, time saving and efficient working which could be achieved during on-site auditing. QField and QGIS have shown that the spatial and temporal visualisation can be developed and customized to meet the need of a big picture representation of distribution, density and clusters of food safety related issues in the country. This visualisation on food safety certifications will help auditors in food safety surveillance monitoring in the conduct for heightened enforcement and in policy planning of future food safety auditing. Further development of QGIS will be helpful in building a National Food Safety Spatial Data Infrastructure for both existing and new databases in handling food safety related data in the ministry.

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