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Use of Smartphones for Rapid Location Tracking in Mega Scale Soil Sampling

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Abstract

Conventional, grid-based sampling location tracking approach with GPS or topographic maps is time-consuming and inconvenient. Therefore, this study combined the freely available virtual/digital globe with recent advancements of smartphone geo-browsers to develop a new sampling location tracking approach. The sampling frame was developed with pre-uploaded point map formulated in GIS environment by combining land-use map and one-kilometer grid with center coordinates. The sampling location grid was uploaded to smartphone and each point was tracked with Google Map path finder using point ID (coded grid coordinate) when searching each sampling location. The suitability of the new approach was tested for soil sample collection from paddy lands distributed in 0.9 million hectares in Sri Lanka. The sampling locations could be reached conveniently with the help of Google path-finder voice direction guide and optional routes. The efficiency of new approach was found to be remarkably high, *i.e.*, over 99% of the 9000 sampling points, which were spread across Sri Lanka having an area of 65,610 km^2. All sampling points in the country could be covered with twelve member field investigation crew who were guided through smartphones uploaded with sampling point grid on six motorbikes within 60 days. The new sampling location tracking approach is effective in terms of cost, time, human resource requirements, thus can be adopted in large-scale soil/plant sampling frames with high accuracy.

Keywords

GIS, GPS, Geo-Browser, Location Tracking, Sampling

1. Introduction

Sample collection is an important component in most of the field surveys as the use of whole population is impossible due to various limitations. Many studies in agriculture related to soil fertility, water quality and productivity assessments have used various techniques to obtain required data precisely [1] [2] [3] [4]. This process involves the *identification* of sampling locations and navigation to those locations to obtain the samples. Moreover, depending on the complexity of the study area, time frame of sample collection and scale of the study, efficient and rapid methods to access sample locations are required. However, due to the lack of efficient technologies and expertise, large scale surveys have not been conducted in most of the developing countries [5] [6] [7]. This has partly hindered the progress of agriculture development and environment sustenance [3] [7] [8].

One of the widely used approaches to identify sampling locations in field surveys is through the use of hand held global positioning systems (GPS) [8] [9]. Despite that the hand held GPS receivers provide accurate data on the coordinates of locations, identifying sampling positions in the field is time-consuming [8] [10] [11]. Therefore, alternative tools are required when finding sampling locations efficiently and accurately. Moreover, describing the spatial variability of soil fertility across fields has been difficult until new technologies such as geographical information system (GIS) were introduced [7] [9] [12] [13]. The GIS holds great promises for improving the convenience and accuracy of spatial data, more productive analysis and improved data access [14] [15]. However, sampler should have the basic awareness on the study region to use these techniques.

Satellite images and aerial photographs have been available for many years. However, the use of those in field surveys was limited due to high cost and issues related to their availability [16]. In this context, the invention of internet-based mapping technologies such as Google Earth and Google Maps provides free satellite images, aerial photographs, and topographic data to demarcate sample points. In order to identify and locate different places in the spatial scale in agriculture and environment researches, GIS and Google Maps are now been widely used [4] [16] [17] [18] [19]. These technologies allow multiple data sets to be visualized, which aids in establishing sample locations. These locations can be then loaded into the Google Map android application in order to supply guidance to pre-determined locations for precise sampling [20]. Moreover, this approach does not require postal address or the support from local people having knowledge about the area to identify sample locations. However, these techniques in agriculture and environment surveys have not widely been applied.

Since the last few years, smartphones have contributed largely to the progression of society. Smartphones can be used as research tools for scientists as they have high computing power allowing a variety of applications to be created [19] [21]. The small size, portable nature, cost-effectiveness and availability are important attractions that make smartphones suitable for field research in agriculture and forestry. Moreover, smartphones are equipped with various types of sensors, which make them a promising tool to assist in various types of activities [19] [21]. The digital age has brought many new mobile-based software applications targeted at farmers, researchers, and others in the agriculture sector. However, the effective use of these tools for advancing sustainability is yet to be explored in detail [22]. Recently, "[23]" brought the promising evidence of using smartphones in analyzing soil samples. Android-based smartphone application in conjunction with commercially-available Quantofix test strips could be used as a soil sample analyzer for providing specific fertilizer recommendations [23]. However, the possibility of using smartphones equipped with required soft wares for directing sample collectors or enumerators to previously determined locations in a wider spatial scale, including remote territories, have not been tested. In the present study, we explored the applicability smartphones to develop a soil sampling frame for large scale fields. Therefore, the objectives of the study were to develop a new method which is convenient, accessible, reliable and effective to identify soil sampling locations, and use smartphone-based Google Maps to reach those sampling locations from paddy fields in Sri Lanka.

2. Materials and Methods

2.1. Study Area

The total paddy land extent in Sri Lanka is 879,863 ha (**Figure 1**). The country is divided into 25 administrative districts, and rice (*Oryza sativa* L.) is cultivated in all the districts in different extents indicating a wide and uneven spatial distribution of the crop [24].

2.2. Sampling Point Selection

A flow chart explaining the development process of new sample collection methodology is given in **Figure 2**.

Distribution of paddy lands in the country has already been mapped by the Survey Department of Sri Lanka (**Figure 1**). The whole country was separated into 1 km × 1 km grids using ArcGIS software, and thereby identifying 65,610 grids. A reference number (*i.e.*, grid identification number; Grid-ID) was given to each grid in order to identify those grids and sampling locations. Topographic sheet numbers based on longitudes (X) and latitudes (Y) were used for grid numbering. The X and Y grid numbers for each grid was generated using Universal Transverse Mercator (UTM) distance coordinates (e.g., X = 130 and Y = 366 will have a grid-ID = 130366). Thus, each one km^2 grid was given a unique grid-ID. Subsample of the grid-ID and other administrative information derived for this study are presented in **Table 1**.

Out of the total number of grids (65,610) in the country, total paddy cultivated extent was distributed only in 35,537 grids while the rest had other land uses. Among the grids having paddy lands, whole area of certain grids was

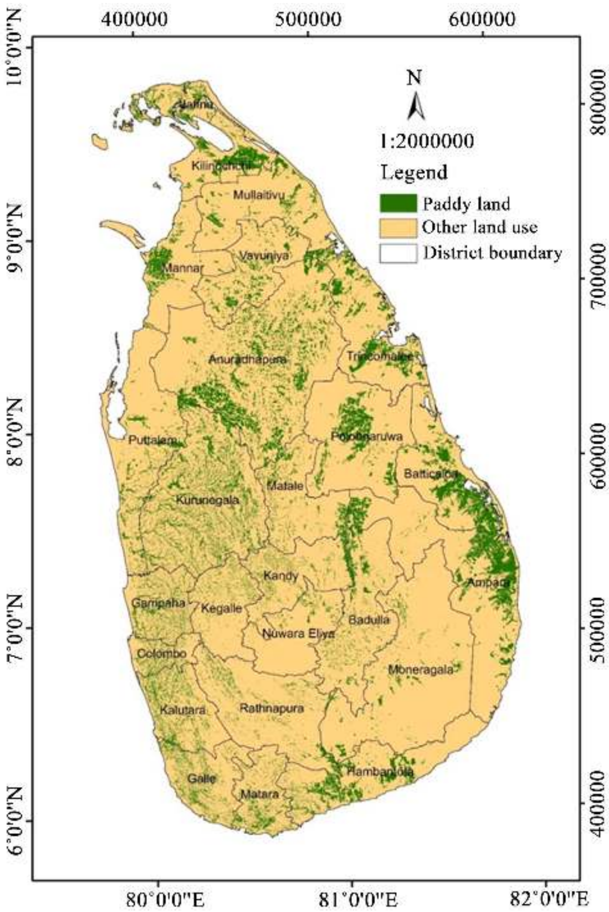


Figure 1. Paddy fields in Sri Lanka overlaid on Google Earth.

Table 1. Subsection of the information derived when identifying one km^2 grids in the country.

Grid-ID*	Paddy area (%)	Province	District	Divisional Secretariat Division (DSD)	Village name
130366	40.54	North Central	Anuradhapura	Mahavilachchiya	Mannaram Junction
136366	37.69	North Central	Anuradhapura	Mahavilachchiya	Palugaswewa
133365	66.78	North Central	Anuradhapura	Mahavilachchiya	Mahavilachchiya
199411	72.84	North Central	Anuradhapura	Padaviya	Sewa janapada
198410	39.97	North Central	Anuradhapura	Padaviya	Buddagala
199410	87.47	North Central	Anuradhapura	Padaviya	Buddagala
200410	48.01	North Central	Anuradhapura	Padaviya	Parakramapura
198409	43.27	North Central	Anuradhapura	Padaviya	Buddagala
199409	90.42	North Central	Anuradhapura	Padaviya	Buddagala
181369	56.09	North Central	Anuradhapura	Rambewa	Pihibiyagollwewa
182369	60.36	North Central	Anuradhapura	Rambewa	Pihibiyagollwewa

*X and Y grid numbers for each grid were generated using Universal Transverse Mercator (UTM) distance coordinates.

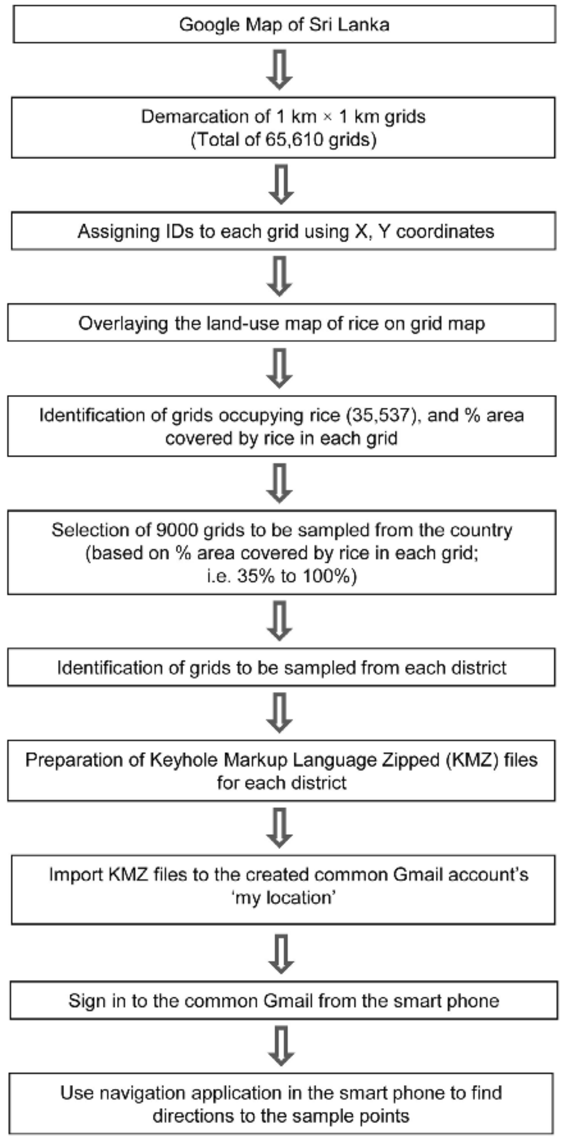


Figure 2. Flow chart explaining the development process of new sample collection methodology.

occupied with paddy lands whereas in some grids paddy lands contained only in a part of the grid (**Figure 3**). Therefore, the frequency of paddy lands as a percentage of one km^2 land area was right skewed indicating the presence of larger proportion of scattered small paddy lands in the spatial scale (**Figure 3**).

In the present study, we did not plan to explore all the grids having paddy lands in the country (*i.e.*, population), but decided to select 9000 samples (grids) in line with the resource availability and percentage paddy extent. We used two approaches to select the samples out of the total grids having paddy lands (*i.e.*, 35,537 grids). As the first approach, 1 km^2 grids containing paddy lands were arranged in an ascending order based on the percentage paddy extent in MS-Excel. It was noticed that the grids containing 100% paddy to 35% paddy could be sampled to reach 9000 sample limit. The selected 9000 grids were

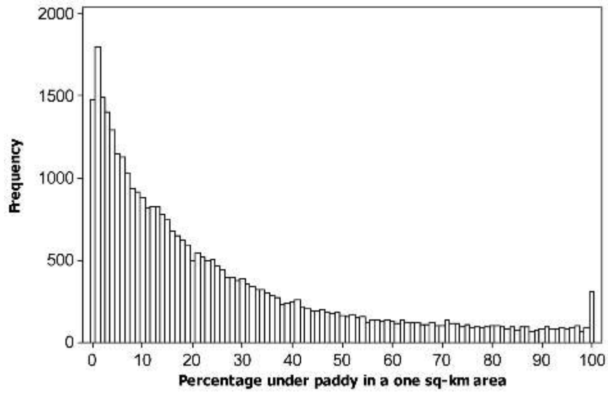


Figure 3. Frequency distribution of paddy lands in the country when the total paddy lands were separated into one km^2 grids (total grid number containing paddy lands was 35,537).

separated into different districts to study the representation from each district (Table 2). As the second approach, each district was given a quota based on the percentage paddy extent in a respective district out of the total paddy extent in the country through proportional allocation (Table 2).

Both methods generated similar and consistent results, therefore we decided to use the first approach to select grids for soil sampling (Figure 4). Once the respective grids were identified with the X and Y coordinates (Table 1), each grid was recognized using the Google Earth software. The grid was prepared based on 1:50,000 and 1:10,000 maps allowing the use of topo-maps during field investigations. The Google Map was used as the base map to facilitate finding of paddy lands. The grids were overlaid on paddy lands map using ArcGIS software. Point map containing center point of each grid was prepared using ArcGIS. Grid ID, district, divisional secretariat division, and the village name of each grid were documented for the purpose of mapping and sample collection (Table 1). After preparing the map using ArcGIS software, the sampling grids which were coded using grid-IDs were converted into a Keyhole Markup Language Zipped (KMZ) file. Keyhole Markup Language (KML) scripting has authorized geoscientist and other producers who use spatial data sets to display field data and maps in a three-dimensional interface [25]. Therefore, KMZ consists of several files to make up a single model [26]. A KMZ file contains place mark featuring a custom name; the latitudinal and longitudinal coordinates and location specific attribute data. In addition, a Gmail account with the name of "AHEAD.DOR@gmail.com" was prepared for the easy access of these Google Maps. Any sampler who has this e-mail address and the password could sign in and access the maps from any location. As the KMZ file consisting a total of 9000 sampling points of the country was large, 25 separate files having sampling points of each district were created (Table 2). Eventually, sampling points were navigated through Google Map application installed in a smartphone by the samplers in the field. Mapping procedure was carried out at the Natural Resource Management Centre of the Department of Agriculture, Sri Lanka.

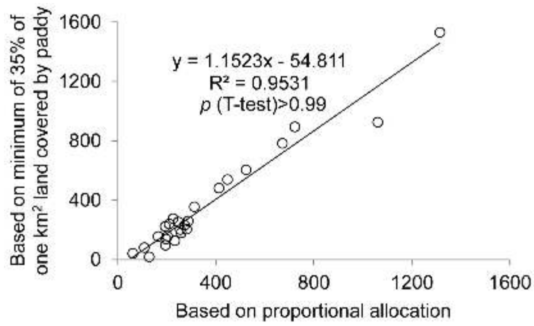


Figure 4. Relationship between the two approaches (as stated in **Table 2**) when selecting samples from 25 districts.

Table 2. District-wise paddy extent in the country and the number of samples allocated to each district based on the proportional allocation or representing over minimum of 35% of paddy area out of one km^2 grid.

District	Total paddy area (ha)	Number of samples based on the proportional allocation	Number of samples based on the minimum of 35% paddy land extent
Ampara	70,679	723	894
Anuradhapura	128,572	1315	1530
Badulla	28,141	288	260
Batticaloa	65,749	673	783
Colombo	10,626	109	81
Galle	24,989	256	202
Gampaha	25,367	259	180
Hambanthota	40,403	413	481
Jaffna	18,971	194	223
Kalutara	27,567	282	204
Kandy	19,063	195	97
Kegalle	12,597	129	19
Kilinochchi	30,608	313	355
Kurunegala	103,733	1,061	925
Mannar	221,489	227	276
Matale	19,851	203	157
Matara	19,265	197	139
Monaragala	16,092	165	156
Mullaitivu	20,565	210	240
Nuwaraeliya	6070	62	42
Polonnaruwa	43,820	448	539
Puttalam	26,719	273	231
Ratnapura	22,784	233	128
Trincomalee	51,248	524	605
Vavuniya	24,233	248	253
Sri Lanka	**879,862**	**9000**	**9000**

3. Results

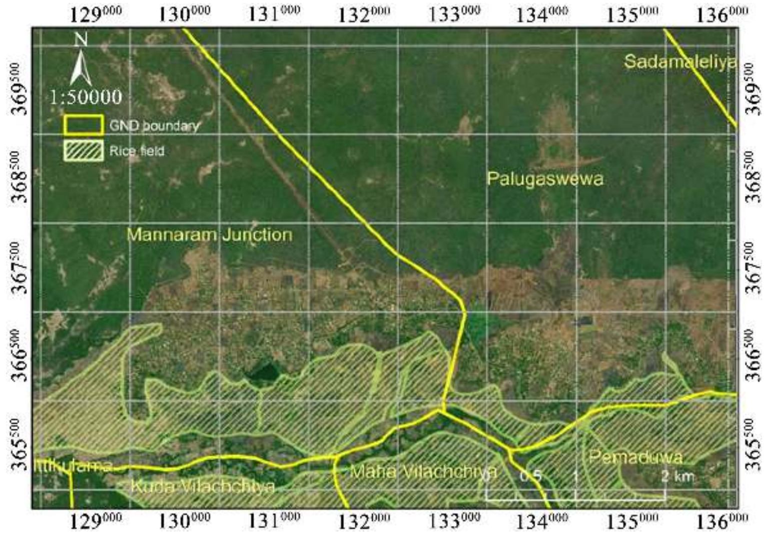
Village boundaries and one km^2 grids were overlaid on Google Earth software map. A sample area of 40 km^2 with "satellite view" of Google Earth software is shown in **Figure 5(a)**. Thereafter, sampling points (*i.e.*, grid-IDs) were inserted to the Google Earth software using GIS to create sample map (**Figure 5(b)**). Sampling points in the map could be easily identified using the "default view" than the "satellite view" in Google Earth software map (**Figure 5(c)**). Once a grid-ID is selected, samplers could navigate to those identified sampling points using Google Map android software from the "current location". Direction feature in the android Google Map software could be used to navigate to those sampling points (**Figure 6**). Once a sample has been taken from a grid, that grid could be tagged (♠) and be shared among other samplers in the field to avoid repetitive sampling (**Figure 6**). Moreover, the location of the coordinator in the field could also be shared within the sampling team (♣), enabling the samplers to reach the coordinator and hand over the collected samples with minimum effort (**Figure 6**).

With this GIS, GPS, Google Maps and smartphone based sampling method 8,809 samples across the country could be covered within 60 days with the use of twelve personnel travelling on 6 motor bikes. Therefore, the average number of samples collected per day was 150, at a rate of 25 samples per bike. Less than 1% of total sampling points could not be reached due to potential risk of those sites due to wild elephant attacks and floods.

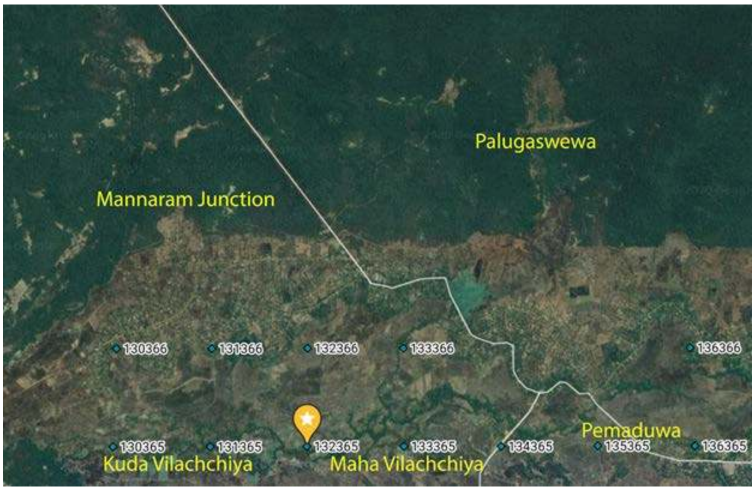
4. Discussion

The present study investigated the potential for employing a smartphone geo-browser in combination with freely available virtual/digital globe to develop a new sampling location tracking approach for large scale soil sampling. The results indicated that smartphone-mediated, Google Map-based novel method has remarkable accuracy, speed, and convenience to access sampling points without any assistance of the local people and awareness of the study region. Samplers were operating in the field in pairs using motor bikes and thus, reaching sampling points could be done much quicker. Because of this reason, a considerably high average number of samples per day per sampler could be collected. This was much needed as the sampling window was narrow *i.e.*, less than 70 - 80 days; from the end of minor cropping season (*Yala*) until the beginning of the land preparation for the major cropping season (*Maha*). Unless this type of sampling procedure based on the Google Maps and smartphone was not adopted, we would not be able to collect 9000 samples across 25 districts within 60 days. Moreover, the use of same group of samplers across the country ensured the collection of samples in a uniform and consistent manner minimizing person-to-person variability.

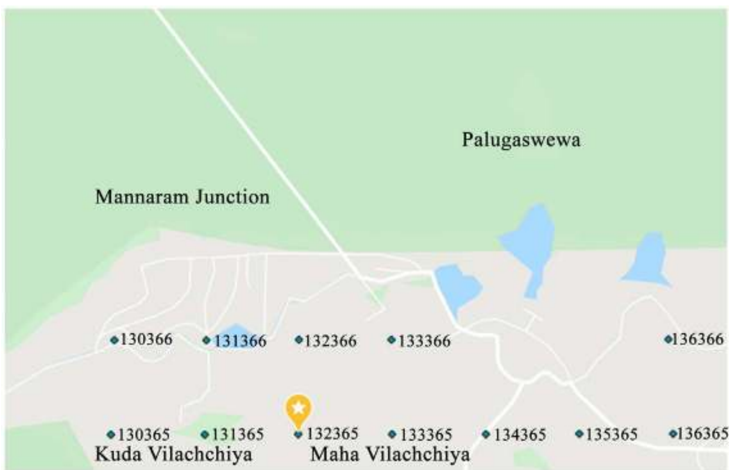
Due to the absence of efficient technologies, systematic and large scale surveys in agriculture and environment have not been conducted in Sri Lanka and in



(a)

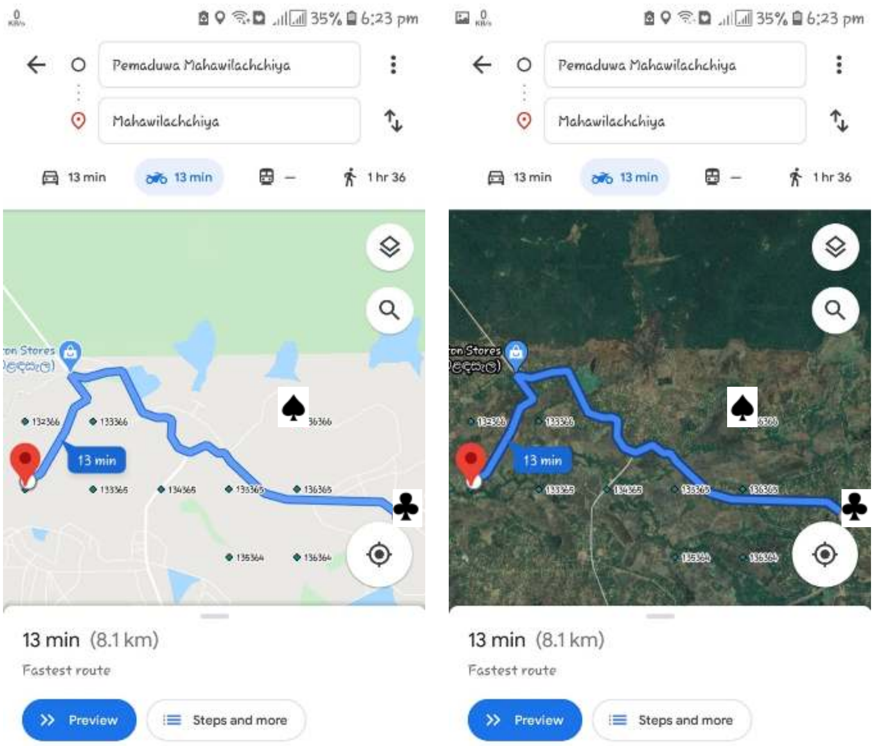


(b)



(c)

Figure 5. (a): Sample of the Google Earth software map after overlaying village boundaries and 1 km² grids; (b): Sample locations under the satellite view on the Google Map; (c): Sample locations under the default view on the Google Map.



(a) (b)

Figure 6. Screeshots displaying the direction feature in the Google map under default (a) and satellite (b) views.

most of the developing countries [5] [6] [7] [27] [28]. This has partly hindered the national, provincial or district level policy level decision making related to key issues such as provision of subsidized mineral fertilizers to Sri Lankan paddy farmers as the spatial heterogeneity in soil fertility and fertilizer management practices have not been tested and documented [29] [30]. Because of these reasons, resource-use efficiency, especially the nutrient-use efficiency in rice cultivation has become low and threats to environment pollution have increased [31] [32]. Nitrogen and phosphorus run-off from agricultural lands is a primary factor in the eutrophication of aquatic ecosystems [31] [32] [33] [34]. The smartphone-based rapid sample collection approach that we have developed could employ in large scale surveys across urban and rural areas in a selected geographical region with minimum cost and time. This will eventually be useful in generating and updating national and regional agriculture databases to be used in decision making.

Field sampling efficiency of any sampling frame depends on numerous factors such as weather, quality of infrastructure, natural disturbances, and institutional support [6] [7] [27] [28] [35] [36]. Motor bikes were used as the mean of transportation during sample collection. Use of motor bikes helped reaching sampling locations through roads and paths that were narrow and poor in quality with minimum disturbance, except for those in some areas of the country due to the floods and threats of wild elephants. In such instances, the alternate paths suggested by the Google Map android system were useful in reaching those sampling points. Therefore, the guidance provided by the android Google Map was enormously effective in maintaining higher sample collection efficiency, despite the field level disturbances.

When improving the effectiveness and efficiency of technology-based sample collection procedures, frequent and continuous updating of databases has great importance [21] [35]. Accurate and reliable agricultural information is the basis of the implementation of modern agricultural technologies [4] [37]. At present, the collection and processing of agricultural information from village level to national level is a complex process [7] [35] [36]. This requires development of portable agricultural information collection system with high degree of integration and a wide range of versatility such as GIS applications [4] [38]. For example, a key database used in this study was the land-use maps in Sri Lanka, which was developed in 2010. Since 2010 to-date, enormous changes may have occurred to the land-use patterns in certain areas, *e.g.*, areas identified as paddy fields in the land-use map were observed as forest covers at present, and *vice versa*, and certain paddy fields have now been used for construction purposes, road networks, and other infrastructure due to the expansion of industrial regions. Therefore, these mismatches observed between land-use maps and actual field observations in the field made us compelled not to collect certain samples, through the number was small (*i.e.*, less than 0.01%). This highlights the necessity of updating current land-use map of the country. When updating databases, frequent coordination and collaboration between line ministries and departments such as Department of Agriculture, Department of Agrarian Development, Department of Wild Life Conservation, Department of Forest Conservation, Department of Irrigation and Land Use Policy Planning Department are very crucial as the governance of certain lands/areas are made by (or shared by) different authorities. Moreover, the information and updates gathered from different institutions should be directed to a centralized institute to update the electronic databases regularly.

The software provided the direction to the center of one km^2 grid, which may not necessarily be a paddy land. In some instances, the paddy lands were located away from the center of a grid. Therefore, after reaching the grid it was necessary to refer to the "satellite view" of the Google Map and locate the paddy lands in that grid. After reaching the paddy land, minimum of four soil samples representing the heterogeneity of that paddy land were taken to produce one composite sample. For example, if the land is with a slope, samples were taken to represent upper, middle, and lower areas along the slope. Hence, the GPS of the exact locations from which samples were collected were not recorded. Therefore, in the present study, it is impossible to give the direction to the exact locations of paddy lands in a particular grid where the soil samples were collected.

In order to reach sampling locations using Google Map software, mobile internet coverage was required. Though this was achieved in satisfactory level in most instances, there were situations where the signal strength was very poor. In such instances, use of "offline map" feature available in Google Map android software helped overcoming the problem. The cutoff-level to obtain a sample from a paddy field was 35% of paddy distribution in one km^2 grid. Hence, the grids having less than 35% of paddy distribution were not selected in the survey. However, if funds and other resources are sufficient, those small, scattered paddy tracks also need to be surveyed.

5. Concluding Remarks

Out of the total land extent of 65,610 km^2 in the country, paddy lands were distributed in 35,537 km^2 grids. Out of 35,537 grids containing paddy, 9000 grids (sq. km) had more than 35% of paddy distribution. The novel sampling technique developed using GIS, GPS, Google Maps, and smartphone android system allowed the collection of over 99.9% of the target samples by six teams (each having two members) employed in the field within 60 days averaging 25 samples per team per day. Sample collection carried out in the study was more uniform and homogeneous. The new approach shows great promise to be applied in field sample collection in agriculture and environmental studies because the dependency on external resources such as local people, extra funds and materials were minimal. Overall, employing smartphone geo-browsers in combination with freely available virtual/digital globe has great potential for location tracking for large scale soil sampling efficiently and accurately, thereby improving sustainable fertilizer management strategies throughout the world. Therefore, this approach shows promise when require collecting large number of samples in wider spatial scale within a very narrow temporal scale.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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