GEO-SPATIAL APPROACH TO HERBICIDE SPRAYING DURING VIETNAM WAR

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Abstract
"Herbicide Sprayed Map 1962-1971" was published in 1999 by 10-80 Committee, which is Vietnamese governmental organization to carry out scientific researches mainly for health and environmental impacts by herbicide spraying during Vietnam War. This atlas aims to provide information on the distribution of herbicide sprayed tracts, paths and density to cover whole extent of Vietnam's territory. The maps are paper-based, and then each map has been digitally scanned and geo-corrected to make vector information for the sake of identification of herbicide contaminated area by so-called "orange", "blue" and "white" agent. Geographical Information System (GIS) and Landsat TM band 3 and 4 data captured on January 16, 1989 have been used to obtain Normalized Difference Vegetation Index (NDVI). In this paper, an experimental analysis has been conducted to compare each NDVI in accordance with herbicide sprayed and not sprayed area near Ben Tre province, southern part of Vietnam. By this comparison, statistically significant deference has been observed between each NDVI average of spayed and not sprayed area.

Introduction
Since 2001, a Japanese medical researchers' team has started studies on human impacts by herbicide spraying during Vietnam War. The study has been focusing on the concentration of Dixons in human blood, milk and fat, its relation to eyesight and diabetes as well as the analysis of environmental samples. These studies were targeted Quang Tri district for herbicide impacted area and Ha Tinh for not impacted area. However, locations of the study were not always right under the herbicide spraying tracts. Since 2005, joint research with spatial science has been started to specify the research target as closely as possible to the actual herbicide sprayed and environmentally damaged areas. As of the moment, every location of herbicide sprayed has been digitalized with GIS. Next, this study will concentrate on diachronic analysis of remote sensing data then identify the areas with least environmental changes after the war, and the results will be reflected on the epidemiologic studies later on.

Materials and Methods
1. Herbicide Sprayed Map
In 1999, Vietnam War related national organization named "10-80 Committee" published an atlas providing herbicide spraying based on the "Database on Vietnam war chemical and their human, environmental and ecological impacts" and "the Mapbook"[3]. The actual "Herbicide Sprayed Map" is consisted of three type of map information showing the distribution of 1) total amount of herbicide with regard to each agent covering whole extent of the country, 2) three graded (high, mid and low) quantity levels of sprayed agents and 3) sprayed tracts and paths. Figure 1 and 2 show the examples of category 2) and 3) in Quang Tri district.

2. Geo-correction
Every map of "Herbicide Sprayed Map" seemed to be originally created by MAPINFO, one of the major GIS software, but we could not obtain original digital data, then each map was digitally scanned with at least 5,000 × 5,000 pixels then geo-corrected by using Image Analysis. Careful geo-correction was conducted following two steps: for the first step, every map was originally drown by Universal Transverse Mercator (UTM) projection but only showed unknown datum of longitude and latitude, and then map data were roughly geo-corrected based on the values of longitudes and latitudes printed on the map. Second step: roughly geo-corrected maps were corrected again by using Landsat TM natural color imageries. These imageries were created by stacking three bands of TM sensor data. Landsat TM's 30×30m ground resolution seems to be quite enough for this purpose because the original scale of "Herbicide Sprayed Map" is as small as to 1:250,000. Figure 3 shows the process and final result of geo-correction covering the part of Da Nang district.

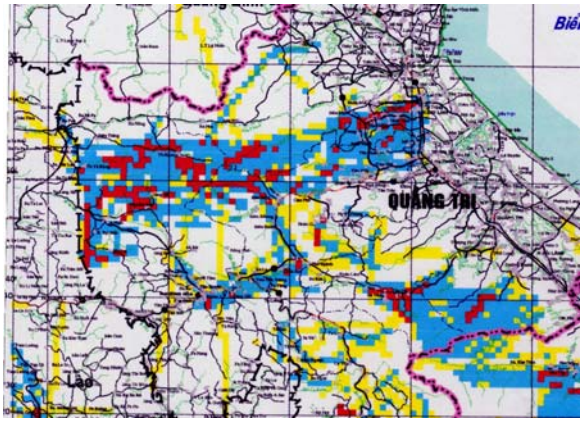

Figure 1.
Three levels of quantity of herbicide spraying

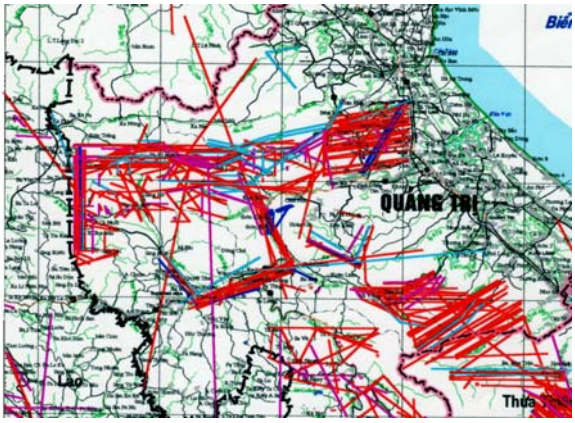

Figure 2.
Paths of herbicide spraying of each agent

3. Making Geographical Spatial Information

Geo-corrected maps were used to extract vector information for both herbicide contaminated areas and paths of spraying with unsupervised classification and manual tracing. Figure 4 shows the spraying paths of Agent Orange. Owing to these processes, it becomes easy to overlay each information: Figure 5 shows the overlaid image of Landsat TM mosaiced imageries and spraying paths of all types of agents throughout Vietnam.

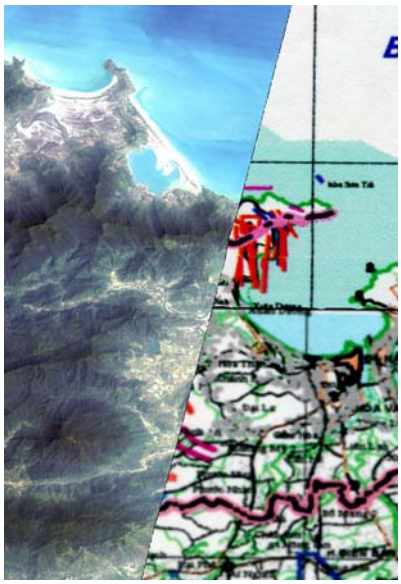

Figure 3

Figure 4

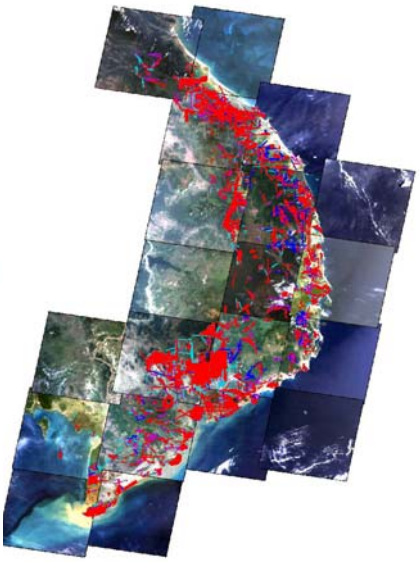

Figure 5

Figure 3: Process of geo-correction by Landsat TM imagery (Left side shows a natural color imagery created by Landsat TM band 1-3; right side indicates Herbicide Sprayed Map. Actual geo-correction was done mainly based on adjustments of locations of shorelines, rivers and roads)
Figure 4: Vector information extracted from Herbicide Sprayed Map (Data are stored by the shape format).
Figure 5: Overlaid Landsat TM mosaiced imageries with vector information covering whole extent of Vietnam.

4. Landsat TM

Artificial satellite Landsat is the longest running enterprise for acquisition of imagery of Earth from space. The

first Landsat was launched in 1972 and its remote sensing data have been received by the ground stations around the world. It is one the most unique resources for global change research for various kinds of fields such as agriculture, cartography and environmental science. TM (Thematic Mapper) is a sensor which is installed on Landsat to collect reflected and/or emitted electromagnetic energy from the visible, reflective-infrared, middle-infrared, and thermal-infrared regions of the spectrum. TM has a swath width of approximately 185 km from a height of approximately 705 km. It is useful for vegetation type and health determination, soil moisture and so forth. The spatial resolution of TM is 28.5 × 28.5 m for all bands except the thermal (band 6), which has a spatial resolution of 120 × 120 m. The larger pixel size of this band is necessary for adequate signal strength. However, the thermal band is resampled to 28.5 × 28.5 m to match the other bands. The radiometric resolution is 8-bit, meaning that each pixel has a possible range of data values from 0 to 255. Table 1 shows the relations between Landsat TM each sensor band and wavelength[4].

Table 1. Landsat TM sensors and their main purposes

Band	Wavelength	Purposes
1 Blue	0.45 to 0.52 μ m	For mapping coastal water areas, differentiating between soil and vegetation, forest type mapping, and detecting cultural features.
2 Green	0.52 to 0.60 μ m	Corresponds to the green reflectance of healthy vegetation. Also useful for cultural feature identification.
3 Red	0.63 to 0.69 μ m	For discriminating between many plant species. It is also useful for determining soil boundary and geological boundary delineations as well as cultural features.
4 Near Infrared Red (NIR)	0.76 to 0.90 μ m	Especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasizes soil/crop and land/water contrasts.

5. Normalized Difference of Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is a simple numerical indicator that can be used to assess whether the target being observed contains healthy live green vegetation or not. NDVI has also been shown to be correlated with green leaf biomass and green leaf area index. Chlorophylls, the primary photosynthetic pigments in green plants absorb light primarily from the red and blue portions of the spectrum, while a higher proportion of infrared is reflected or scattered. NDVI tends to increase with increases in green leaf biomass or leaf area index. Rock and bare soil have similar reflectance in the red and the near infrared, so these surfaces will have values near zero. NDVI is calculated from the following formula to obtain 8-bit integer of 0 to 255 for creating each pixel of imagery:

$$NDVI = ((NIR - Red) / (NIR + Red) + 1) \times 128)$$

6. Experimental comparison of NDVI between herbicide sprayed and not sprayed area

Typical herbicide sprayed and not sprayed areas, both seems to have the same type of original vegetation before the war time, are carefully selected for an experimental comparison of NDVI. The targeted Landsat TM data were captured on January 16, 1989. Thank you to the Global Land Cover Facility maintained by University of Maryland, data were able to download for free[5].

Figure 6 shows the NDVI black-and-white 256-graded imagery of target area, near Ben Tre province. Figure 7 shows the enlarged imagery of the analyzed areas with spraying paths of each herbicide agent. In this imagery, Area A shows the sprayed area and Area B does the not spayed area.

Results and Discussion

Fundamental spatial data and result of statistical analysis is shown in Table 2. As the values shown in this table, statistically significant difference ($p < 0.01$) has been occurred between each average of NDVI. This result implies that the impacts of herbicide spraying continued at least as of 1989, about 15 years after the Vietnam War. But it is needless to say that we have to confirm various factors which may affect the difference of NDVI. It may derive from artificial development and/or natural climate changes after the war. As of the moment, the authors

cannot conclude whether herbicide spraying impacts are sure to be reflecting on NDVI or not. NDVI is one of major and the most convenient index to access the conditions of vegetation, but many scientists and researchers point out its limitation. At the same time, however, we cannot support some research conclusions that environmental impacts of herbicide spraying had remained short because of evaporation and optical degradation of the herbicides: most of their results are based on experiments which had been done in the United States during or after the war, not based on the data obtained from the actual sprayed sites in Vietnam[6]. We will continue scientific researches 1) to make clear the duration of environmental impacts with geo-spatial and diachronic approaches, 2) to identify the areas where the impacts still continue, 3) to find out environmental factors to decide the fate of herbicides; every one of them will reflect the results of on-site monitoring in Vietnam.

Figure 6. 256 graded imagery of NDVI near Ben Tre Province

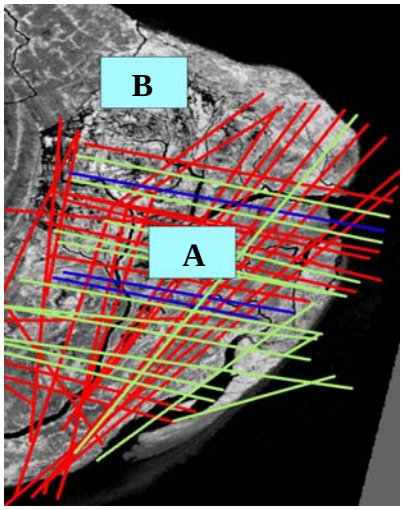

Figure 7. Enlarged imagery of target areas with herbicide spraying paths

Table 2. Fundamental spatial data and the result of analysis of NDVI (UTM, zone48)

	Area (ha)	Center of Northing, Easting	Average of NDVI	Variance of NDVI
Area A	430	1118588, 691790	138.84	6047.75
Area B		1124360, 690426	181.07	4717.76

Acknowledgements

This research has been conducted under corporations of 10-80 Committee of Vietnam and special thanks have to be dedicated to Dr. Tran Manh Hung for his offer of "Herbicide Sprayed Map". In addition, this research has been supported by Grants-in-Aid for Scientific Research of Ministry of Education and Science (No. 17406016, Research representative: Dr. Teruhiko Kido, School of Health Science, Kanazawa University).

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