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Assessing the long-term effects of famine on primary productivity in North Korea using Landsat TM/ETM+

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Abstract

In the mid to late 1990s, a severe famine occurred in North Korea. The famine was triggered by flooding, and as crops failed, people picked fields bare for the remaining sources of food, even stripping bark from trees. This may have led to widespread land degradation that has permanently reduced the agricultural productive capacity of North Korea, but due to the closed regime it is impossible to assess this on the ground. Remote sensing was therefore used to test this theory. Landsat TM/ETM images were processed to extract a vegetation index that was compared to monthly gridded global precipitation data, for both pre and post famine study periods. This revealed that the vegetation index was strongly correlated to preceding precipitation, as was expected, and that for the same level of precipitation, significantly lower vegetation index values were observed in the post-famine study period. These results support the theory that the famine led to a permanent reduction in primary productivity, however the study was forced to rely on an extremely limited public archive of Landsat TM/ETM images, which significantly constrained the length of the study periods and the temporal resolution within the study periods. A more detailed study that incorporates non-public Landsat TM/ETM archives as well as a comparison to a nearby reference site is needed to generate more conclusive results.

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1. Introduction

North Korea is a unique country in many respects. Its political system and official ideology – Juche – are perhaps among its most unique aspects. Juche is a blend of Stalinist central command economics, Marxist/Leninist rhetoric and Confucian values with a strong emphasis on national self-reliance. During the era of Soviet influence, North Korea was able to prosper as a component of the broader Eastern Bloc economy, primarily as an industrial producer. In the early 1990s, the Eastern Bloc began to collapse, as the policies of the Gorbachev government led to the eventual collapse of the Soviet Union. The loss of its primary benefactor and trading partners left North Korea isolated from the world, and while China stepped in to fill the power vacuum left by the Soviets, the transition was anything but smooth. Under the Juche ideology, North Korea turned inwards, and attempted to become entirely self sufficient in all production, including agriculture (Haggard & Noland, 2007). In the mid to late 1990s, a severe famine occurred in North Korea. Due to limited access by international media, the exact causes and extent of the famine remain unknown. What is known is that the famine was initially triggered by floods, and due to mismanagement spiralled out of control, to the point where people were eating crops before they were fully grown, stripping bark from trees and hunting small mammals for protein. As a result of the prevailing ideology and disengagement with international markets, there were insufficient food imports to cover the domestic shortfall. As the famine took hold, the centrally planned economy continued to dictate patterns of agricultural production, and harvests were collectivized and redistributed according to the priorities dictated by the ruling Korean Workers' Party (KWP). Without the right to cultivate private gardens, North Korean citizens were forced to gather food by any means possible (Howard-Hassmann, 2012). According to eyewitness accounts, this included stealing from state-run farms before a crop was fully developed, thereby reducing the total eventual yield, as well as hunting rodents and, in severe cases, even stripping bark from trees to make into soup (Kang, 2005). Given topsoil loss and other damage is likely to have occurred during the floods that initially triggered the famine, starving individuals picking the ground bare is likely to have led to further topsoil loss, collapse of terraces and other land degradation.

This study sets out to test the hypothesis that land degradation caused by the famine has permanently decreased the productive capacity of North Korean agricultural land, by using analysis of remote sensing data to attempt to identify a step-change in primary productivity around the time of the famine. Changes in biomass or net primary productivity can be measured by calculating vegetation indeces, based on the ratio of surface reflectivity at certain wavelengths. If this theory is verified, it has important implications for the long-term viability of the Juche ideology within the constraints of the North Korean environment. It also explores a mechanism by which civilians can use publicly available remote sensing data to gather agrometeorological intelligence, and assess the validity of production statistics issued by agencies of nation states.

1.1. Problem background

The famine of the mid to late 1990s in North Korea is largely attributable to macroeconomic and geopolitical conditions, combined with policies driven by the Juche ideology. North Korea's mountainous terrain and corresponding lack of arable land means that agricultural self-sufficiency is likely to be impossible; indeed, the famine proved this point. Prior to the mid-90s, North Korea could rely on trade with the Eastern Bloc to supply bulk grains and supplement domestic food production. With the change of Soviet policy under Gorbachev and then the collapse of the Soviet Union, this became impossible (Haggard & Noland, 2007). China filled the gap to an extent, but by the mid-90s both China and Russia began to demand market prices for agricultural exports to North Korea (Bluth, 2008). Various models have been proposed to ensure a secure food supply for North Korea into the future, including boosting domestic production, external trade and external aid. Given the constraints of the North Korean environment, only models that include food imports have been found to be viable in the long term (Noland et. al., 2001). The Juche ideology called for self-sufficiency as the solution, but China, Japan and South Korea – all countries with similar geophysical constraints - have experienced massive economic growth due to engagement with free markets to purchase the required bulk foodstuffs to feed their population (Haggard & Noland, 2007).

Official sources of information concerning agricultural production in North Korea are difficult to obtain, and those that are provided are of unreliable integrity (Haggard & Noland, 2009). The North Korean government does publish various statistics on population, agricultural output and rationing, but these data are inconsistent, published infrequently, and generated using unknown methods or methods that are subject to heavy skewing. For example, official population figures show the population continuing to expand at the official rate of 1.5% throughout the famine, while all other estimates show a sharp population decline (Lee, 2005).

Based on the figures that are available, agricultural production in North Korea peaked around 1989 and has fallen since then. The decline directly coincides with the collapse of the Eastern trading bloc, which led to shortages of fuel, fertilizer and machinery. By 1994, food shortages began to emerge. In July and August 1995, catastrophic floods wrought destruction on the country's remaining crops. The area of arable land in North Korea totals 1.58 million hectares, 15% of which was destroyed by the floods (Noland et. al., 2001). The political situation meant that free market mechanisms were not available to cope with this, and the shortfall in domestic production meant a shortfall in available food for the country's population. The state-run public distribution system (PDS) collapsed, and employees of state-run enterprises ceased to be provided with the rations upon which they relied to survive. The outside world began to become aware of the extent of the famine due partially to the testimony of North Koreans who had fled the country in search of food. 1997 marked the peak of the famine, according to the consensus of reports from North Korean refugees. The World Food Programme (WFP) assessed the situation with eyewitness accounts and described the country as being "on the knife edge of a major famine" (Lee, 2005).

1.2 Food balance data

Estimates of famine-related deaths in North Korea vary widely. Some put it on the order of 2.8-3.5 million based on extrapolation of data from a single province, while US congressional staffers put it at 900k – 2.4 million. South Korean sources estimate 1.6-3 million deaths between 1994 and 1998, peaking in 1997 (Haggard & Noland, 2009 / Lee, 2005).

To arrive at such figures, food balances are generated, which tally food availability (domestic production + imports + foreign aid) against human demand. A food balance based on undisclosed sources is shown in figure 1 as an example.

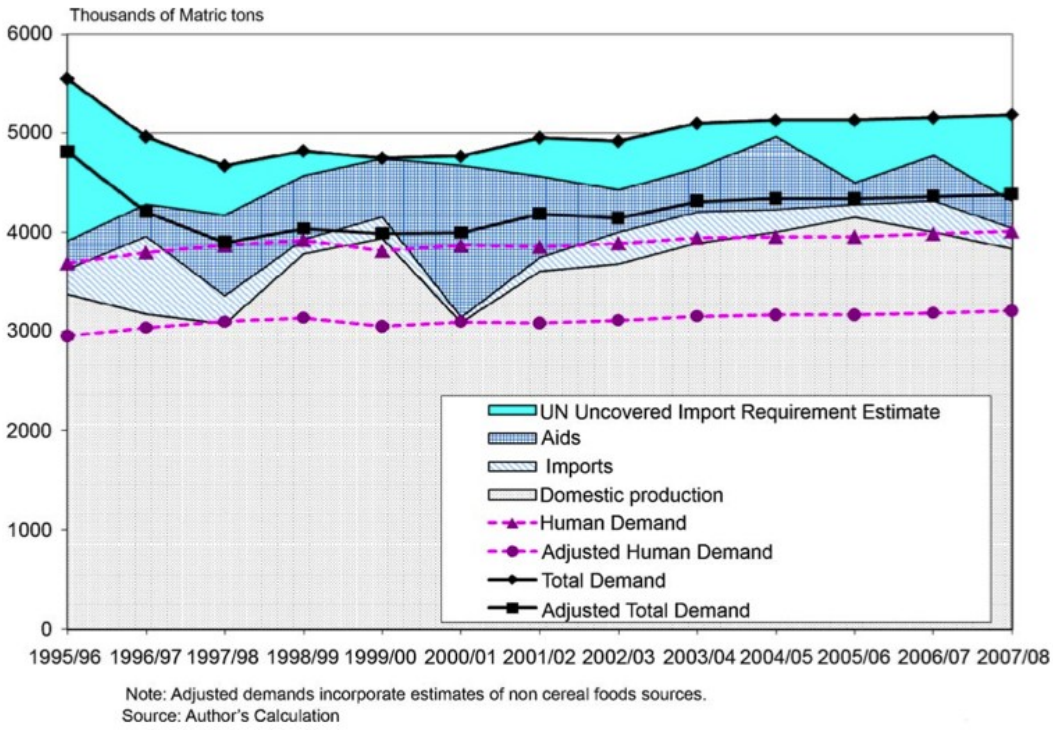

Figure 1. North Korean food balances, 1995/6 to 2007/8. Source: Haggard & Noland, 2009.

To estimate demand requirements, a population estimate is multiplied by the standard caloric requirements for human nutrition. On the supply side, domestic production is the biggest component. Since production cannot be measured directly, figures are based on combined estimates of acreage and yields. Acreage is measured through satellite imagery, although the satellite and sensor from which this imagery is taken is not clearly stated. There are various ways of estimating yields, with no consensus technique. For example, the (South) Korean Rural Development Administration (KRDA) uses satellite imagery combined with model farms employing North Korean techniques to estimate yield per acre. The United Nations Food & Agriculture Organization (FAO) uses selective field sampling to estimate yields. This approach may be accurate locally, but it is more broadly constrained by access to fields for sampling. For political reasons the North Korean government may only allow sampling of productive fields, which would not provide an accurate proxy for the rest of the country (Haggard & Noland, 2009). The FAO estimates for 1981-2012 are shown in figure 2 below.

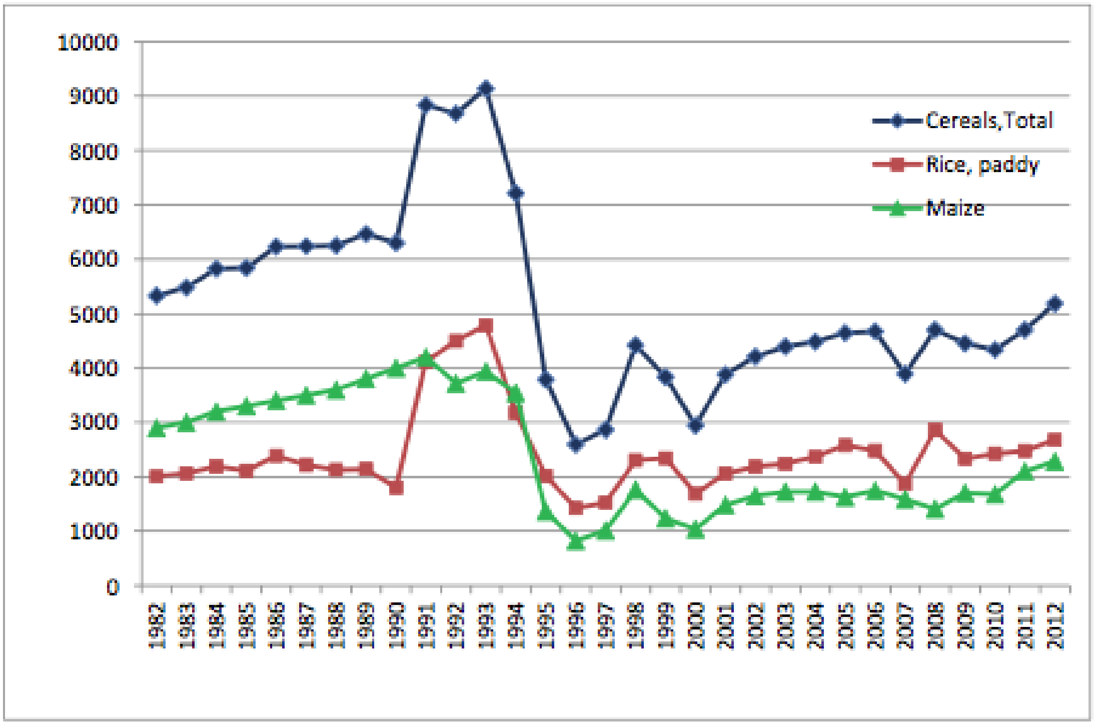

Figure 2: North Korean domestic cereal production, 1981-2012 (thousands of tonnes). Source: United Nations Food & Agricultural Organization (FAO)/World Food Programme (WFP), 2012.

The North Korean government itself does publish various statistics on population, agricultural output and rationing, but as previously mentioned, these data are inconsistent, published infrequently, and generated using unknown methods or methods that are subject to heavy skewing (Lee, 2005). The official figures shown in figure 3 are for a single province, but are clearly different from the FAO and WFP figures shown in figure 2.

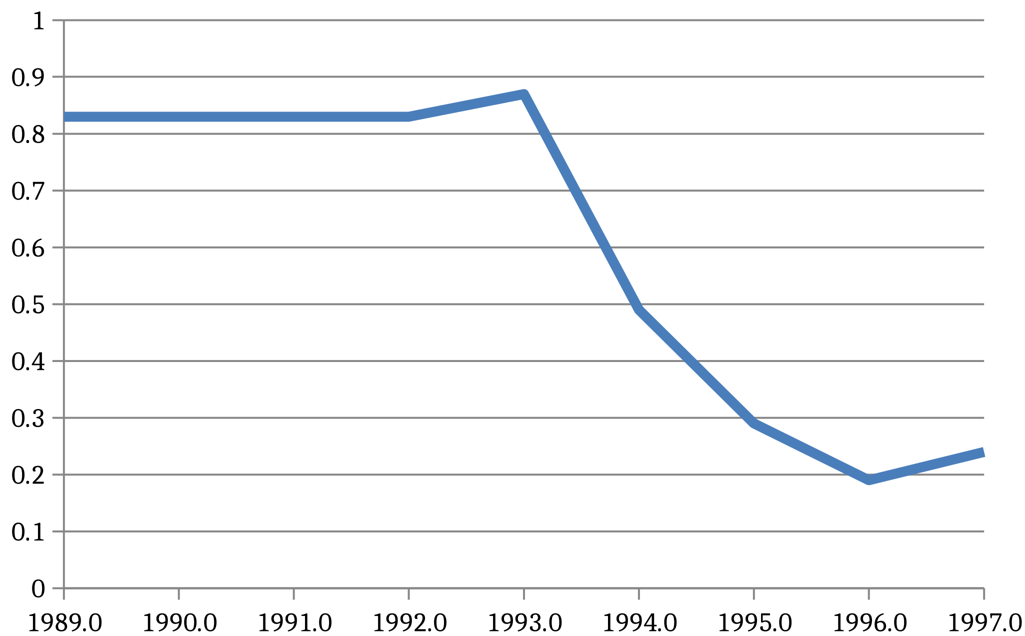

Figure 3: Rice and Maize production in North Hwanghae province, 1989-1997. Source: Democratic Peoples Republic of Korea (DPRK)/United Nations Development Programme (UNDP), 1998.

The study being proposed is predicated on the premise that the North Korean government's own figures are not accurate or reliable, and that remote sensing should be employed not to calibrate the official figures, but to substitute for them. This is not the first attempt to use remote sensing in such a way to gauge North Korean food production.

1.3 Previous remote sensing analysis

The Joint Research Centre of the European Commission (JRC) operates an agrometeorological program that periodically publishes bulletins on North Korean food production. These bulletins are based on modeled precipitation and a remotely sensed vegetation index. The rainfall data are derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) numerical model, which provides gridded data with a spatial resolution of 0.25 degrees. The vegetation index is taken from the SPOT-VEGETATION archives provided by VITO. These are created by calculating the normalized difference vegetation index (NDVI) from the SPOT VEGETATION sensor, with a resolution of 1km^2. The NDVI values are time smoothed to reduce noise from cloud coverage and aerosols. Flat areas, defined as those with a mean surface slope of < 2 degrees, are classified as rice growing, while areas with a mean surface slope between 2 and 8 degrees are classified as maize growing (Joint Research Centre of the European Commission, 2009). Figures 4 and 5 show example products of the JRC analysis for a single major agricultural province.

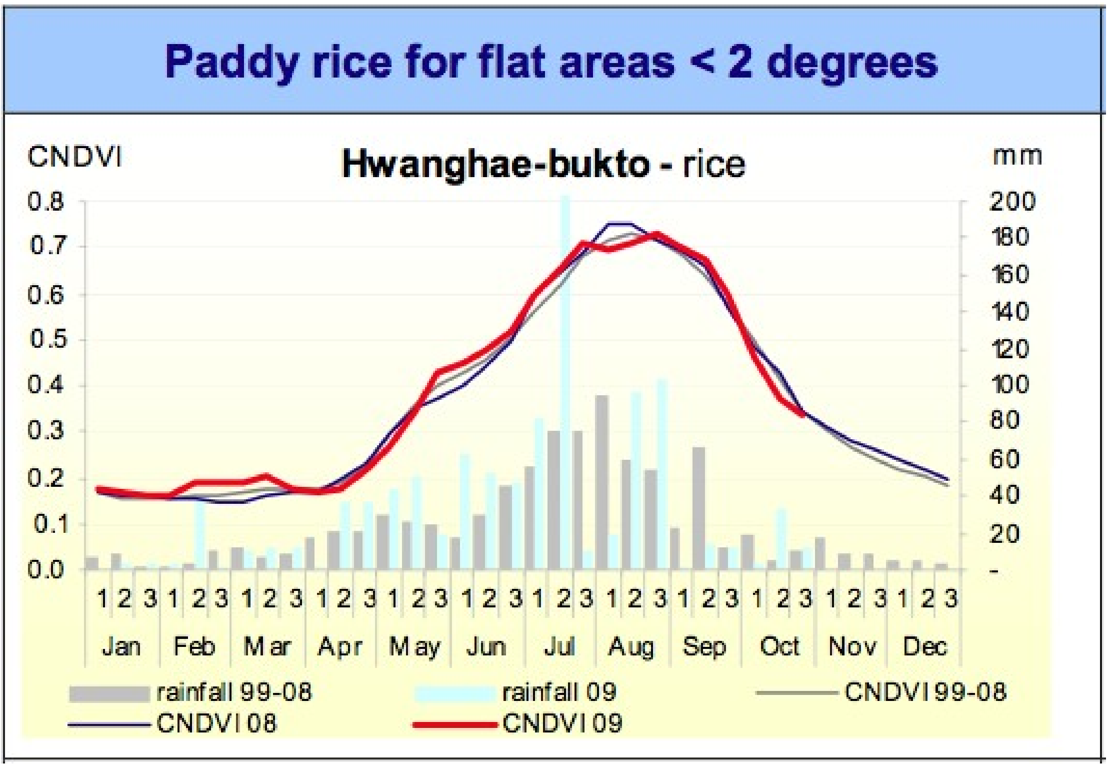

Figure 4: Estimated rice productivity in North Hwanghae Province in 2009. Source: Joint Research Centre of the European Commission, 2009.

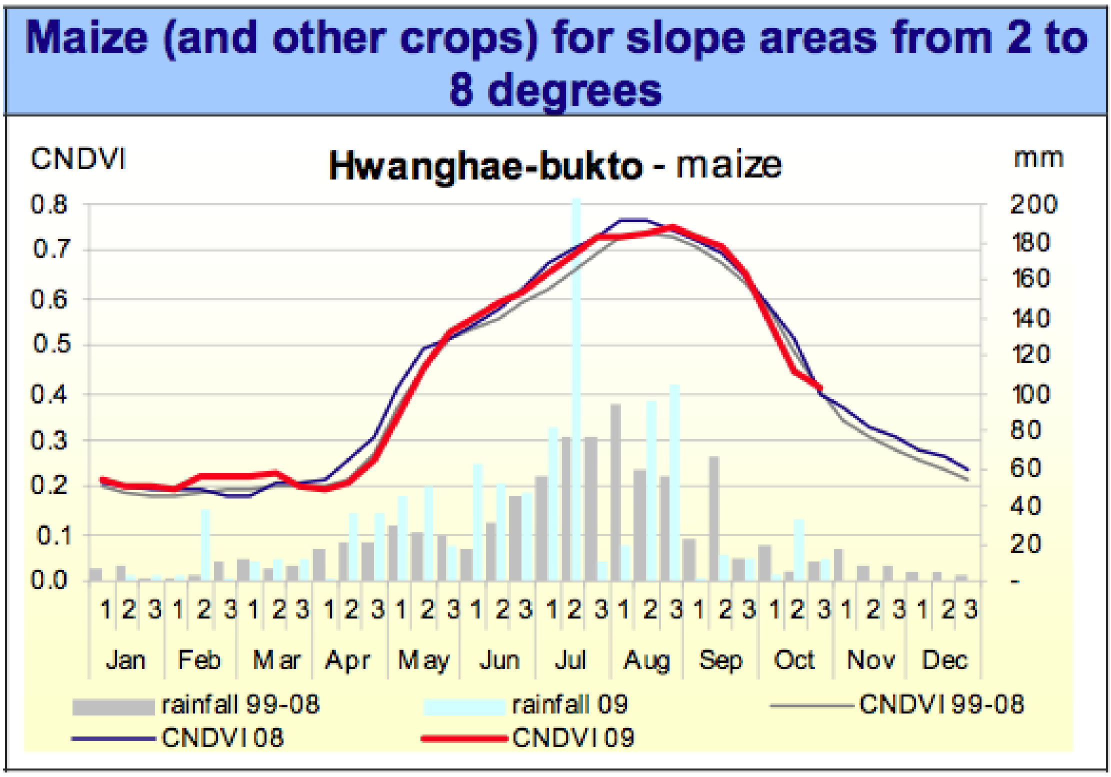

Figure 5: Estimated maize productivity in North Hwanghae Province in 2009. Source: Joint Research Centre of the European Commission, 2009.

These data are only published periodically by JRC, with no historical archive that could be used to analyze the period of the 1990s famine.

2. Methods

This study calls for analysis of long-term multi-spectral imagery with suitably high spatial (< 100m) and temporal (monthly) resolutions. The SPOT-VEGETATION data used by the aforementioned JRC analyses only extend back to 1998, so they are not appropriate. Landsat images from the multi-spectral scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) are potentially an ideal data source for this study. Landsat TM imagery is available back to 1982, with a temporal resolution of 16 days (NASA, 2012). This imagery and corresponding metadata is freely available. Landsat TM imagery is broken down into scenes with a size of 185km x 172km. Due to time and resource constraints, it is necessary to focus this study on a single Landsat TM scene.

2.1 Site selection

The selected Landsat TM scene must encompass a major productive agricultural region within North Korea. Production of food grains is concentrated in the eastern part of the country surrounding the capital, in the provinces of North and South Pyongan and North and South Hwanghae. As shown below in table 1, these provinces combined account for a large proportion of the country’s grain production, while occupying a relatively small area.

Province	Paddy			Maize		
	Area	Yield	Prodn.	Area	Yield	Prodn.
	‘000 ha	t/ha	‘000 t	‘000 ha	t/ha	‘000 t
Pyongyang	21	5.2	112	7	4.4	31
S. Pyongan	82	5.8	471	60	3.7	222
N. Pyongan	101	4.9	494	89	4.1	368
Chagang	7	5.1	34	35	3.6	127
S. Hwanghae	142	4.2	598	89	4.1	364
N. Hwanghae	61	5.0	307	82	4.1	334
Kangwon	30	4.0	121	37	3.7	138
S. Hamgyong	63	4.8	303	61	3.9	239
N. Hamgyong	27	3.8	103	54	2.9	158
Ryanggang	1	3.0	4	8	2.1	16
Nampo City	28	4.8	133	9	4.7	43
DPRK	**563**	**4.8**	**2 681**	**531**	**3.8**	**2 040**

Table 1: Main-season crop area, yield and production of grains in North Korea in 2012, broken down by province. Source: United Nations Food & Agricultural Organization (FAO)/World Food Programme (WFP), 2012 (table 6).

These provinces further represent a good choice of site as they have historically been more accessible to the World Food Program and other outside observers, meaning that the ground truthing provided by WFP estimates for these provinces is of a higher quality for calibration of the remote sensing estimates. During the peak of the famine, the North Korean regime tightly controlled access to most parts of the country, as shown in figure 6.

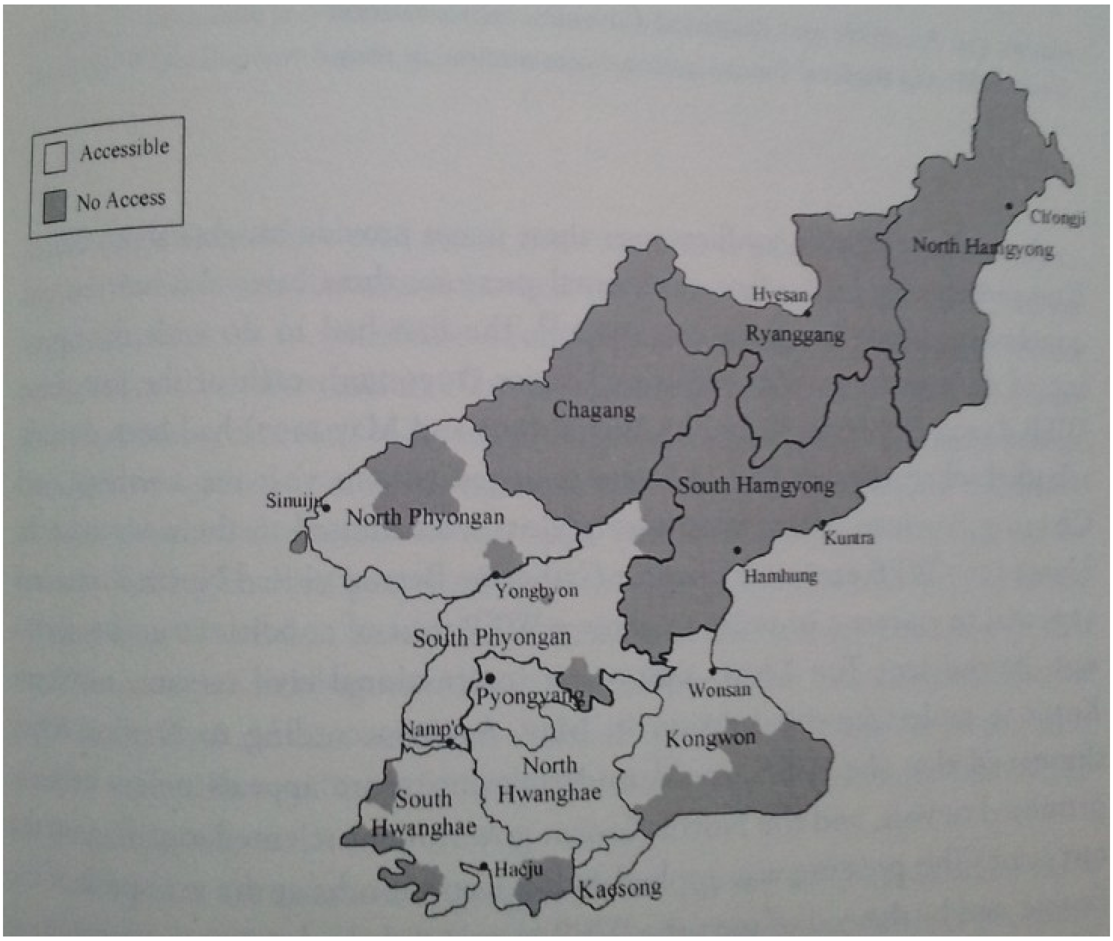

Figure 6: Accessible and restricted counties of North Korea in 1995-1996. Source: Haggard & Noland, 2007.

Furthermore, a single Landsat TM/ETM+ scene (path 117, row 33) neatly encapsulates this region, encompassing parts of all four aforementioned provinces, as well as the capital Pyongyang. While this scene also includes a sizeable portion of ocean, it is the only available scene that both encapsulates a major agricultural region and is entirely contained within the borders of North Korea. The selected scene is shown as a map overlay in figure 7.

Figure 7: Landsat TM/ETM+ scene Path: 117, Row: 33. Source: USGS, 2012.

2.1.1 Climate data

A study in China using high resolution gridded NDVI and precipitation data from standard meteorological stations found a strong correlation between NDVI and precipitation, with a coefficient of correlation of 0.96. The same study also considered NDVI and temperature, yielding R^2=0.86 (Bi et. al, 2005). This demonstrates that precipitation is well correlated to NDVI under normal conditions, and that significant variation between observed NDVI and precipitation would indicate anthropogenic factors. This permits a degree of distinction between variation in NDVI due to climatic factors and variation in NDVI due to anthropogenic factors or long-term environmental damage.

The State Hydro-Meteorological Administration (SHMA) is North Korea's meteorological agency. While the SHMA is a member of the World Meteorological Organization (WMO) and shares reference data from 27 sites on the WMO Global Telecommunication System (GTS), no public archive of these data could be located, and they are unlikely to extend back for a sufficient period in time to facilitate this study if they could be obtained (SHMA, 2011). It is therefore necessary to rely on gridded global datasets that include North Korea.

The National Oceanic and Atmospheric Administration (NOAA) provides the Global Precipitation Climatology Centre (GPCC) data set freely. The GPCC data are available in several forms, with temporal coverage extending back to 1901 in one form. The GPCC monitoring product covers from 1986 to present, providing gridded precipitation values with a 1 degree spatial resolution and a monthly temporal resolution. This product is generated by interpolating observation data from SYNOP, CLIMAT and other messages transmitted via the WMO GTS onto a grid. This is based on data from more than 8100 stations, presumably including North Korean stations which, as noted above, transmit messages via the GTS (Rudolf et. al., 2010). The GPCC data are therefore a reasonable source of precipitation measurements against which to compare the vegetation index values. The GPCC spatial and temporal resolution is limited, but is potentially sufficient to highlight a longer-term change in vegetation indeces not well correlated to a corresponding change in precipitation, which would support the hypothesis being tested.

2.1.2 Study area

To constrain the scope and maximize the accuracy of the study, a 1x1 degree grid cell was selected as a study area. This study area must be entirely contained within the selected Landsat TM scene, encompass a productive agricultural area, and map exactly to a grid cell from the GPCC data. This will make comparison with precipitation data straightforward. The most suitable study area according to these criteria is the area bounded by 125°E 39°N, 125°E 38°N, 126°E 39°N and 126°E 38°N.

A manually digitized polygon was defined to bound the study area, as shown in figure 8. This polygon was drawn to ensure that it fell within the defined 1x1 degree area, included known core agricultural areas, and excluded ocean, major cities, river mouths and scene edges where data may be unreliable. The polygon was checked against MODIS land cover data for the year 2002. The vast majority of the study area is classified as Croplands (12), with some areas of Cropland/Natural vegetation mosaic (14) and Mixed forest (5) (USGS, 2012b).

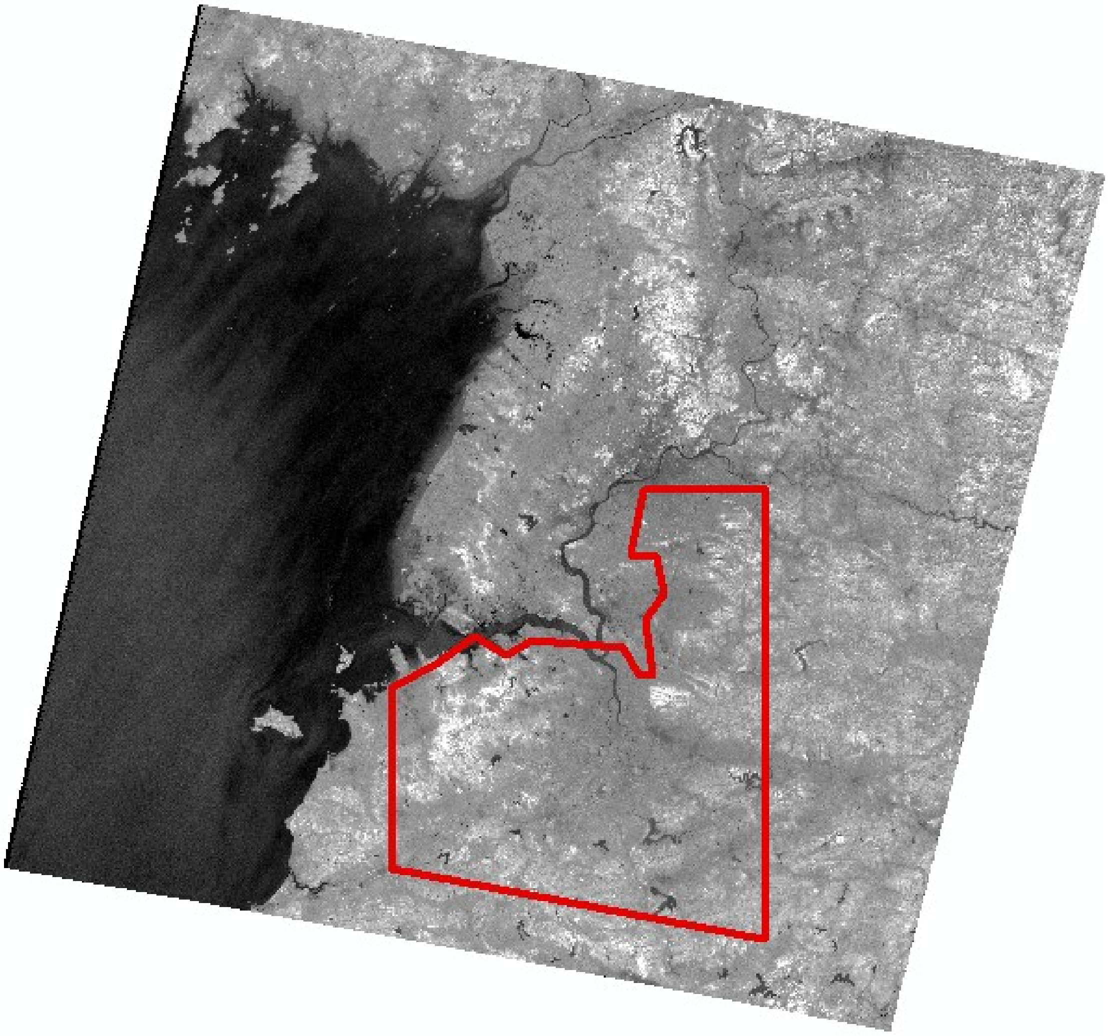

Figure 8: Manually digitized polygon bounding the study area, shown within Landsat TM scene path: 117, row: 33

2.2 Data acquisition

The availability of public Landsat TM/ETM+ scenes was an unexpected constraint to this study. While the USGS public archives extend back to 1982, they only have comprehensive coverage for scenes that are collected by a United States ground station (USGS, 2012c). Scenes for path: 117, row: 33 were usually collected by the Hatoyama ground station run by JAXA. These scenes are not made publicly available by JAXA, and at the time this study was conducted, Restec (the commercial agency responsible for selling scenes collected by JAXA) was not operating due to a computer security breach. A limited number of scenes have been imported into the USGS archives, and it was on these scenes that this study was forced to rely. This proved to be a significant constraint; once scenes that had cloud cover > 10% or ETM+ SLC-OFF were omitted, the only reasonable way to approach the original problem was to look at two three-year periods, one before the famine (1991-1993) and one after the famine (2000-2002). The selected scenes are listed in Appendix A.

GPCC total monthly precipitation data was acquired for the grid cell bounded by 125°E 39°N, 125°E 38°N, 126°E 39°N and 126°E 38°N for each month within the two three-year study periods.

2.3 Data analysis

For each Landsat TM/ETM+ scene, an NDVI layer was calculated from the Red and NIR bands, using the formula:

NDVI = (NIR - RED) / (NIR + RED)

This layer was then clipped to the study area polygon. For each clipped NDVI layer, summary statistics were computed, including mean and standard deviation. The mean NDVI values were then compared to the corresponding precipitation from the GPCC data. The time delay between a rainfall event and response in NDVI has been estimated to be up to 4 weeks in typical environments (Wang et. al., 2003). Therefore, the total monthly precipitation for the month in which the scene was recorded, and the preceding month, were used. If the scene was taken within the first week of a month, then the total precipitation for the two preceding months was used.

In order to establish some evidence for the hypothesis being tested, it is important to be able to demonstrate that a change in NDVI occurred after the famine which is not simply the result of differing rainfall. Since precipitation and NDVI are strongly positively correlated, any significant change in NDVI for the same amount of rainfall needs an explanation, and land degradation due to the famine is a potential explanation.

3. Results

The mean NDVI calculated for each scene is shown in figures 9 & 10, on a scale of -1 to 1.

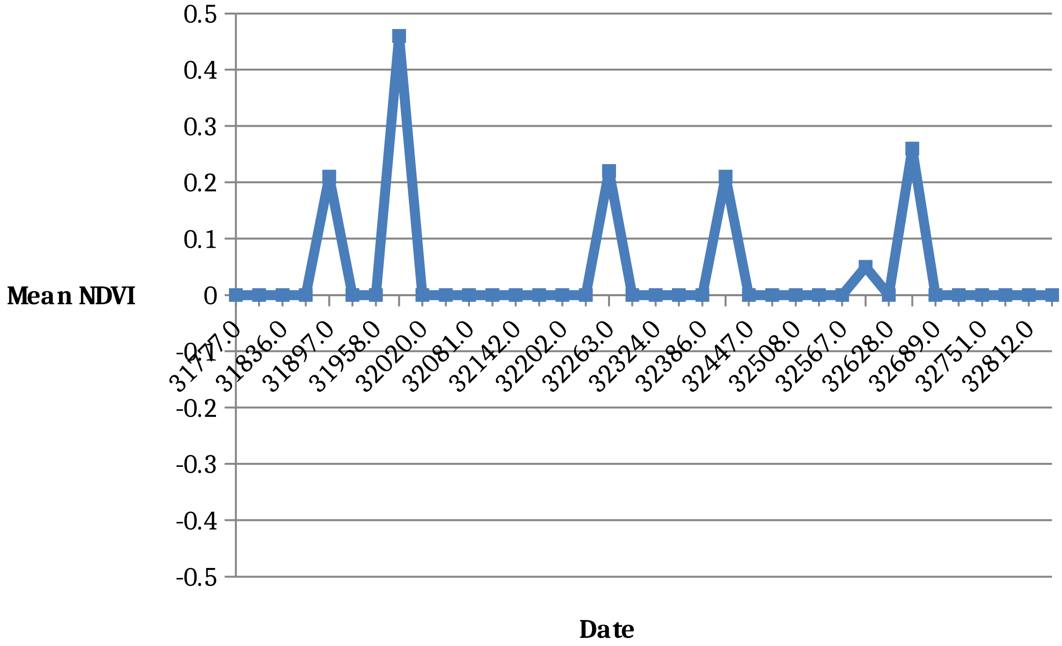

Figure 9: Mean NDVI for scenes processed in the pre-famine (1991-1993) period.

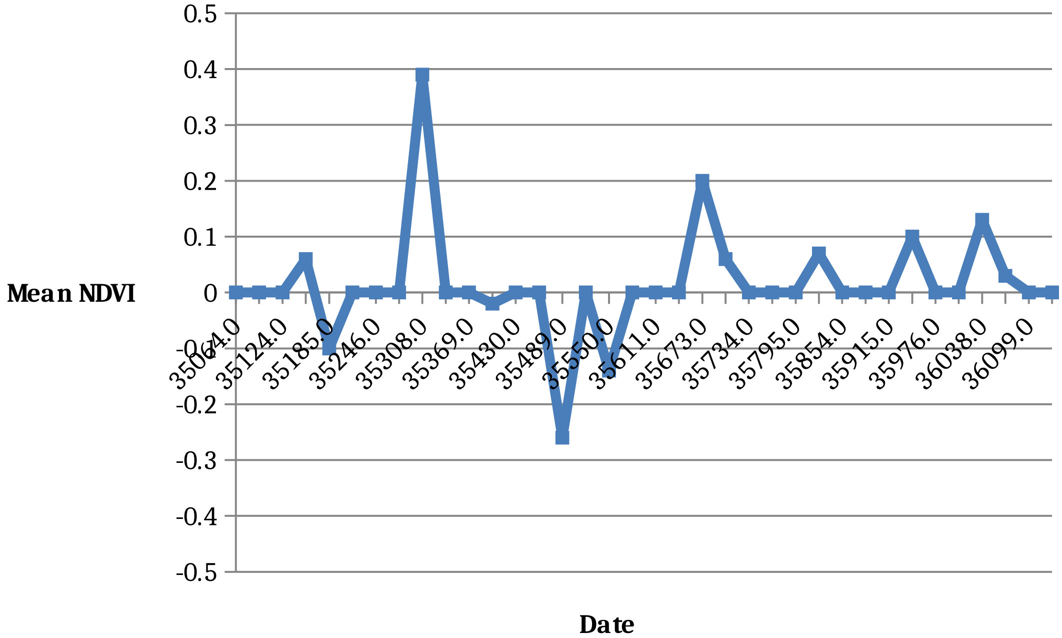

Figure 10: Mean NDVI for scenes processed in the post-famine (2000-2002) period.

At first glance it is clear that the mean NDVI is consistently lower across the 2000-2002 period. The monthly precipitation for both the pre and post famine study periods is shown below in figures 11 & 12. By visual inspection, it can be seen that the mean NDVI roughly corresponds to rainfall for the same period. However, it is also clear that the 1991-1993 data in particular are too sparse to reflect the full rainfall trends across the study period. For example, the major rainfall event in July 1993 is not captured, as the latest scene processed for this period was from 07 July 1993.

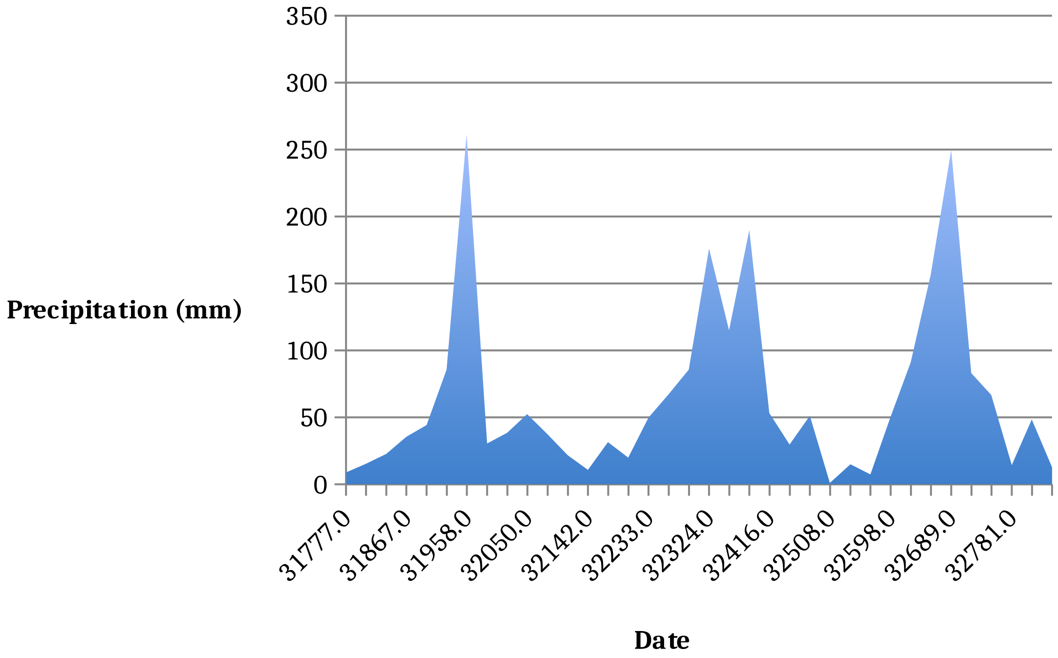

Figure 11: Monthly precipitation 1991-1993. Source: GPCC.

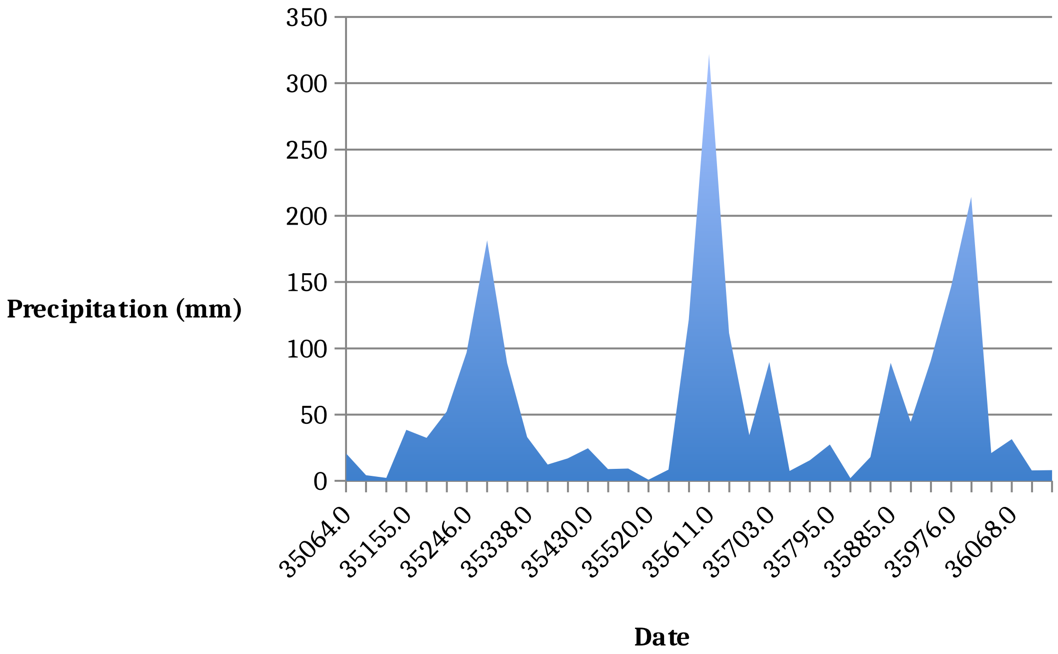

Figure 12: Monthly precipitation 2000-2002. Source: GPCC.

While the 1991-1993 data are indeed too sparse, they do demonstrate a strong positive correlation between NDVI and rainfall, as shown in figure 13. Compared to the 2000-2002 data shown in figure 14, the linear regression line has approximately the same slope (0.001) but has a significantly different intercept (0.056 compared to -0.107). This shows that the relationship between NDVI and rainfall is consistent between the two periods, but that for the 2000-2002 period, the same quantity of rainfall corresponds to significantly lower NDVI.

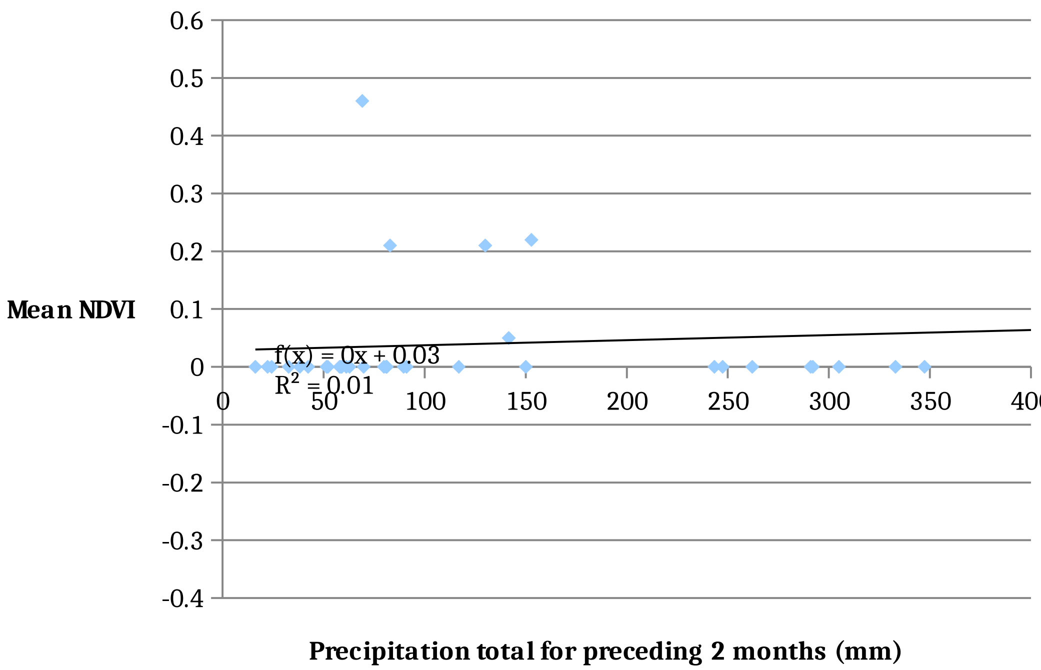

Figure 13: NDVI compared to rainfall 1991-1993.

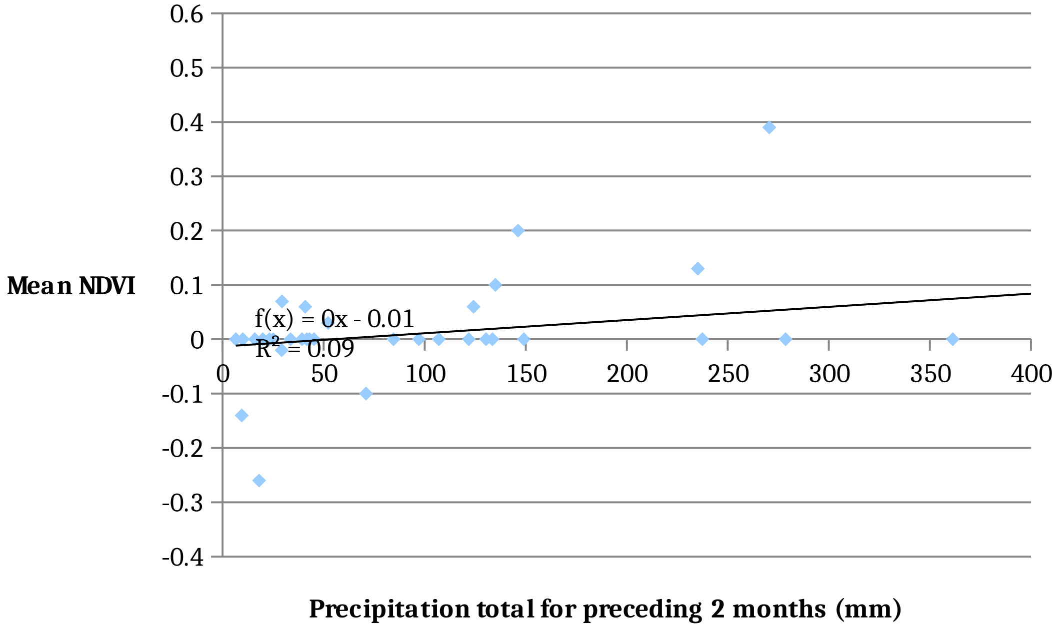

Figure 14: NDVI compared to rainfall 2000-2002.

The 2000-2002 period includes a large number of scenes that correspond to low rainfall (< 50mm), which the 1991-1993 period does not. Figure 15 shows NDVI compared to rainfall for 2000-2002 with the low rainfall scenes removed. The regression line equation remains very similar, so these low rainfall scenes do not appear to be the cause of the discrepancy in NDVI/rainfall relationship between the pre and post famine periods.

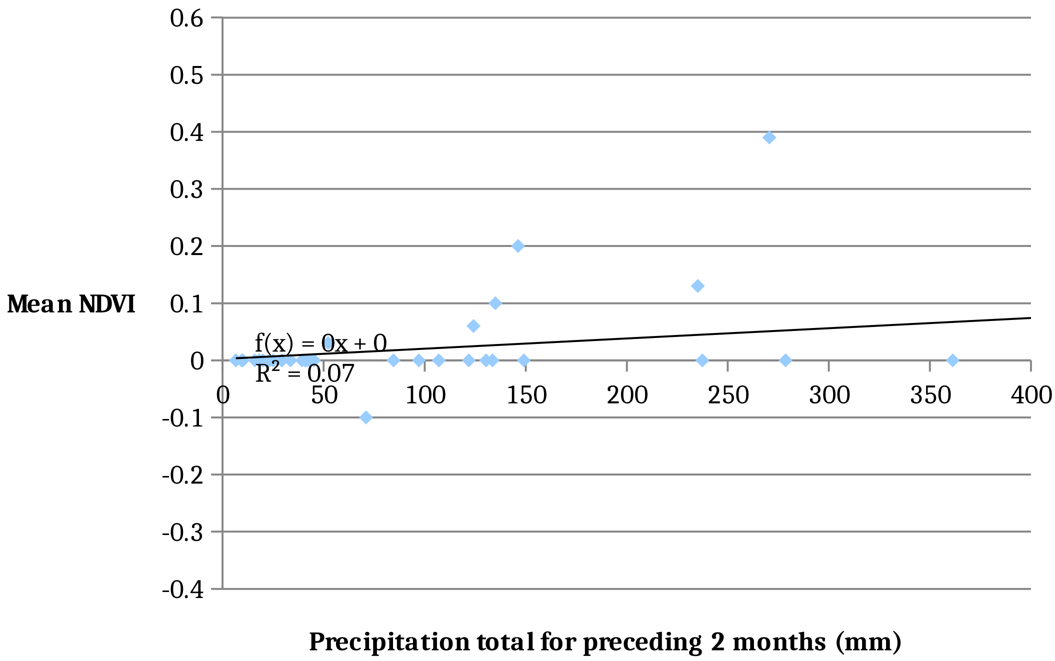

Figure 15: NDVI compared to rainfall 2000-2002, excluding data where precipitation total for preceding 2 months is < 50mm.

This provides some tentative support for the hypothesis this study set out to test.

4. Discussion

While the results show that the same rainfall corresponds to lower NDVI for the post-famine period, there are several flaws in this study that preclude drawing anything but a tentative conclusion from this. The most critical flaw is the lack of Landsat TM/ETM data, especially for the pre-famine period. For a stronger conclusion to be drawn, it would be necessary to access the complete set of available scenes from JAXA, and improve both the temporal range and temporal resolution of the study. This would also support a more rigorous statistical approach to comparing the pre and post famine periods. The ideal technique would be interrupted time series analysis, showing the trend in relationship between precipitation and NDVI both before and after the famine. Due to the lack of data, this technique was not feasible, and it was necessary to rely on a simple comparison of the linear regression equations for the before and after famine data sets. Precipitation data with a finer spatial and temporal resolution would also improve the analysis, but no such data are publicly available.

If such a more rigorous analysis produced results that match those of this study, it would still be difficult to establish the causative factor for the decline in NDVI response to rainfall after the famine. For example, North Korean agricultural practices in the 1980s may also have resulted in land degradation. In order to boost productivity during the 1980s, the North Korean government mandated continuous cropping and excessive application of chemical fertilizers. This is likely to have led to a decline in soil health and quality. Simultaneously, agriculture was expanded into areas not well suited, leading to denudation and soil erosion (Noland, 2007).

It is also possible that the decline is due to broader environmental factors that are not limited to North Korea, and not a result of the famine or North Korean policies. One way of testing this would be to perform the same analysis for a nearby study area in South Korea or the demilitarized zone (DMZ) separating North and South Korea. The land area covered by the Landsat scene used for this study is contained entirely within the borders of North Korea. Therefore it would be necessary to select a separate scene that encompasses an appropriate area of South Korea or the DMZ, and perform a similar analysis for this scene. Given time constraints and the difficulty in obtaining data, it was not possible to perform this step as part of this study.

The analysis performed in this study is also a potential technique for testing official food production figures. From the FAO figures shown in figure 2, the period 1991-1993 had very high output of cereals, and the period 2000-2002 had significantly lower output. This concords with the observed results, but again it would be necessary to analyze a longer time period to establish any real conclusion about whether the trends in the official production figures map to those observed in remotely-sensed vegetation indeces.

This study serves as a starting point for using remote sensing to test the theory that land degradation caused by the famine has permanently decreased the productive capacity of North Korean agricultural land. The results tentatively support this theory, but a more detailed study that incorporates the JAXA archives and includes a comparison to a reference site in South Korea or the DMZ is needed.

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Appendix A. Landsat TM/ETM+ scenes

Date	Satellite/Sensor	Scene ID
22/05/1991	Landsat 5 TM	LT51170331991142XXX03
26/08/1991	Landsat 5 TM	LT51170331991238HAJ04
01/06/1992	Landsat 4 TM	LT41170331992153XXX02
15/10/1992	Landsat 5 TM	LT51170331992289BJC00
25/04/1993	Landsat 5 TM	LT51170331993115BJC00
06/07/1993	Landsat 4 TM	LT41170331993187XXX02
28/04/2000	Landsat 5 TM	LT51170332000119BJC00
22/05/2000	Landsat 7 ETM+	LE71170332000143EDC00
19/09/2000	Landsat 5 TM	LT51170332000263BJC00
16/12/2000	Landsat 7 ETM+	LE71170332000351EDC00
22/03/2001	Landsat 7 ETM+	LE71170332001081EDC00
10/06/2001	Landsat 7 ETM+	LE71170332001161EDC00
14/09/2001	Landsat 7 ETM+	LE71170332001257EDC00
01/11/2001	Landsat 7 ETM+	LE71170332001305EDC00
09/03/2002	Landsat 7 ETM+	LE71170332002068EDC01

29/06/2002	Landsat 7 ETM+	LE71170332002180EDC00
17/09/2002	Landsat 7 ETM+	LE71170332002260EDC00
04/11/2002	Landsat 7 ETM+	LE71170332002308EDC00