BIRZEIT UNIVERSITY

College of Graduate Studies

Institute of Water and Environmental Science

Environmental Impacts of the Separation Wall-Induced Floods on the Soil Biosphere and Crops in Western Qalqilya

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M. Sc. Thesis
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1105388

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The findings, interpretations and conclusions expressed in this thesis do not necessarily reflect the view of the Birzeit University, the view of individual member of the MSc Defense Committee or the view of their respective employers.

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Abstract

Qalqilya is located at northern West Bank of Palestine. The city is surrounded with the Separation Wall built on their land by Israel. This colossal infrastructure prevents rainwater from flowing into flood plains and causes the city something it had never experienced before, *floods*. This thesis investigated environmental impacts of the Wall-induced floods of January 2013 on arable land facing the Separation Wall. Assessed parameters are soil bacteria, heavy metal contents, soil structure, plant growth and socio-economic aspects. Higher microbial contamination was observed in flooded soils. There was no clear evidence of flood negative impacts on other parameters. However, the history of floods is short and continuous investigation will be needed to further verify and understand environmental impacts of floods.

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Chapter 1: Introduction

Palestine suffers from *floods*. This statement may sound far-fetched or false. Flood is generally considered as a natural disaster and it is usually associated with regions of high precipitation rates. When the amount of runoff exceeds the capacity of a receiving body of water, water overflows on the land and it becomes a flood. Bangladesh, India and Pakistan for instance are frequently hit by floods after intensive heavy rainfalls. Palestine is classified in semi-arid climatic zone with a total annual precipitation ranging from 400- 600 mm in the past decade (Richard and Issac, 2012). There are not even permanent rivers. Yet, floods can and do occur here. A major cause of flood in Palestine is theIsraeli Separation Wall. This gigantic infrastructure confines runoff, preventing it from following its natural path to flood plain. This work investigates environmental impacts of this human-induced flood on agricultural land in the city of Qalqilya, northern West Bank of Palestine.

In April 2002, the Israeli government's Ministerial Committee on National Security Affairs decided to erect a physical barrier separating Israel and the West Bank in order to control the entry of Palestinians from the West Bank into Israel. The decision was approved by the government in June and the construction of the Separation Wall began in the same year (B'Tselem, 2012).

The Separation Wall comprises a complex series of electronic fences, barbed-wire fences, earth mound and trenches. The average width of the barrier is 60 meters. In some locations it is consisted of concrete slabs of six to eight meters high. If completed as planned, the Separation Wall will be as long as 709 kilometers. Its course does not however abide by the Green Line which demarcates the West Bank and Israel. Approximately 85 % of the Wall will in fact run inside the Palestinian territory (OCHA, 2011), enclosing and/or isolating numerous Palestinian cities and villages. This goes in discordant to the peace agreements between the Palestinian Liberation Organization and the Government of Israel. The Interim Agreement on the West Bank and the Gaza Strip signed in 1995 between the two parties stipulates that neither party will 'change the status of the West Bank and the Gaza Strip pending the outcome of the permanent status negotiations'. In 2004, the International Court of Justice (ICJ) delivered an advisory opinion in a report called Legal Consequences of the Construction of a wall in the Occupied Palestinian Territory: Construction of the Separation Wall severely hinders the right of self-determination by the Palestinian people. Israel cannot justify the Wall and accompanying regime as military requirements or as means of national security or public order and thus violates international law. The advisory opinion calls on Israel for cease of construction and demolition of existing wall (ICJ, 2004).

The ICJ opinion has not so far been honored by the Government of Israel. Since construction of the Separation Wall, the Palestinian people, particularly those living in its vicinity, have been facing manifold difficulties and obstacles. According to figures provided by UNRWA's Barrier Monitoring Unit (BMU), the communities directly impacted by the Wall amount to 173 at the present time.

The Separation Wall has already swallowed up vast area of land. Furthermore, access to the land beyond the Wall is very hard due to permit and gate regime.

Thus, agriculture-based livelihoods of thousands of families have been seriously undermined. As agriculture is the most important income-generating sector in Palestine, economic impacts are far reaching (OCHA, 2013).In addition, most people have psychologically been affected by the sheer fact that they have to live with a Wall in their backyard (BMU, 2013).

This research investigates the impact of the Separation Wall-induced flood on the soil and crops in the west of Qalqilya city. Soil in the Qalqilya Governorate together with Jenin and Tulkarem Governorates is known to be the most fertile soil in Palestine. The city was chosen because agriculture is economically very important and most severely hit by Separation Wall-induced floods in the West Bank.The city of Qalqilya was one of the first which saw the completion of the Separation Wall as early as ten years ago in 2003. The city is surrounded by the Wall on three sides: concrete wall to the west, and circumferential fences to the north and the south which are narrowing towards the east (Fig. 1). The Separation Wall severs Qalqilya from half of that fecund agricultural land (UNDP, 2003) and much of the agricultural land beyond the Separation Wall has become inaccessible to land owners and farmers (Negotiations Affairs Department, 2004). Farmers are largely obliged to subsist on the remaining land, degradation of which may render their agriculture and livelihoods unsustainable.

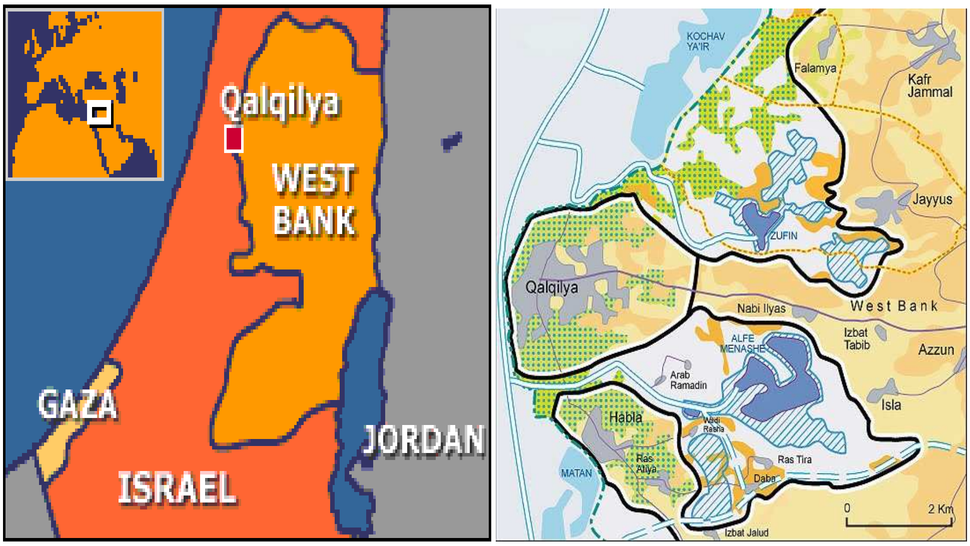

Figure 1.*Left*: location of Qalqilya governorate (source: BBC). *Right*: Qalqilya city surround by the Separation Wall (source: Political Tours, 2011)

The city is located on slopes which facilitate runoff to increase velocity and the concrete wall at the bottom of the city traps this runoff from flowing to floodplain which is now beyond the Wall. Since the erection of the Wall therefore, Qalqilya city with no flood history in the past has been experiencing severe floods in winter season. Notably the floods in the 2005 and 2013 caused a huge destruction of crops and fruit trees. 32 farmers (approximately 200 dependants) cultivate agricultural land at the lowest topography along the concrete wall and are now repeatedly hit by floods. Each time flood occurs they incur significant damages on agricultural produce.

An additional problem exists. Between the Separation Wall and the agricultural land, there is a natural stream in which wastewater is discharged. During flood, the stream overflows and transports wastewater out onto the adjacent land. This may contaminate the soil with hazardous elements such as heavy metals and pathogens (Provin *et al.*, 2008; Centers for Disease Control and Prevention, 2011) and poses potential risk to humans.

The study purports to contribute to a better understanding of the impacts of floods on the soil caused by the Separation Wall and to assist the invention of mitigation measures to soil degradation. It is hoped that the information will be shared with farmers of other flood-hit areas.The goal of my study is to bring to light yet another impact of the Separation Wall on Palestinians. Others, such as human right groups and UN organizations, especially the BMU have highlighted many of socio-economic impacts. However, my thesis draws attention to a little-studied aspect of the Separation Wall. This is particularly important in view of the fact that the international community has done very little to throw their weight behind the ICJ opinion about the Separation Wall.

Accordingly, this research has two hypotheses: 1) floods have negative impacts on the soil system and undermines its fertility, reducing microbial activity and crop productivity; 2) wastewater overflowed by floods contaminates adjacent land. The study involves three objectives as below:

1) To shed light on the environmental impacts of the Separation Wall-induced flood on agricultural land and crops in western Qalqilya;
2) To facilitate the creation of mitigation measures for flood-affected land in western Qalqilya;
3) To disseminate and share relevant information with other flood-affected farmers in Palestine over.

Chapter 2: Literature Review

Construction of an impervious physical barrier hinders the migration of fauna and flora and the movement of a vital element such as water. In basins that have been modified or whose flow has been obstructed, lower parts of rivers are often flooded (Gil and Rodríguez, 2010). For instance, Black (2008) reported that the 2008 Mississippi River flood was called a man-made disaster by many experts. The massive flood was attributed largely to torrential spring rains in the Upper Mississippi Valley. But some scientists argued that those rains were made worse by structures such as levees and other man-made interventions wrought upon the Mississippi River over time, resulting in the immense flood.

Examples of floods caused by an infrastructure such as a wall are uncommon because there are simply only few walls built by countries to demarcate their border. The most well-known one is the Border Wall that the United States built along the Mexican border. Part of the wall running along Nogales city in northern Mexico is made of concrete slabs. In 2008, this concrete wall trapped rain runoffs and inundated Nogales city, covering the city with a sheet of water of 2 m high in some places. Damages on houses, vehicles and infrastructure were amounted to over eight million dollars (Gil and Rodríguez, 2010). Misak and Al-Hurban (2013) investigated environmental impacts of different land use forms on land degradation in Kuwait and reported that the Bund Wall between Kuwait and Saudi Arabia disturbs and traps surface runoff in various zones along its route.

Apart from these countable examples, studies of environmental impacts of floods caused by artificial walls are few and far between. Therefore, literature describing adverse impacts of general floods has tobe sought after.

Damages of floods on agricultural land can be an immediate destruction of on vegetation stands. If a soil has no vegetation cover, floodwaters can wash away more easily the topsoil which is usually rich in organic matter, nutrients as well as fertilizers applied by farmers and which has better soil structure (Commonwealth Scientific and Industrial Research Organisation, 2011).

The danger of floodwaters is not only its physical force, but the water can also be heavily polluted with sewage and filth (Black, 2008). Evidence supports this general understanding. Wade *et al*. (2004) explored the correlation between occurrences of gastrointestinal illness and floodwaters in the mid-western United States. They confirmed an increase in the incidence of gastrointestinal symptoms during the floods. They also found that gastrointestinal symptoms were not related to tap water consumption but rather associated with direct contact with floodwaters and this effect was particularly pronounced in children. In the field studies after hurricane-induced floods, researchers detected the rise of fecal coliform bacteria in surface water (Pardue *et al*.,2005;Plumlee*et al*.,2005; Roper *et al*., 2006).

Floodwaters are as well very often laden with other contaminants including agrochemicals, petroleum products, detergents, and toxic metals (Black, 2008). All of these substances can pose serious problems to agricultural soils and therefore many case studies have been undertaken to investigate soil and crop contaminations after floods. In the Netherlands for example, researchers explored the association of heavy metal soil contamination with flood frequency using the case study of the River Meuse (Albering *et al*., 1999). They found that out of five analysed metals, higher concentrations of Cd and Pb occurred in more frequently flooded river bank soils. Ibragimow *et al.* (2013) compared heavy metal contents of sediments before and after the flood of a Polish river. Their results turned out that Cd and Cr were higher in flooded sediments but Cu, Ni, Pb and Zn were higher in pre-flooded sediments and the authors suggested that grain size and organic matter contents were responsible for this result. A study by Maliszewska-Kordybach*et al.*(2012) however reached a very different conclusion. They looked at the effects of floods on Polish agricultural soils in terms of ten heavy metals (As, Cr, Cd, Pb and so on) and nine polycyclic aromatic hydrocarbons (PAFs) and found no significant increase of any elements and compounds due to the flood. They attributed these findings to the absence of industry and other polluting activities in the environs of the studied area. The findings of Maliszewska-Kordybach*et al*. are in harmony with the result of earlier research in Czech Republic by Vácha *et al*. (2003) in which persistent organic pollutants (various hydrocarbons) and heavy metals were examined but no conclusive results indicating contamination of soils by floodwaters were obtained.

Albering *et al.*(1999) analysed heavy metal concentration in arable and fodder crops and found within background value ranges of the Netherlands. Contrary to their findings, a case study of plants grown in the Elbe Floodplains, Germany (Gröngröft*et al.*, 2005) demonstrated high mobility of heavy metals due to non calcareous character of the soils with low pH (4.1 – 6.9) and resultant uptake by pasture vegetation. Although factors such as plant species, sampled plant organs and time of the season influence plants' uptake of metals, metal concentrations in all plant samples directly after the flood exceeded EU maximum values for animal feed. However, no universal conclusion can be drawn from all these studies and each finding is a study specific. Degree of soil and plant contamination by heavy metals are influenced by miscellaneous factors including the frequency and intensity of floods, soil characteristics such as pH, particle size, mineralogy**,** non fluvial sources, the vicinity to industry or other polluting activities.

In addition to the transport of contaminants or toxic substances, floods can put a soil in waterlogging conditions. A waterlogged soil is depleted of oxygen and becomes anaerobic. Wetland plants have evolved to survive such anoxic conditions and are equipped with special air channels called aerenchyma. Aerenchyma transports oxygen down to root zones while releasing out various metabolically generated gases such as carbon dioxide and ethylene. Such transport lessens the risk of asphyxiation under soil flooding or more complete plant submergence, and promotes radial oxygen loss from roots leading to oxidative detoxification of the rhizosphere (Blom, 1999; Jackson and Armstrong, 1999). But dryland plants do not have such mechanisms and their growth can be easily impeded in waterlogged soils. Numerous attempts have been made to study responses of economically important crops to waterlogging conditions. Malik *et al.*(2002) conducted an experiment to evaluate the effect of different durations of waterlogging and subsequent drainage on young wheat and observed various adverse effects. During waterlogging, the seminal root system stopped growing and leaf nitrogen concentration was severely decreased. When waterlogged pots were drained, seminal root mass did not recover to control values, even when waterlogging lasted only three days. This was because the existing apices died and no new lateral roots were initiated. By the end of the experiment, shoot mass remained two- to three-fold lower in plants from all waterlogged treatments compared with continuously drained controls, due to lower tiller numbers and shorter final leaf lengths in previously waterlogged plants. The results demonstrate that even a short period of waterlogging has considerable long-term effects on the growth of young wheat plants. Similar findings are reported by previous works. Drew and Sisword (1979) used young barely plants and studied the development of waterlogging damage in terms of plant nutrient status and changes in soil properties. The experiment revealed that within 48 hours of waterlogging, injury to seminal roots and reduction in the rate of leaf extension occurred and the net rates of uptake of N, P and K dropped. Thompson *et al.*(1992) evaluated the tolerance of three different genotypes of wheat in waterlogged soil and found out that waterlogging largely decreased shoot fresh weight and reduced the growth of seminal roots.

This literature review has demonstrated that floods can have both immediate and long-term effects on the soil and crops. Areas that local floods affect can be relatively small as is the case of Qalqilya city, but the impacts on people living in those areas are significant and moreover the same individuals are likely to be repeatedly affected. For farmers, to be recurrently struck by floods has grave implications: their livelihoods entirely depend on land resource and they cannot just abandon their land to leave for elsewhere.

Environmental impacts of the Separation Wall in Palestine have been well documented by BMU and the Applied Research Institute Jerusalem (ARIJ). Their research is based on observation and interviews with people/representatives of Wall-affected local communities. However, scientific studies of environmental impacts of floods seem to be poorly undertaken if not at all. Moreover, the Israeli Separation Wall-induced flood is very different from any other natural or anthropogenic flood examples: the Wall is not constructed in the owner country's land but in the majority on Palestinian territory, violating international law. Despite that, flood gates built in the Separation Wall are not accessible to the Palestinian Authority to maintain and clean (BMU, 2013). The opening and closing of flood gates are entirely left in the hands of Israeli Army. When a flood takes place and submerges anything on its way such as crops and greenhouses for hours, the Palestinian Authority can do nothing but keep asking Israeli Army to open the flood gates in order to get rid of flood water. The Separation Wall has been unilaterally built and there is no hope of dismantlement in foreseeable future. The accumulation of the above facts makes my research very unique and pioneer.

Chapter 3: Materials and Methods

3.1 Study area and soil sample collection

The specific study areas were selected in coordination with the Ministry of Agriculture in Qalqilya. A primary field visit took place at the end of January 2013 in order to visually assess damage caused by the floods which occurred in early January.In mid-March, the 2nd field visit was carried out. Four control treatment plots were chosen from agricultural land at the very north end of the concrete wall as those were not affected by the floods. Seven other plots which were located several hundred meters away southward were selected as flood affected plots. The total number of plots was 11 as shown in Table 1. Treatment 1 was the farthest from the Separation Wall and Treatment 10, the closest. From each one of the 11 plots, three replicate soil samples were taken at a depth of 0 to 30 cm using a spade. They were put into clean plastic bags, marked and brought to the laboratory of the Birzeit University on the same day.

Table 1.A list of 11 soil treatments, descriptions and plot indication for plant samples.

Treatment number	Descriptions	Vegetable samples taken
1	Control for all	
2	Control for green vegetables	Green onion and parsley
3	Control for guava	(New branch length)
4	Control for lettuce	Lettuce
5	Flooded peach orchard	
6	Flooded peach orchard	
7	Flooded green vegetable field	Green onion
8	Flooded green vegetable field	Parsley
9	Flooded lettuce field	Lettuce
10	Flooded guava orchard	
11	Flooded guava orchard	(New branch length)

3.2 Plant sample collection

On the same day as the soil sample collection, three different species of green leafy vegetables were chosen: green onion, parsley and lettuce. These vegetables were selected as they were fully grown at that time. Three samples of green onion and parsley were randomly uprooted from three spots of Treatment 2 plot. Their above-ground heights were immediately measured and recorded in the field. Other three samples of green onion from Treatment 7 and three samples of parsley from Treatment 8 were likewise picked up and measured. After the measurement, all samples were put into clean paper envelopes. With respect to lettuce plant, several samples were taken at four spots in Treatment 4 and 9 plots (Table 1 above) and put into clean plastic bags. All vegetable samples were transported to the laboratory of the Birzeit University on the same day and placed in a refrigerator.

3.3 Soil analysis

3.3.1 Microbial analysis

The objective of microbial test lied in detection of *Escherichia Coli* (E. coli) which is a gram-negative bacterium, and considered as a good indicator of the presence of other pathogens, hence microbial contamination. To this end, EMB agar was used as culture media due to its selectivity to gram negative bacteria. In EMB agar, *E. coli* develops colonies and appears in distinguished sheen green colour with a dark center (Lal and Cheeptham, 2007). 1.0 g of soil was measured and put into a glass test tube containing 10 ml of 0.9 % saline water which was pre-autoclaved at 121°C for 15 minutes. The soil sample was well mixed with the saline water using a vortex device for a few minutes. From this stock solution, an aliquot of 1ml was taken with a disposable pipette and put into another autoclaved glass tube with 10 ml of saline water. The second solution was well blended again. Lastly 0.1 ml from the diluted solution was pipetted onto an EMB agar plate and evenly spread over using a glass spreader which was soaked in 70% ethanol and flamed in a Bunsen burner. Two duplicates per soil sample were produced. In total, 66 EMB plates (3 replicates x 2 duplicates for each of the 11 treatments) were inoculated with the solutions and placed in an incubator at 37° C for 24 hours. Number of colonies was counted. Firstly the mean of two duplicates for each replicate was obtained and then the final mean value for each treatment was worked out. Based on these resultant mean values, colony forming unit (CFU) per gram soil was calculated with the following equation(Yousef and Carlstrom, 2003):

CFU/g = number of colony/dilution factor

3.3.2 Heavy metal analysis

Air-dried soil samples were first sifted through a stainless steel sieve with 5mm openings and ground in a mortar with a pestle. The soil samples were then sieved once again with a 50 µm stainless steel mesh. 0.5 g of pulverized soil from each sample was measured and put into a clean 20 ml scintillation vial. The soil was digested with aqua regia. The aqua regia soil digestion method is considered efficient and satisfactory to get an estimate of the maximum element availability to plants' uptake. It is a most conventional method and internationally accepted by organisations such as USEPA and ISO . The method invloves treating a soil sample with a 3:1 mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) as described by Gaudino *et al.* (2007). Aqua regia was prepared using HCL ≥ 32 % (Sigma Aldrich, Germany): HNO_3 65 % (Merck, Germany). 12 ml of the aqua regia was mixed with the soil sample in a vial. Then the vials were heated on a preheated hot plate for several hours at 110° C. The digested solutions were diluted with 20 ml of double distilled water (DDW). They were transferred into a 100 ml volumetric cylinder after being filtered through Whatman no. 1 paper and diluted again with DDW to make a final volume of 100 ml. All glass items were acid-soaked in 3% HNO_3 and rinsed with DDW prior to usage and in between samples. The diluted solutions were delivered to the Aquaculture Laboratory of Al Quds University in Abu Dis, East Jerusalem, and the concentrations of 11 trace metals, namely Tl, Pb, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se and Cd, were analyzed with inductively coupled plasma mass spectrometry (ICP-MS)(Agilent Technologies 7500 series, Japan).For accurate quantitative determination of heavy metals in water samples, an internal standard method was used using (In) as internal standard and a multi-standard calibration method: (22 metals standard (Ag 10 ppm, Al 50 ppm, B 50 ppm, Ba 10 ppm, Bi 100 ppm, Ca 10 ppm, Cd 10 ppm, Co 10 ppm, Cr 50 ppm, Cu 10 ppm, Fe 10 ppm, K 100 ppm, Li 50 ppm, Mg 10 ppm, Mn 10 ppm, Mo 50 ppm, Na 50 ppm, Ni 50 ppm, Pb 100 ppm, Sr 10 ppm, Tl 50 ppm, Zn 10 ppm, matrix 5% HNO3). Each sample was analyzed three times and the results are expressed as mean ± SD (SD: standard deviation). Relative standard deviation (RSD) of the three results are calculated and found to be less than 5% for all samples for all metals analyzed in this study, reflecting the precision of the method for the analysis of these heavy metals. Calibration curves for all metals analyzed were constructed by plotting the ratio of the intensity of the analyte metal to that of the internal standard (In) vs. concentration of the trace metal (in ppb), and the results showed that the calibration curves were linear with correlation coefficient (r2) greater than 0.999 for the trace metals analyzed.

3.3.3 Structure

Soil structure was determined in the field on 30th May 2013 jointly with an expert from the Palestinian Ministry of Agriculture, Ramallah. Both surface and subsurface structures were assessed, using as a reference the Guidelines for Soil Description issued by FAO (2006).

3.4 Plant analysis

3.4.1 Green vegetable growth

Three growth parameters were recorded: fresh weight, length and number of branches. Since the length of green onion and parsley samples were measured in the field, only their weight and number of branches were measured in the laboratory. As to lettuce sample, a number of leaves were counted instead of a number of branches and the measurement of all three parameters was carried out in the laboratory.

3.4.2 Chlorophyll content

Chlorophylls were extracted by means of 80 % acetone as described by Sadasivam and Manickam (1996). Representative leaves of each plant sample were arbitrarily chosen and minced with a stainless knife and mixed well. 1 g was weighed and ground to a pulp in a clean mortar. 20 ml of 80 % acetone was added in the pulp. The mixture was poured into a clean, labeled centrifuge tube. Having made sure the weights of all the tubes with mixture to be equal, the tubes were centrifuged at 5,000rpm for 5 minutes. Then the supernatant was transferred to a clean 50 ml volumetric tube. Remaining residue of each sample underwent the same processes of extraction. The 2nd supernatant was poured into the same volumetric tube. The volume of all the volumetric tubes containing the supernatants was leveled to be 50 ml with 80 % acetone. Solution was pipetted into a clean cuvette and absorbance was read at 645, 663 and 652 nm against the blank (80% acetone) using a spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific, USA). The amount of chlorophyll per gram fresh plant tissue was calculated using the following equations (Sadasivam and Manickam, 1996):

$$\text{mg chlorophyll a/g tissue} = 12.7\ (A663) - 2.69\ (A645) \times \frac{V}{1000\ xW}$$

$$\text{mg chlorophyll b/g tissue} = 22.9\ (A645) - 4.68\ (A663) \times \frac{V}{1000\ xW}$$

and

$$\text{mg total chlorophyll/g tissue} = 20.2\ (A645) - 8.02\ (A663) \times \frac{V}{1000\ xW}$$

where A = absorbance at specific wavelengths,

V = final volume in ml of chlorophyll extract in 80% acetone

and W = fresh weight of plant tissue extracted in g.

3.4.3 Guava new branch growth

Growth of new branches was assessed in the field in early June 2013. A length of the 3^{rd} new branch from the tip of an entire branch situated at approximately 1.5 m high from the ground was measured. Ten branches were chosen per tree and the same procedure was repeated with randomly selected three healthy-looking guava trees in three different spots: closest to the Separation Wall, middle and the farthest from the Wall in Treatment 2 (non-flooded) and 10 (flooded), respectively.

3.5 Socio-economic farmers' interview

A questionnaire was prepared with the help of people who have sociology background. It was designed to tease out major social and economic discrepancies before and after the Separation Wall was built. Interviews with five most flood-affected farmers took place in mid-August 2013 in Qalqilya city.

3.6 Statistical analysis

The CoStat statistical package (CoHort Software, Monterey, USA) was used for the analysis of variance (ANOVA), and the comparison of the means was conducted using the Least Significant Difference (LSD) test at $P \leq 0.05$ ($n=3$, unless otherwise indicated).

Chapter 4: Results

The impact of flooding due to the Separation Wall was assessed through series of tests, which include analyses of soil and plant samples, and socioeconomic aspects. Throughout the results section, T1 is considered as the control for all other treatments. The plots (T5, T7, and T10) that were closest to the Wall are considered here as likely to be the most contaminated plots, and a special emphasis is accordingly placed on these treatments.

4.1 Soil Parameters

4.1.1 Bacteria

Figure 2 reflects the degree of contamination of 11 treatments. As expected the lowest contamination (0 CFU) was recorded for T1 plot (the control plot) whereas the highest (6.5×10^3 CFU)was found atT 7plot.

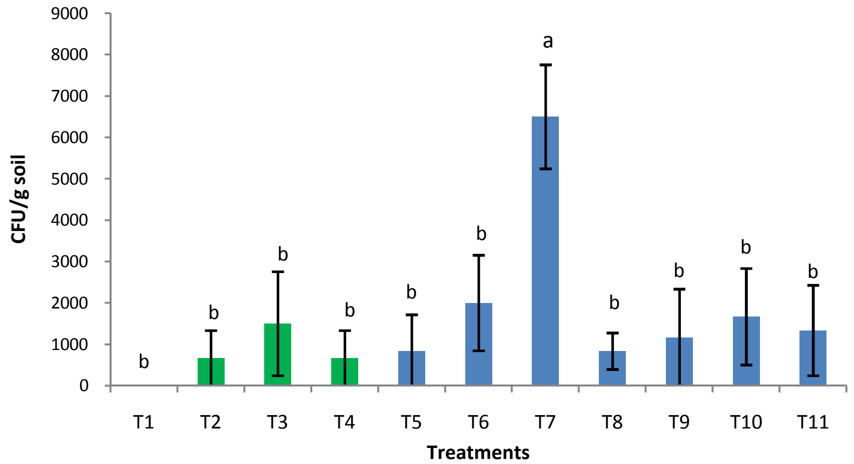

Figure 2.Degree of contamination of soil expressed as colony forming units (CFU/g soil) of 11 treatments (mean ± SE). Green bars indicate non-flooded soils and blue bars, flooded soils. T1 is the farthest from and T5, 7 and 10 are closest to the Separation Wall. Means were taken from 3 replicates. Means with the same letters are not significantly different at $p \leq 0.05$.

On EMB agar, lactose-fermenting gramnegative bacteria (generally enteric) produce strong acid, lowering pH of the medium. Initially colourless eosin dye in EMB reacts with this change in pHand lactose fermenters develop into dark-coloured colonies (HIMEDIA, 2011). In contrast non lactose-fermenters grow colourless colonies (Fig. 2 left). Colonies of *Escherichia coli* which are vigorous lactose fermenters show a typical metallic sheen with very dark center (Lal and Cheeptham, 2007). However, in this soil analysis, no such distinguishable *E. coli* colonies were detected. Instead, colonies which have a dark centre surrounded by light coloured rim, so-called 'fish-eye' were found and counted (Fig.3 right). Bacteria that form this type of colonies on EMB agar usually include most strains of *Enterobactor*and *Klebsiella* (Seal and Pleyer, 2007), both of which are opportunistic pathogens(Guentzel, 1996).From Figure 1, it seems that flooded soils had greater CFUs of gram negative bacteria than control soils.

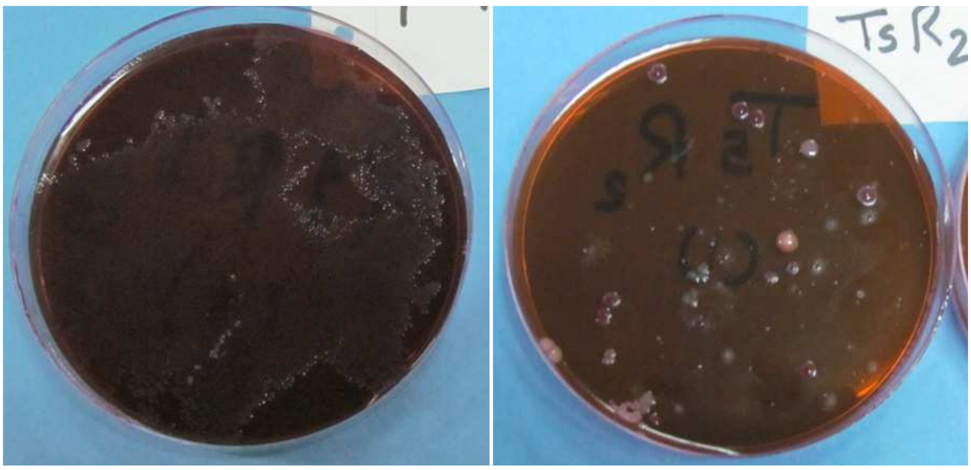

Figure 3.*Left*: colourless colonies of non-lactose fermenting bacteria found in T1. *Right*: several fish-eye colonies of *Enterobactor* or *Klebsiella* appeared in T5.

4.1.2 Soil contamination with heavy metals

In terms of trend, four elements showedclear trends, in which their concentrations were much higher in non-flooded soils than in flooded soils. These are Cr, Ni, Mn and Co (Fig.4D, G, E and F). To a lesser extent, V and Se followed a similar tendency (Fig.4C and K). Pb demonstrated the opposite trend, in which its levels were generally higher in flooded soils (Fig.4B). The concentrations of other five elements, namely Tl, Cu, Zn, As and Cd, seemed to fluctuate with no noticeable trend (Fig. 4A, H, I, J and L).

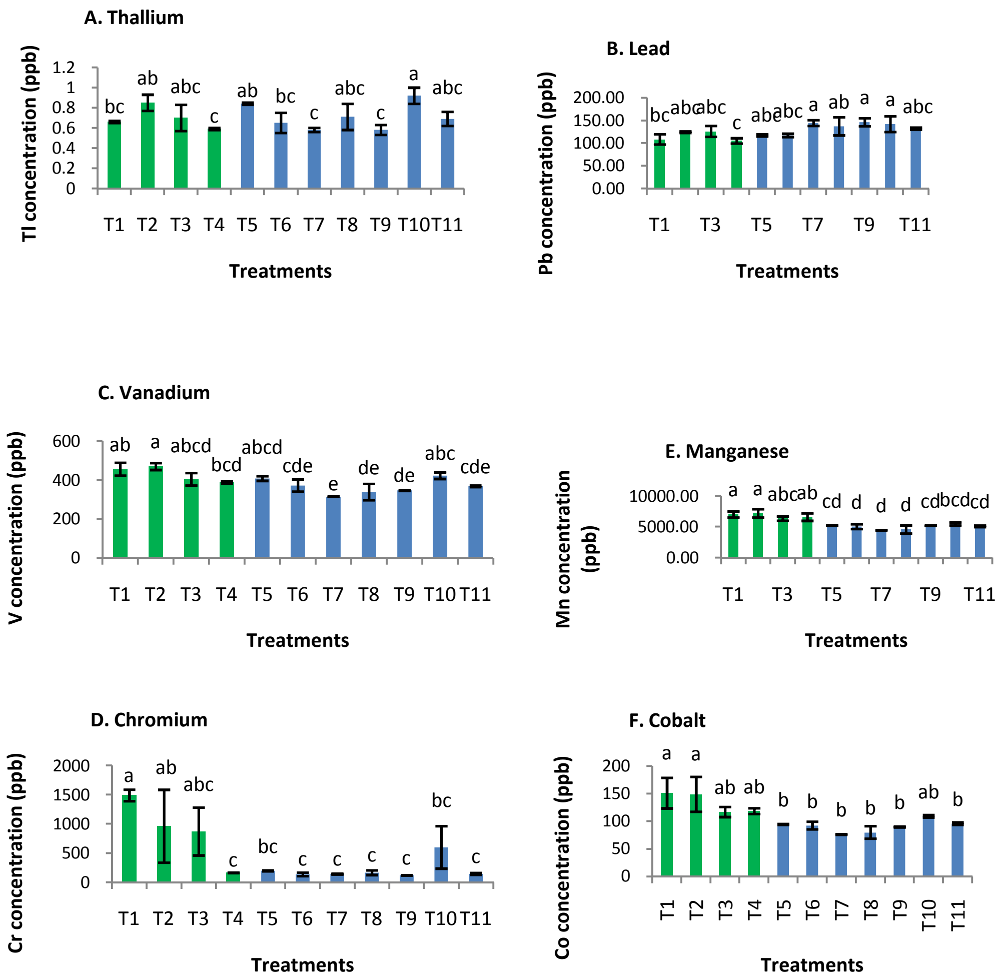

Figure 4. Concentrations of 12 heavy metals in soils (mean ± SE). Means were taken from 2 replicates. Green bars indicate non-flooded soils and blue bars, flooded soils. Means with the same letters are not significantly different at $p \leq 0.05$.

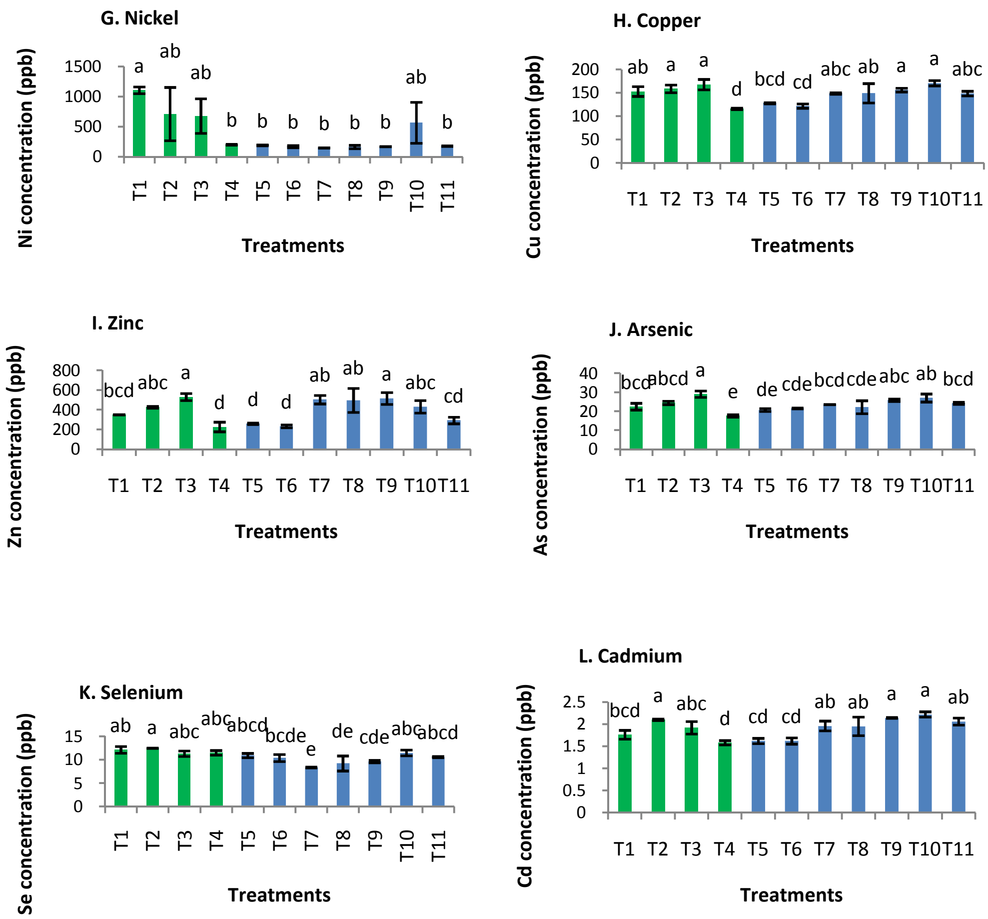

Figure4 (continued). Concentrations of 12 heavy metalsin soils (mean ± SE). Means were taken from 2 replicates. Green bars indicate non-flooded soils and blue bars, flooded soils. Means with the same letters are not significantly different at $p \leq 0.05$.

Trace elements occur naturally, but their natural concentrations are seldom at toxic levels (USDA Natural Resources Conservation Service, 2000). Amount of trace elements in soils largely depends on original parent rocks (Adriano, 2001).Therefore a range of trace element concentration is highly variable depending on the soils.Use of common ranges or average concentration of trace metals in soil as an indicator of whether or not a soil is contaminated is not appropriate unless the native concentration of trace elements (background levels) in a specific soil is known (USDA Natural Resources Conservation Service, 2000).To the best of author's knowledge, such data wasunavailable for the soils in the studied area. Therefore the results of the current study are to be compared withavailable data in the literature. As can be seen in Table 2, all 12 heavy metals, which reflect their levels in the soils during the spring time, show much lower concentrations than the normal soil range as well as the toxic range.

Table 2. Range of concentrations (expressed in ppm) of 12 heavy metals compared with normal soil range and toxic range for plant growth

Elements	Concentration range	Normal soil range[a]	Concentration considered toxic range for plant growth[b]
Tl	0.00058 - 0.00092	0.1 - 0.8	-
Pb	0.10502 - 0.14615	2 - 300	100 - 400
V	0.31477 - 0.46968	3 - 500	-
Cr	0.1181 - 1.48847	5 - 1500	75 - 100
Mn	4.4818 - 7.18999	20 - 10000	1500 - 3000
Co	0.07594 - 0.15086	0.05 - 65	25 -50
Ni	0.14969 - 1.1067	2 - 750	100
Cu	0.11561 - 0.1706	2 - 250	60 - 125
Zn	0.22795 - 0.53028	1 - 900	70 - 400
As	0.01746 - 0.02905	0.1 - 40	20
Se	0.00835 - 0.0125	0.5 - 55	-
Cd	0.00158 - 0.00222	0.01 -2	3.0 - 8.0

[a]Bowen (1979).
[b]Ross (1994); Singh and Steinnes (1994).

4.1.3 Structure

For each of five treatments, three plots were chosen and soil structures were studied. As there was no structural difference among a set of the three plots, representative soil structures from each treatment are shown in Table 3. Soils of two control treatments were of the same structure: blocky subangular to granular. The surface soil of T8 was a mixture of crumbly and blocky subangular and the sub-surface was granular. T10 had a granular surface but subangular to blocky angular structure at a sub-surface level. T 11 had blocky subangular to blocky angular both at the surface and sub-surface.

Table 3.Soil structure assessed in situ. T2 and 3: not flood-affected. T8, 10 and 11: flooded soils. S (surface) and SS (subsurface) are separately described only when different from each other.

T2	T3	T8	T10	T11
Blocky subangular to granular	Blocky subangular to granular	S: crumbly to blocky subangular SS: granular	S: granular SS: Blocky subangular to blocky angular	Blocky subangular to blocky angular

4.2 Plant Parameters

4.2.1 Growth Parameters

4.2.1.1 Weight:

Among the three green leafy vegetables, green onions grown in non-flooded soils were much heavier than those grown in flooded soils (Fig.5A). The mean weight of nine control samples was 66.8 g, while that of green onions grown in flooded soils was 30.0 g. Two other vegetables showed areverse trend. Both parsley and lettuce grown in flooded soils turned out to be heavier thanthe plants grown in control soils. The mean parsley weight from flooded soils was 79.2 g and it was 36.9 g from control soils (Fig.5B). Lettuce's mean weights were 394.3 g in flooded soils and 252.7 g in control soils, respectively (Fig.5C).

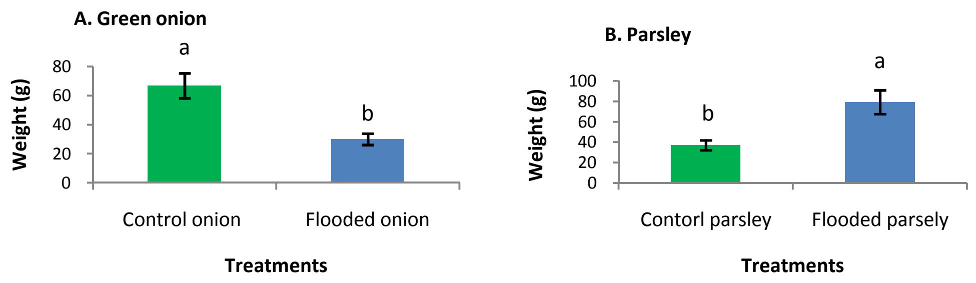

Figure 5. Mean weight of green leafy vegetables grown in control and flooded soils (mean ± SE). A = green onion, B = parsley and C = lettuce. Means with the same letters are not significantly different at $p \leq 0.05$.

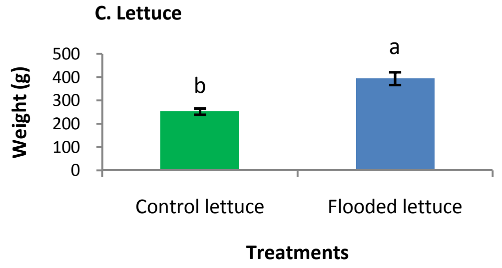

Figure 5 (continued). Mean weight of green leafy vegetables grown in control and flooded soils (mean ± SE). A = green onion, B = parsley and C = lettuce. Means with the same letters are not significantly different at $p \leq 0.05$.

4.2.1.2 Length:

Control green onion was much taller (67.7 cm)than flooded onion (41.3 cm) as shown in Fig. 6A.A difference between control parsley and flooded parsley was not significant (Fig.6B). Regarding lettuce, the mean length of flooded lettuce was 27.6 cm which was considerably taller than control lettuce with the mean length of 23.1 cm (Fig. 6C). Guava trees grown in flooded soils had a longer new branch mean length (18.3 cm) than those in control soils (17.9 cm) but the difference was only 0.4 mm and non-significant (Fig. 6D).

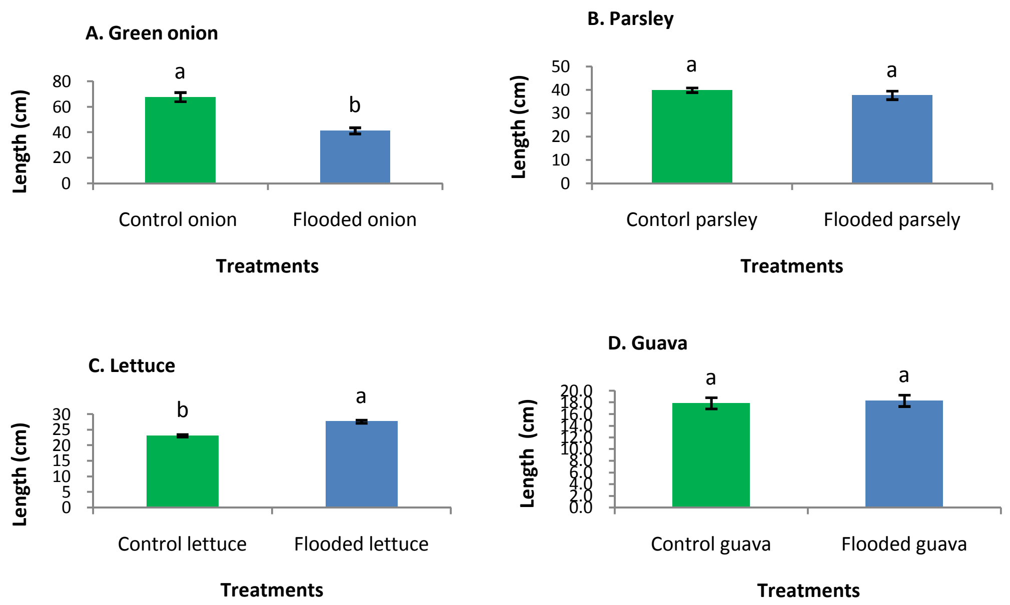

Figure 6. Mean length of green leafy vegetables grown in control and flooded soils (mean ± SE). A = green onion, B = parsley and C = lettuce, D = guava tree. Means with the same letters are not significantly different at $p \leq 0.05$.

4.2.1.3 Number of leaves or branches:

There was little, non-significant difference in the mean number of green onion leaves (Fig. 7A). For parsley, the number of branches was counted instead of leaves since the plant had too many small leaves to count. Parsley grown in flooded soils had a greater number of branches, 29.7 than control parsley with the mean branch number of 12.6 but this difference was statistically not significant (Fig. 7B). With respect of lettuce, the mean leaf number of flooded lettuce was 26 which were considerably larger than control lettuce mean value of 22.8 (Fig. 7C).

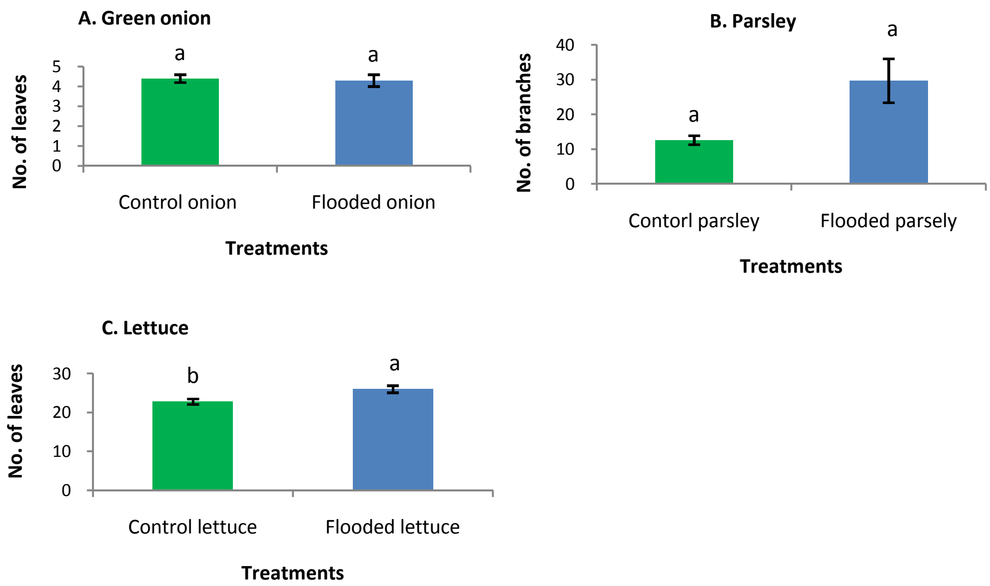

Figure7. Mean number of leaves of green leafy vegetables grown in control and flooded soils (mean ± SE). A = green onion, B = parsley and C = lettuce. Means with the same letters are not significantly different at $p \leq 0.05$.

4.2.2 Chlorophyll contents

Chlorophyll *a* concentration of control green onion was slightly higher than that of flooded onion (Fig.8A). Flooded green onion showed higher values of both chlorophyll *b* and total chlorophyll concentrations (Fig.8B and C). Regarding parsley, samples taken from flooded soils had superior values in all three chlorophyll parameters. On the contrary, lettuce grown in control soils had greater concentrations of *b* and total chlorophyll (Fig. 8B and C).However, all of the differences between three pairs of control and flooded vegetables are statistically insignificant.

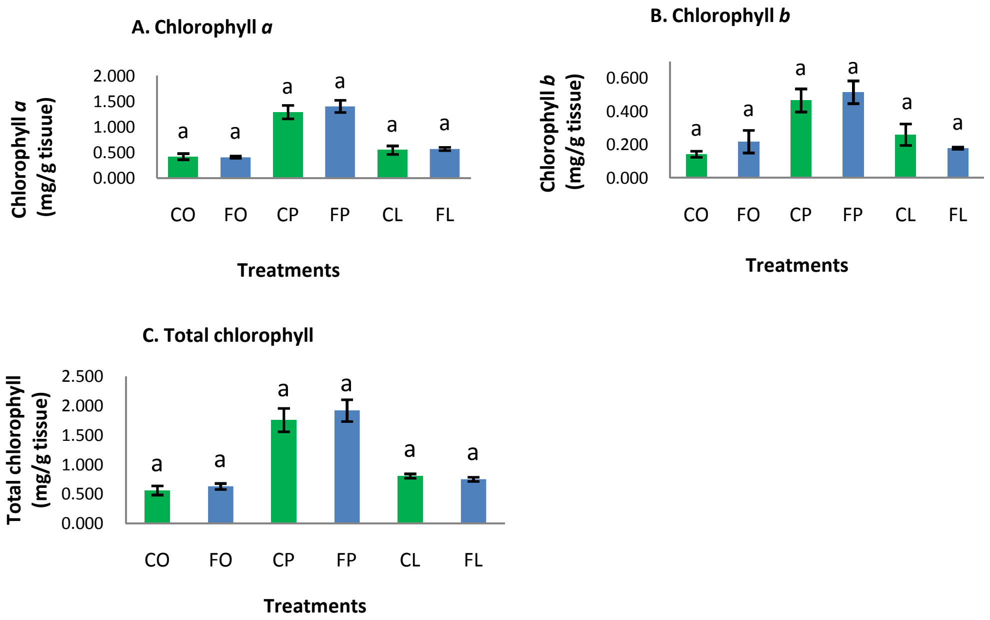

Figure 8. Chlorophyll contents of green leafy vegetables expressed in mg/g fresh tissue (means ± SE). A = chlorophyll *a*, B = chlorophyll *b* and C = total chlorophyll. Green bars indicate vegetables grown in control soils and blue bars for those grown in flooded soils. CL = control lettuce, FL = flooded lettuce, CO = control green onion, FO = flooded green onion, CP = control parsley and FP = flooded parsley. Means with the same letters are not significantly different at $p \leq 0.05$.

4.3 Socio-economic impacts of flood

Results of five individual interviews were summarized in Table 3. Five farmers, who have farms of sizesrangingfrom 5 and 50 donums and differ also in types of their agriculture, which include green houses, open-fields, were interviewed.Depending on land proximity to the Wall and topography, the areas of land hit by Wall-induced floods vary between 5 and 20 donums, which represent 20 to 100 % of their farm size. Floods reach minimum 100m and maximum up to 200m from the Wall over their agricultural land.

Two immediate effects of floodson the land were waste material deposits and soil compaction.After the flood event, land,be it open-field or greenhouse, has to be left for 2 – 4 weeks since the soil was fully saturated with water. Thedeposited waste needed manual removal and compacted soil required much more time and energy to plough. When soil compaction of matured orchards is too severe, farmers cannot do much to restore the soil; only mechanical digging can loosen the soil but they cannot bring in a large tractor without causing damages to fruit trees.

Some farmers see the vegetables planted in flooded soils grow more slowly than those in non-flooded soils and/or show symptoms of nutrient deficiency. In those cases, they feel obliged to apply more fertilizer both in terms of quantity and frequency. Extra fertilizer application adds more time and energy on top of manual waste removal and more laborious plough. Their working hours have generally increased by 150 to 200 %. A peach farmer said that 70 out of 220 peach treesdid not survive the floods. The peach trees were 9 year-old andwould have lived up to 30 years had there been no flood. Decrease in saleable products in tandem with a lower productivity resulted in 30 to 50 % of income loss.

Under those circumstances, they changed (or intend to change) crop types from their traditional cash crops,like peach to more flood-tolerant, e.g. guava or pomegranate, or to fast-growing plants such as moroheiya instead of tomatoes.To make up for substantial income loss, their coping mechanisms include getting a regular job and finding land elsewhere. As a community, counter-measures taken against flood were clearing off rubbish from the Wadi in order to ease runoff flow and putting earth mounds along to prevent overflow.

Table 4. Summary of interviews held with five farmers who cultivate agricultural land just beside the Separation Wall.

	Questions	**Answers**
1	A range of current farm size adjacent to the Wall	5 – 50 donums
2	A range of land size affected by all-induced flood	5 – 20 donums
3	Flood reaching distances from the Wall	100 – 200 m
4	Flood effects on soil	Waste deposit (plastic, wood, plant material, metals) and soil compaction.
5	Flood impact on land management	- Land and/or green house untouchable for 2 - 4 weeks after flood; - Increase in working hours (much more time required to remove debris, put irrigation network back into place and plough compacted soil; - Increase in fertilizer application; - Limited orchard management as soil compaction too severe; - Change in type of crops from leafy vegetables to fruit trees, or from more profitable, slow growing to less profitable fast growing vegetables.
6	Impacts on fauna and flora	-Increase in type and amount of weeds; - New type of insects and snails; - Tree death in Wadi; - Disappearance of wild animals and birds which farmers used to catch as food source (rabbits, sand partridges and their eggs).
7	Socio-economic impacts of flood	- Decrease in saleable product - Decrease in productivity - Loss of income by 30 – 50 %
8	Coping mechanism for income loss	-Find another land away from flooded area; - Get a job -Cut down expenditures of going out and eating out.
9	Counter-measures to flood by community	-Clean wadi to facilitate water flow -Put earth mounds around wadi.
10	Situation in 10 year's time	- Will be the same; - Will have acquired more agricultural land elsewhere away from the Wall; - Will have shifted to more flood tolerant plants such as guava, mango, avocado, pomegranate.

Chapter 5: Discussion

5.1 Soil Parameters

5.1.1 Soil contamination with Bacteria

It is known that flood waters commonly contain microbial contaminants (Centers for Disease Control and Prevention, 2011). Microbial analysis of the current study revealed that flooded soils showed generally higher degree of enteric microbial contamination.In particular, the highest CFU was marked with treatment 7, which is the closest to the Separation Wall. Due to direct and potential health impacts, microbial contamination of water sources after flood has been well studied, but few have attempted to analyse post-flood soil microbial contamination. The finding of the current study is in agreement with one of such rare studies, that of Plumlee *et al.* (2005). Researchers concluded, following their environmental assessment after floods caused by two hurricanes, Katarina and Rita in the USA, that the microbial levels were in general consistent with those that would be expected to be encountered in flooded soils under the direct influence of untreated wastewater.

The enteric bacteria live mainly in the lower intestine of humans and other warm-blooded animals *(*Guentzel, 1996; Winfield and Groisman, 2003). Out of their normal habitat, they can be a cause of human health problems. The survival of such enteric bacteria outside their main hosts has been therefore studied by many researchers. To name a few, a field experiment of bacteria survival on the surface of effluent-irrigated grass demonstrated that T_{90} (= the time required for bacteria to be reduced by 90 %) of bacterial pathogens ranged from 6 to 38 hours, depending on solar regime, temperature and grass moisture content (Sidhu, Hanna, and Toze, 2008). A similar field test was conducted by Manios, Moraitaki and Mantzavinos (2006). They analysed coliform inactivation rate on grass and soil wetted wastewater, which underwent secondary and chlorination treatment. The number of coliforms was substantially reduced in two hours but a visible regrowth occurred after that. On the other hand, Casteel, Sobsey and Mueller (2006) investigated faecal contamination of agricultural soils before and after hurricane-associated floods in eastern North Carolina, and analysed both pre- and post-flooded agricultural soils to determine MPN (Most Probable Number) of total coliforms, faecal coliforms and *E. coli*. In that study, E. coli was detected in non flood affected and flooded soils alike and its levels in post-flood soil samples were not significantly higher than the pre-flooded soil samples.

It is worth to mention here that the survival of enteric bacteria may be compromised when found beyond their normal habitat, due to many biological, chemical and environmental factors that include soil moisture, soil type, temperature, solar regime, nutrient availability, predation and competition with resident microbes over essential nutrients and water (McKinney, 2004; Morgen *et al.*, 2010; Sidhu*et al.*, 2008; Manios *et al.*, 2006). Most of these factors are well described in a review compiled by Jamieson *et al.* (2002). Not only does each one of these variables affect independently faecal bacteria survival, their interactions also control the survival rate. A large number of individual factors and their intricate relations result in varying research findings as illustrated with the above instances.

The study site, Qalqilya has a Mediterranean climate, and due to its proximity to the Mediterranean Sea and low altitude of 44 m, it has very mild winter with a temperature of around 15°C to 20°C. Moreover, rain events concentrate in winter season (Richard and Issac, 2012). Such conditions are considered promotive for bacterial growth. As soil samples used for this study were taken in mid March, any contamination due to flooding is expected to be obvious. Although EMB agar which is particularly appropriate for *E. coli* cultivation was used, any colony of *E.coli* was detected in the current study. It is possible that simply *E. coli* was absent in the studies soils. Another possible reason is due to the fact that soil is inhabited with a rich variety of microbes. If lactose nonfermenters such as *Salmonella enteritidis* are present in a soil sample, they utilize the acid produced by *E. coli* as energy source. This results in an insufficient acid accumulation to precipitate out the eosin methylene blue in agar. Consequently, green metallic sheen which is typical characteristic of *E. coli* colonies observed on EMB agar does not come into view (ASM Microbe Library, 2007). In this case, the detection of *E. coli* becomes difficult and their colonies resemble to those fish-eye colonies found in this study which are normally produced by species such as *Klebsiella* and *Enterobacto*r. Lastly, soil conditions might have changed to disadvantage of *E. coli* survival even if they had existed after the flood in January 2013.

Concerning *Klebsiella* and *Enterobacto*r, which are also members of enteric bacteria, and differently from *E. coli*, their natural habitats are seemingly more extensive, ranging from human and animal intestines, sewage, soils, surface waters, industrial effluents and vegetation (Bagley, 1985; Grimont and Grimont, 2006). This ubiquity of these bacteria probably explains why presence of enteric bacteria was observed also in the control soils in the current study. However, judging from the fact flooded soils had higher enteric bacteria CFUs, it would be appropriate to conclude that flood water was an additional source of bacteria.

5.1.2 Soil contamination with heavy metals

The analysis of heavy metals in soils in the present study brought somewhat mixed findings. Concentrations of Pb and Cd were generally higher in flooded soils, whereas several other metals, in particularCr and Ni, to a lesser degree alsoMn and Co, showed markedlyelevated levels in control soils than in flooded soils. Other elements such as Tl, Zn and As displayed fluctuation with no distinguishable trend between control and flooded soils.

Similar variation of heavy metal concentrations in flooded soils was documented by Ibragimow *et al.*(2013). Their comparative study found that out of six heavy metals identified (Cd, Cr, Cu, Ni, Pb and Zn), only Cd and Cr showed higher concentration levels in flooded sediments and the remaining four heavy metals were higher in pre-flooded sediments. Many other researchers evaluated heavy metal loads in flood-affected agricultural soils, using their national legal limits or background levels as a reference. (e.g., Eulenstein, Müller and Helming, 1998; Albering *et al.*, 1999; Vácha*et al.*, 2003; Maliszewska-Kordybach *et al.*, 2012). However, their findings were not straightforward, either. Taking an example of Albering *et al.* (1999) who conducted a study after the flooding of the River Meuse, the authors concluded that high concentrations of Cd and Pb were observed in flooded soils but As and Cu levels fell below the Dutch agricultural clay soil standards.

As illustrated by studies, analyses of heavy metals in soils do not always bring about clear-cut results. It is because the mobility ofheavy metals in the environment is difficult to predict due to the fact that heavy metals can undergo numerous reactions with the diverse soil components (EPA, 1999). Alloway (1995) and Kabata-Pendias (2010) have provided detailed account of processes and factors that affect fate of heavy metals in soils.

The mobility of a metal is usually determined by its ability to sorb to a substrate. Among a number of soil properties, two interrelated ones, namely redox potential (electron availability in a system) and pH are identified to be the most influential variables on heavy metal mobility (Langmuir *et al*., 2004; Kabata-Pendias, 2010). Since redox potential and pH can be significantly changed by flood (Ponnamperuma, 1984; Patrick *et al*., 1991; McLean and Bledsoe, 1992), these parameters are of a particular relevance to the present heavy metal study.

A well-drained soil maintains a quite constant composition of various gases due to a rapid exchange of gases with the atmosphere. Flood blocks this gas exchange pathway and cuts of oxygen supply route. In a waterlogged soil, remaining oxygen is quickly used up by biological activity and the redox potential starts dropping. It is for the reason that the absence of oxygen subdues aerobic microorganisms and instead favours facultative anaerobes followed by strict anaerobic microorganisms. Facultative and obligate anaerobes use other oxidizedsoil components such as NO_3^-, Mn^{4+}, Fe^{3+} and SO_4^{2-} in this order as electron acceptors and this process turns the soil into reducing conditions. This effect of waterlogging on soil redox potential has been illustrated by numerous previous studies (e.g., De-Campos *et al*., 2009; Yaduvanshi *et al*., 2010; Zheng and Zhang, 2011; Almendros, Gonzalez and Alvares, 2013).

Simultaneously with depletion of oxygen, waterlogging conditions preventCO_2 from being released to the atmosphere, which leads to the built-up of the gas in a soil. Together with organic acids from the microbial degradation of organic matter (EPA, 1999), accumulated CO_2 decreases a naturally high pH of calcareous soils (Ponnamperuma, 1984). In addition, a lower pH can further enhance soil reducing conditions and if soils are rich in organic matter, a drop in redox potential as well as pH will proceed faster and to a greater degree (Ponnamperuma, 1984;Langmuir *et al*., 2004).

There are several good reasons to believe that the soils of the studied area underwent chemical change with respect to redox potential and pH. First, the soils were inundated and waterlogged over 24 hours with the maximum water table as high as 3 m in early January 2013. Second, cultivated soils normally contain a high level of organic matter (Alloway, 1995) and the soil in Qalqilya is renowned for its fertility. Hence, it could be said that the studied soils had a relatively high content of organic matter. Third, the soil in Palestine on the whole is known to be very calcareous, i.e. high pH. This is associated with the geological character of the region that the parent rocks largely consist of carbonate/calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). A pre-analysis of the soils taken from the study area in late January 2013 revealed that the mean pH values of control soils and flooded soils were 8.04 and 8.03, respectively. It should be noted that these high pH readings were not surprising as the soil samples were taken some time after the flood and chemical changes caused by waterlogging are mostly restored once the soil is drained and becomes aerobic (oxidizing) conditions (Ponnamperuma, 1984). Decreases in the redox potential and pH may have, separately or as combined factors, given the mobility to certain metals (Madrid, 1999). As illustrated by the above-mentioned preferential sequence of oxidised soil constituents that anaerobic organisms exploit under waterlogging conditions, manganese, for instance, is readily reduced when the soil becomes void of oxygen (Patrick and Turner, 1968). Since Mn^{2+} is more mobile than its oxidized insoluble form, Mn^{4+}, it is possible that reduced Mn found its way out from soil solution via an uptake by plants (Albering*et al.*,1999; Gröngröft *et al.*, 2005) or migration downwards the soil profile. This could explain why the concentration of Mn is clearly lower in flooded soils than in control soils.

A soil with a high pH favours the retention of cationic metals and but decreases that of anionic metals as shown in Table 5 below.

Table 5.Correlation between metal mobility and pH

Mobility	pH range of 4.2-6.6	pH range of 6.7-8.8
Relatively mobile	Cd, Ni and Zn	As and Cr
Moderately Mobile	As and Cr	Cd and Zn
Slowly / Slightly mobile	Cu, Pb and Se	Cu, Pb and Ni

Source: Schmitt and Sticker(1991)

Hence a lower soil pH may have had important impact on some cationic metals which are otherwise held with soil substrate via pH-dependant charge. This could help explain why most of cationic metals such as Ni, Co, Zn and to a lesser extent, V (vanadium), show lower concentrations in the flooded soils. As to anions such as As and Se, a lower soil pH deprives their mobility. However, lower redox potential counteracts this effect of the low pH and can reduce these anions to be more mobile forms. The conflicting effects of low pH and redox potential on anionic metals seems to account for somehow ambiguous results of As and Se concentrations in the current study. Chromium is a complicated metal as it can exist either as Cr^{3+} or $CrO4^{2-}$ (Langmuir *et al*., 2004). Lower concentrations of this metal in flooded soils can be therefore interpreted in two ways: Cr^{3+} was released from soil substrate because of lower pH, or $CrO4^{2-}$ was reduced to Cr^{3+} due to decrease in redox potential. Higher concentrations of Pb and Cu in flooded soils relative to in control soils may be attributable to stronger affinity of these two metals to soil (McLean and Bledsoe, 1992) or suggest the presence of some anthropogenic sources such as metal pipes and insecticides (Wuana and Okieimen, 2011).

It has to be mentioned that the results observed in Treatment 5, 6, 7 and 8 are also indicative that waterlogging conditions affected soil pH and redox potential. These treatments are located at topographically lowest levels in the studies area. Flood water started accumulating there first and receded last, meaning that these treatments experienced the longest period of waterlogging conditions. The longer waterlogging lasts, the greater a decrease occurs in both redox potential and soil pH. Lowest concentration values observed with several metals in these treatments can justify this rationalization. For example, two lowest concentration values of

Zn, Cd and Cu occurred in T5 and 6. Four of lowest levels of Co, As, Ni, Mn and Cr were observed in all of T5, 6, 7 and 9.

With the lack of quantified background baseline, i.e. the concentration of trace metals in soils as they existed before flooding, the present study paper assumes the heavy metal levels in the control soils to be indicative of background baseline. Upon this assumption, it could be inferred that the studied area have soils with naturally low heavy metal contents. In fact, the concentration values of all 12 metals analysed fell much below the mean contents in surface soils on the world level (Bowen, 1979; Kabata-Pendias, 2010).The current study did not confirm that, as a generalisation, flooded soils contained particularly higher heavy metal concentrations than flood-unaffected soils. However, markedly lower concentration of certain metals strongly indicate that flood-induced changes in soil pH and redox potential did occur and these changes are likely to have increased the mobility of those metals, resulting possible removal or disappearance of those metals out of surface and subsurface soils by the means of plant uptake or leaching. Therefore, although the history of flood in Qalqilya is relatively young, the investigation of heavy metals in flooded soils will need to be continued in future.

5.1.3 Structure

The soil structure assessment *in situ* of the current study took place in the end of May 2013. Soil structure of two control treatments, T2 and T3, were both granular to blocky subangular. Four flooded treatments, namely T7, T8, T10 and T11 showed slight variation. T8 had crumbly to blocky subangular at a surface and granular at subsurface. T10 had a very similar structure with T2 and T3: granular at the surface and blocky subangular to blocky angular. An exception was T11, which did not have granular structure but only had blocky subangular to blocky angular structure. Prior to this field study, soil samples which were taken from the same treatment plots in mid March 2013 were evaluated for their structure in the laboratory. The results of two assessments were compatible to each other, and it was clear that the structures of flooded soils did not differ much from the structures of control soils, indicating that there was no apparent sign of damage of flood on soil structure.

Soil structure is defined as the arrangement of soil particles (sand, silt, clay) into porous aggregates. Soil structure also refers to the arrangement of these aggregates separated by pores and cracks (FAO, 1985). It is worth mentioning here that soil structure is of great importance for agriculture as it affects water and air movement through soil, and greatly influencing soil's ability to sustain life and productivity (Chan, 2011). Unlike soil texture which refers to the proportionate distribution of the different sizes of mineral particles in a soil (Brown, 1998), soil structure is not permanent and can be altered by biotic factors, such as plant roots, bacteria and macrofauna such as earthworms (Whiting *et al.*, 2011), and abiotic factors such as the physical forces of shrinking and swelling created by changes in water status of soils, freezing and thawing and tillage (Oades, 1993).

Flood can have significant adverse effects on soil structure. Two major processes of soil structural degradation associated with flood are slaking and dispersion.

Slaking refers to macroscopic collapse of soil aggregate into smaller fragments and dispersion denotes the complete breakdown of soil aggregates into primary particles of clay, silt, sand and organic materials (Chan, 2011). These breakdowns of soil aggregate rise from various changes brought by waterlogging conditions: the reduction in cohesion with increase in water content, deflocculation of clay as a result of dilution of the soil solution, pressure of entrapped gases, and stress caused by uneven swelling of different soil particles and the destruction of cementing agents (Ponnamperuma, 1984; Coder, 1994).

The types of the soil structure observed in the present study are those of normal soils. Granular structure is usually found in surface layers and considered to be a good soil structure that allows moderate water flow (Perry, 2009). Blocky subangular or blocky angular are often found in lower soil profile and common structure in Terra Rossa, Brown Rendzinas found in Qalqilya area (ARIJ, 1996). However, lack of evidence of flood impacts on soil structure at the times of the assessment does not necessarily mean that the waterlogged soil did not undergo any destructive processes. The strength of soil structure is normally measured in terms of aggregate stability or structural stability, and published literature has illustrated negative effects of waterlogging conditions on this aspect. For example, De-Campos *et al*. (2009) argued that short-term reducing (anaerobic) conditions caused by flood decreased aggregate stability. Research by Bazzoffiand Nieddu (2011) demonstrated that after one day of submergence, soil structural stability already decreased. It is therefore reasonable to presume that the flood gave rise to some kind of stress on soil structure but the soils recovered from such disturbance.

One of plausible explanation for the above presumption is the antecedent soil moisture content effect (Taboada, 2003). Antecedent soil moisture content means simply the initial or previous soil moisture content before an addition of water. When a dry soil is subjected to rapid wetting, it is much more vulnerable to structural breakdown via slaking than a wet soil (Lal and Shukla, 2004; Chan, 2011). In Qalqilya, rain events concentrate in winter months and the highest precipitation is usually recorded in December. It is hence reasonable to believe that the soil had contained a relatively high amount of moisture prior to the flood in the following month. Thus, even if slaking or dispersion had actually occurred during the time of soil submergence, damage on the soil would have been less severe than on dry soils. The effect of antecedent soil moisture content has been confirmed by studies. A study by Truman *et al*. (1990) concluded that an increase in initial water level in a soil improved the resistance of an aggregate to the forces of raindrops and flowing water, thereby lessening particle detachment. According to Vermang *et al*. (2009), the erodibility of soil decreased with increasing antecedent soil water content. An experiment conducted by Hardie *et al*.(2010) demonstrated that antecedent soil moisture strongly influenced the depth and rate of water infiltration, and reported that in wet soils, water flew much slower and to shallower depth than in dry soils.

Another possibility is related to two aspects of soil structure, namely stability (resistance) and resilience. Stability signifies the ability of the soil to retain its structure during a disturbance and resilience denotes the capacity of the soil to restore itself after a disturbance (Seybold *et al*., 1999; Chan, 2011) Since soil resilience is determined by the interaction of soil physical, chemical and biological properties and processes (Blanco-Canqui and Lal, 2008), some soils are inherently resilient while others are not. Among factors that make some soils more resilient to a perturbation, earlier studies point to organic matter and clay contents of soils. A work which examined the effect of organic matter (OM) on clay wettability and soil aggregate stability revealed that soil organic matter increased aggregate stability (Chenu *et al*., 2000). The authors attributed this finding to OM's ability to increase internal cohesion of aggregates, rendering a soil more resistant to slaking and differential swelling of clays. De-Campos *et al.* (2009) found that cultivated soil rich in OM together with clay and Fe oxides has more stable aggregate.At thetime of the flood, the fields were covered with vegetables such as cabbage and carrots. They were damaged by flood water and left in the field until the soils became drained and workable. Therefore, it is possible that those vegetables increased organic matter content of the soils, which had initially good amounts of OM as argued in the preceding Heavy metal discussion in 4.1.2

It has to be also noted that at the time of soil sample collection, both in March and May 2013, the soils in the studied area were already cultivated.That the farmers left water saturated soils for 2 to 4 weeks intact might as well have prevented the soils from a mechanical stress of compaction, since this process of structural damage can occur if the soil is worked while too wet (Chan, 2011).

It can be thus deduced that the antecedent moisture content effect in conjunction with soil structure stability contributed to lessening flood-induced damage on the soil structure. Furthermore, soil resilience coupled with farmers' good post-flood soil management facilitated a relatively quick recovery from presumed disturbance. Absence of granular structure in treatment 11 may imply that this treatment suffered more from degradation processes than other flooded treatments. This is probably owing to the fact that a soil is such a heterogeneous and dynamic environment, and not all the treatments soils had the same antecedent moisture content, structural stability and resilience.

5.2 Plant Parameters

5.2.1 Physical Growth

Four plant species, namely green onion, parsley, lettuce and guava, were assessed for various growth parameters. Green onions in control soils grew better than in flooded soils, whereas parsley and lettuce in flooded soils showed better physical growth than their counterparts in control soils. The growth difference of guava trees, the length of new branches, was negligible between control and flooded soils.

Effects of waterlogging soils on plants are widely described in literature. Among those, the most well-known adverse effects are the suffocation of plant roots, accumulation of toxic components including reduced species (NO_2^-, Mn^{2+}, $Fe^{2+}$and S^-), mibrobial metabolites and fermentation products, and leaching and denitrification of nitrogen (Kozlowski, 1984; Jackson and Drew, 1984; Cronk and Fennessy, 2001; Neumann and Römheld, 2012). Some positive effects include the release of important nutrients, especially phosphorus. In oxidized soils;

phosphorus is usually found as PO_4^{3-} and absorbed on to iron oxyhydroxides, putting it beyond plant's reach. Under anaerobic conditions, Fe^{3+} is reduced to Fe^{2+}, freeing and making it more available to plants (Cronk and Fennessy, 2001). However, once the soil becomes aerobic, this reaction is reversed and the availability of phosphorus decreases.

These flood effects on dryland crops have been demonstrated by many studies (e.g. Drew and Sisword, 1979; Coutts, 1981; Justin and Armstrong, 1987; Thompson *et al*., 1992; Zhou and Lin, 1995; Malik *et al*., 2002). These authors all concluded from their experiments that waterlogging soils impaired plant growth one way or another. It has to be noted that most experiments were conducted under *actual* waterlogging conditions. The present study looked at the growth of vegetables which were planted *after* the soil was sufficiently drained from floodwater and became workable. However, comparable data for plants grown after flood could not be located by the author. Therefore other research findings are not applicable to the present discussion, with the exception of guava tress which actually lived waterlogging conditions caused by the flood. It turned out that differences in guava tree growth between control and flooded soils were non-significant.

Not only does sensitivity to flood vary largely among plant species, many attributes of the plant, time and duration of flooding, nature of floodwater and site characteristics also significantly affect a degree of plants' flood tolerance (Kozlowski, 1997). Coder (1994) argues that, as ageneral rule, broadleaved trees tolerate better than conifer species; middle-aged trees are less vulnerable toflood damage than young or old trees; flood in winter is less disturbing to trees than in summer; and flood damage is less severe when plants are in a dormant stage. A study of Sitka Spruce Seedlings by Coutts (1981) confirmed that plants which were dormant at the time of waterlogging were more tolerant and supported the last point presented by Coder.

Guava is considered to be moderately tolerant to flood stress of a short period (Crane and Balerdi, 2013). The flood in Qalqilya occurred in winter when guava trees were less active. Moreover, guava trees were of matured age. The initial flood tolerance of guava, the age of trees in tandem with the timing of the flood probably explains the insignificant growth difference among control and flooded treatments.

Most of direct impacts of the flood on the other three plants are excluded from consideration. However, nitrogen deficiency due to leaching or denitrification can be a lasting impact of flood. Onion family is best grown in well-drained and fertile soils (Cornell University, 2006; Browning, 2014). Therefore, it is possible that green onions planted in flood soils had less nitrogen availability relative to control soils and as a consequence, their growth was inferior to that of green onions in control soils. On the contrary, parsley and lettuce grew better in flooded soils.A possible reason for this result may be related to pests. Both parsley and lettuce can be attacked by soil residing organisms such as cutworms, wireworms and root rot nematodes (AUSVEG, 2014). These pests are aerobic and are intolerant to oxygen deficiency in flooded soils (Gowen, 1997; EPA,1997).

Therefore, flood might have contributed to a decrease in the population of these pests, resulting in better growth of parsley and lettuce in flooded soils. Least but not last, fertilizer application has to be taken into consideration. Flood-affected farmers observed that in terms of both speed and size, the rate of growth of vegetables planted in flooded soils was lower to that of vegetables in flood-unaffected soils.Therefore, they applied more fertilizer in flooded soils and this could be another explanation for why parsley and lettuce developed better in flooded soils.

5.2.2 Chlorophyll contents

Chlorophyll is vital for photosynthesis and thus directly related to agricultural productivity. A trend detected in the chlorophyll analysis shown in Table 6 is consistent with the trend observed with the above plant physical growth: plants which physically grew better also showed higher chlorophyll *a* (Chl *a*) levels, and those are control green onion, flooded parsley and flooded lettuce. With respect to chlorophyll *b* (Chl *b*), no pattern was found. However, differences in all Chl *a, b* and total between three pairs of control and flooded vegetables are not statistically significant.

Nevertheless it is of note that observations made with Chl a/*b* ratios weresimilar to the results of Chl *a* ratio*:* control green onion and flooded lettuce had higher Chl *a*/*b* ratios than flooded green onion and control lettuce. A difference in Chl a/*b* ratios between control and flooded parsley treatments was insignificant. Chl *a*/*b* ratio of C3 plants normally ranges between 2.4 and 3.2 (Black, 1973) and the average ratio is around 3:1 (Marshall and Proctor, 2004). The Chl a/b ratios of control green onion, parsley in both control and flood treatments and flooded lettuce are in the region of the average.

Table 6. Chlorophyll content of three plants as a function of treatment

		Chlorophyll content (mg/g frwt)			Chl *a*/*b*
Plants	Treatment	*a*	*b*	Total	ratio
Green onion	Control	0.420	0.143	0.563	2.937
	Flooded	0.410	0.219	0.629	1.872
Parsley	Control	1.293	0.467	1.760	2.769
	Flooded	1.406	0.516	1.922	2.725
Lettuce	Control	0.547	0.261	0.808	2.096
	Flooded	0.571	0.180	0.751	3.172

Chlorophyll content and Chl*a*/*b* ratio of plants are influenced by phonological changes, ontogenetic drift in specific leaf area (Dale and Causton, 1992) and other exogenous factors including irradiance and nutritional status. For example, chlorophyll is continually being produced and broken down during plant growing season (Eckarde, 2009; Tackett, 2011). A most known factor influencing Chl *a*/*b* ratio is light regime and this has been illustrated by many studies (e.g. Dale and Causton, 1992; Malavasi and Malavasi, 2001). This is because that, although both Chl *a* and Chl *b* participate in light harvesting, Chl *a* is the primary pigment involved in photosynthesis (Lodish *et al*., 2000) and special forms of only Chl *a* are linked into energy-processing centres of photosystem. Strong light provides abundant photons and favours Chl *a* activity for energy processing, leading to consequential higher Chl *a*/*b* ratio. In weak light however, optimisation of leaf function necessitates more investment of leaf resources in light harvesting rather than energy processing. As a result, the relative abundance of Chl *b* which absorbs light of slightly different wavelengths (Campbell and Farrell, 2007) increases and thus the Chl *a*/*b* ratio decreases (Chow *et al*., 2010).

These differential functions of Chl *a* and Chl *b* could explain why the results of chlorophyll content were consistent with the results of plants' physical growth analysis. Greater Chl *a* values found in control onion, flooded parsley and flooded lettuce, and higher Chl *a*/*b* ratio observed in control green onion and flooded lettuce may suggest stronger photosynthetic activities in these plants, resulting in their better growth.

5.3 Socio-economic impacts of flood

Five farmers were interviewed for the present study. They make up over 15 % of farmers whose lands are now situated along the Separation Wall west of Qalqilya. They constitute a representative sample of the overall flood-affected farmers in this area.

Flooding of areas used for agricultural activities is showing a variety of negative impacts. The magnitude of these depends on the vulnerability of the population as well as the frequency, intensity and extent of flooding (Associated Programme on Food Management, 2013). Agriculture is one of the sectors most susceptible to flood impacts. In particular, impacts on arable land can be more severe than on other forms of agriculture because the production entirely depends on the land. For example, in the report on the impacts of the UK summer 2007 floods published by the Environment Agency of UK (2010), the estimated flood loss in arable production was twice as large as in grassland or livestock rearing.

Thieken *et al*. (2008) classified flood damage in the agricultural sector into several categories. These include: 1) damage on agricultural land, particularly crop loss and adverse effects on plant growth; 2) damage to buildings, machinery and equipment; 3) damage to stocks or supplements (feeding stuff, fertilizer, seeds) and 4) other costs (e.g. clearing and cleaning-up costs, costs for repairing damaged agricultural infrastructure such as farm tracks or irrigation systems).

The interviews with the affected farmers brought to light two particularly severe impacts. The most tangible direct impact was the destruction of crops under cultivation at the time of the flood. The adverse effect of floods on agriculture has been well documented in similar socio-economic studies (e.g. Islam, 2000; Buitelaar *et al*., 2007; Armah *et al*., 2010). The mild winter climate in Qalqilya enables the farmers to cultivate crops year around and to produce vegetables during off-season, such as tomatoes which fetch a good price when there is less market competition. This equates with substantial and immediate loss of income. According to Thieken *et al*. (2008), another damage of floods corresponds to losses incurred by, and classified as, other costs. In the current study, water-saturated soils need to be left for certain periods of time until they are sufficiently drained in order to avoid damage on soil structure. This period constitutes time loss and is equivalent to a disruption of agricultural production. Secondly the farmers reported the floodwater transports and deposits on land a large quantity of various waste materials which necessitates manual, labour-intensive removal.

Lastly, the Qalqilya farmers claimed that their soils are compacted by the floodwater and require more labour and time to plough. These are indirect, extra costs that the farmers incur due to the floods before they can resume crop cultivation.

The average land size of those farmers affected by the floods and interviewed in this study ranges between 5 and 20 donums. This may not appear to be significant. However, when taking into consideration that the range of their farm holding is between 5 to 50 donums, their losses are appreciatively large in proportion. Therefore the floods damage between 40 % and 100 % of the farmers' lands. As a consequence, the sum of tangible direct and indirect losses of income amounts between 30 to 50 %.

In another study looking at post-flooding undertaken by Whittle *et al*. (2010) in the UK, it was revealed that people's sense of the future changed in different ways. Some showed fatalistic attitudes towards flood whereas others developed their own resilience strategies for future floods. A similar observation was made with the farmers interviewed in the present study. Notwithstanding the substantial loss of income caused by the flood, one farmer neither had any vision nor envisaged any coping strategies. He answered that his situation would anyhow remain the same for the coming 10 years. The other respondents reported either to have to cut down on expenditure to compensate their losses or seek income diversification measures, such as working in part-time employment.

In Qalqilya, severe Separation Wall-induced floods have so far only occurred several times since the Wall was built in 2003. Although due to global climate change the overall mean precipitation is predicted to decrease in the Mediterranean Region (IPCC, 2013), Palestinian researchers observe that periods of heavier rainfall will be concentrated in shorter time (Mimi and Abu Jamous, 2010). This implies that the risk of flood hazards is likely to increase. Flood intensity and frequency will most likely increase and affect the same farmers even harder.

For as long as the current political situation and related constraints do not change, farmers are forced to adapt various kinds of coping strategies. If their vulnerability is to be reduced, sustainably, community-based resilience approaches, where institutions, organisations and the community cooperate have to be devised. If however, this approach does not work out, it is left to the farmers to pursue other longer-term strategies. This could mean flood tolerant crops could be introduced, but there will also be a possibility that farmers will chose to neglect their land, migrate to elsewhere, and abandon their originally fertile lands.

Chapter 6: Conclusions

The city of Qalqilya had never experienced floods until Israel built the Separation Wall. This massive infrastructure cuts the city off the floodplains and does no longer allow runoffs to flow out of the city. As a result, Qalqilya has been hit by devastating floods last several years. This paper investigated environmental impacts of floods induced by the Separation Wall in the western Qalqilya.

The result of soil bacteria analysis revealed that flooded soils had greater number of colonies of enteric bacteria. Notably, the largest CFU was observed in the treatment which was the closest to the Separation Wall. Enteric bacteria were also found in non-flooded soils. However, higher degree of contamination observed in flooded soils implied that floodwater was an additional source of enteric bacteria presumably originated in wastewater. Although the EMB agar was chosen for its sensitivity of *E. coli* which is an indicator of fecal contamination, this species of bacteria was not detected. Possible explanations for this result are: 1) the soils were free of *E. coli*; 2) the bacteria died off outside their normal habitat, i.e. lower intestines of warm-blooded animals; 3) a soil hosts numerous microbes and other bacteria which use acid produced by *E. coli* on EMB agar might have obscuredthe presence of *E. coli*.

With regard to heavy metal concentrations in soils, the examination revealed that the soils in the study area generally containedmuch lower levels of heavy metals compared with the world normal range. Out of 12 elements analysed, Pb and Cd showed higher concentrations in flooded soils. Several other elements such as Cr, Ni, Mn and Co exhibited the opposite trend that their levels were much higher in non-flooded soils. No clear trend was seen in the concentration of remaining elements such as Tl and Zn. These mixed results may stem from the fact that heavy metals can react with the various soil components and in varied ways, making their mobility unpredictable. Floods can have significant impacts on soil redox potential and pH by rendering soils waterlogged. A Soil saturated with water becomes void of oxygen and consequently its redox potential decreases. At the same time, the pH of calcareous soil lowers due to the accumulation of trapped CO_2. Decreases both in the redox potential and pH could have, independently or jointly, increased the mobility of cationic metals such as Ni, Co, Zn, leading to lower concentration values of those elements in flooded soils. Lower redox potential can also enhance anionic metals' mobility, whereas lower pH decreases their mobility. Thus, these converse effects may be a reason behind equivocal values of anionic heavy metal concentrations such as As and Se. Fate of heavy metals that gained mobility in saturated soils is not a focus of the present research. However, possible destinations include uptake by plant roots and migration down to lower soil profiles.

The assessment of soil structure did not show differences between non-flooded and flooded soils. Given the fact that the floods in January 2013 kept the land inundated 24 hours with the maximum water height of 3 m, it would be reasonable to presume that the shear floodwater affected soil structure in one way or another. However, it is plausible that the antecedent moisture content effect and structure stability provided by high OM contents in the soils cushioned the impacts of floodwater on soil structure. Furthermore, original soil resilience together with farmers' good soil management seems to have encouraged a rapid restoration of supposed structural damages.

Among four plant species examined, guava was the only species which experienced the floods. However, no significant growth difference was observed between flood-unaffected and flood-affected guava trees. Guava is known to be fairly tolerant to short-period flood stress, especially when the tree is less active in cold season. This would explain the absence of growth difference. Other three crops showed varied results. Green onion grew better in flood-unaffected soils, whereas parsley and lettuce showed overall better development in flooded soils. Since these plants were all planted after the floods, direct impacts of floodwater were excluded from consideration except nitrogen shortage. It is possible that floodwater encouraged nitrogen leaching and anoxic conditions of saturated soils favoured denitrification. Both of these processed make this macronutrient less available to plants. A post-flood effect which could be associated with an inferior growth of green onion cultivated in flooded soils is a smaller availability of nitrogen. Superior growth of parsley and lettuce in flooded soils could be ascribed to a probable drop in aerobic pest population such as cutworms and root nematodes. In addition, it has to be noted that the farmers applied to flooded land more fertilizers, which may have as well contributed to this result.

With respect to the two research hypotheses, the conclusion drawn from the results of plant growth and soil structure assessments did not hold the first hypothesis that floods have negative impacts on the soil system and undermine its fertility and hence crop productivity. The second hypothesis that wastewater overflow by floods contaminates adjacent was to good degree supported by the results of soil bacteria analysis. It has to be reminded that this study was conducted several weeks after the floods took place in January 2013. Therefore it cannot be ruled out that this time lag may have affected the results of the study or even attenuated some negative impacts of the floods. In other words, had the study been conducted immediately after the floods, it might have reached very different results. Floods can have both an immediate and a long-term impact on agricultural activities. Having been cut off from the lands beyond the Separation Wall, farmers are largely obliged to subsist on the remaining land. The degradation of such precious resource may render their agriculture and livelihoods unsustainable.

To develop a more complete understanding of theenvironmental impacts of the Separation Wall induced flood,acontinuous and long-term investigation will be required. Further research particularly within the following areas should be conducted:(i)characterization of floodwater itself in terms of bacteria and heavy metal load,(ii)the analysis of plant uptake of heavy metals, in particular by perennial crops, (iii) the effects of organic matter such as manureon soil structure resilience and mobility of heavy metals, (iv) the feasibility study of gradual shift to flood-tolerant crops.The history of floods in Qalqilya is relatively short. Nobody can predict with certainty future precipitation trends. Even so, the one thing is in no doubt that there will be floods as long as the Separation Wall stands there. It is thus not possible to prevent flood in Qalqilya and other areas where the Separation Wall blocks water flow then efforts have to be made to minimize its damage.

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الخلاصة

<u>عنوان الرسالة</u>:تاثير الفيضان الناتج بفعل جدار الفصل العنصري على بيئة التربة الزراعية والنباتات المزروعة في منطقة غرب قلقيلية

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تعاني مدينة قلقيلية الواقعة في شمال الضفة الغربية (فلسطين) من اثار جدار الفصل والذي تم بناءه من قبل اسرائيل. أدى بناء الجدار ببنيته الهائلة الى منع مياه الأمطار من الجريان في مساراتها الطبيعية مما أدى وبصورة متكررة الى فيضان مياة الأمطار الى الأراضي الزراعية والوحدات السكنية المجاورة. هذا الفيضان لم يسجل مطلقا قبل إنشاء جدار الفصل وهدف هذه الدراسة هو إستكشاف التأثيرات البيئية لفيضان عام 2013 الناتج بسبب جدار الفصل على الأراضي المستزرعة. تمت دراسة التغيرات الحاصلة على بكتيريا التربة، محتوى الترب من المعادن الثقيلة، بنية التربة، نمو وتطور النباتات، والتاثيرات الإجتماعية الإقتصادية للفيضان. توضح النتائج أن الفيضان أدى الى تلوث جرثومي عالي بينما لم يكن هناك تغيرات واضحة في المؤشرات الأخرى. كون تاريخ الفيضان ما زال قصيرا تستدعي الحاجة دراسة مستمرة لإستكشاف التأثيرات بعيدة المدى للفيضان.