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**Analysis of climatic variability and its environmental impacts across the
occupied Palestinian territory**

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1. Introduction

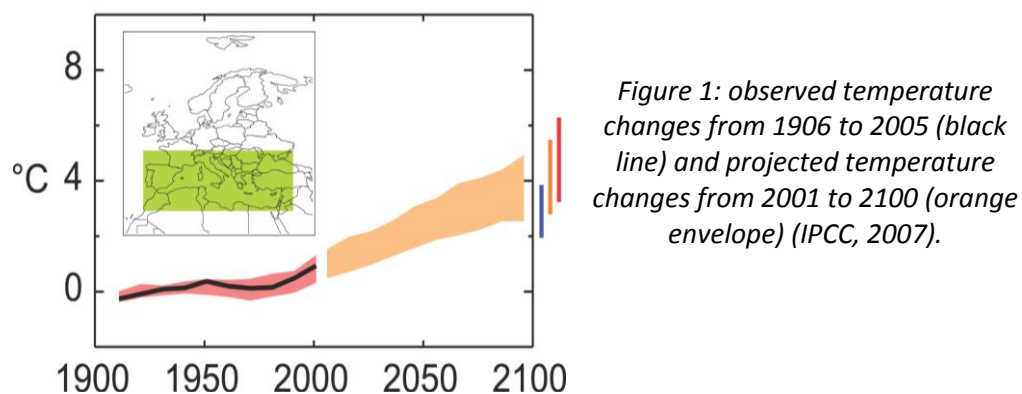
This concept paper will summarise the findings following an analysis of historical climatic data for the occupied Palestinian territory (oPt). Data on temperature and rainfall has been compiled and analyzed to assess the extent to which climate change is occurring. Climatic data is also analyzed against water availability data (discharge from springs and abstraction from groundwater wells) to assess if there is a correlation between changes in climate and water resource availability. This paper will start by defining the process of climate change and its anticipated regional changes as projected by the Intergovernmental Panel on Climate Change (IPPC). A summary of the potential impacts of these changes on water resource availability and land use will follow the analysis. The analysis contained within this report can help decision-makers within the Palestinian environmental sector to aid the development of appropriate environmental policy to respond to climatic change. These changes will impact agricultural production, food security, water resource availability, and land use and further influence the rate of economic development and growth across the oPt, as further outlined in this paper. Data from different time periods has been collected from a variety of sources, notably the Palestinian Metrological Department (2000-2012), the O2WS Jerusalem Weather Station (1964-2012) and the National Oceanographic and Atmospheric Administration (NOAA) of United States Department of Commerce (1845-1964).

2. Climate Change

Climate Change, as defined in the United Nations Framework for Climate Change (1992), refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCCC, 1992). Climate varies naturally over time; however climate change has accelerated in recent decades corresponding with intense anthropogenic activity such as the burning of fossil fuels, urbanization, industrial activities, and deforestation. Climate change presents serious and long-term challenges which have the potential to affect every part of the globe; including the oPt. Extreme weather events, such as droughts have noticeably increased in recent decades across the oPt, particularly in the southern and eastern slopes (ARIJ, 2011). The United Nations Convention to Combat Desertification (UNCCD) states that drought exists when; *"precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems"* (UNCCD, 2007). Consequently, increased incidences of drought will increase the vulnerability of rural people across the oPt such as

farmers and livestock herders, who utilise land resource production systems to sustain a livelihood. The impact of drought further erodes the coping mechanisms of vulnerable people who are also affected by the economic stagnation of rural communities, high food prices, and the closure regime imposed by the Israeli occupation since the second Intifada.

The Fourth Assessment Report (2007) published by Intergovernmental Panel on Climate Change (IPCC) states that climate change will result in changes in temperature and rates of precipitation. The report publishes the output of climate models which project regional changes based on historical observations. The report states that temperature has increased, and will continue to increase more than the global mean across the Mediterranean region (which includes Israel and the oPt), particularly in the summer months (IPCC, 2007). In addition, the annual number of precipitation days has, and will continue to decrease, combined with an increase in the length of the longest dry spells (IPCC, 2007). These changes will encourage more summer droughts and heat waves across the Mediterranean region (IPCC, 2007). Figure 1 shows the simulated output of the Mediterranean regional model which illustrates observed and projected temperature changes simulating a gradual future warming ranging between 2.2°C to 5.1°C from 2001 to 2100¹.



3. Temperature

Data from 1964 for Jerusalem and data from 2000 for the West Bank governorates and the Gaza strip has been compiled, analyzed and illustrated in the following figures. Figure 2 shows mean annual temperature from 1964 to 2011 in Jerusalem. It shows annual variability over the 47 year period. The highest annual temperature recorded in this period was 19.3°C in 2010, and the lowest annual temperature was 16.1°C in 1967. Analyses of the data ranges cannot determine if mean temperature is either increasing or decreasing but the calculated trend-line indicates an overall

¹ The bars at the end of the orange envelope in figure 1 represent different IPCC projected climate scenarios. For more details see section 11.1.2 of the IPCC Fourth Assessment Report, Climate Change 2007.

increase since 1964. This is due to peak temperatures increasing within observed temperature cycle patterns. Temperature peaks are observed every 8-10 years. Following a peak, the temperature cycle follows a pattern by gradually dropping, stabilizing and then peaking again.

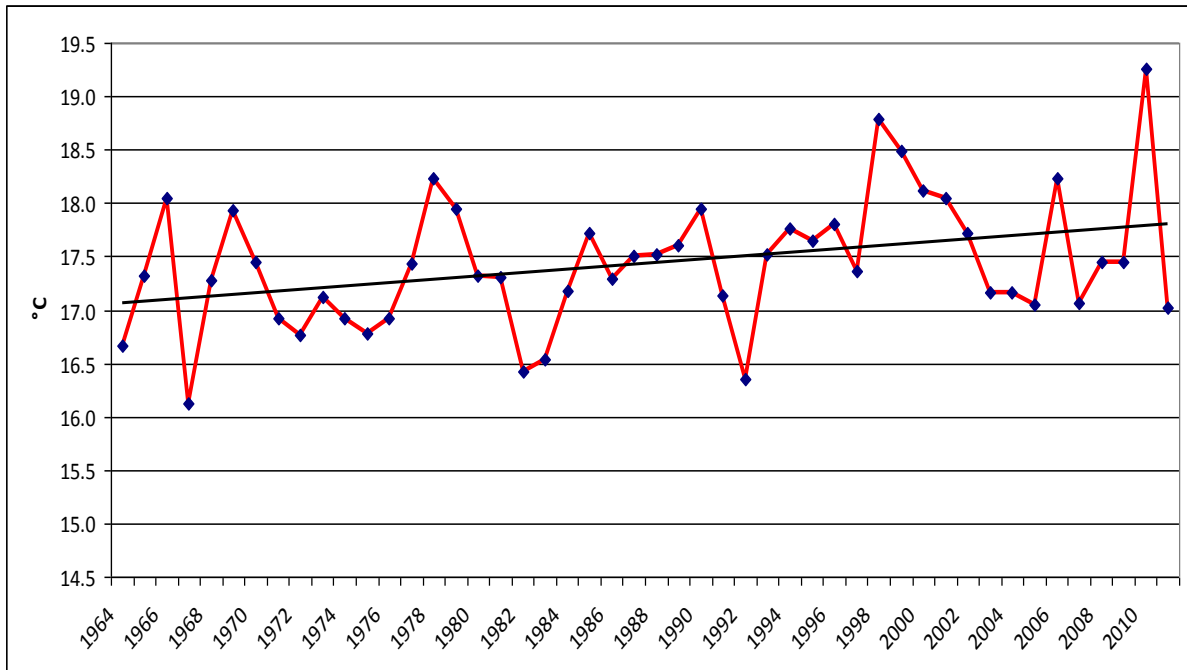


Figure 2: mean annual temperature (1964-2011)

Analysis of data ranges for summer and winter temperatures also reveals no significant changes (figure 3). The analysis does however reveal that annual summer temperatures are more gradual and show little variability, while winter temperatures are more erratic experiencing dramatic changes each year. Temperature cycle patterns can be observed clearly in the summer months of June, July and August, but less clearly in the winter months due to the erratic nature of temperature changes in December, January and February. A continued analysis of maximum temperatures experienced in the summer months from 1964 reveals a gradual increase. Maximum temperature does not fall below 40°C until 2000 when thereafter it is observed 4 times (figure 4).

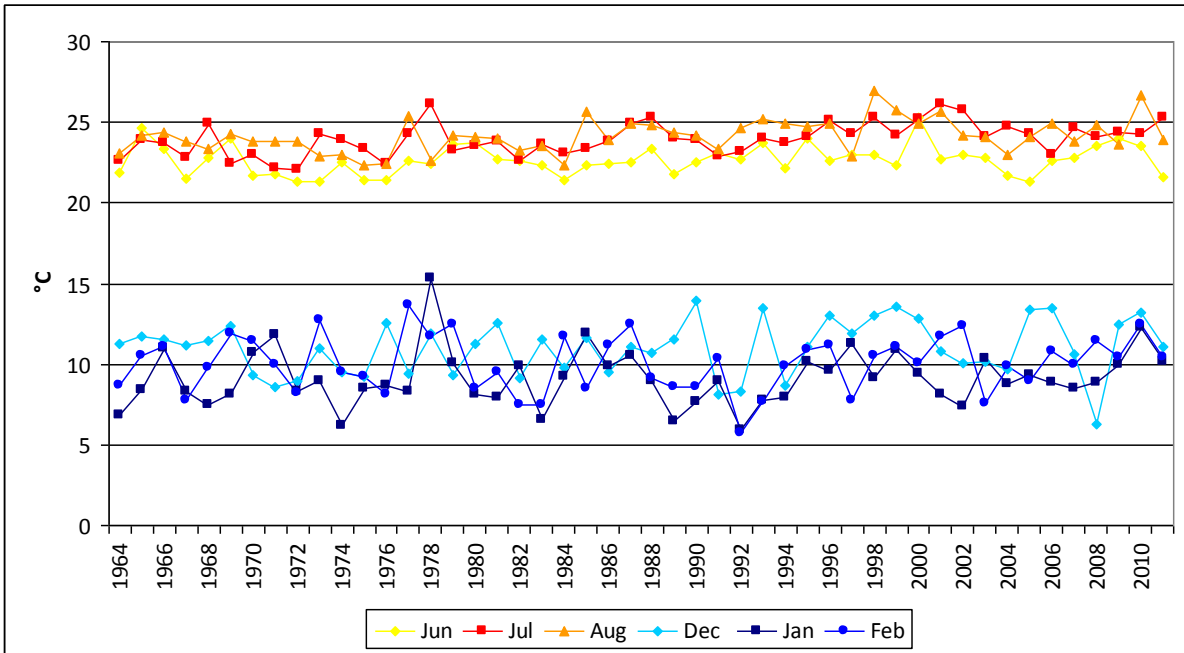


Figure 3: mean annual temperatures in the summer and winter months (1964-2011)

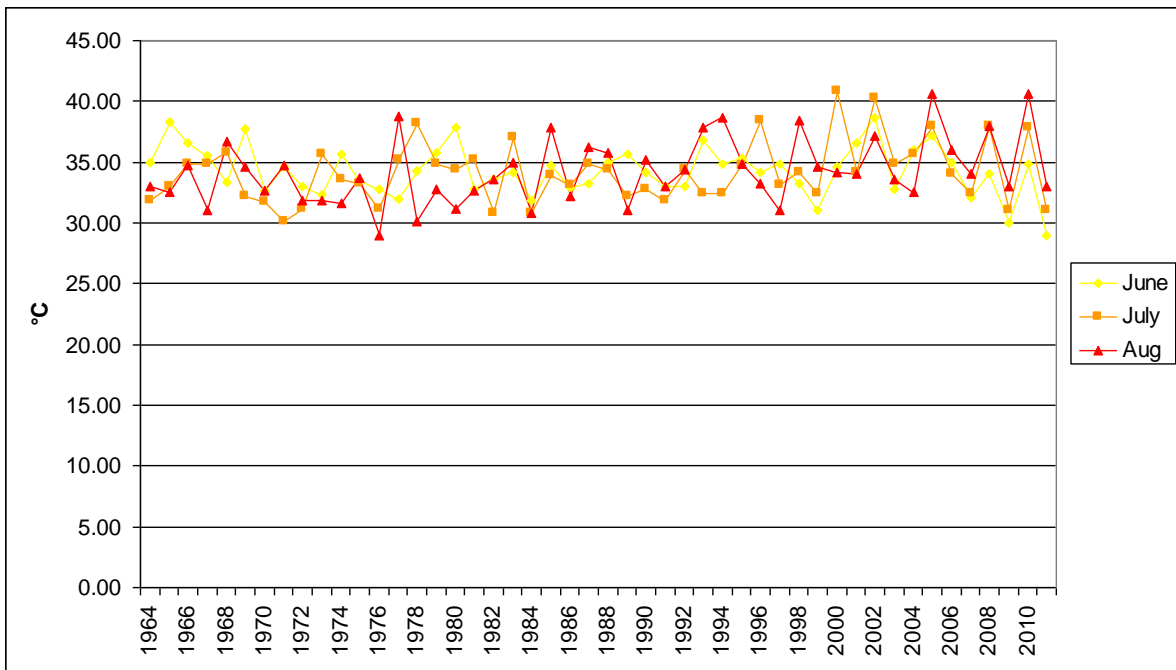


Figure 4: maximum annual temperature in the summer months (1964-2011)

A more in-depth analysis focuses on the changes in temperature over the last 10 years (2001-2011) across the West Bank. Analysis of this most recent data in temperature confirms the existence of a temperature cycle pattern. From 2001 the temperature across the West Bank remains gradual at around 19°C until it drops off in 2007 to 15°C and then dramatically rises to 21.5°C in 2010, dropping again in 2011. Based on this time period, average annual temperature is set at 18.1°C as represented in figure 5. Analysis of winter and summer seasons during the 10 year period (figures 6 & 7) also

reflects patterns illustrated in figure 3; gradual variability in summer temperatures and erratic variability in winter temperatures.

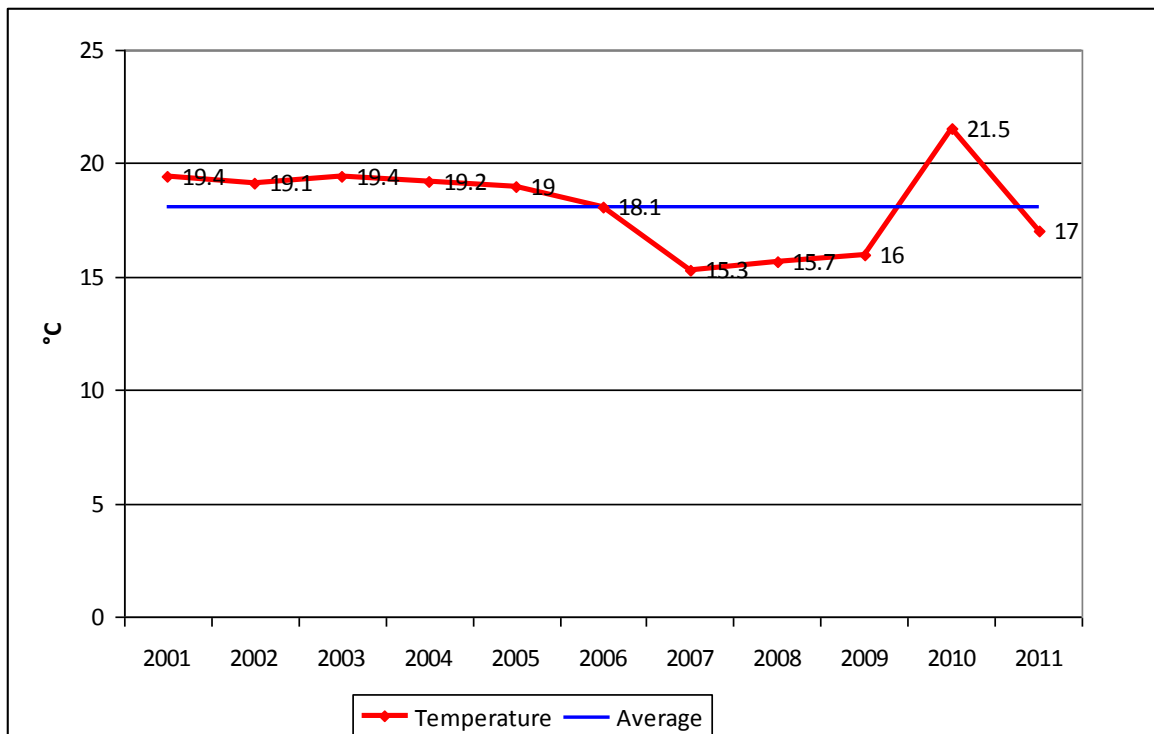


Figure 5: annual mean temperature (2001-2011)

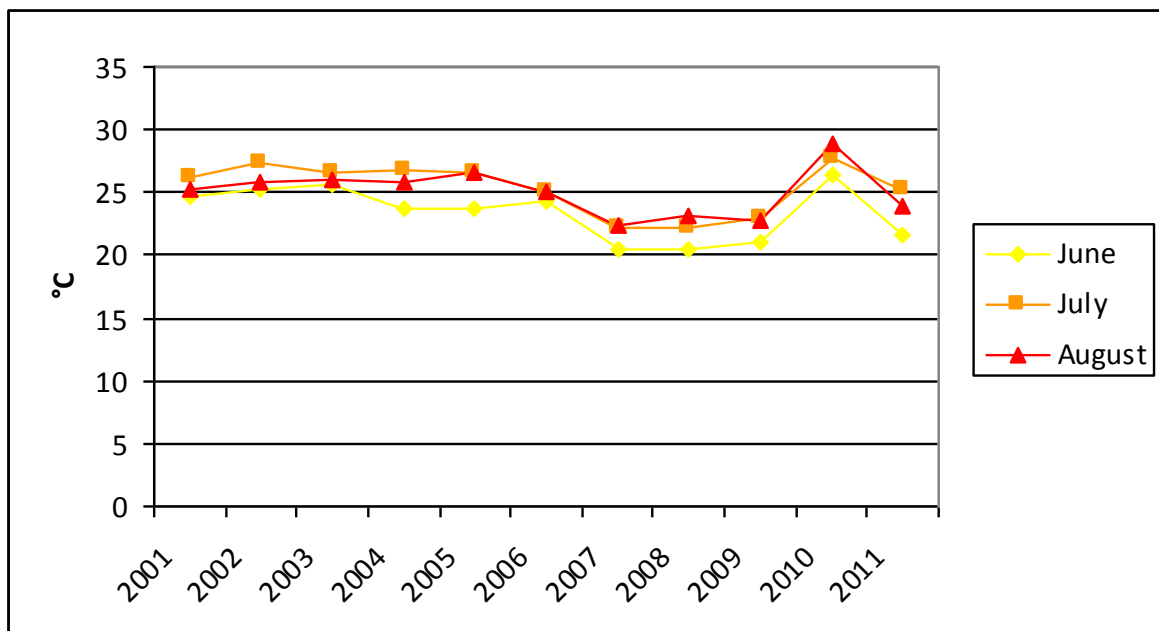


Figure 6: annual mean summer temperatures (2001-2011)

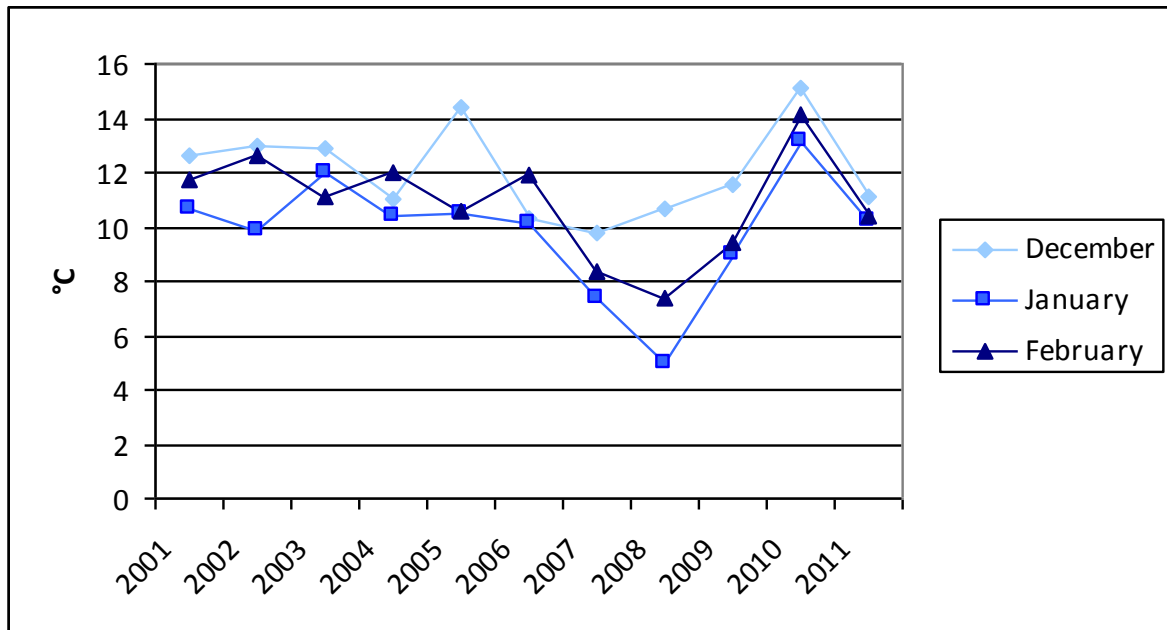


Figure 7: annual mean winter temperatures (2001-2011)

Data on temperature was also gathered and analyzed at the regional level. Data from the 11 governorates of the West Bank revealed unique changes in temperature. Over a 10 year period (2000-2010), the same temperature cycle patterns occur as revealed in figure 8 which shows gradual temperatures, a period of cooling, followed by a sharp increase. Changes are most prominent in the Eastern and the Northern governorates of the West Bank. The southern and central governorates (Hebron, Bethlehem, Jerusalem, and Ramallah) have little variability and mean annual temperatures remain mild. This is due to the influence from a high topography which ranges from 750-900 metres above sea level. In comparison Jericho sits at 258 metres below sea level and, as illustrated in figure 8, a distinct heat island usually exists across the Jericho governorate which experiences annual mean summer temperatures of 30-32°C and maximum summer temperatures can reach 47°C. Figure 9 reveals temperature at the governorate level in the year 2010 which experienced the peak in the observed temperature cycle pattern. In 2010 mean annual temperature reached 21.5°C, pushed up by a mild winter and a hot summer. Figure 9 clearly shows that Jericho's heat island dominates temperature records across the West Bank and that Ramallah experiences the mildest temperatures. Figure 9 further illustrates that each governorate experiences a gradual increase in temperature from January to July-August, followed by a gradual decrease towards December. However there are a few anomalies to this rule such as Salfit governorate which experiences an average decrease in temperature in May in comparison to April.

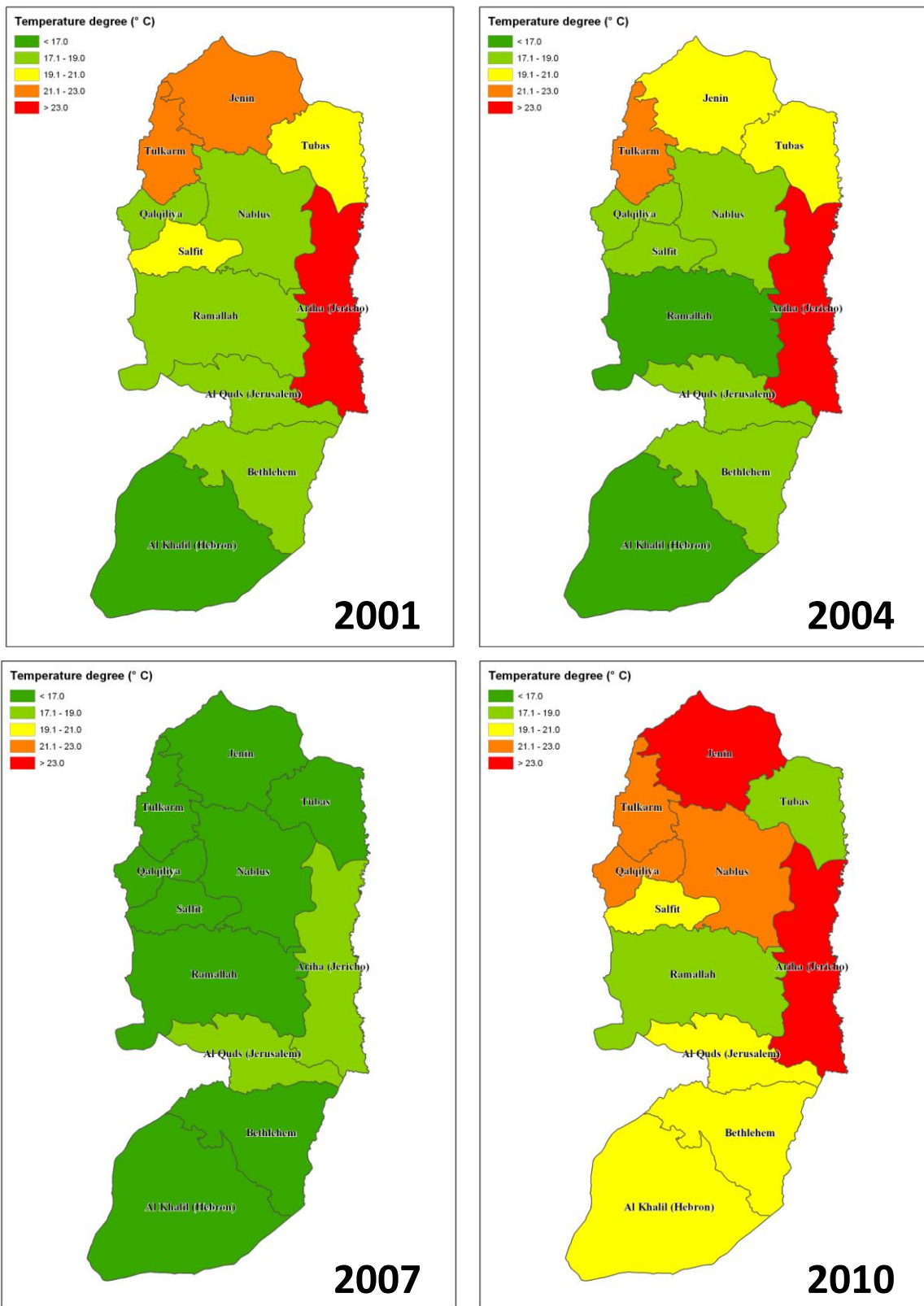


Figure 8: visualization of mean temperature variability at the West Bank governorate level

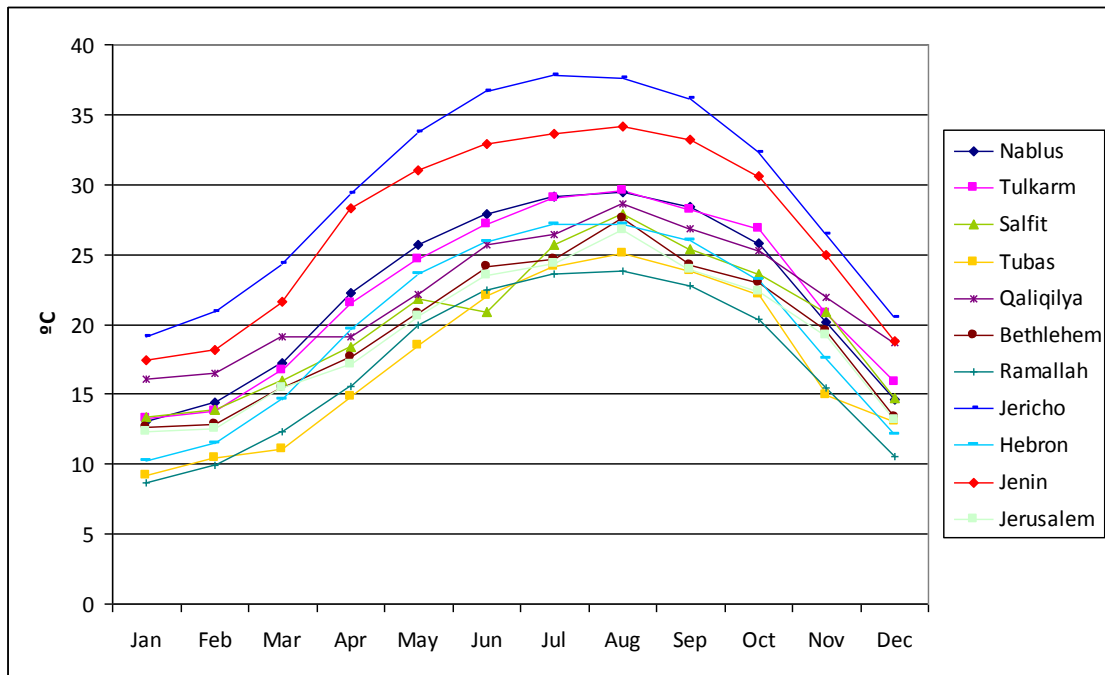


Figure 9: mean temperature variability at the governorate level in 2010

Climatic data for the Gaza Strip is scarce due to damages caused to metrological stations by the Israeli military in 2007. Temperature data that is available has been illustrated in figure 10 which shows mean annual temperature from 1997-2007. It shows a clear increase in mean temperature over the 10-year period. The Gaza strip experiences warmer mean annual temperatures in comparison to the West Bank with average temperatures over this 10 year period recorded at 20.6°C. A temperature cycle pattern is once again observed in this data.

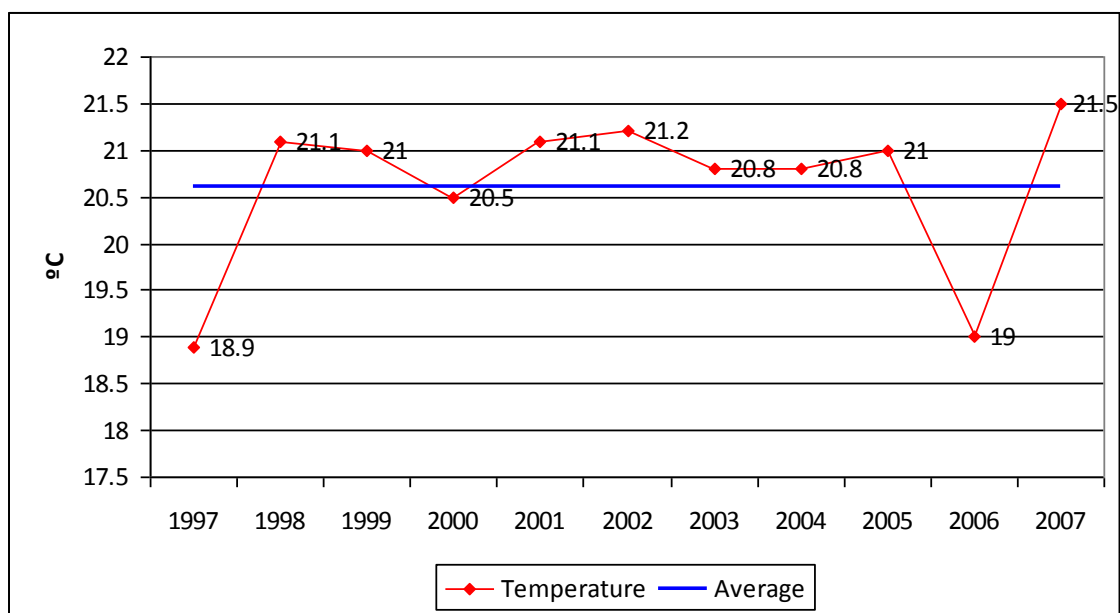


Figure 10: mean annual temperatures in the Gaza Strip (1997-2007)

4. Rainfall

Rainfall records for Palestine date back to 1845 where measurements were first taken at the Scottish hospital in Jerusalem (NOAA, 2012). ARIJ has compiled this historic data into a database for analysis. Figure 11 shows total annual rainfall in Jerusalem for the rainy seasons from 1845 to 2012². It reveals the extent of annual variability over the 167 year period. The calculated trend-line indicates that rainfall is decreasing. Analysis of the data ranges between rainy seasons determines that rainfall is decreasing at an average rate of 1.4mm per year. This relates to a reduction of 233.8mm in total annual rainfall since 1845. The highest recorded rainfall was 1,091mm during the 1877-1878 rainy season, and the lowest recorded rainfall was 206.3mm during the 1959-1960 rainy season. Figure 11 reveals a significant point of transition in rainfall patterns. Prior to the 1920s rainfall showed greater variability and often peaked above 900mm per year. After the 1920s, and to the current day, rainfall rarely peaked above 900mm and often reached record lows between 200-300mm per year.

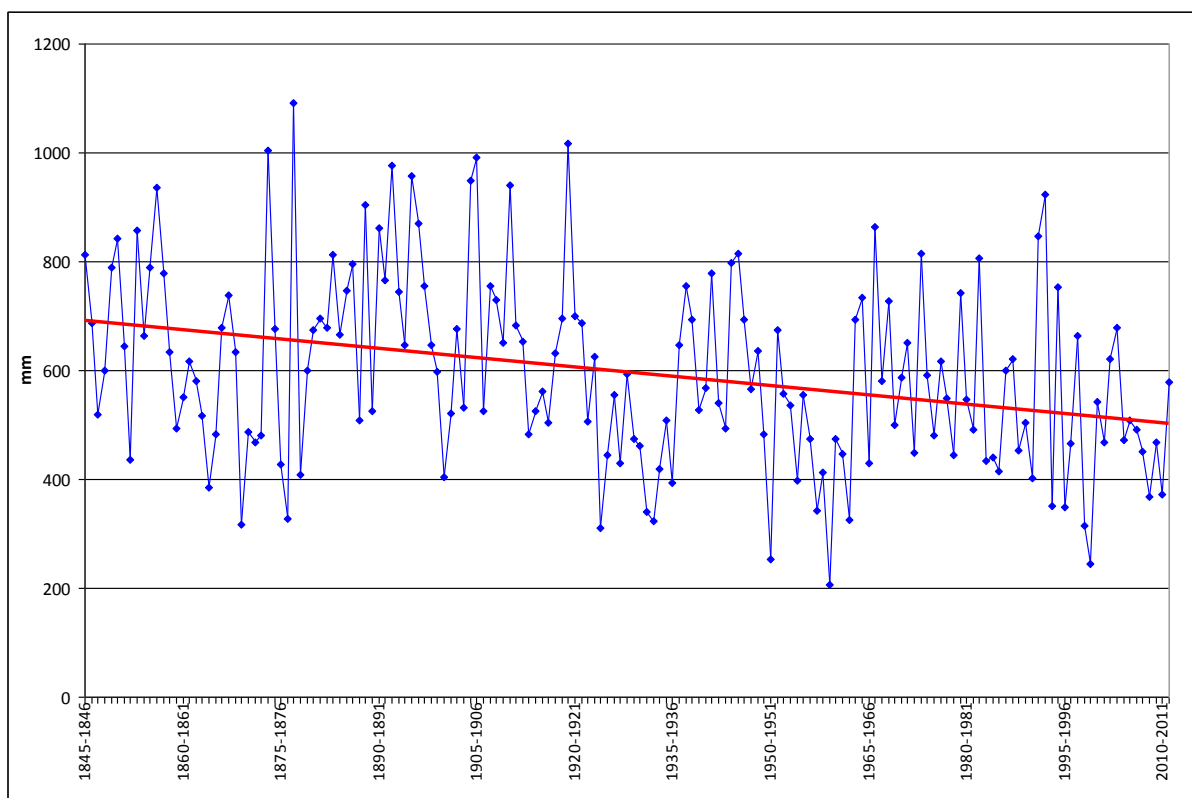


Figure 11: total annual rainfall in Jerusalem (1845-2012)

² The rainy season in Palestine typically starts in December and ends in March however incidents of rainfall do occur in the months before December and after March. Rainfall is rarely recorded in the months of June, July and August. The ARIJ rainfall database incorporates all incidences of rainfall within each year illustrated as a rainy season, e.g. September 2000 to August 2001

It is difficult to assess the existence of any rainfall patterns within figure 9 so a narrower data range has been analyzed, as shown in figure 12. Figure 12 shows total annual rainfall in Jerusalem for the rainy season from 1964 to 2012. The trend-line indicates a reduction in rainfall which is also reflected in the analysis of the data ranges between rainy seasons which states that rainfall is decreasing at an average rate of 3.3mm per year. This amounts to a decrease of 155.1mm since 1964. This figure illustrates that the rate of rainfall reduction has accelerated in recent decades when compared to data from 1845. Figure 12 also reveals rainfall cycle patterns, a similar phenomenon shown from analyses of mean annual temperature. The patterns show greater variability but follow a similar trend to temperature; rainfall is decreasing in cycles with periods of gradual rainfall followed by a slump, and then a peak. Figure 13 illustrates the same time frame used in figure 5 (2001-2011) to illustrate a rainfall pattern cycle. Figure 13 highlights that the pattern is less evident than temperature cycles but usually occurs every 8-10 years. Over the 10 year period the average total rainfall was estimated at 490.1mm as expressed in figure 13. An analysis of the data ranges between rainy seasons illustrated in figure 13 reveals an average reduction of -23.2mm per year – a sharp decrease in comparison to previous decades.

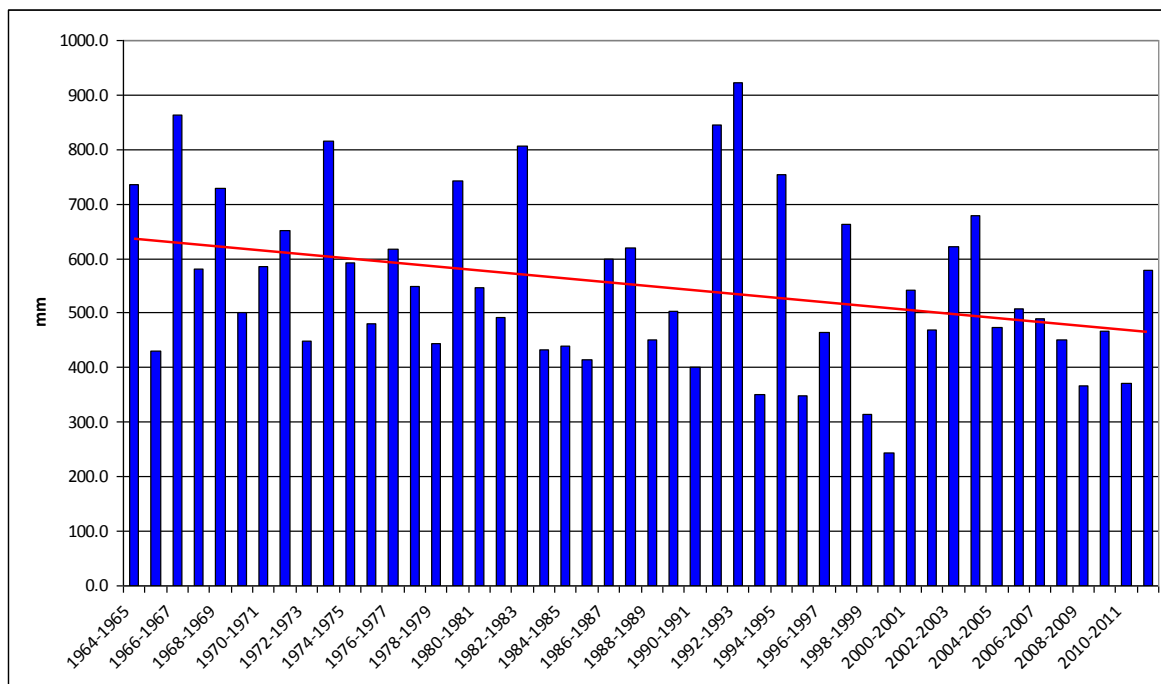


Figure 12: total annual rainfall in Jerusalem (1964-2012)

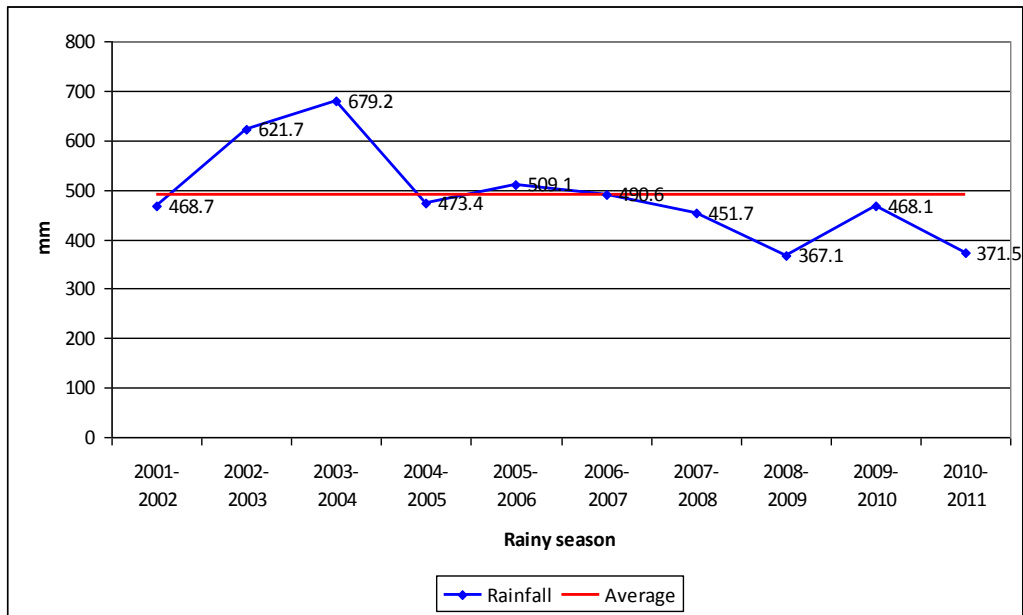


Figure 13: West Bank total annual rainfall (2001-2011)

Rainfall patterns were also analyzed at the governorate level to determine any regional changes. Figure 14 illustrates observed rainfall in the Gaza Strip which follows a similar trend as observed rainfall across the West Bank, which is decreasing. Figure 15 depicts changes in rainfall across the West Bank which illustrates regional variability, most notably in the Southern and Eastern governorates. The decrease in rainfall as highlighted in figures 11, 12 and 13 is particularly acute in Hebron, Bethlehem and Jericho governorates which receive the lowest total rainfall. Jericho experiences the lowest total annual rainfall reaching lows of 97.1mm in 2010, and Ramallah experiences the highest reaching peaks of 943.3mm in 2003.

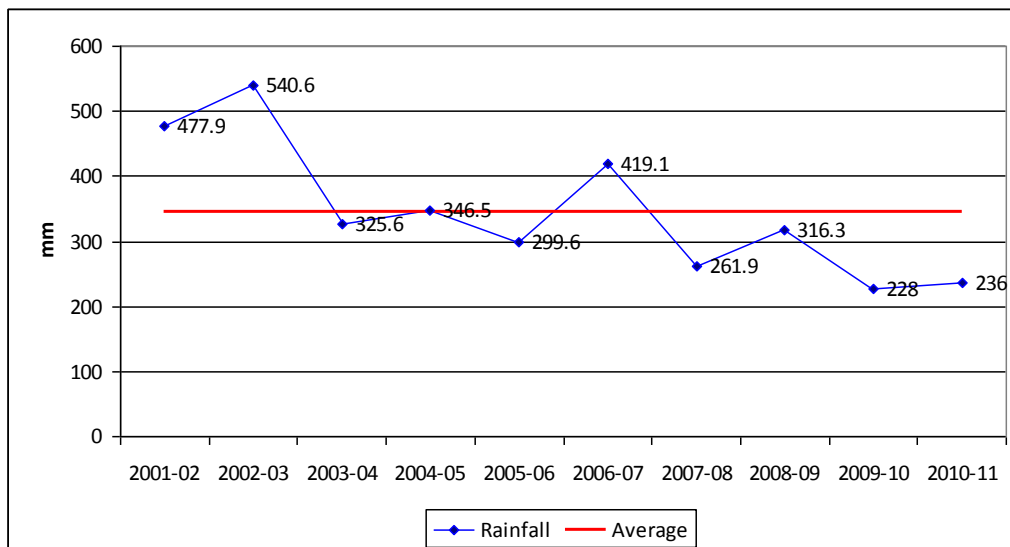


Figure 14: Gaza Strip total annual rainfall for rain seasons 2001-2011

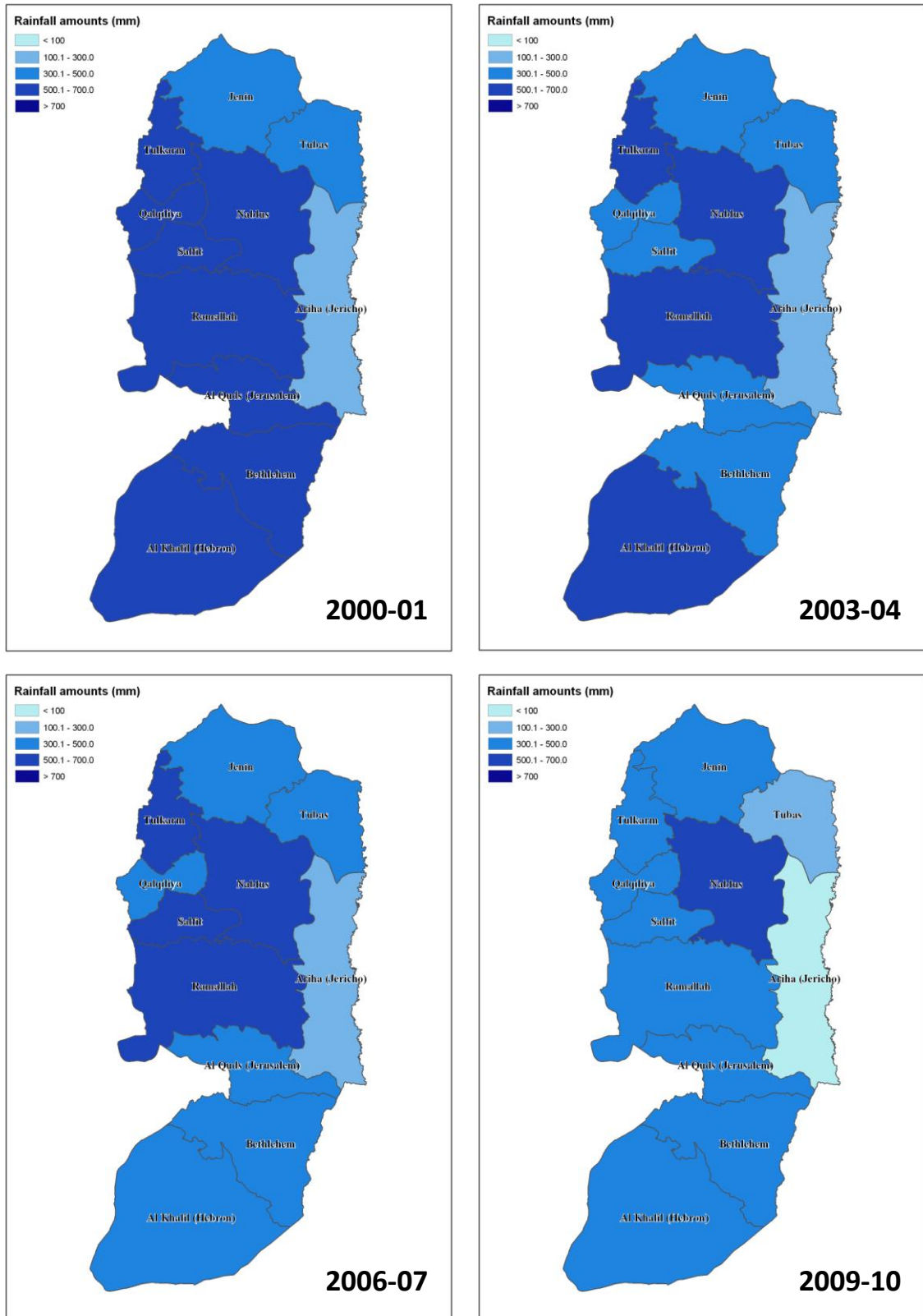


Figure 15: visulisation of total annual rainfall at the West Bank governorate level

Figure 16 shows rainfall patterns at the governorate level for the rainy season 2009-2010 which received a below average total rainfall of 468.1mm. The low rainfall can be attributed to a sharp

deficit of rainfall in the month of January. In comparison to regional temperature shown in figure 8, rainfall shows greater variability across the governorates. This again can be linked to the influence of the topography of the West Bank.

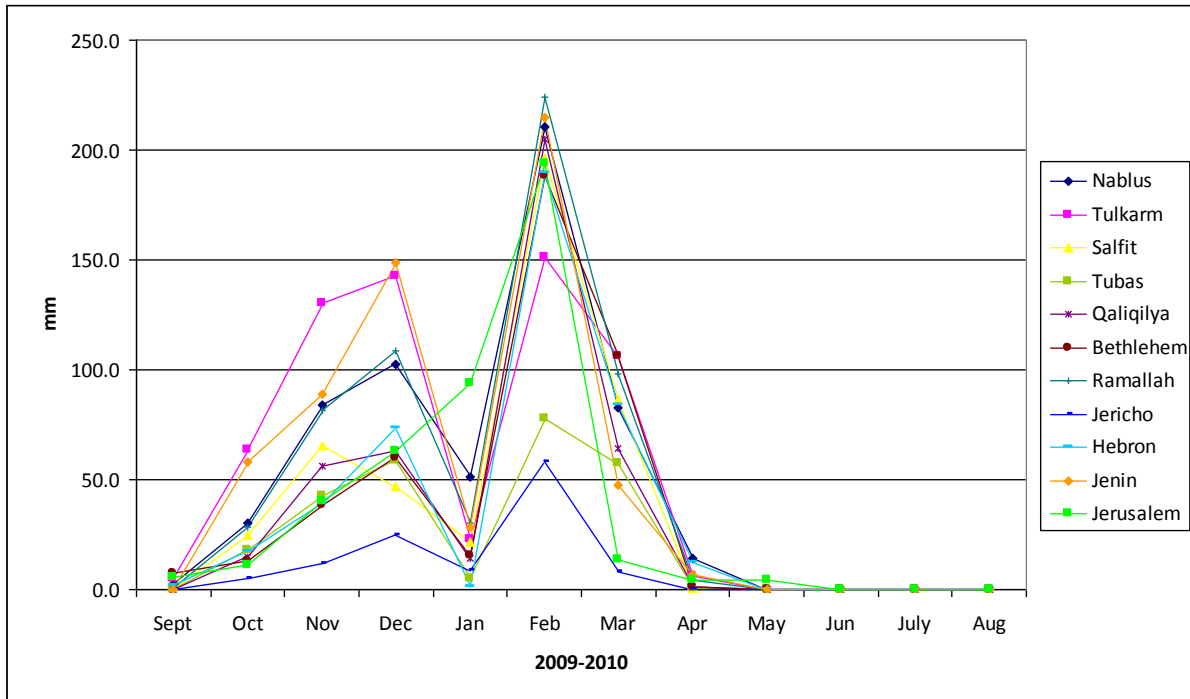


Figure 16: total rainfall variability at the governorate level for the 2009-2010 rainy season

Upon further analysis of the temperature/rainfall cycle patterns, it is clear there is a relationship between the two as expressed in figure 17. Figure 17 compares mean annual temperature with total annual rainfall from 1964 to 2011. It is clear that years of high total rainfall correlate with years of low average temperature, and vice versa. For example, in 1998 mean annual temperature was high at 18.8°C, but total annual rainfall was low at 243.9mm. In comparison, in 1992 average temperature was low at 16.2°C but total annual rainfall was high at 922.4mm. This relationship can be observed almost every year at different rates of variability.

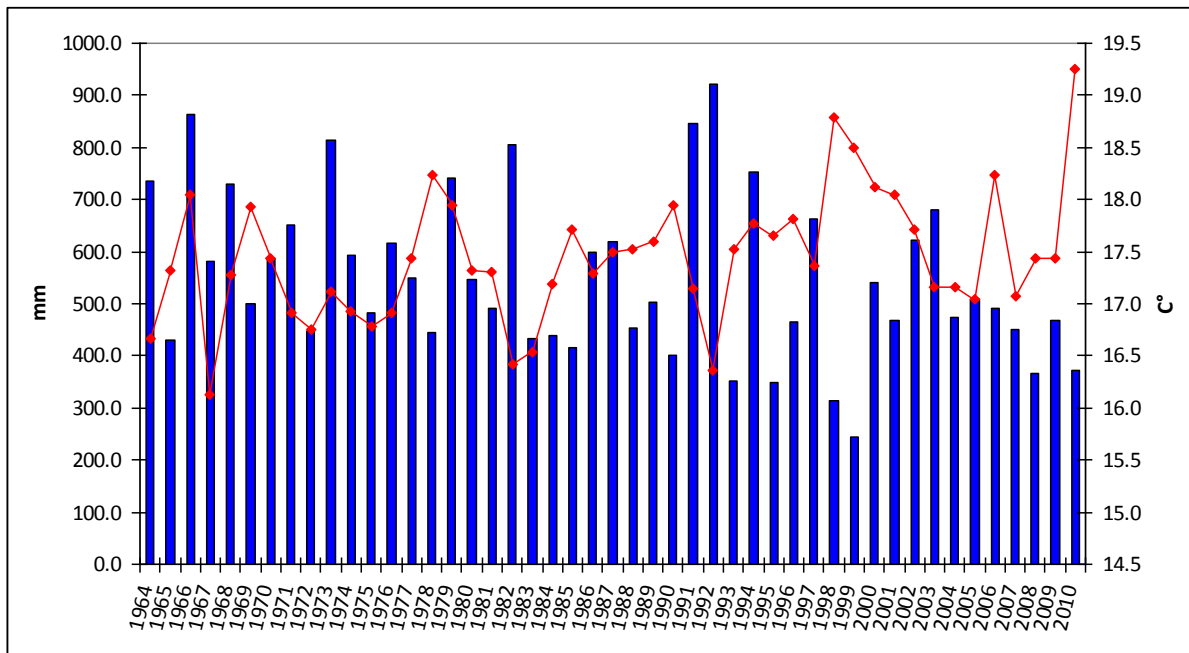


Figure 17: Jerusalem total annual rainfall (bar graph) compared to mean annual temperature (line graph) from 1964 to 2012

5. Water availability

This analysis will continue by comparing climatic data with local water resource availability indicators. Local water resource indicators relate to data on water abstraction from Palestinian groundwater wells and discharge from local springs. Groundwater is the main source of water for Palestinians across the oPt with 73% of the total local resources obtained from groundwater wells, and the rest produced by local springs (PWA, 2012). Local resources meet 64% of West Bank Palestinian demands and the remaining 36% is reliant on purchases from Mekorot, Israel's national water company (PWA, 2012). In Gaza local resources meet 95% of demand however the water quality is extremely poor due to saline intrusion, a result of severe over-pumping of the Coastal Aquifer. Figure 16 and table 1 compares the annual quantity of water abstracted from groundwater wells and annual discharge from springs, with mean annual temperature and total annual rainfall. It appears that total annual rainfall correlates positively with the annual discharge of springs. As shown in table 1 and figure 16, the lowest recorded annual rainfall is 367.1mm in 2008 which correlates with a sharp decline in the discharge of springs measured at a low of 25.2 MCM³. This is expected as the higher the rainfall, the higher the water table and thus the rate of recharge for local springs.

The low recorded rainfall of 2008 led to a drought episode across the oPt which limited water availability. This is also highlighted in figure 16 which reveals that the low rainfall experienced in

2008 corresponds with a low annual groundwater abstraction rate of 225.7 MCM³. Low annual rainfall depletes the recharge rate of groundwater wells which limits the quantity available to Palestinians. This situation is further compounded by the water restrictions imposed by the Israeli occupation which limits Palestinian abstraction and prioritises supply for Israeli settlements and the Israeli population. Figure 18 illustrates no correlation between annual average temperature and water availability indicators however the high abstraction rate experienced in 2010 (244 MCM³) could be linked to increased demands for water due to higher temperatures.

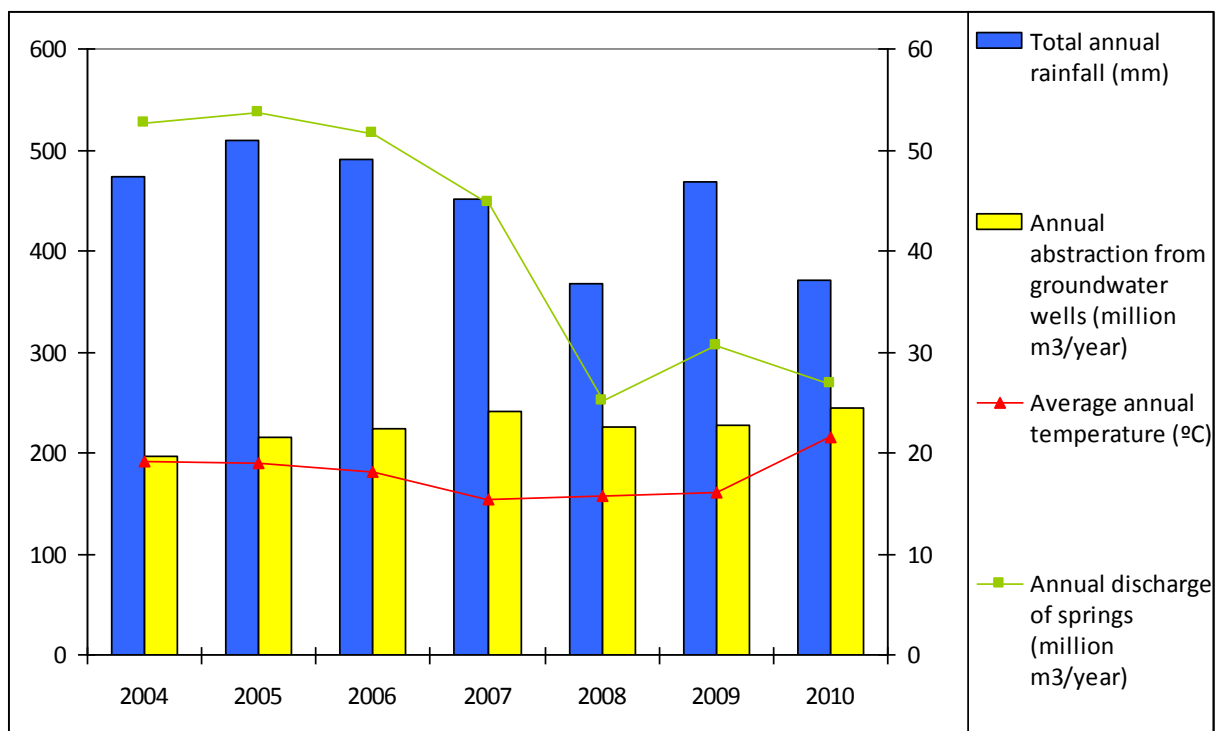


Figure 18: climatic variability compared to the availability of local water resources

| oPt | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Total annual rainfall (mm) | 473.4 | 509.1 | 490.6 | 451.7 | 367.1 | 468.1 | 371.5 |
| Average annual temperature (°C) | 19.2 | 19 | 18.1 | 15.3 | 15.7 | 16 | 21.5 |
| Annual abstraction from groundwater wells (million m3/year) | 196.1 | 214.7 | 223.5 | 241.2 | 225.7 | 227.2 | 244 |
| Annual discharge of springs (million m3/year) | 52.7 | 53.6 | 51.7 | 44.8 | 25.2 | 30.6 | 26.8 |

Table 1: Climatic and water availability indicators. Source: PWA, 2012

6. Impacts of climate change on land use

The previous sections of this report revealed that temperature is increasing and rainfall is decreasing across the oPt and these changes correspond with increased incidences of drought. Drought induced by climatic changes will alter land use patterns as fertile areas become increasingly vulnerable to desertification. The UNCCD (2007) defines desertification as; *"land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities"*. Land degradation across the oPt will reduce the area of arable lands and limit their potential. Table 2 quantifies land use across the oPt in 2006 and highlights that arable land constitutes 2559.2 km² or 42.5% of land use. The arrival of desertification will seriously diminish the area and capacity of arable lands leading to reduced agricultural productivity which will further harm the Palestinian economy that is heavily reliant on agriculture to support growth. The impact of desertification is further aggravated by Israeli territorial expansion policies in the West Bank. As also highlighted in table 2, Israeli settlements and the Separation Wall are confiscating vast areas of productive agricultural land.

| Land use | West Bank area (km ²) | % of the total area | Gaza Strip area (km ²) | % of the total area | Total area (km ²) |
|--|-----------------------------------|---------------------|------------------------------------|---------------------|-------------------------------|
| Arable lands | 2361.3 | 42.5 | 197.9 | 54.5 | 2559.2 |
| Rangelands | 753.7 | 12.5 | - | - | 753.7 |
| Forests and wooded areas | 78.9 | 1.3 | - | - | 78.9 |
| Private plant cover lands | 213.8 | 3.7 | 7.6 | 2.1 | 221.4 |
| Open spaces with little or no vegetation | 1693.6 | 29.3 | 71.4 | 19.7 | 1765 |
| Palestinian built-up areas | 314.2 | 6.6 | 82.3 | 22.7 | 396.5 |
| Israeli settlements and Separation Wall | 244.3 | 4.1 | - | - | 244.3 |
| Internal water | 1.3 | 0 | 0.9 | 0.3 | 2.2 |
| TOTAL | 5661.1 | 100 | 360.1 | 100 | 6021.2 |

Table 2: Land use across the oPt. Source: ARIJ 2006

Figure 19 shows aerial photographs of agricultural lands near the Israeli settlement of Ro'i in the Jordan valley. It gives an indication of what may happen if desertification continues to accelerate in the region. The photographs reveal that agricultural land is gradually drying and shrinking due to the arrival of more arid conditions and desertification in the region. The photographs from 2001 and 2004 reveal rich and fertile agricultural fields. In comparison, the photographs from 2007 and 2011 reveal dry and arid conditions with reduced activity and lack of cultivation. The photographs cross the same time periods shown in figure 15 (2000-2011) which reveal that rainfall is decreasing in the Jordan Valley, notably in the governorates of Tubas and Jericho. This pattern corresponds with the

images of figure 19 which shows a reduction in agricultural area over time due to the onset of drought and the associated transition from arable to arid land. This continued phenomenon will further reduce the capacity and size of agricultural lands which will further restrict the livelihoods of Palestinians in the area.



2001



2004



2007



2011

Figure 19: aerial photographs of agricultural lands in the Jordan Valley

6. Conclusion

This analysis has revealed that the climate is changing over time; temperature is increasing and rainfall is decreasing across the oPt. The rate of climate change is gradual but its continued projection will increase the occurrence and intensity of drought. These findings confirm the observations and projections of the IPCC for the region. The IPCC projections claim that these

changes will intensify within this century and so a response to these changes is of utmost urgency. A reduction in annual rainfall will add increased pressure on local water resources as less rainfall equates to less recharge for groundwater aquifers and local springs. An increase in temperature will further increase the demand for water from a growing Palestinian population. This pressure is further compounded by the Israeli occupation which denies Palestinian sovereign control over resources and prioritises water demands from Israel. A reduction in rainfall and an increase in temperature will further alter land use as areas of the oPt become vulnerable to drought and desertification. In addition, projected climatic change will alter the productivity of agriculture and agro-ecosystems. Some crop yields and trees may prosper from increased temperatures but the majority of crops that are grown for the local market will suffer from a reduction in available water. Drought induced by climate change may endanger agro-biodiversity and the balanced ecosystems that many species are reliant on. The impacts on the environment as a result of climate change will further impact the Palestinian economy. Reduced productivity from the agricultural sector will result in a significant loss of livelihood and food insecurity for many Palestinians and further force food prices upwards. A water deficit will also increase water prices and increase dependency on Mekorot that currently supplies 36% of Palestinian water supplies (PWA, 2012). A more in-depth analysis on the economic impacts of climate change should follow-up this report. This analysis, combined with a specific report on the economic impacts of climate change, will allow decision-makers within the Palestinian National Authority and civil society organizations to formulate policy and develop response mechanisms that will effectively address climate change.

References

ARIJ, 2012. ARIJ database. Applied Research Institute-Jerusalem (ARIJ).

ARIJ, 2011. 'Status of the Environment in the Occupied Palestinian Territory: Chapter 5, Access to water and wastewater management in the OPT'. Applied Research Institute - Jerusalem (ARIJ). November 2011.

Intergovernmental Panel on Climate Change (IPCC), 2007. '*Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*'. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

NOAA, 2012. 'Palestine climate data'. National Oceanographic and Atmospheric Administration United States Department of Commerce. [online] Available: http://docs.lib.noaa.gov/rescue/data_rescue_palestine.html#o39775798. Accessed: 15/08/2012

Palestinian Metrological Department, Palestinian National Authority, 2012.

PWA, 2012. Palestine Water Supply Report 2010. Palestinian Water Authority, Palestinian National Authority, March 2012.

UNCCD, 2007. Drylands soil: sustaining life on earth, United Nations Convention to Combat Desertification (UNCCD): transforming drylands. United Nations Convention to Combat Desertification (UNCCD)

UNFCCC, 1992. *'The United Nations Framework Convention on Climate Change'*. United Nations, 1992

02WS, 2012. Jerusalem Weather Station, Archive. [online] Available: <http://www.02ws.com/station.php?&lang=0>. 15/08/2012.