Palestinian National Authority
Palestinian Water Authority

السلطة الوطنية الفلسطينية
سلطة المياه الفلسطينية

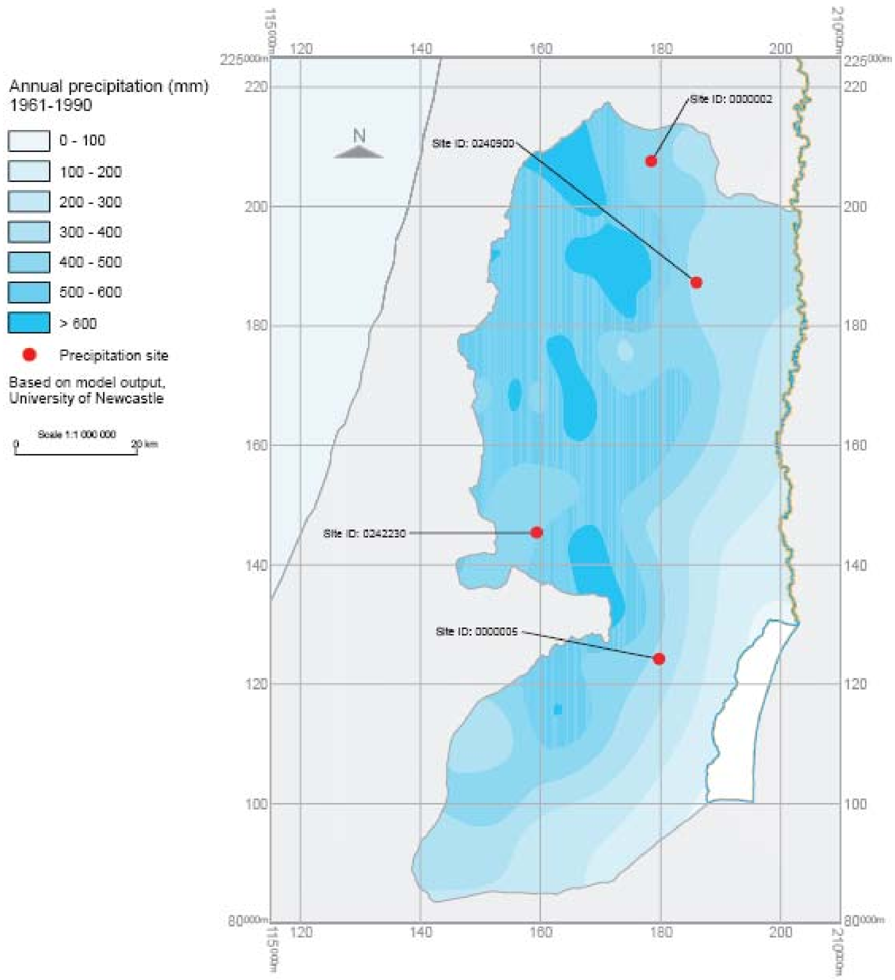
Sustainable Management of the West Bank and Gaza Aquifers

UNIVERSITY OF NEWCASTLE

Department for International Development

DFID

Stochastic Space-Time Modelling of West Bank Rainfall for Present and Future Climates



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The SUSMAQ Project

The aim of the project is to increase understanding of the sustainable yield of the West Bank and Gaza aquifers under a range of future economic, demographic and land use scenarios, and to evaluate alternative groundwater management options. The project is interdisciplinary, bringing together hydrogeologists and groundwater modellers with economists and policy experts. In this way, hydrogeological understanding can inform, and be informed by, insights from the social sciences. The results of the study will provide support to decision-making at all levels in relation to the sustainable yield of the West Bank and Gaza aquifers.

The project runs from November 1999 to October 2004, and is a partnership between the Palestinian Water Authority, University of Newcastle upon Tyne. The project is funded by the United Kingdom Government's Department for International Development (DfID).

Project Results Dissemination

The project disseminates its results through the project website www.ncl.ac.uk/susmaq, newsletters, workshops, technical meetings, publications in conference and scientific journals.

Bibliographical Reference

This report should be referenced as: SUSMAQ (2005). Stochastic Space-Time Modelling of West Bank Rainfall for Present and Future Climates. Report No. SUSMAQ - RAIN #42 V4.1, Sustainable Management of the West Bank and Gaza Aquifers, Palestinian Water Authority (Palestine) and University of Newcastle upon Tyne (UK).

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1. Overview and introduction

1.1. Background and previous work

Knowledge of the spatial and seasonal variability of rainfall over the mountain aquifers of the West Bank is crucial to the planning and operation of the groundwater resources. Two concerns have been raised regarding changes in rainfall threatening the water resources of the West Bank, and have motivated the research reported here.

The first concern is the threat from the effects of global warming. Current predictions from General Circulation Models (GCMs) are for significant decreases in annual rainfall over the region by the 2050s. This is combined with an increase in temperatures, causing higher losses from evaporation and changes in snow accumulation and melt. These combined effects pose a serious threat to groundwater resources, which need to be accounted for in planning the sustainable management of resources in the future. A further issue, little understood at present, is that of the effect of variations in rainfall intensity on groundwater recharge. It is likely that even if annual rainfall remains the same under climate change, that there will be changes in the number of wet days and therefore rainfall intensity, which will have significant impacts on the efficiency of recharge.

The second concern was raised by recent studies of rainfall over Israel, which have shown evidence of a trend in annual rainfall. The trend is characterized by a decrease in rainfall over northern Israel, and an increase in the more arid south. It is not known whether this trend affects the West Bank itself, as insufficient observational data from the West Bank have been used in the studies to date and the region lies between the zones of most marked increase and decrease. Similarly, insufficient data have been available from climate modelling studies to determine future impacts on the West Bank, due to the lack of high resolution climate models for the region.

The rainfall research programme of SUSMAQ therefore aims to assess the impacts of possible changes in rainfall regime on groundwater resources, in order to supply guidance for the sustainable management of the groundwater resources of the West Bank. This was achieved by executing the following tasks:

- Collection and analysis of West Bank rainfall records to identify spatial patterns and temporal trends;
- Relation of spatial patterns and trends to the regional climate and topography
- Development of stochastic rainfall models for the West Bank capable of reproducing the space-time properties of rainfall important for recharge, for both present and future climates;
- Assessment of the likely impacts of climate change or other trends on rainfall and groundwater recharge.

The work was programmed in three phases:
A. Preliminary assessment to provide immediate guidance for management and planning;
B. Detailed risk-based assessment of climate change impacts, using stochastic rainfall models;
C. Regional climate modelling at higher resolution, taking land use changes into account.

Mindful of the need for rapid availability of guidance, the preliminary assessment of climate impacts on aquifer recharge was made using immediately available GCM output and reported in Phase A. The second, more detailed assessment has been made using existing methods of producing future rainfall scenarios, together with stochastic rainfall models developed specially to simulate rainfall in this region. This work is referred to as Phase B and is reported here.

A further phase of work (Phase C, reported separately) has used a Regional Climate Model to produce finer resolution future scenarios than are available from GCMs. This allows topographic influences to be taken into account directly, albeit at a broad scale (25km x25km), as well as assessing the effects of possible land use changes.

1.2. The rainfall regime of the West Bank and adjacent regions

Most of the rainfall occurs in the months December to February. The highest annual totals are some 800 mm in the north of Israel and the mountains of the West Bank, decreasing in the rain-shadow of the mountains, to less than 100 mm in the Negev desert and southern parts of Israel. At present, recharge occurs in a well defined wet season with low evaporation, but clearly, with high and rising evaporation throughout the rest of the year, any changes in the seasonal and spatial patterns of the rainfall regime are crucially important for groundwater recharge.

In general, annual rainfall across the West Bank and Israel increases with both latitude and elevation, and decreases with distance from the coast (Steinberger and Gazit-Yaari, 1996). The rainfall gradient with latitude is usually explained by the variation in frequency of the main rain-bearing weather systems originating over the Mediterranean, as the region lies on the boundary between the Mediterranean and desert climate regions. The effect of elevation is the well-known phenomenon of orographic enhancement of rainfall, where windward facing mountain slopes receive above average rainfall amounts. The effect of distance from the coast may be explained by the progressive reduction in atmospheric moisture moving away from its principal source, the Mediterranean Sea.

1.3. Observed trend

A study by Ben-Gai et al. (1994) showed that the annual rainfall in southern Israel has increased by up to 30%. A further study (Steinberger and Gazit-Yaari, 1996) revealed that rainfall amounts have also decreased in the area to the north of Tel Aviv. They also showed that in the coastal area south of Tel Aviv and western slopes of the West Bank mountains the rainfall increased. These increases are characterized by an increase in rainfall at both ends of the rainy season (i.e. in October and April), predominantly at urban locations (Otterman et al., 1990).

The north-south rainfall trend is clear and spatially coherent, and further evidence is afforded by the state of Taberiya Lake, where levels have decreased considerably since the early 1970's. Although the rate of extraction has doubled since 1958, Steinberger and Gazit-Yaari (1996), showed that the falling levels are well correlated with, and dependent on, the preceding seasonal rainfall. They therefore identified the decreasing trend in seasonal rainfall as the main cause of the falling lake levels.

A possible cause of these changes is the establishment of the National Water Carrier (NWC) to transport water primarily for irrigation from the relatively wet north to the drier south. This has resulted in significant changes in land use in the southern coastal regions of Israel, which may in turn be responsible for changes in surface energy and moisture exchanges leading to changes in rainfall. This mechanism is discussed and described in the Phase C report.

1.4. Preliminary assessment of climate change impacts – Summary of Phase A

Current global climate models predict decreases in rainfall and increases in evaporation in the Middle East, as part of global warming and its impacts on atmospheric circulation patterns. Output from the Hadley Centre HadCM2 Coupled Ocean-Atmosphere General Circulation Model predicted temperature rises of around 3 deg C by the 2050s; this will increase potential evapotranspiration (PE) by some 15% or so, although the effects on actual evapotranspiration are more difficult to estimate without using a hydrological model calibrated for the region. The model also predicted significant decreases in annual rainfall. The magnitude of the predicted changes is sufficient for disastrous impacts on water resource availability in the region to be a serious possibility.

This conclusion is verified by the IPCC regional vulnerability report (IPCC, 1997), which concludes that in the Middle-East, "*Water is an important limiting factor for eco-systems, food and fiber production, human settlements and human health in this arid region of the world. Climate change is anticipated to alter the hydrological cycle and is unlikely to relieve the limitations placed by water scarcity upon the region*."

Of course, part of such a change may already have commenced in the last thirty years, but it is difficult to differentiate between natural climate variability and a trend caused by anthropogenic global warming on a decadal time scale. Steinberger and Gazit-Yaari (1996) associated the decreased rainfall in the north of the country with changes in atmospheric circulation, but there is insufficient observational information available to identify either climate change or just natural variability as the cause of the observed trend with any certainty. This attribution is further complicated by the possible influence of land use change.

1.5. Programme for Phase B

To apply the climate conditions and rainfall patterns derived in Phase A to a recharge model more realistically, it is necessary to ‘downscale’ the large scale rainfall patterns to the site specific monthly, daily and hourly rainfall data required by the recharge model.

The development of a stochastic space-time rainfall model is a main requirement of this task. This model should realistically reproduce the key spatial and seasonal characteristics of the rainfall fields responsible for groundwater recharge. Furthermore, it should also be capable of reproducing rainfall fields under assumptions of changes in climate, either occurring by natural variability, or by anthropogenic forcing and global warming. An important aspect of the model performance is that the simulated rainfall series should reproduce the observed daily and (if necessary) hourly intensity statistics, as these may be crucial for recharge in a semi-arid environment.

The second requirement is to use downscaling methods to produce space-time rainfall scenarios for the region, using GCM scenarios as a starting point. A suitable model for generating rainfall data has been developed at WRSRL over the last ten years or so, the Generalized Neyman-Scott rectangular Pulses (GNSRP) stochastic space-time rainfall model. The GNSRP can be used to generate space-time data representative of the different scenarios which will then be used as inputs to recharge models to generate future scenarios of water resource availability for use in a risk-based assessment of sustainable yield.

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