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Original Articles

Estimating groundwater recharge using the chloride mass-balance method in the West Bank, Palestine

Estimation de la recharge hydrogéologique par la méthode du bilan massique des chlorures en Cisjordanie, Palestine

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Abstract

The quantification of natural recharge rate is a prerequisite for efficient and sustainable groundw … of water supply i… replenis… to estimate recha… of the Moun… was calculat… enishment volume … recharge

138.5×10^6 m^3/year. Finally, the recharge rate for the Western Basin was between 122.6 and 323.6 mm/year, with a total average recharge volume of 324.9×10^6 m^3/year. The data reveal a replenishment potential within the estimated replenishment volumes of previous studies for the same area. Also, the range was between 15 and 50% of total rainfall, which is still within the range of previous studies. The geological structure and the climate conditions of the western slope were clearly play an important role in the increment of total volume. In some cases, such as the geological formations in the Northeastern Basin, the interaction between Eocene and Senonian chalk formations result in minimum recharge rates.

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Résumé

La quantification de la recharge naturelle est un pré-requis pour une gestion efficace et durable des ressources en eaux souterraines. Puisque l'eau souterraine est la seule source pour l'alimentation en eau de la Cisjordanie, il est primordial d'estimer le taux de renouvellement des aquifères. Nous avons utilisé la méthode du bilan de masse des chlorures afin de calculer la recharge en différents sites du Mountain Aquifer en Cisjordanie, représentatifs des trois bassins hydrogéologiques. La recharge du bassin Est a été estimée entre 130.8 et 269.7 mm/an, avec un volume total de 290.3×10^6 m^3/an. Pour le bassin Nord-Est, la recharge se situe entre 95.2 et 269.7 mm/an, avec un volume total de 138.5×10^6 m^3/an. La recharge du bassin Ouest, finalement, s'échelonne entre 125.7 et 323.6 mm/an avec un volume de 324.9×10^6 m^3/an. Ces données révèlent un potentiel de renouvellement plus important que les volumes estimés lors d'études antérieures dans la même région. La structure géologique et les conditions climatiques sur le versant ouest jouent manifestement un rôle important pour la c … . Dans certains … enne du bassin N … inférieures.

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1 INTRODUCTION

Groundwater is the main source of water for Palestinians in the West Bank; rainfall harvesting is a secondary source. Limited natural water resources, over-exploitation, salinization and contamination of the groundwater resources are critical management issues. Three hundred springs and 60 groundwater wells drain freshwater from carbonate rocks of Upper Cretaceous and Tertiary age, with a total discharge of about 130×10^6 m^3/year (GTZ report, 1995; Nasser Eddin & Nuseibeh, 1995; Palestinian Water Authority, 2003).

The amount of water used for domestic purposes in the West Bank in 2003 was estimated at 64.7×10^6 m^3 (Palestinian Water Authority, 2003). The Palestinian Central Bureau of Statistics estimated the population of the West Bank as 2 313 609 in 2003 (PCBS, 2004), which means an average water share at 86 L per capita per day, assuming zero water losses. This volume is small in comparison with the 150 L per capita day recommended by the World Health Organization. In addition to this shortage, 257 Palestinian communities are still not connected to the water networks. Taking into consideration the natural population growth, additional water networks need to be constructed. The annual water shortage in the West Bank reached 60×10^6 m^3 in 2003 (Palestinian Water Authority, 2003). To satisfy the increasing demand, new wells have been drilled during the last 10 years, in addition to many illegal shallow wells (up to 150 m depth) that were drilled in the Northeastern and Eastern basins, in the Jenin and Jericho areas in particular. While the natural replenishment of the aquifer systems in the West Bank depends on the recharge rate from rainfall, identifying this component is of key importance to the aquifer's sustainability. The objective of this study is to estimate recharge rates at different sites of the West Bank by using the chloride mass-balance method.

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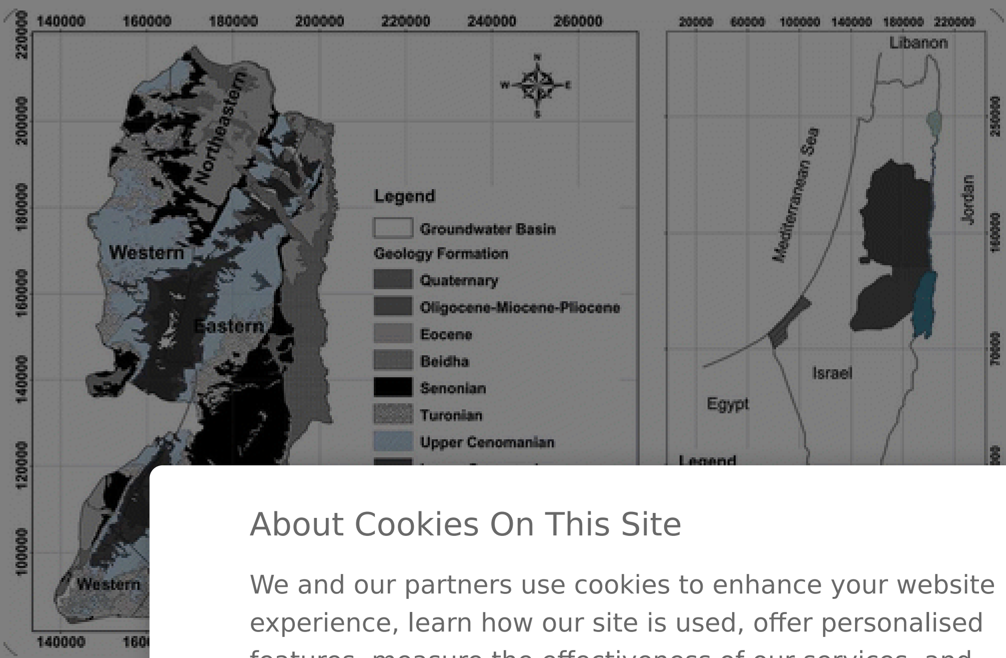
locations is one of the basic requirements for proper management and protection of groundwater resources.

The West Bank Mountain Aquifer extends from north to south and is mainly composed of limestone, dolomite and chalk of Upper Cretaceous to Tertiary age (Fig. 1). The Jordan Rift Valley is the largest structural feature in the area. Tal A'sur is the highest point in the northern West Bank, with an elevation of 1022 m above sea level (ARIJ, 1996). The Dead Sea is the lowest part and has an elevation of 410 m below sea level. The surface water divide runs parallel to the north–south axis of the mountain ridge. The change in climate from semi-humid on the western slopes of the mountains to semi-arid and arid on the eastern slopes and on the Dead Sea shore, respectively, reflects the rainfall distribution that exceeds 600 mm/year on the mountain ridge and is less than 100 mm/year on the Dead Sea shore (Arad & Michaeli, 1967; Husary et al., 1995; Palestinian Water Authority, 2006). Rain occurs mainly during the winter and spring seasons, while the intensity of rainfall varies from 1 year to another. In general, 75% of the rain falls between November and March. When the rainfall intensity exceeds 50 mm per day or reaches 70 mm in 48 hours there is surface runoff (Rofe and Raffety, 1963, 1965).

Fig. 1 Geological map of the West Bank (source Rofe and Raffety, 1963).



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2473 km^2 extending from the top to the foot of the mountain in the Jordan Valley (Table 1). The rainfall ranges from 650 mm at the summit to 150 mm in the Jericho area (Arad & Micheali, 1967; Husary et al., 1995; Palestinian Water Authority, 2006). Limestone, dolomite, chalky limestone and chalk of Upper Cretaceous to Tertiary age cover the catchment area. The Plio-Pleistocene aquifer system in the Jordan Valley is part of this basin and consists of gravel, sand, silt, clay and evaporites (Begin, 1974). In places with less than 200 mm annual rainfall, the direct recharge is neglected as most of the rainfall evaporates due to the high temperatures. Recharge to this aquifer depends on the occurrence of wadi flooding, where floodwater crosses the alluvial deposits of the wadi floor during the winter months (Marei & Vengosh, 2001).

Table 1 Formation outcropping in the three groundwater basins in the West Bank (km^2)

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The Northeastern Basin, which is shared between the Palestinians and Israelis, has a catchment area of about 976.8 km^2 inside the West Bank boundary. Upper Cretaceous limestone, and chalky limestone, and Tertiary chalky limestone and chalk cover the catchment area, which receives an annual rainfall of 500–600 mm. There are two aquifer systems in this basin: the Eocene and the Turonian-Cenomanian aquifer.

The catchment area of the Western Basin extends westward from the mountain ridge to the coastal area over the political boundaries of the West Bank. The catchment area covers about 1771.9 km^2 inside the West Bank (Table 1). Limestone and dolomite cover most of the catchment area, which receives an annual rainfall of 650 mm on the mountain top to 450 mm in the coastal area.

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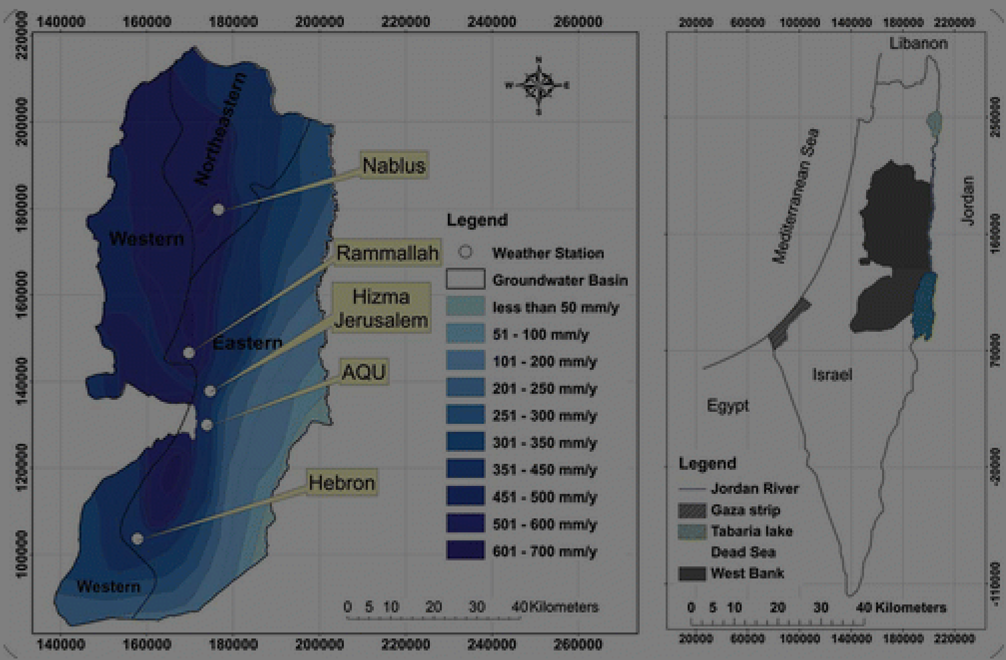
3 METHODOLOGY

3.1 Data collection and analysis

An average rainfall contour map generated by the Palestinian Water Authority indicates the evolution over the last 20 years during which rainfall was measured at 63 weather stations in the study area (Palestinian Water Authority, 2006). This map was used to estimate the recharge rate as an input component (Fig. 2).

Fig. 2 Average annual rainfall (mm/year) distribution in the West Bank (source Palestinian Water Authority, 2006).



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A total of 118 rainfall samples were collected for chemical analyses during the hydrological years from 2001/02 to 2004/05 at the weather station at AQU, and other samples … and 2008. Water sa… through 0.45-μm … ge of chlorid… t chloride cont… the average … g/L.

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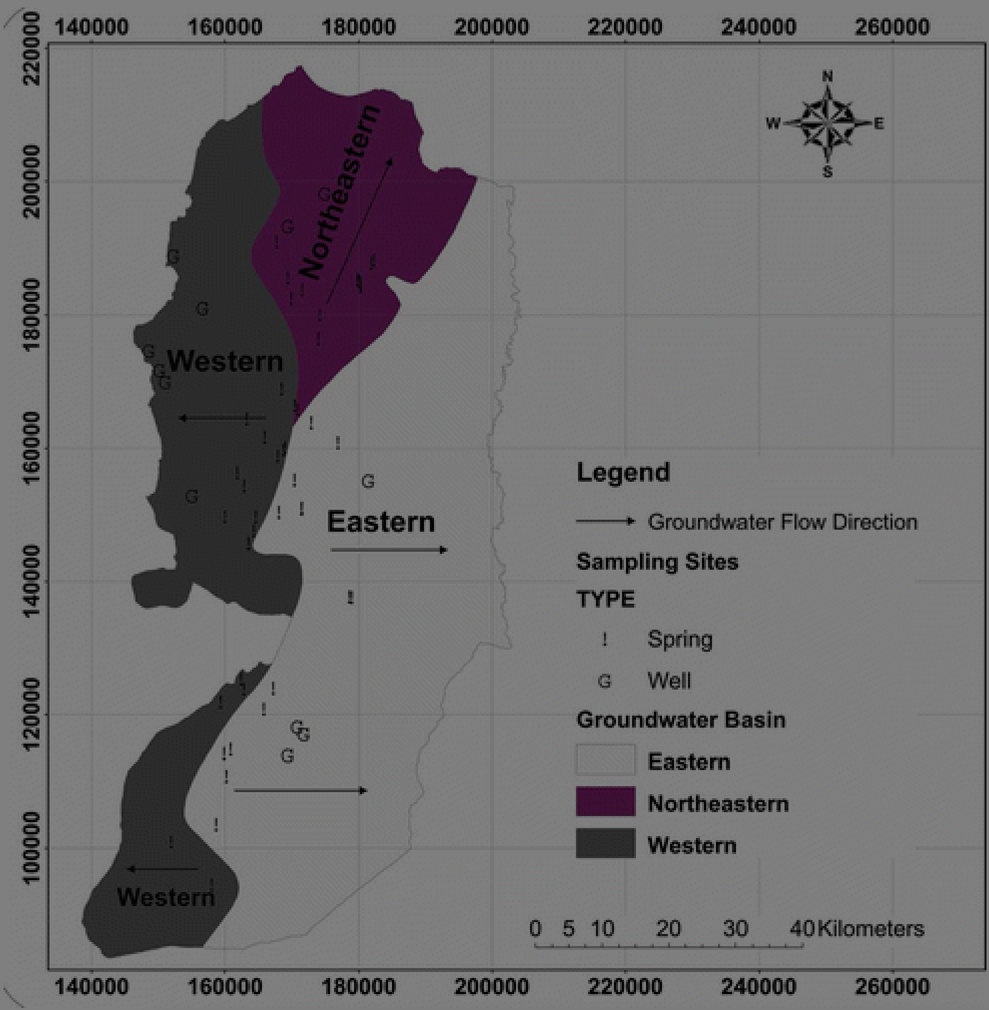
Groundwater samples were collected from 59 sampling sites across the three groundwater basins (Fig. 3). Within each basin, areas of different rock formations were distinguished and the related area was calculated using ArcGIS 9.0 software (Table 1). The recharge rates and volumes were calculated for each formation, after which the recharge volume was estimated for each basin. Impermeable chalky formations of Senonian age and the Quaternary Lisan formation were excluded from the calculation.

Fig. 3 Groundwater sampling sites.



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values were calculated using the Cl^-/Br^- molar ratio for both rainwater and groundwater, where the ratio for the latter was estimated to be 300 (Rosenthal, 1987).

Variations in the amount of rainfall from one year to another have a slight impact on the average chloride content because it depends on the intensity and duration of the rainfall events, rather than the precipitation total for the hydrological year.

3.2 Recharge estimation

3.2.1 Chloride mass-balance method

Chloride is regarded as a suitable environmental tracer since it is highly soluble, conservative and not substantially absorbed by vegetation. The chloride mass-balance method is convenient and inexpensive because of its simple data requirements. Recharge can be estimated by:

(1)

where R is recharge (mm/year); P is rainfall (mm/year); is weighted average chloride concentration in rainfall (mg/L); and is average chloride concentration in groundwater (mg/L).

The weighted average () is calculated according to the following equation:

where P_1 is the first rainfall event (mm) and C_1 is the corresponding chloride concentration in the rainfall (mg/L), for 1 to n events.

To determine the weighted chloride average for each hydrological year, the chloride concentration of each rainfall event is first multiplied by the amount of rainfall. The summation of these individual components is then divided by the total annual rainfall.

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Table 4 Groundwater sampling sites, hydrochemical values, rainfall and corresponding calculated recharge estimates for the West Bank

The assumptions necessary for successful application of the chloride mass-balance method are:

1. The absence of additional chloride sources such as dissolution of minerals, use of road salts and any potential source of pollution like wastewater.
2. Chloride is of a conservative nature in the system meaning that the ion neither leaches from, nor is absorbed by, aquifer sediments and does not participate in any particular chemical reaction.
3. The depth of the groundwater table should be deep enough to prevent groundwater evaporation.
4. Surface runoff should be minimal.

The first assumption is almost impossible, especially in the case of the Western and Northeastern basin areas. A large amount of wastewater is generated by the communities in the upper mountains and drains down through wadi flow, which makes the opportunity for fresh sewage water mixing high. Moreover, the Jordan rift valley formations, which cover a large part of the Eastern basin, contain a high quantity of salty rocks. All of the previous factors make the presence of excess chloride unavoidable, and this amount of excess chloride should be taken into account in calculations. In our study we used the Br/Cl molar ratios in rain and groundwater to calculate any addition of chloride to the recharged water during its pathway. Both Cl^- and Br^- behave conservatively. Rosenthal has suggested the Cl^-/Br^- molar ratio in the groundw … or the rainwate … d to approxir … red values in the r … .

The chlo … lison & Hughes, … 989; Lerner et al., 19 … 2002). Note that Edmunds et al. (1988) conclude that the amount of chloride removed through vegetation is usually balanced by the amounts released by plant decomposition.

Subyani (2004) used the chloride mass-balance method in Wadi Tharad, western Saudi Arabia, and estimated that the recharge rate was around 11% of the effective annual rainfall. Bazuhair & Wood (1995) also used the method in the wadi systems of the Asir and Hijaz mountains. In general, recharge was found to be between 3 and 4% of precipitation. They conclude that the chloride mass-balance method appears to be a useful technique to rapidly estimate groundwater recharge, or constrain estimates of groundwater recharge in certain arid areas.

In their paper, Simmers & de Vries (2002) summarize the current understanding of recharge processes, identify recurring recharge-evaluation problems, and report on some recent advances in estimation techniques. Emphasis is placed on semi-arid regions because this is where the need for information is greatest. The paper concludes that multiple tracer approaches (Cl^-, ^3H) probably offer the best potential for reliable results in local studies that require “at-point” information.

Kerh et al. (1998) adopted the chloride mass-balance method to estimate groundwater recharge in the Pingtung Plain, Taiwan. Based on the measured and calculated results for all sites, groundwater recharge was estimated at 15% of the annual rainfall, excluding recharge from additional irrigation water. They conclude that this information can improve the accuracy of future groundwater simulation and management models in the plain.

Unfortunately, few studies were found to have applied this method in Palestine. According to the Coastal Aquifer Management Program in the Integrated Aquifer Management Plan (Palestinian Water Authority, 2000) the Water Resources Action Program estimated recharge coefficients in areas of dune sand and clayey soil. The coefficie ... es and applying ... tal estimate ... . Another study ... the Faria Drai... 77.2 mm ... ifer.

3.3 Em...

The natural recharge of aquifers is a function of precipitation, along with many other factors such as geology, soils, vegetation, land use, climatic conditions, topography, land form and groundwater conditions. Based on studies of the correlation between rainfall and natural recharge, a number of empirical relations have been identified. Goldschmidt & Jacobs (1959) developed a relationship between rainfall and base flow data in the period between 1943/44 and 1953/54. Since there was very little well abstraction at the time, the total annual spring flow was considered equal to the annual recharge to the basin. The formula applied is:

(2)

where R is the recharge in mm/year; P is the annual rainfall in mm/year.

Instead of 0.86, Mandel & Shiftan (1981) used 0.90 as a coefficient in equation (2) for recharge in Mediterranean climates.

The following equations were used as the basis for the development of annual recharge estimates by Guttman & Zukerman (1995):

(3)

(4)

(5)

These equations were later modified by the SUSMAQ project team (Abu Sa'da et al., 2004) to give:

(6)

(7)

(8)

Other more complicated formulas for empirical relationships between precipitation and recharge have also been developed. For example, Sinha & Sharma (1988) developed an equatior

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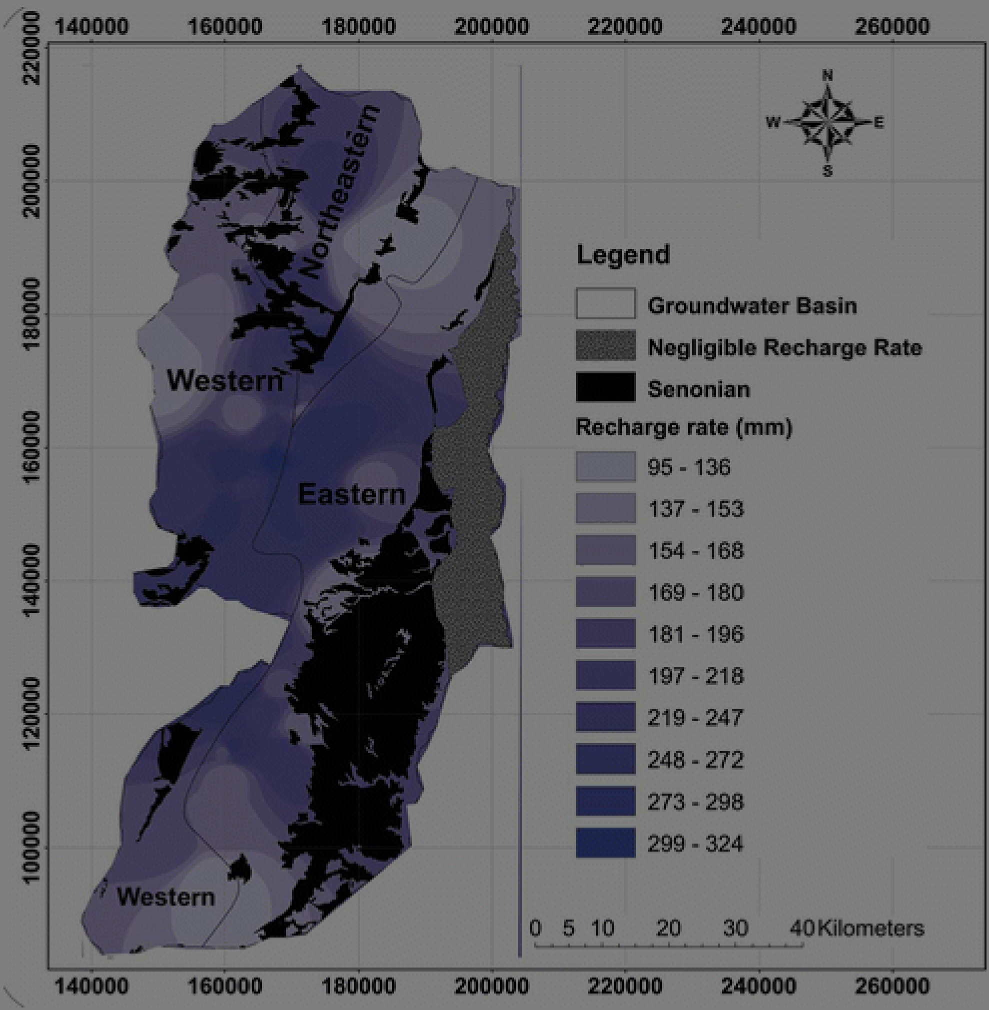
The weighted average of chloride contents in the rainwater samples collected at the five sampling sites range between 6.95 and 12.81, with an average 9.30 mg/L. This value is close to the value of 9.06 mg/L estimated by Herut et al. (1994). We implement a new chloride average value of 8.97 mg/L taking into consideration our measurements and the values of Herut et al. (1994). Table 4 and Fig. 4 summarize the recharge rate estimation results after application of the chloride mass-balance method.

Fig. 4 Recharge rates estimated for the West Bank using the chloride mass-balance method.



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is mostly used as rangeland. Recharge rates calculated by various authors range between 130.2 and 259.3 mm/year. The chloride mass-balance method shows that the annual recharge rate is between 130.8 and 269.7 mm/year (Table 5), and a recharge volume of 290.3 × 10^6 m^3/year (Table 6).

Table 5 Recharge rate in mm/year in groundwater basins of the West Bank

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Table 6 Estimated recharge volume (10^6 m^3/year)

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4.2 Northeastern Basin

A total of 19 groundwater samples were collected from this basin. The chloride concentration Ranges from 20.0 to 59.4 mg/L and the Na^+/Cl^- ratio ranged from 0.86 to 1.0. The nitrate concentrations were 5.3–19.5 mg/L. The high chloride contents in some samples can be ascribed to the low permeability chalky limestone formation and the thick soil horizon in some areas (Rofe and Raffety, 1963); the percentage of excess chloride reached 2% of measured chloride in these samples. Most of the land is used for agricultural purposes (mainly olive trees) and relies on rainfall. In the northern part of the basin, some of the land is also irrigated and vegetables are cultivated. The source of nitrate in groundwater samples is related to nitrification of organic matter in the soil horizon as well as percolation of irrigation water (Hem, 1970).

Rofe and Raffety (1965) calculated the average actual recharge to range between 50 and 250 ... hloride mass-ba ... thod, the average ... and 269.7 ... le 6).

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to 43.0 mg/L, and the Na^+/Cl^- ratio ranged between 0.86 and 1. The highest chloride concentrations were found in the coastal area, where the soil horizon is a few metres thick and irrigation activities are widely distributed. The average nitrate content concentration ranged from 2.0 to 39.0 mg/L. According to our chloride mass-balance calculation, the estimated recharge rate in this area ranges from 122.6 to 323.6 mm/year (Table 5), and a recharge volume of 324.9×10^6 m^3/year (Table 6).

4.4 Comparison with previous estimation

Table 6 shows our estimates of recharge volume for the West Bank Mountains aquifers, and the previous estimation from many other studies. The data reveal higher replenishment potential volume (753.2×10^6 m^3/year) than previous studies for the same area (Table 6). Also, the range was between 15 and 50% of total rainfall, which is still within the range of previous studies.

5 CONCLUSIONS

Recharge in semi-arid regions like the West Bank can be estimated using the chloride mass-balance method. An average chloride concentration in rainfall of 8.97 mg/L was applied for the calculations. Recharge areas covered in impermeable chalk and Quaternary formations along the Jordan rift valley were excluded from the calculation of the total recharge volume. Recharge rates range from 15 to 50% of rainfall, which is still within the range of previous studies records. Low recharges rates were found in areas of chalky limestone in the Northeastern Basin, and along the western margin of the eastern slopes of the Mountain Aquifer.

In most of the samples the Na^+/Cl^- ratio is less than 1 and close to the marine ratio, and the NO_3 … rs were applied t… excess chloride, … method the total est… he shallow Plio-…

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This research was conducted as part of the Groundwater Availability and the Fate of Pesticide Input research project (GAPI) funded by the German Ministry of Education and Research (BMBF).

REFERENCES

1. Abdulghaffar , S. , Bazuhair , A. and Wood , W. W. 1996 . Chloride mass-balance method for estimating ground water recharge in arid areas: examples from western Saudi Arabia . J. Hydrol. , 186 : 153 – 159 .
Google Scholar

2. Abu Sa'da , M. , Aliewi , A. , Kalbouneh , A. , Messerschmid , C. and Yassin , R . 2004 . Monthly recharge estimation in Wadi Natuf, Palestine. , SUSMAQ Project, PWA Internal Report, Ramallah-Palestine
Google Scholar

3. Allison , G. B. and Hughes , M. W. 1978 . The use of environmental chloride and tritium to estimate total recharge to an unconfined aquifer . Aust. J. Soil Res. , 16 : 181 – 195 .
Web of Science ® | Google Scholar

4. Allison , G. B. and Stone , W. J. 1985 . Recharge through karst and dune elements of a semiarid landscape . J. Hydrol. , 76 : 1 – 25 .
Web of Science ® | Google Scholar

5. ANTEA ... 998 .
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6. Arad , ... stern
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7. ARIJ (Applied Research Institute) . 1996 . Environmental Profile for the West Bank: Ramallah District. Bethlahem, Palestine. , 4
Google Scholar

8. Bazuhair , A. and Wood , W. 1995 . Chloride mass balance method for estimating groundwater recharge in arid areas: examples from western Saudi Arabia . J. Hydrol. , 186 : 153 – 159 .
Google Scholar

9. Begin , Z. B. 1974 . The geological map of Israel, Sheet 9-III: Jericho, 1:50 000. Explanatory note. Geological Survey of Israel. ,
Google Scholar

10. Blake , G. S. and Goldschmidt , M. J. 1947 . Geology and Water Resources of Palestine , Israel, , Jerusalem : Government of Palestine, Department of Land Settlement and Water Commissioner .
Google Scholar

11. CDM & Morganti (1997) Comprehensive planning framework for Palestine water resources development – Final Report, PWA – Ramallah.
Google Scholar

12. Edmunds , W. M. , Darling , W. G. and Kinniburgh , D. G. 1988 . “ Solute profile techniques for recharge in semi-arid and arid terrain ” . In Estimation of Natural Groundwater Recharge , Edited by: Sommers , I. 139 – 158 . Dordrecht : Reidel . NATO ASI Series C222
Google Scholar

13. Edmu … c approach
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14. Freeze … : Prentice-

Google Scholar

15. Ghanem , M. 1999 . Hydrogeology and hydrochemistry of the Faria drainage basin/West Bank , Germany : PhD Thesis, TU Bergakademie Freiberg .
Google Scholar

16. Goldschmidt , M. J. and Jacobs , M. 1959 . Precipitation over and Replenishment of the Yarkon and Nahal Hatteninim Underground Catchments , Ministry of Agriculture – Water Authority, Hydrological Service Jarusalem, Palestine .
Google Scholar

17. Report , GTZ . 1995 . Middle East regional study on water supply and demand development. , Revised draft report phase I, Eschborn, Germany
Google Scholar

18. Guttman , J. and Zukerman , H. 1995 . Flow Model in the Eastern Basin of the Judea and Samaria Hills , Tel-Aviv : Tahal Consulting Engineers Ltd . 01/95/66
Google Scholar

19. Hem , J. D. 1970 . Study and interpretation of the chemical characteristics of the natural water . US Geol. Survey Water Supply Paper , 197 : 363
Google Scholar

20. Herut , B. , Spiro , B. , Starinsky , A. and Katz , A. 1994 . Source of sulfur in rainwater as indicated by isotopic δ 34 data and chemical composition, Israel . Atmos. Environ. , 29 (29) : 851 – 857 .
Google Scholar

21. Husar … fall data from t … and Gaza Stri … yne, UK, and the …
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22. Kerh , T. , Ting , C. S. and Liao , C. J. 1998 . Estimation of groundwater recharge using the chloride-mass balance method, Pingtung Plain, Taiwan . Hydrogeol. J. , 6 : 282 – 292 .
Google Scholar

23. Lerner , D. N. , Issar , A. and Simmers , I. 1990 . Groundwater Recharge; a Guide to Understanding and Estimating Natural Recharge. International Contributions to Hydrogeology , Hannover : Heise . Vol. 8
Google Scholar

24. Mandel , S. and Shiftan , Z. L. 1981 . Groundwater Resources: Investigation and Development , London : Academic Press .
Google Scholar

25. Marei , A. and Vengosh , A. 2001 . Source of salinity in groundwater from Jericho area, Jordan Valley . Ground Water , 39 (39) : 240 – 248 .
PubMed | Google Scholar

26. Nasser Eddin , T. and Nuseibeh , M. 1995 . Palestinian Fresh Water Springs Description, Flow & Water Quality Data 1970–1994 , Jerusalem, Israel : Palestinian Consultancy Group (PCG), The Commercial Press .
Google Scholar

27. Palestinian Water Authority . 2000 . Coastal aquifer management program , Integrated Aquifer Management Plan (Task 3) Report, Internal Report, PWA, Ramallah, Palestine .
Google Scholar

28. Palest
Goog

29. Pa l, Internal
Repor
Goog

30. PCBS (Palestinian Central Bureau of Statistics) . 2004 . Population statistics report, Annual Report, Ramallah, Palestine. ,
Google Scholar

31. Rofe and Raffety . 1963 . West Bank. Hashemite Kingdom of Jordan. Central Water Authority , Westminster, London : Rofe and Raffety Consulting Engineers .
Google Scholar

32. Rofe and Raffety . 1965 . West Bank. Hashemite Kingdom of Jordan. Central Water Authority , Westminster, London : Rofe and Raffety Consulting Engineers .
Google Scholar

33. Rosenthal , E. 1987 . Chemical composition of rainfall and groundwater in recharge areas of the Bet Shean-Harod Multiple Aquifer system, Israel . J. Hydrol. , 89 : 329 – 352 .
Web of Science ® | Google Scholar

34. Scarpa , D. J. 1994 . " Eastward groundwater flow from the Mountain Aquifer " . In Water and Peace in the Middle East , Edited by: Isaac , J. and Shuval , H. 193 – 203 . Amsterdam : Elsevier Science, B.V .
Google Scholar

35. Selaolo , E. T. 1998 . Tracer studies and groundwater recharge assessment in the eastern fringe of the Botswana Kalahari , The Netherlands : PhD Thesis, Free University Amsterdam .
Google Scholar

36. Sharm ... of
enviro ... ples " . In
Estima ... – 173 .
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37. Simm ... of processes

Google Scholar

38. Sinha , B. P. and Sharma , S. K. 1988 . " Natural groundwater recharge estimation methodologies in India " . In Estimation of Natural Groundwater Recharge , Edited by: Simmers , I. 301 – 311 . Dordrecht : Reidel . NATO, ASI Series

Google Scholar

39. Subyani , A. 2004 . Use of chloride mass-balance an environmental isotopes for evaluation of groundwater recharge in the alluvial aquifer, Wadi Tharad, western Saudi Arabia . Environ. Geol. , 46 : 741 – 749 .

Web of Science ® | Google Scholar

40. WRAP (Water Resources Action Programme) . 1994 . Palestinian Water Resources, a Rapid Interdisciplinary Sector Review and Issues Paper , Ramallah : The WRAP Taskforce .

Google Scholar