ELSEVIER

Journal of Hydrology 255 (2002) 263–265

Journal of Hydrology

www.elsevier.com/locate/jhydrol

Discussion

Reply to comment on 'Long-term rise in a Sahelian water-table: the Continental Terminal in South-West Niger' by Leduc, C., Favreau, G., Schroeter, P., 2001. Journal of Hydrology 243, 43–54

G. Favreau[a,b], C. Leduc[a,*], P. Schroeter[c]

[a]IRD, UMR HSM, B.P. 5045, 34032 Montpellier Cedex, France
[b]LHGI, Université Paris-sud, 91405 Orsay Cedex, France
[c]La Acedia, 29690 Casares, Spain

Received 19 July 2001; accepted 29 August 2001

In our paper (Leduc et al., 2001), we described the exceptional rise in the water-table in the Niamey region over the last four decades and explained it by a change in land use. We exploited a very large quantity of hydrodynamic and geochemical groundwater data that had been gathered over a period of more than 10 years (more than 18 000 instantaneous level measurements, tens of years of automatic recordings, hundreds of chemical and isotopic samplings from groundwater and the unsaturated zone). We assumed that in the study area groundwater recharge is mainly, if not solely, an indirect process. In this paper, we only dealt with hydrodynamic data but our schema was in fact constructed from all the information available. Clearance of natural vegetation and its replacement by millet fields and fallows increased surface runoff and consequently the volume of water in temporary ponds and streams and, as a result, groundwater recharge. In their comment, Bromley et al. (2001) expressed their belief that the large increase in groundwater resources is significantly due to local diffuse infiltration under the millet fields. We are unable to share their opinion.

Before developing our reply in four sections, we would like to recall a few facts: (i) Points with a natural seasonal variation in the water-table are always located close to a temporary stream or pond (Leduc et al., 1997); conversely, wells in cultivated areas away from ephemeral streams never show seasonal fluctuation. (ii) The surface runoff has obviously increased. Analysis of aerial photographs showed a considerable widening of gullies, up to four-fold. As confirmed by the native farmers, temporary ponds are more numerous (Favreau, 2000). The increase in silting up of the pond bottoms, due to an increased erosion, is further evidence of increased surface runoff (Martin-Rosales and Leduc, 2001).

The first point in our reply concerns the representativity of the measurements. Bromley et al. (2001) cited the results obtained by Gaze et al. (1997) for five storm events in 1993 and 1994 over a sandy terrace, specific to the west bank (D'Herbès and Valentin, 1997). At this location, the overall gradient of the millet field is nil and no flow took place across the field boundary. This is not representative of the whole Niamey area: millet fields are generally on sandy hill-slopes, with topographic gradients of a few percent, e.g. 4.7% in Peugeot et al. (1997). Consequently, significant runoff is observed — 11–13% for 1992 and 1993 in Peugeot et al. (1997). Lastly, Loireau

* Corresponding author. Fax: +33-4-67-14-47-74.
E-mail address: christian.leduc@mpl.ird.fr (C. Leduc).

0022-1694/02/$ - see front matter
PII: S0022-1694(01)00517-0

(1998) showed that the most recently colonized lands are located at the foot of the plateaux, where the slopes are steeper. Recent millet fields are therefore likely to present even higher runoff.

The comment also cited other papers referring to estimates of infiltration under millet fields in the same area. The operating protocol is of fundamental importance. For instance in Klaij and Vachaud (1992) 'the crop was hand weeded regularly'. Lamachere (1991) and Peugeot et al. (1997) showed that in natural millet fields, after 80–100 mm of rainfall, the impact of weeding on infiltration becomes nil. In south-west Niger, where the mean annual rainfall is 565 mm, weeding is carried out only one or two times during the rainy season (D'Herbès and Valentin, 1997). A measurement made shortly after weeding or made in a regularly weeded plot cannot adequately represent the mean functioning of a natural millet field managed by native farmers.

The second point concerns the hypothesis put forward by Bromley et al. (2001) that water draining to below 1.5 m under millet is potentially available for recharge to the water-table. This significant assumption requires demonstration in a region where the unsaturated zone is deep (up to 75 m), the dry season long (7 or 8 months) and the potential evaporation high (2900 mm yr^{-1}). Using neutron probe measurements in a millet field East of Niamey, Peugeot et al. (1997) showed that during the dry season, soil water was fully dried out to a depth of 3.4 m; in spite of high infiltrated volumes for the whole rainy season ($\sim$400 mm in 1992–1993), they concluded that no water contributed to recharge below the millet fields. Again near Niamey, an isotopic study based on the theory of Barnes and Allison (1983) showed typical evaporation profiles to a depth of 5 m by the end of the dry season (Taupin et al., 1991). Many other works, in semi-arid western Africa (e.g. Fontes et al., 1986) as well at a global scale (Coudrain-Ribstein et al., 1998) have also shown that water loss by evaporation can take place at even greater depths in the unsaturated zone.

The third point when dealing with diffuse recharge is the time lag between the change in land use and its impact on the water-table. Allison et al. (1990) estimated this as a function of the recharge rate, the depth to the water-table and the difference in the soil volumetric content before and after land clearance. In their study area in Australia, where much of the native vegetation had been cleared 50–100 years earlier, the present recharge was estimated about 20 mm yr^{-1}, and no rise in the water-table was noticeable for depths of more than 30 m. In our study area, where most clearing has taken place over the last 50 years, the depth to the water-table is 35 m in median, and is generally between 25 and 60 m in the cultivated areas. South of Niamey, Bromley et al. (1997) estimated that a diffuse recharge of 13 mm yr^{-1} moves vertically with a speed of 0.1 m yr^{-1}. The expected transit time should exceed one century. A reasonable diffuse recharge is not compatible with the synchronism of land clearance and the rise in groundwater level observed since the 1950s. Further, it is not compatible with the fact that the whole water-table is rising irrespective of the depth to the water-table (Favreau, 2000; Leduc et al., 2001).

The fourth point concerns groundwater hydrochemistry. Groundwater is very poorly mineralized (unpolluted median lower than 100 $\mu S\ cm^{-1}$) in spite of long residence times (up to 2500 yr according to radioisotopic data). Thousands of years of rainfall have accumulated large quantities of salts in the upper part of the unsaturated zone. As long as the pathways that allow infiltration to reach the groundwater remain unchanged, groundwater salinity remains similar. If a significant diffuse recharge develops, it should leach salts from the soil and groundwater conductivity should rise at the same time as the water-table. Up until now, thousands of conductivity measurements failed to show any significant change at locations away from the ephemeral streams and temporary ponds (Favreau, 2000).

These four points show that an increase in diffuse recharge under the millet fields cannot be put forward to explain the long-term rise in the water-table near Niamey. Diffuse recharge, if it exists, is presently weak and has no visible impact on long-term rise in the water-table: thus the long-term rise is necessarily due to the increase in surface runoff. The comment by Bromley et al. (2001) illustrates the risk in extrapolating a local, limited observation to a much larger scale. Because of their extreme variability in time and space, studying hydrological processes in semi-arid areas requires a great number of measurements in order to be adequately representative and significant. Crossing of independent methods make their interpretation more reliable.

References

Allison, G.B., Cook, P.G., Barnett, S.R., Walker, G.R., Jolly, I.D., Hughes, M.W., 1990. Land clearance and river salinisation in the western Murray basin, Australia. J. Hydrol. 119, 1–20.

Barnes, C.J., Allison, G.B., 1983. The distribution of deuterium and oxygen 18 in dry soils. 1. Theory. J. Hydrol. 60, 141–156.

Bromley, J., Edmunds, W.M., Fellman, E., Brouwer, J., Gaze, S.R., Sudlow, J., Taupin, J.D., 1997. Estimation of rainfall inputs and direct recharge to the deep unsaturated zone of southern Niger using the chloride profile method. J. Hydrol. 188–189, 139–154.

Bromley, J., Taylor, C., Gash, J., 2002. A comment on 'Long-term rise in a Sahelian water-table: the Continental Terminal in South-West Niger' by C. Leduc, G. Favreau and P. Schroeter, J. Hydrol. 243, 43–54. J. Hydrol. 255, 260–262.

Coudrain-Ribstein, A., Pratx, B., Talbi, A., Jusserand, C., 1998. L'évaporation des nappes phréatiques sous climat aride est-elle indépendante de la nature du sol? C.R. Acad. Sci. Paris IIa 326, 159–165.

D'Herbès, J.M., Valentin, C., 1997. Land surface conditions of the Niamey region: ecological and hydrological implications. J. Hydrol. 188–189, 18–42.

Favreau, G., 2000. Caractérisation et modélisation d'une nappe phréatique en hausse au Sahel: dynamique et géochimie de la dépression piézométrique naturelle du kori de Dantiandou (sud-ouest du Niger). PhD Thesis. Paris XI University, France.

Fontes, J.C., Yousfi, M., Allison, G.B., 1986. Estimation of long-term, diffuse groundwater discharge in the northern Sahara using stable isotope profiles in soil water. J. Hydrol. 86, 315–327.

Gaze, S.R., Simmonds, L.P., Brouwer, J., Bouma, J., 1997. Measurement of surface redistribution of rainfall and modelling its effect on water balance calculations for a millet field on sandy soil in Niger. J. Hydrol. 188–189, 267–284.

Klaij, M.C., Vachaud, G., 1992. Seasonal water balance of a sandy soil in Niger cropped with pearl millet, based on profile moisture measurements. Agric. Water Mgmt. 21, 313–330.

Lamachère, J.M., 1991. Aptitude au ruissellement et à l'infiltration d'un sol sableux fin après sarclage. Soil water balance in the Sudano-Sahelian zone. Proceedings of the Niamey Workshop, vol. 199. IAHS, Wallingford, UK pp. 109–119.

Leduc, C., Bromley, J., Schroeter, P., 1997. Water-table fluctuation and recharge in semi-arid climate: some results of the HAPEX-Sahel hydrodynamic survey (Niger). J. Hydrol. 188–189, 123–138.

Leduc, C., Favreau, G., Schroeter, P., 2001. Long-term rise in a Sahelian water-table: the continental terminal in south-west Niger. J. Hydrol. 243, 43–54.

Loireau, M., 1998. Espaces, ressources, usages: spatialisation des interactions dynamiques entre les systèmes sociaux et les systèmes écologiques au Sahel nigérien. PhD Thesis. Montpellier III University, France.

Martin-Rosales, W., Leduc, C., 2001. Dynamiques de vidange d'une mare temporaire au Sahel: l'exemple de Banizoumbou (sud-ouest du Niger). C.R. Acad. Sci. Paris submitted for publication.

Peugeot, C., Esteves, M., Galle, S., Rajot, J.L., Vandervaere, J.P., 1997. Runoff generation processes: results and analysis of field data collected at the East central supersite of the HAPEX-Sahel experiment. J. Hydrol. 188–189, 179–202.

Taupin, J.D., Dever, L., Fontes, J.C., Guero, Y., Ousmane, B., Vachier, P., 1991. Evaluation de l'évaporation à travers les sols par modélisation des profils isotopiques sous climat sahélien: exemple de la vallée du Niger. Soil water balance in the Sudano-Sahelian zone. Proceedings of the Niamey Workshop, vol. 199. IAHS, Wallingford, UK pp. 159–171.