Geophysical and hydrogeological evaluation of rising groundwater level in the coastal areas of Lagos, Nigeria

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ORIGINAL PAPER

Geophysical and hydrogeological evaluation of rising groundwater level in the coastal areas of Lagos, Nigeria

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Abstract The paper reports the change in groundwater level observed in 30 wells in ten locations in southern Nigeria. Borehole data confirmed the electrical resistivity soundings which indicated the presence of topsoil, medium sand, sand, clayey sand and coarse sand. In some cases, there was little apparent change in the rate of groundwater rise, but from the data obtained it can be concluded that in the years 2000–2004 the average yearly rise was 0.3 m while between 2004 and 2007 it rose on average by 0.5 m. This rise in groundwater level has serious implications for both existing structures and the nature of the foundations for future building. The electrical resistivity survey was found to be a helpful tool in detailing the morphology of the groundwater surface and is recommended for ongoing monitoring.

Keywords Electrical soundings · Geoelectric sections · Coastal aquifers · Groundwater level

Résumé L'article présente les changements de niveaux piézométriques observés dans 30 puits dans dix endroits de sud du Nigéria. Des données de sondage ont confirmé les conclusions de sondages électriques qui indiquaient la présence d'un sol superficiel, de sable moyen, de sable, de sable argileux et de sable grossier. Dans certains cas, il y avait peu de changement apparent dans la vitesse de remontée de nappe, mais à partir des données obtenues on pouvait conclure que des années 2000 à 2004 la moyenne annuelle de remontée de nappe était de 0,3 m tandis qu'entre 2004 et 2007 ce niveau montait en moyenne de 0,5 m par an. La montée du niveau piézométrique a des conséquences sérieuses à la fois pour les structures existantes et pour la conception des fondations des bâtiments futurs. La prospection géophysique par la méthode des résistivités électriques s'est avérée être un outil efficace pour détailler la morphologie de la surface piézométrique et est recommandée pour les surveillances à venir.

Mots clés Sondages électriques · Coupes géo-électriques · Aquifères côtiers · Niveau piézométrique

Introduction

Over the last few years, there has been a steady rise in groundwater levels observed in several parts of Lagos State, Nigeria. This has already caused some environmental problems in such areas as Ikoyi, Owode, Victoria Island and Ajegunle. In part, this rise may be related to the deterioration in the quality of groundwater due to pollution of the aquifers from the surface or by saline intrusion from both the lagoon and the sea. Akinrimisi et al. (2005) report that some boreholes producing freshwater in Ikoyi and Victoria Island in 1999 were abandoned due to saltwater invasion in 2001. This has led to a reduction in groundwater abstraction in the coastal areas of Lagos. Where groundwater abstraction is reduced, the water table rises and in time a new water table and groundwater flow regime will be established. If pumping is stopped, then the groundwater system will move towards the natural, pre-abstraction condition (Wilkinson 1985).

The groundwater level (GWL) is an important consideration in geotechnical design and foundation construction for both surface and underground structures in coastal

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cities. In 2000 the GWL in the study area was between 4.2 and 5.6 m but by 2006 it had risen to between 1.5 and 3.4 m (Oyedele 2006). Although rainfall figures are not available, June is usually the wettest month. The adverse effects of the rising groundwater level have been noticeable in Lagos in the past few years with several cases of flooding and the deterioration, settlement and/or collapse of engineering structures reported. The problems associated with rising water levels are international phenomena. From the available literature, Table 1 highlights some cases from various parts of the world.

A large number of methods for measuring soil water level/content are reported in the literature, some of which are given in Table 2. Basically these can be described as destructive or non-destructive. The former involves taking repeat samples using a soil auger/core sampler, hence the geology is continually disturbed. Alternatively, standpipe piezometers can be installed or the groundwater level obtained from existing wells.

Electrical resistivity is a non-destructive method which combines speed, accuracy and cost-effectiveness in defining the depth to groundwater as well as variation, extent and inter-relationship of aquifers with respect to their geological setting in the type locality (Oyedele and Meshida 2006; Oyedele 2006; Olorunfemi et al. 2004; Boyce and Kaseoglu 1996). The present study used this method to delineate the geoelectrical and hydrogeological morphology of the subsurface as a means of evaluating the rate of rise in groundwater level in the coastal area of Lagos, Nigeria.

Geological setting

Lagos State is situated in the southwestern part of Nigeria. Some 60% of the area consists of mangrove swamps in a low-lying coastal region (Omatsola and Adegoke 1981).

Table 2 Various methods of groundwater level measurements

	Methods	Type/nature
1	Gravimetric method	Direct, destructive
2	Electrical resistivity method	Indirect, non-destructive
3	Capacitance method	Indirect, non-destructive
4	Gamma radiation method	Indirect, non-destructive
5	Neutron method	Indirect, non-destructive
6	Remote sensing method	Indirect, non-destructive

The state lies within the Dahomey Sedimentary Basin which extends from the eastern part of Ghana through Togo and the Benin Republic to the western margin of the Niger Delta (Fig. 1). The basement rocks are unfossiliferous Pre-Cambrian sandstones overlain by gravels weathered from these strata. The overlying marine shales, sandstones and limestones are of Albian to Santonian age.

Jones and Hockey (1964) grouped all the Cretaceous sediments as the Abeokuta Group although Omatsola and Adegoke (1981) subsequently sub-divided the sequence into three, namely, Ise, Afowo and Araromi formation. Ogbe (1972) identified the Ewekoro and Akinbo Formations. In Lagos State and some parts of the Dahomey Basin, the Ilaro Formation is overlain by coastal plain sands and recent sediments (Fig. 1).

Data collection and processing

The electrical resistivity measurements were carried out using the Schlumberger electrode configuration (Fig. 2) and ABEM 4000. The current and potential electrode spacings varied from 1 to 200 m for the current electrodes and from 0.25 to 7.0 m for the potential electrodes. About 30 vertical electrical soundings (VES) were obtained.

Table 1 International case histories of rising groundwater level

	Country	Extent of rise	Cause
1	London territories (after Wilkinson and Brassington (1991))	Rise of 20 m between 1968 and 1985	Groundwater abstraction reduced by 46%
2	Liverpool (after Wilkinson and Brassington (1991)	2.5 m between 1975 and 1985	Groundwater abstraction reduced by 80% over 20-year period
3	France (after Bergeron et al. (1983)	4 m between 1980 and 1985	Groundwater abstraction reduced due to factory closures
4	USA (New York) Soren (1976)	2.5–3 m between 1976 and 1977	Groundwater abstraction reduction
5	Japan (Tokyo) Ohta (1987)	Not measured	Groundwater abstraction reduction
6	The Persian Gulf States La Dell (1986)	Not measured	Leakage from city main sewers and water logging

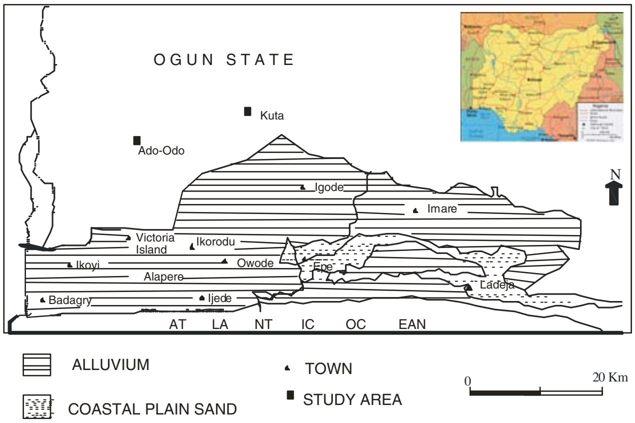

Fig. 1 Geological map of Lagos (Kampsax and Showed 1997)

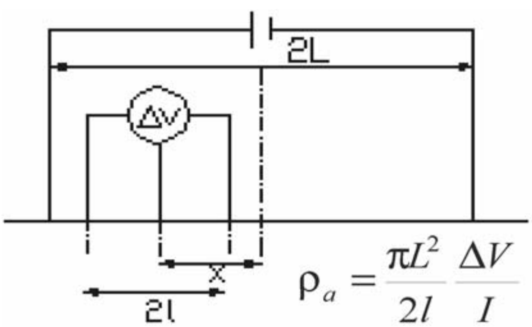

Fig. 2 The Schumberger electrode configuration

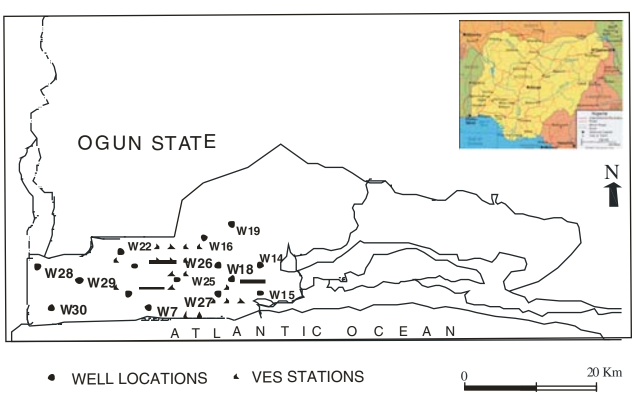

Fig. 3 Map of the study area showing wells and VES stations

The location and distribution of the VES stations were based on the available space and accessibility (Fig. 3).

Thirty vertical electrical sounding data were obtained from Ikoyi, Victoria Island, Owode, Ajegunle and Agboyi. The VES data were interpreted using the curve matching technique; the results are given in Table 3. Using the respective thickness and resistivity of each layer, geo-electric sections were prepared (Fig. 4). Contoured maps of the observed groundwater level were prepared using the

Table 3 Observed geophysical parameters, June 2007

VES station	Apparent resistivity of groundwater level (Ωm)	Depth to groundwater level (GWL) (m)
1	116	0.84
2	141	0.87
3	132	0.78
4	137	0.81
5	120	0.96
6	204	1.23
7	205	0.93
8	179	0.78
9	122	0.93
10	118	1.38
11	340	1.14
12	189	0.87
13	164	1.38
14	364	1.32
15	101	1.14
16	265	1.44
17	66	1.83
18	49	0.72
19	30	1.08
20	57	0.54
21	68	0.48
22	84	0.42
23	240	0.63
24	206	0.66
25	82	0.48
26	53	0.84
27	62	0.93
28	40	0.72
29	20	0.87
30	61	0.93

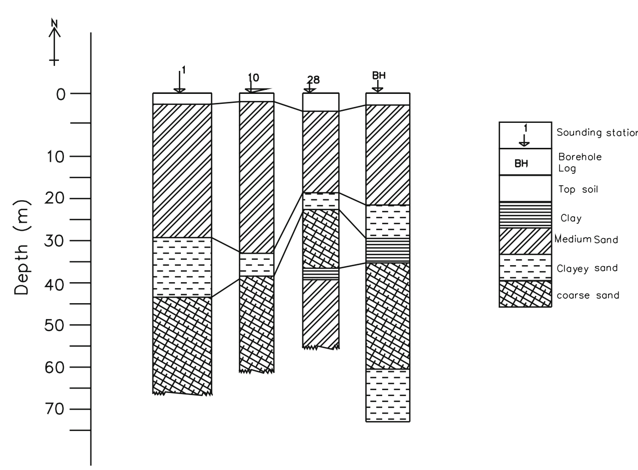

Fig. 4 Inferred geoelectric section correlated with borehole log

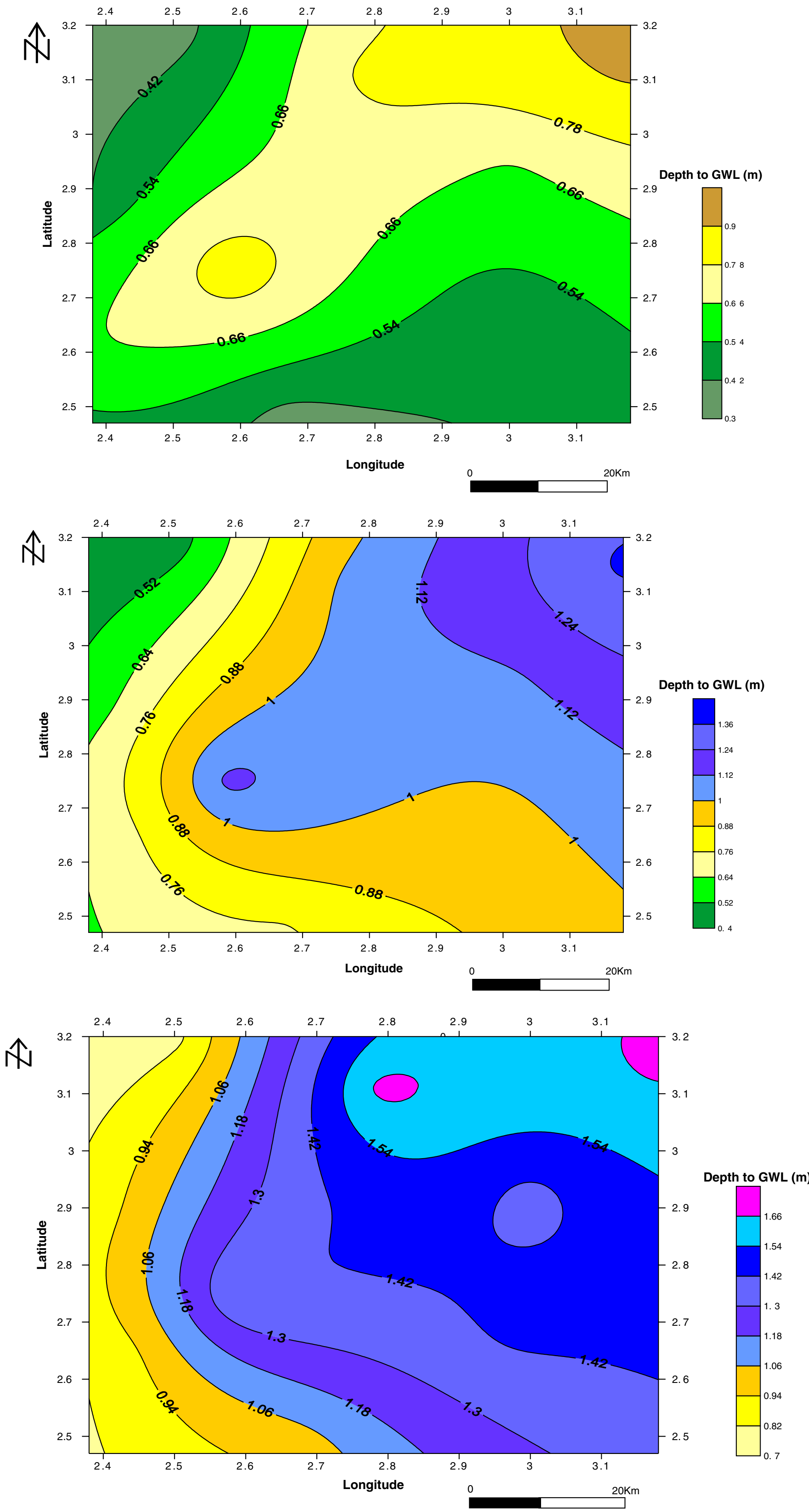

Fig. 5 **a** Observed groundwater level from hydro-geological data in June, 2007. Contour interval is 0.12 m. **b** Observed groundwater level from hydro-geological data in June 2004. Contour interval is 0.12 m. **c** Observed groundwater level from hydro-geological data in June, 2000

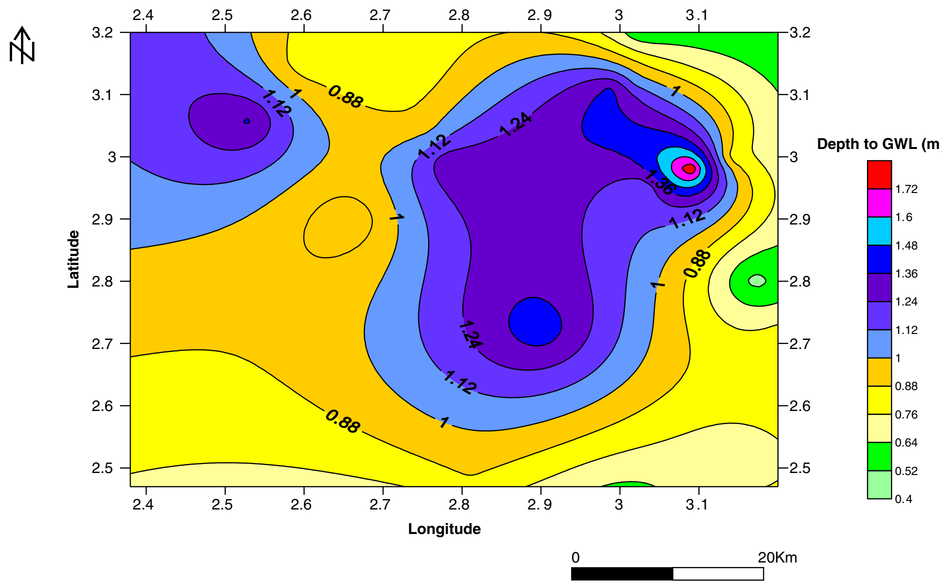

Fig. 6 Inferred groundwater level from hydro-geophysical data in June, 2007

SURFER package for June 2000, 2004 and 2007 (Fig. 5a–c). The inferred levels obtained from the geophysical survey are given in Fig. 6.

Table 4 reports the ground water levels in three shallow wells at each of ten stations in in the study area between June 2000 and June 2007. The hydrographs are shown in Fig. 7.

Results and discussion

The geoelectric sections from three resistivity soundings conducted in close proximity to one well have been correlated with the known lithologies (Fig. 4). The results from sounding nos. 1, 10 and 28 show 4–5 layers which correspond to topsoil, medium sand, sandy clay, clay and

Table 4 Groundwater level from sampled wells

Location		June 2000			June 2004			June 2007		
Owode	Well no.	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3
	GLW (m)	1.40	1.35	1.69	1.03	1.26	1.01	0.71	0.55	0.50
Ajegunle	Well no.	W_4	W_5	W_6	W_4	W_5	W_6	W_4	W_5	W_6
	GLW (m)	1.38	1.36	1.40	1.08	0.96	1.02	0.63	0.60	0.44
Alapere	Well no.	W_7	W_8	W_9	W_7	W_8	W_9	W_7	W_8	W_9
	GLW (m)	1.45	1.86	1.29	0.96	1.10	0.84	0.49	0.63	0.42
Agboyi	Well no.	W_{10}	W_{11}	W_{12}	W_{10}	W_{11}	W_{12}	W_{10}	W_{11}	W_{12}
	GLW (m)	1.42	1.77	1.26	1.15	1.38	0.93	0.86	0.86	0.84
Ijede	Well no.	W_{13}	W_{14}	W_{15}	W_{13}	W_{14}	W_{15}	W_{13}	W_{14}	W_{15}
	GLW (m)	1.68	1.62	1.63	1.38	1.45	1.09	0.96	0.84	0.56
Ikorodu	Well no.	W_{16}	W_{17}	W_{18}	W_{16}	W_{17}	W_{18}	W_{16}	W_{17}	W_{18}
	GLW (m)	1.69	1.68	1.47	1.07	1.20	1.16	0.81	0.93	0.85
Iwaya	Well no.	W_{19}	W_{20}	W_{21}	W_{19}	W_{20}	W_{21}	W_{19}	W_{20}	W_{21}
	GLW (m)	0.97	0.87	0.96	0.74	0.55	0.48	0.56	0.40	0.33
Ikoyi	Well no.	W_{22}	W_{23}	W_{24}	W_{22}	W_{23}	W_{24}	W_{22}	W_{23}	W_{24}
	GLW (m)	0.85	0.80	0.84	0.56	0.56	0.44	0.42	0.40	0.33
Victoria island	Well no.	W_{25}	W_{26}	W_{27}	W_{25}	W_{26}	W_{27}	W_{25}	W_{26}	W_{27}
	GLW (m)	0.78	0.77	0.72	0.44	0.55	0.49	0.36	0.36	0.333
Badagry	Well no.	W_{28}	W_{29}	W_{30}	W_{28}	W_{29}	W_{30}	W_{28}	W_{29}	W_{30}
	GLW (m)	0.87	0.83	0.85	0.69	0.72	0.63	0.68	0.57	0.63

GWL groundwater level (m), W_1 well number

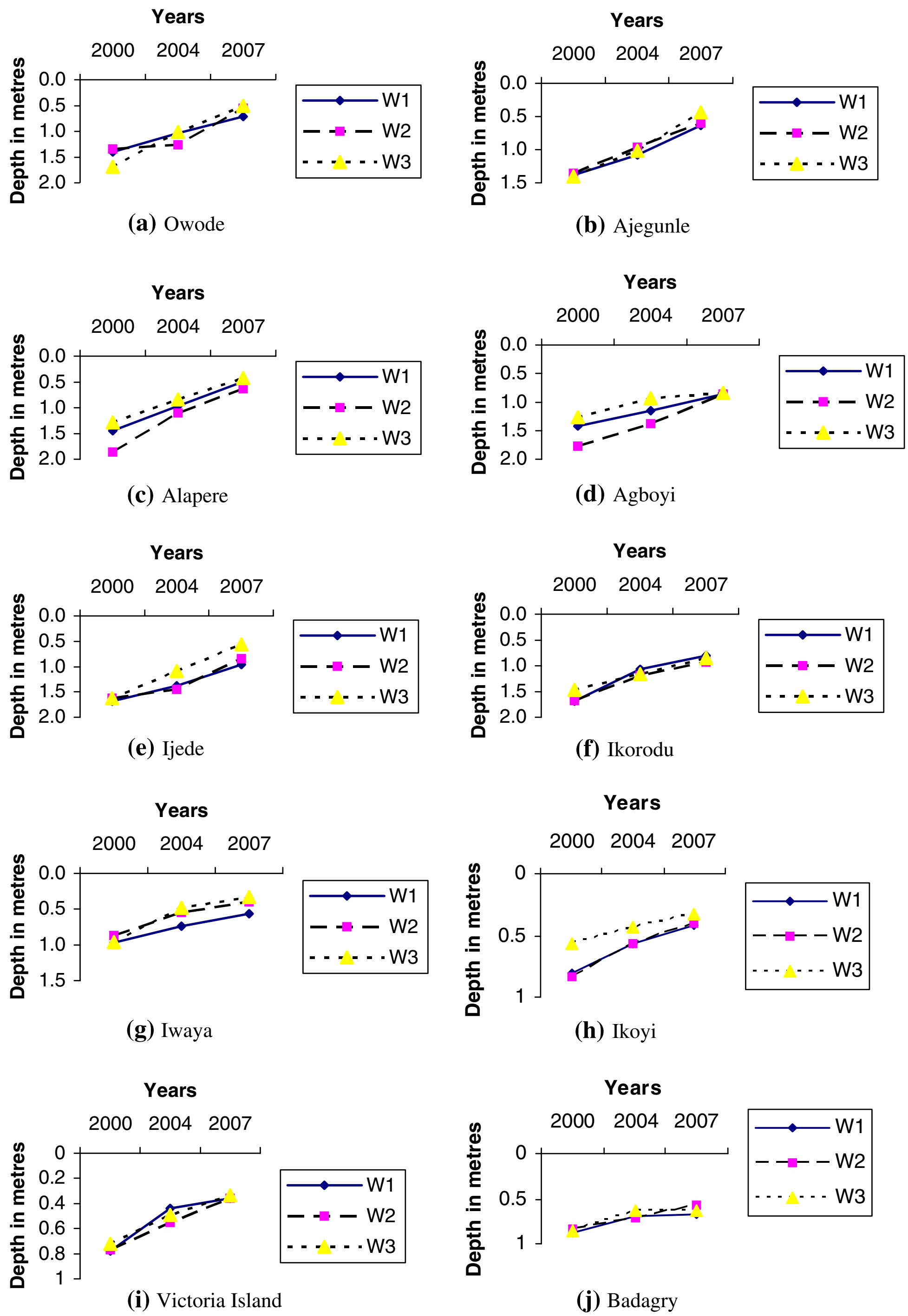

Fig. 7 a–j Hydrographic plots of groundwater levels for the years 2000, 2004 and 2007 in the studied areas

coarse sand, as typified in the borehole log. The data were used to evaluate the variation in the rate of rising groundwater levels from one location to the other, as well as to monitor the trend and yearly rise in groundwater levels.

At Owode, between 2000 and 2004 the GWL rose by 0.4 m per year and between 2004 and 2007 by 0.9 m per year. At Iwaya, it rose by 0.2 and 0.4 m for the two periods respectively. At Ikoyi, the rises for the two periods were 0.3 and 0.5 m/year. However, in Victoria Island and Badagry, there was no apparent average yearly rise, the GWL remaining at 0.5 m at the former and 0.2 m at the latter. On average, the yearly rise in groundwater was observed to be 0.3 m from 2000 to 2004 and 0.5 m from

2004 to 2007. If this is maintained, the water levels will rise above the sandy formation within the next few decades.

A number of structures are founded in this material and it is anticipated future foundations would also extend to the sand stratum. The consequences of a significant elevation in the water table on the environment and engineering structures would involve flooding, swelling of clays, reduction in bearing capacity, hydrostatic uplift pressures, chemical attack and difficulties during construction.

Conclusion

The results of the electrical resistivity and hydrogeological measurements undertaken in the coastal areas of Lagos have established that a steady rise in groundwater levels is taking place, at an average rate of 0.3 m/year between 2000 and 2004 and 0.5 m/year between 2004 and 2007.

This may be related to a reduction in groundwater abstraction as a consequence of the deterioration in the groundwater quality due to seawater intrusion and/or pollution from the surface. However, it may also be related to an increase in precipitation and/or sea level rise related to climate change.

Whatever the reason for the rise, it is important that engineers assess the significance of this for both the stability of existing buildings and the nature of the foundations used for new structures. In addition, in order for such information to be available, it is essential that both local and regional authorities undertake the necessary monitoring. The study has shown that electrical resistivity is a powerful tool in the evaluation and monitoring of rising groundwater levels.

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