Groundwater protection incorporated into land use planning: a study from Cebu City, the Philippines

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Abstract Municipal water suppliers to many Asian mega-cities rely on imports of surface water because recent rapid urban expansion threatens local groundwater quality. However, shallow groundwater resources beneath these cities are still utilized by private wells irrespective of health implications. If the quality of shallow resources is to be maintained, potentially polluting activities must be encouraged to locate in areas where groundwater is naturally protected. Groundwater vulnerability techniques are an appropriate, low cost management tool for defining both areas of natural protection and areas requiring strict land use controls. The UK vulnerability methodology, adapted for Philippine conditions, enables land to be zoned according to: soil and aquifer properties, depth to groundwater, and proximity to perennial rivers. The resulting 16 groundwater vulnerability zones have been simplified, for routine regulatory use, into a four-zone Development Constraint Map, which identifies the planning controls necessary to protect groundwater quality.

INTRODUCTION

In common with many parts of southeast Asia, the Philippines has, until recently, experienced rapid economic development. Urban and industrial expansion and population migration result in increasing demand for water supplies in urban areas. When urban population growth outstrips basic infrastructures for sanitation and refuse disposal, widespread on-site disposal of wastes to the ground can occur (Foster & Lawrence, 1995) and locally, shallow aquifers can be polluted.

Most water companies supplying southeast Asian cities import surface water over long distances. Nevertheless groundwater abstraction in some cities, including Manila, has increased because of the construction of private wells in the absence of municipal supplies (Foster & Lawrence, 1995). Inevitably these uncontrolled, unmonitored and untreated shallow wells can pose serious health hazards.

Groundwater is strategically and economically important to present and future water supply in the Philippines and is the principle source of dry season river flows, which in turn are often used for potable supply. It is imperative that a mechanism for groundwater protection is established that avoids impractical universal controls of land use but ensures that economic growth is fostered.

Groundwater vulnerability concepts recognize that some soil and hydrogeological situations offer greater protection to groundwater than others (IAH, 1994) and resulting vulnerability maps identify where groundwater needs protection. This technique is most appropriate in areas where there are many groundwater abstractions

(Foster, 1986). Groundwater vulnerability can be assessed in different ways and case studies have been described from around the world (IAH, 1994) but none have been reported from southeast Asia. Therefore the UK approach to assessment, pioneered by the Environment Agency (1998) and developed by Cranfield University Soil Survey and Land Research Centre, has been adapted to local conditions.

STUDY AREA

The study area on Cebu in the Philippines (Fig. 1) was chosen because the sustainability of the local groundwater resource is threatened by rapidly expanding populations in Cebu and Mandaue Cities. The area covers the two cities on the coast and stretches inland to include parts of three local watersheds. Cebu has a tropical climate with annual mean temperatures of 28°C. Approximately 85% of the mean annual rainfall for Cebu City of 1625 mm falls during May to October.

The area is underlain by a variety of sedimentary and igneous rocks (Table 1). The Carcar Formation, a poorly bedded to massive, coralline limestone is an important aquifer and forms two topographic regions: low limestone foothills rising from almost sea-level to about 50 m a.m.s.l. which are overlooked by rugged, deeply dissected hills, reaching to over 200 m a.m.s.l. Groundwater flow is largely through fractures and sporadic solution channels. A second important aquifer is represented by Quaternary alluvium forming the coastal plain and sites of Cebu and Mandaue cities.

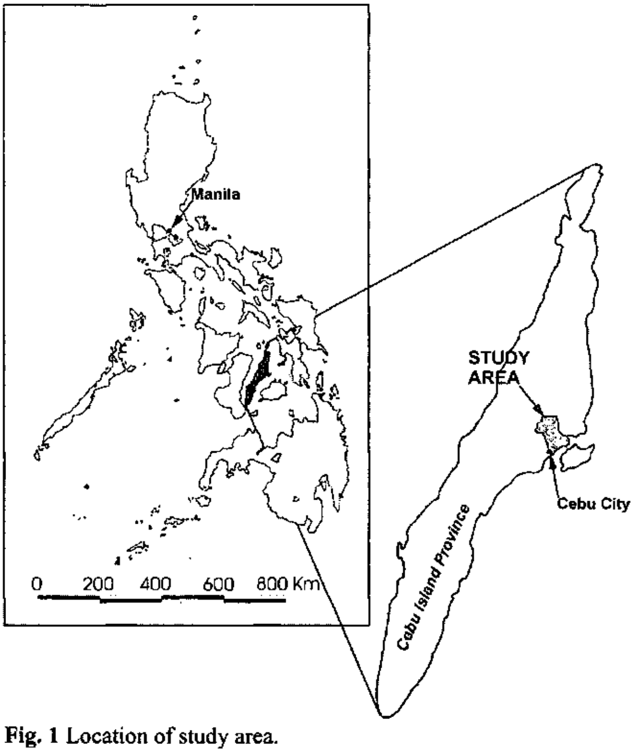

Fig. 1 Location of study area.

Table 1 Geology of study area.

Age	Formation	Lithology
Quaternary	Alluvium	Highly variable
Late Pliocene–early Pleistocene	Carcar Formation	Coralline limestone (occasional mudstones and sandstones)
Middle Miocene	Bulacao Andesite & Talamban Diorite	Andesite Diorite
Early Miocene	Malubog Formation	Pyroclastic rocks and lavas
Cretaceous	Mananga Group	As above
Pre-Cretaceous	Tunlob Schist	

(= unconformity)

Igneous rocks in the study area are unimportant for municipal water supply, although small springs provide local drinking water.

An original soil survey of Cebu, based principally on geomorphological regions, shows only 12 soil types on the whole of the island (Barrera & Aristorenas, 1954). A reconnaissance survey of the study area by the authors has improved the understanding of the relationship between soil and geomorphology and confirmed the severe erosion described by Hernandez & Lucas (1954) and Quiazon (1972).

GROUNDWATER VULNERABILITY ASSESSMENT

The key characteristics determining the vulnerability of groundwater to pollution are those properties of the soil-rock column which affect pollutant movement from land to groundwater. The principal factors are the leaching potential of any soil layers, the nature and permeability of the underlying unsaturated zone, and, in unconfined aquifers, the depth to groundwater or, in confined aquifers, the depth to aquifer material.

The rate of pollutant movement and attenuation within the soil are assessed by the *Soil Leaching Potential* classification (Palmer *et al.*, 1995). All soils identified by the reconnaissance survey of Cebu have been allocated to a leaching potential class (Table 2) based on the soil water regime (cause, depth and duration of waterlogging), soil texture and thickness and the amount of organic matter available for natural attenuation.

The greater the *depth to groundwater* the greater the opportunity for pollutants to be attenuated within the unsaturated zone. Whenever unconfined aquifers are overlain by permeable soils, depth to groundwater is usually the most important factor determining the travel time of pollutants reaching the water-table. As there is insufficient spatial information available on depth to groundwater, it was only practicable to identify three broad depth classes which have been added to the standard UK methodology. These are undoubtedly a generalization of a complex distribution pattern. The classes are based on: the geomorphology of land overlying the aquifers: the flat alluvial plain where the water table is shallow (<10 m); low limestone foothills and low terraces of the alluvial plain where the depth to groundwater is generally moderate (10–35 m); and the high limestone hills where the water table is deep (>35 m).

Table 2 Soil properties and topography of the geological units.

Geological deposit	Topography	Soil features	Soil leaching potential*
Made ground	Level, just above sea level	Unknown	HU
Alluvium	Flat, low-lying land often flooded	Regularly waterlogged	H1
	Slightly raised land	Permeable, well drained	I1
Carcar formation	Low foothills	Deep, well drained	I1
	High hills (slopes)	Thin soil cover; frequent rock outcrops	H1
	High hills (summits)	Variable soil thickness	H3/I1
Malubog formation	High relief; rounded steep sided cones	Significant soil development but locally severely eroded	I1
	Limestone hill cappings	Shallow soil in resistant limestone	H1
Talamban Diorite / Bulacao Andesite	Low relief; dense dendritic erosion pattern	Deeply weathered; sandy texture	H2
Mananga Group	Sharp crested, narrow parallel ridges	Variably weathered; extensive severe erosion	H3
Tunlob Schist	Subdued relief	Moderately deep soil	I1

*H – High, I – Intermediate, U – Built up, 1 > 2 > 3.

The properties of the unsaturated upper part of an aquifer also affect the speed of pollutant movement to groundwater. All geological strata are subdivided into *aquifer classes* (Major, Minor and Non-Aquifers) based on their inherent permeability and the likelihood of fracture flow. The aquifer classification has been put into a national context by reference to the *Groundwater Availability Map of the Philippines*, recently reprinted on behalf of the Presidential Task Force on Water Resources Development and Management (MGB, 1997). The seven aquifer types shown have been amalgamated to provide a pragmatic aquifer classification (Table 3). In the study area, the Carcar Formation and Quaternary alluvium are Minor Aquifers and the Tunlob Schist, Mananga Group, Malubog Formation, Talamban Diorite and Bulacao Andesite are Non-Aquifers.

Shallow groundwater in the weathered, permeable upper zones of the Non-Aquifers probably locally contributes recharge to adjacent Carcar Formation. Furthermore, run-off from land on Non-Aquifers contributes to the perennial rivers which recharge the downstream Carcar Formation and alluvial aquifers. So wherever Non-Aquifers potentially supply recharge to the aquifers of the study area they have been placed in a distinct Non-Aquifer (contributing) subclass.

Table 3 Aquifer classes based on MGB (1997) aquifer types.

Aquifer class	MGB (1997) aquifer type	Yields (boreholes unless stated)
Major Aquifer (Highly permeable)	Intergranular: extensive and highly productive Fractured: fairly extensive and productive	Mostly 50–100 l s^{-1} 3–50 l s^{-1}; spring yields up to 1000 l s^{-1}
Minor Aquifer (Variably permeable)	Intergranular: fairly extensive and productive Intergranular: local and less productive Fractured: less extensive and productive	About 20 l s^{-1} Mostly 2–20 l s^{-1} Well yields up to 3 l s^{-1}
Non-Aquifer (Negligibly permeable)	Rocks with limited groundwater potential Rocks without any significant known groundwater	Yields mostly less than 1 l s^{-1} Yields mostly less than 1 l s^{-1}

GROUNDWATER VULNERABILITY MAP

The three maps prepared for the study area: soil leaching potential, aquifer class and depth to groundwater, have been overlaid and a groundwater vulnerability map constructed (Fig. 2).

DEVELOPMENT CONSTRAINT MAP

The Groundwater Vulnerability map, with 16 out of a possible total of 42 classes, can be difficult to interpret. The concept of a Development Constraint Map (Fig. 3) has therefore been promoted and a matrix (Table 4) used to amalgamate the vulnerability classes into four zones, each defined by the degree of constraint required to protect groundwater. The hazards facing groundwater quality are greatest in Zone 1 and can be summarized as follows:

Zone 1 Development represents a very high risk to groundwater quality. The same level of risk should be assumed around all sinkholes and production boreholes in the unconfined aquifers to a radial distance of 100 m. Only non-polluting industries are acceptable in this zone, as any pollutants are likely to move rapidly to groundwater.

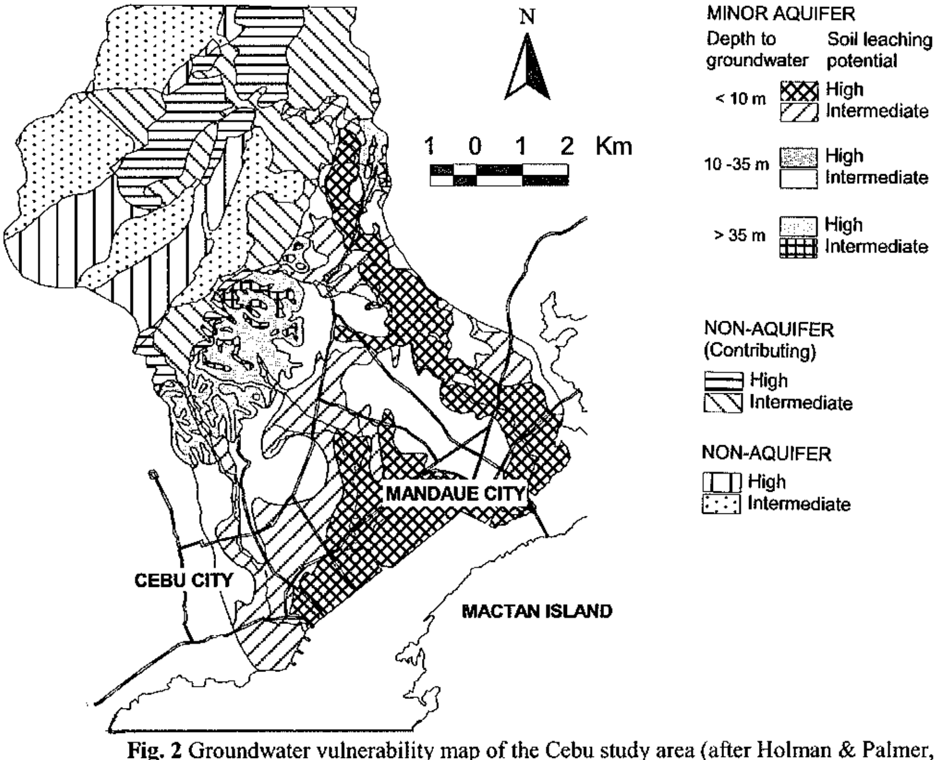

Fig. 2 Groundwater vulnerability map of the Cebu study area (after Holman & Palmer, in press). Soil leaching potential subclasses have been omitted for clarity.

Zone 2 Development here also represents a high risk to groundwater quality, as surface pollutants are likely to move rapidly to groundwater. Potentially hazardous and polluting industries should be discouraged, and only allowed following the appraisal of detailed site investigations by suitably qualified specialists. It is likely that strict design precautions will be required for the majority of developments.

Zone 3 Development poses some risks to groundwater quality but less so than in Zones 1 or 2. Potentially polluting industries may be considered, subject to evaluation and incorporation of any necessary design constraints.

Zone 4 Development poses little risk to groundwater quality. However, it is desirable to evaluate and monitor any development to ensure surface water quality is not compromized.

DISCUSSION

If good quality drinking water is to be sustained groundwater protection must be an integral part of the Philippine environmental protection process. Potential impacts on groundwater quality are not assessed in the Environmental Compliance Certificate which is a legal requirement for all companies either proposing or carrying out potentially polluting activities.

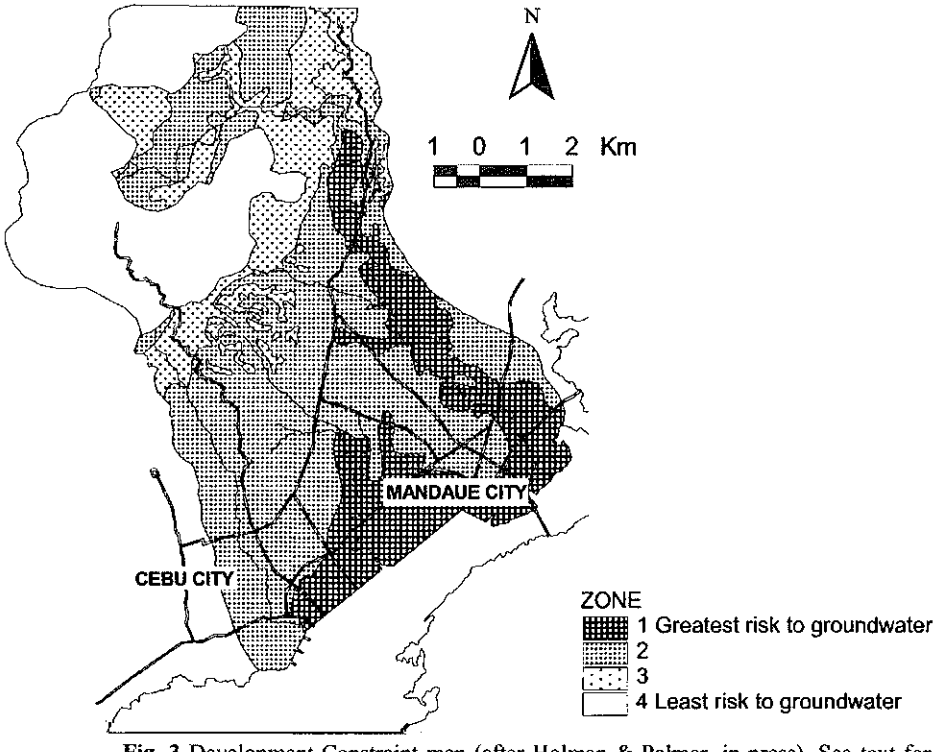

Fig. 3 Development Constraint map (after Holman & Palmer, in press). See text for full explanation of zones.

Table 4 Derivation of Development Constraint zones for the Cebu study area.

Aquifer class	Soil leaching potential class: High leaching potential (H1, H2, H3 and HU)		Intermediate leaching potential (I1)	
Minor Aquifers	Depth* <10 m	Zone 1	Depth <10 m	Zone 2
	Depth† 10–35 m	Zone 1	Depth 10–35 m	Zone 2
	Depth >35 m	Zone 2	Depth >35 m	Zone 3
Non-Aquifers (contributing)		Zone 2		Zone 3
Non-Aquifers		Zone 4		Zone 4

*Depth to groundwater

†The greater (10–35 m) depth to groundwater in the limestone foothills (compared to the alluvium) has been assumed to be negated by the potentially greater vertical hydraulic conductivity of the limestone.

A groundwater protection policy should incorporate a synthesis of relevant soil and hydrogeological information in a clear, simple and unequivocal way. Gathering the large amounts of a site-specific data required to use quantitative groundwater vulnerability methodologies, on a regional or national basis, is prohibitively expensive. The vulnerability mapping technique introduced in Cebu is designed to use established archive maps and databases held by the National Survey organizations.

The maps makes no attempt to provide quantitative site-specific answers to either contaminant travel times or contaminant attenuation capacity. They are designed to provide a relative ranking system for land in order to facilitate the integration of groundwater issues into the decision-making process in a consistent and defensible manner. Undertaking expensive site investigations can then be targeted at specific sites, where the classifications incorporated in the maps will provide a basis for local vulnerability assessments.

CONCLUSIONS

Groundwater is used extensively for small scale water supply in the expanding urban centres of the Philippines but groundwater quality is threatened by unplanned urban expansion. A consistent and rigorous national groundwater protection policy is needed. The viability of the established UK groundwater vulnerability methodology for use in the Tropics has been demonstrated and this low cost approach, using archive data, can form the basis for the protection of the country's groundwater resources.

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