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A Preliminary Review of Groundwater Vulnerability Assessment and Pollution Status in Kenya

Revisione preliminare sull'utilizzo di metodi di Groundwater Vulnerability Assessment e sullo stato della contaminazione delle acque sotterranee in Kenya.

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Riassunto: Le acque sotterranee rappresentano il 95% delle riserve di acque dolci su scala globale. L'utilizzo di acque sotterranee è sensibilmente aumentato nel corso degli ultimi 50 anni ed è destinato ad aumentare ancora a causa dell'elevata vulnerabilità delle risorse idriche superficiali alle attività antropiche e ai cambiamenti climatici. I processi di contaminazione rappresentano una seria minaccia per la disponibilità idrica e la sostenibilità delle acque sotterranee. Il deterioramento della qualità delle acque sotterranee e i processi di contaminazione legati alle attività antropiche comportano dei seri rischi per la salute umana e degli ecosistemi, portando così alla necessità di utilizzare metodi di Groundwater Vulnerability Assessment. Il concetto di Groundwater Vulnerability Assessment risale ai primi anni '70 ed è stato applicato in diversi casi come strategia ambientale per un'accurata pianificazione dell'uso del suolo e per la formulazione dei processi decisionali e delle policy, al fine di preservare la risorsa idrica sotterranea dai processi di contaminazione. In questo studio viene presentata una revisione della letteratura rispetto ai processi di contaminazione delle acque sotterranee e all'utilizzo di metodi di Groundwater Vulnerability Assessment in Kenya. Lo studio rivela una scarsa conoscenza dei metodi di Ground water Vulnerability Assessment per la salvaguardia delle risorse idriche sotterranee contro i processi di contaminazione. Lo studio rivela anche l'importanza di applicare metodi di Groundwater Vulnerability Assessment per la gestione e protezione delle risorse idriche sotterranee in Kenya.

Keywords: *Groundwater Vulnerability Assessment, pollution, climate change; Kenya.*

Parole chiave: Groundwater Vulnerability Assessment, inquinamento, cambiamenti climatici, Kenia.

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Abstract: *Groundwater represents 95% of the world's available freshwater. The use of groundwater has significantly increased over the past 50 years and is expected to rise in future due to high vulnerability of the surface water resources to anthropogenic activities and climate change. However, pollution is becoming a major threat to groundwater availability and sustainability. The deteriorating groundwater quality and increasing contaminations from anthropogenic activities poses detrimental risks to human health and ecosystem in many ways, thereby necessitating the need to undertake Groundwater Vulnerability Assessment. The concept of Groundwater Vulnerability Assessment is dated back in the early 1970s and since then applied in many developed countries as an environmental strategy for proper land use planning, decision making and policy formulations in attempt to protect and conserve groundwater from contamination and depletion. In this study, a literature review on groundwater pollution and vulnerability assessment in Kenya is provided. The study revealed poor knowledge and application of the Groundwater Vulnerability Assessment methods in safeguarding groundwater resources against pollution and depletion. The study also brings to limelight the importance of applying Groundwater Vulnerability Assessment in management and protection of groundwater resources in Kenya.*

Introduction

Groundwater is an important, valuable and renewable natural resource which constitutes about 95% of freshwater on our planet Earth, making it essential to human life and economic development (Foster et al. 2013). Groundwater supplies 85% and 50% of rural and urban water needs respectively (Kumar et al. 2006).

About 17 million people living in Arid and Semi-Arid Lands (ASALs) of Kenya meet water demand from groundwater resources because of the surface water scarcity and erratic rainfall pattern (Mumma et al. 2011). Demand for groundwater is expected to rise, owing to population increase and continuous depletion of surface water resources (Mumma et al. 2011).

Despite these important contributions to human development, groundwater bodies are facing degradation and depletion from human activities and climate change, unless protected (Doll et al. 2012; Mishra et al. 2014). Groundwater pollution is nearly always the result of human activity. The concept of Groundwater Vulnerability Assessment (GVA) arose from the need to protect groundwater bodies against contaminations (Aller et al. 1987). It came into existence back in the 1970s, to address the problem of groundwater pollution induced by human activities in France (Albinet et al. 1970).

The natural attenuation processes occurring within the zone located between the pollution source and the aquifer determine the level of groundwater pollution in a given area. Areas where the soils, subsoils and bedrocks do not provide adequate attenuation, have higher chances of pollutants reaching the groundwater. The GVA therefore helps to identify regions which are more vulnerable to pollution owing to their subsurface characteristics and presence of polluting sources (Gogu et al. 2000).

The aim of the GVA is to subdivide a region according to the vulnerability of the groundwater to surface pollution (Foster et al. 1987; Vrba et al. 1994). A vulnerability map provides necessary information to control and plan land use and related human activities as an integral part of an overall policy of groundwater protection at national, regional and catchment level. The four general objectives typically achieved by GVA are: (1) to facilitate policy analysis and development at the local and regional level, (2) to provide management programs, (3) to inform land use decisions, and (4) to provide general education and awareness about the importance of managing groundwater resources (National Resource Council 1993).

There are three main approaches developed in the past to evaluate GVA: (1) process-based models, (2) statistical models, and (3) overlay and index models. The process-based approaches consider the physical processes of groundwater dynamics and the associated fate and transport of pollutants in the environment. The statistical models apply statistics to establish a relationship between the occurrence of pollutants and the most response variables influencing vulnerability. The overlay models combine thematic maps of various hydrogeologic parameters believed to be influencing groundwater dynamics by assigning a weight and rating scale to each of the parameters (National Resource Council 1993).

Kenya has seen a drastic depletion of surface water supplies in recent years due to climate change and variability, causing a shift towards a greater reliance on groundwater countrywide (Mumma et al. 2011). As such, it is important to prevent and protect groundwater resources from surface pollution and impact of climate change to secure clean and continuous supply of groundwater for future generations. Conducting GVA to surface pollution and managing climate change contributors constitutes a major and necessary step towards attaining sustainable groundwater resources development. In this paper, an attempt is made to analyze the available literature on groundwater pollution status and concept of GVA methods and its application in prevention, protection and management of groundwater resources in Kenya.

Study Area

Location

Kenya lies on the eastern side of the African continent bordering Indian Ocean. It shares international boundaries with Uganda in the west, Tanzania in the south, Sudan and Ethiopia in the north and Somalia in the east. The country is bounded by latitudes 5° 20' N and 4° 40' S and longitudes 33° 50' E and 41° 45' E. Territorial area is 582,646 km^2 and it is divided into water area of 11,230 km^2 and land area of 571,416 km^2. The major part of the inland water surface area is covered by a portion of Lake Victoria and Lake Turkana. Of the land area, approximately 490,000 km^2 (more than 80% of the land area) is classified as Arid and Semi-Arid Land (ASAL). The remaining area of about 81,000 km^2 is classified as non-arid and profitably usable lands, sustaining a substantial portion of Kenyan economy and human population. The location map of Kenya is shown in Figure 1.

Climate

Climate in Kenya is mainly influenced by latitude, altitude, topography, the distance from large bodies of water and the movement of Inter Tropical Convergence Zone (ITCZ). Rainfall is affected by the large Lake Victoria, the complex topography of Great Rift Valley and high mountains like Mount Kenya and Elgon. A relatively wet and narrow tropical belt lies along the Indian Ocean coast and behind it, stretches large and expansive areas of ASALs. Kenya generally experiences bimodal rainfall, with long rain season (between March-May) and short rain season (between October-December) occurring in most places. The mean annual rainfall in the country is over 680 mm and varies from about 200 mm in ASAL areas to about 1,800 mm in humid areas.

Topography

Kenya is characterized by a tremendous topographical variability, ranging from glaciated mountains to a desert landscape. Two distinct physical regions characterize its topography: the lowland areas and upland ones. The physiographic environments include equatorial, tropical, savannah, volcanic, glacial and tectonic zones. These physiographic environments are influenced by Kenya's geology. The elevations vary greatly from sea level at Indian Ocean to over 5,500 m above the mean sea level at the peak of Mount Kenya (Fig.1).

Hydrogeology

The main aquifers in Kenya are closely linked with three major rock systems. These are the volcanic rocks, the basement metamorphic rocks, and the quaternary sedimentary rocks. The volcanic rocks cover 26% of the country land masses and their lithology include phonolites, trachytes, tuffs and basalts. The thickness of theses rocks varies from few meters to hundreds of meters. The aquifer in these rock formations are often confined.

The Precambrian metamorphic basement covers about 17% of the country and is widely distributed in central, western and north western parts of Kenya. Granites, gneisses and schists are the dominate lithology of these rock formations.

The sedimentary rocks cover 55% of the land cover in the country and predominate in eastern, north eastern parts and

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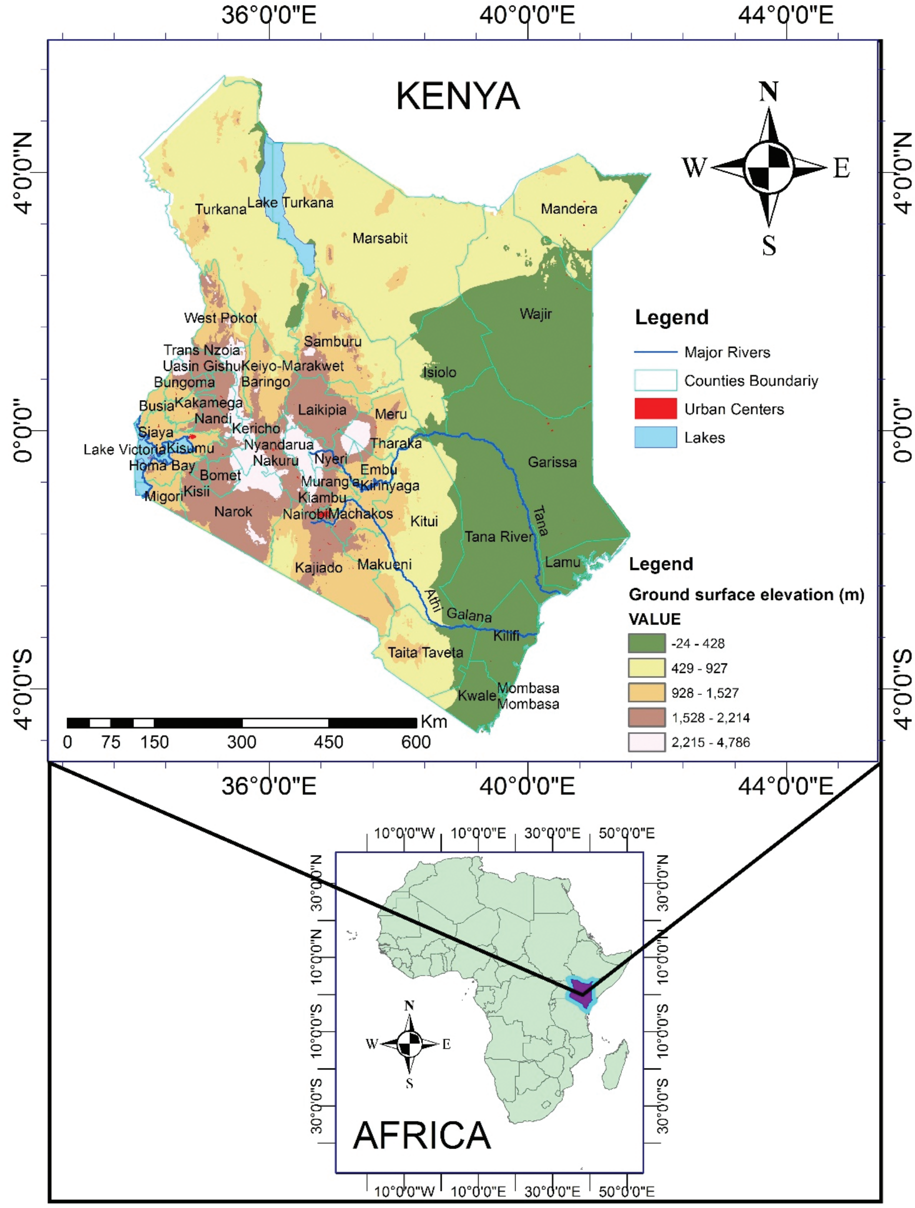

Fig. 1 - Location map of Kenya.

Fig. 1 - Localizzazione geografica del Kenya.

around Lake Victoria. The lithology varies from sand, clay, sandstone, shale and limestone. The volcanic and quaternary geological formations are particularly rich in groundwater.

Kenya has an estimate potential of about 1.04 billion cubic meter/year of fresh groundwater yield and only 0.18 billion cubic meter/year (about 17.3%) has been exploited for domestic use, industries, irrigation and ecological needs by 2009 (Mumma et al. 2011). Groundwater is supplied through shallow wells, springs and drilled boreholes. The current groundwater abstraction rated is estimated at 7.21 million Mm^3/year, a negligible insignificant fraction compared to the 'safe' (amount which can be abstracted without depletion of the aquifers in a given time period) groundwater abstraction rate of 193 million Mm^3/year (Pavelic et al. 2012).

Groundwater pollution in Kenya

Pollution of groundwater from industrial wastes, agricultural chemicals and fertilizers and municipal wastes has become common in many countries of the world (Liang 2016). Once groundwater is polluted, the clean-up process is very expensive, time consuming, requires advanced technologies and may persist for years, decades, or even centuries (Todd et al. 2005). Therefore, it is important to prevent groundwater pollution rather than restoring polluted groundwater resources.

The status of groundwater pollution in Kenya cannot be stated statistically as there is no comprehensive study carried out to ascertain this, despite the existence of potentially harmful surface pollutants due to human activities and rapid development in numerous urban centers and agricultural activities. The few studies that have been performed in Kenya showed evidence of groundwater pollution occurring at local scale.

Microbial pollution linked to onsite sanitation systems (septic tanks and soak pits) in urban and peri-urban areas, has been reported in groundwater of Mombasa and Kwale as early as 1997 (Tole 1997).

Kargi area of Marsabit County was on news during the year 2000 for the unfortunate incidence of massive deaths of livestock after consuming water from an old and restored well. Point-source nitrate pollution at livestock watering points, which was believed to be from livestock faeces (rich in nitrate), occurred in excess of 750 to 890 mg/l as NO_3^- and poised the animals. The nitrate from livestock faeces might have been released into sandy aquifers during the recharge (Aquasearch Ltd. 2010).

Munga et al. (2006) studied pollution and vulnerability of water supply aquifers in Mombasa. The study indicated a high level of groundwater contamination by microbial contaminants, especially in the high-density housing settlements of Kisauni area, which was attributed to on-site sewage disposal methods dominated by pit latrines and septic tank / soak pit systems.

Kimani-Murage et al. (2007) investigated the quality of groundwater from shallow and deep wells in Langas, a Kenyan slum, and found out that 100% and 97% of water samples from shallow wells and deep wells, respectively were positive for thermotolerant coliforms. The presence of thermotolerant coliforms indicates fecal contaminations which was associated with presence of pit latrines.

A study conducted to assess seasonal variation in physicochemical and microbiological quality of groundwater in Ruiru, Kiambu County (Olonga et al. 2015) revealed that the boreholes and shallow wells in the area were bacteriologically contaminated and therefore not suitable for domestic purposes unless treated. High concentration of fluorides, nitrate and turbidity exceeding World Health Organization (WHO) standards were also noted.

Groundwater resources have also been degraded by human-related activities such as over-abstraction leading to both groundwater level decline and groundwater quality deterioration in Dadaab Merti and Nakuru District (UNICEF KCO 2004; Kuria 2008).

Potential Impacts of Climate Change on Groundwater Resources in Kenya

Assessing impact of climate change on groundwater resources is an important issue that has not received too much attention in the scientific literature until recent times (Harrie-Jan Hendricks Franssen 2009). Climate change simply represents changes in meteorological parameters, such as temperature and precipitations and changes in these parameters affect groundwater recharge, storage and levels, thereby causing vulnerability to climate change (Stuart et al. 2011). Floods and droughts, associated with extreme climate events, have very devastating effects on the groundwater system. While the floods are important sources of groundwater recharge droughts decreases groundwater storage and level (Morin et al. 2009).

Kenya like other sub-Saharan African countries faces the uncertainty and potential risks of climate change. The cycles of droughts and floods have occurred frequently in the last one decade. Temperatures have risen throughout the country and rainfalls have become irregular and unpredictable. Major rivers and lakes have reduced volumes during droughts, and many seasonal ones have completely dried up (Mogaka et al. 2009).

During the droughts, excessive water is abstracted from the groundwater aquifers to cushion against the impacts of drought. Nairobi aquifer system have experienced significant water level decline, water quality change and depletion due to over-abstraction and exploitation to meet water demands posed by impact of climate change (Mogaka et al. 2009; Mumma et al. 2011; Nyakundi et al. 2015; Okello et al. 2015).

Despite the existing potential impact of climate change on groundwater resources, there is no substantial research carried out to that effect. In fact it is difficult to determine the degree to which groundwater resources are sensitive to climate change, given the relatively poor level of understanding of Kenyan aquifers (Mumma et al. 2011).

Groundwater Vulnerability Assessment concept

Since late 1960s and early 1970s, there is a growing awareness of the risk to groundwater contamination and increasing pre-occupation to determine and protect groundwater quality. This is because regeneration of polluted groundwater aquifers is prohibitively costly. Since then, the scientists have sought to study groundwater vulnerability to have a common understanding of the GVA concept and approaches in order to handle groundwater pollution.

The widely used definition of groundwater vulnerability is: "Groundwater vulnerability is the tendency of or likelihood for, contaminants to reach a specific position in groundwater system after introduction at some location above the uppermost aquifer" (Vrba et al. 1994; National Resource Council 1993).

GVA identifies regions where groundwater is likely to become contaminated as a result of human activities and translate this information into groundwater vulnerability map that can be used to direct regulatory, monitoring, educational, and policy development efforts to prevent or minimize the harmful impacts on groundwater quality (Kaur 2011).

There are many approaches developed to evaluate the vulnerability of groundwater to induced contaminations. These include: (1) overlay and index methods; (2) statistical inference methods; and (3) process-based mathematical methods. The overlay and index method combines thematic maps of physical parameters believed to influence groundwater dynamics and contaminant transport. Each of these parameters are assigned relative scores according to degree to which that parameters protects or leaves vulnerable the groundwater in the regions (National Resource Council 1993). Examples are the widely used DRASTIC index (Aller et al. 1987) and the GOD index (Foster 1987).

The statistical method correlates, at various spatial scale, contaminant occurrence within a given area with response variables (intrinsic properties of aquifer systems), in an attempt to predict the probabilities of contamination. Examples are the logical regression model (Teso et al. 1996), the principal component analysis (Abdi and Williams 2010), and the discriminant and cluster analysis (Troiano et al. 1997).

The process-based methods can predict the fate and transport of contaminants from known sources with accuracy in a localized area, by applying fundamental physical principles to predict the flow of water in porous media and the behavior of chemical constituents carried by that water. Examples are the Behaviour Assessment Models (Jury et al. 1987) and the Attenuation Factor (Rao et al. 1985).

In the early 1990s, GVA and mapping became increasingly utilized as a screening tool for protection of groundwater quality (Foster et al. 2013) due to the development of the above mentioned GVA models. GVA was carried out at different scales from local to regional and national levels (Howden et al. 2012). Over the years, numerous GVA mappings have been performed at regional and national scale in many developed and developing countries of the world (Stevenazzi et al. 2017; Liang et al. 2016; Diodato et al. 2013; Yin et al. 2013; Huan et al. 2012; Alwathaf et al. 2011; Awawdeh et al. 2010; Saidi et al. 2010; Baalousha 2006).

In the African continent, especially Sub-Saharan African countries (SSA), the situation is very different due to limited hydrogeological data, lack of skilled professionals, inapplicability of most of the vulnerability methods and lack of funds (Oke et al. 2017). The Working Paper 6 of African Climate Policy Centre (ACPC) of United Nations Economic Commission for Africa (Altchenko et al. 2010), highlights a few studies conducted on the hydrogeology of SSA countries as shown in Table 1.

GVA application in Kenya

Despite the importance of GVA methods as illustrated above, their application in management and protection of groundwater resources in Kenya is scarce. The few studies conducted were done by international bodies (such as the World Bank) and students in institutions of higher learning like Universities.

GVA using the DRASTIC model and GIS analytical tools was first attempted in Kisauni, Mombasa (Munga et al.2006). The result of the DRASTIC model indicated that the aquifers in the northern and south-eastern parts of the Kisauni and south-western part of the Mombasa Island were the most vulnerable to surface pollution. However, the conclusion by the authors did not provide recommendations on what to be done next, in spite of identifying vulnerable areas.

Suwai Janet (2012) determined the spatial intrinsic variability of groundwater vulnerability to pollution in Lake Nakuru basin using Protective cover and Infiltration condition (PI) method (Zwahlen, 2003). Vulnerability map generated through the PI method indicated low vulnerability in most parts of the study area due to strong protective covers.

Ezekiel et al. (2016) studied the vulnerability of coastal aquifers to saltwater intrusion, along the northern coast of Mombasa, using the GALDIT model (Chachadi et al. 2001), an adaption of the DRASTIC model, to map vulnerable areas. The output of the model indicated low, moderate and high vulnerability at 20%, 55% and 25% respectively, during the dry season, and 13%, 64% and 23% respectively during the rainy season. The suggestion was put forward to restrict groundwater abstraction at the regions which consistently fell under high vulnerability class for the two periods, in order to protect aquifers against seawater intrusion.

Tab. 1 - Hydrogeological studies and maps available in selected SSA countries (Oke et al. 2017).

Tab. 1 - Studi di carattere idrogeologico e cartografia disponibile in paesi SSA selezionati (Oke et al. 2017).

Study	Location	Scale	Data
Howard et al., (1992)	Uganda	Country	Groundwater potential
Wright (1992)	Africa	Continent	Groundwater potential
Chilton et al., (1995)	Africa	Continent	Groundwater potential
Biemi (1996)	Ivory Coast	Country	Groundwater availability
Taylor et al., (2000)	Uganda	Country	Groundwater potential and balance, flow types,
Tindimugaya (200)	Uganda	Country	Groundwater potential and balance
Macdonald et al., (2001)	Ethiopia	Country	Groundwater availability
Taylor et al., (2004)	Uganda	Country	Groundwater potential, flow types
Mantin et al., (2005)	Volta Basin	Basin	Groundwater potential
Woodford et al., (2006)	South Africa	Country	Groundwater balance
Tindimugaya (2008)	Uganda	Country	Groundwater sustainability, storage capacity
WHYMAP (2008)	Africa	Continent	Groundwater resources
Forkuour et al., (2011)	Northern Ghana	Sub-country	Groundwater potential, accessibility

Conclusions and Recommendations

According to the available literature and technical reports, groundwater is generally polluted in Kenya, especially from on-site sanitation systems such as: pit latrines, soak pits and septic tanks and other agricultural sources. It is also evident that no particular long term measures were and still are put in place to curb increasing groundwater contaminations from human activities.

The importance of GVA approaches in prevention and protection of groundwater resources is depicted in its numerous applications worldwide. The perspective of GVA is to translate impact information into relevant policy formulation and practice guidelines in order to identify and implement feasible adaptation measures. However, for a country like Kenya, which heavily depends on groundwater for rural, urban development, agricultural activities and industries, the importance of GVA in protection of groundwater resources is yet to be considered.

The study reveals a number of challenges facing groundwater resource management, hence predicting higher chances of vulnerability to pollution and climate change unless is reversed. First, land use continues to be addressed through many uncoordinated legal and policy frameworks that have done little to unravel the many issues that affect land use management and in extension groundwater resources management.

Secondly, there is lack of coordination and cross-sector linkages among agencies related to groundwater resources management. The management decisions in physical planning, land use planning, and agricultural activities are made without considering the implications of such decisions on groundwater resources.

Third, the laws and regulations of Kenya provides for to the identification and mapping a groundwater protection and vulnerability zones as early 2006. This has not being accomplished to date.

Fourth, key groundwater conservation provision in law, such as Groundwater Conservation Act (GCA) has not been acted upon. According to this Act, groundwater recharge areas and aquifer protection zones should be mapped and gazetted for protection against pollution.

Fifth, the Environmental Management Policy (EMP) of 1999c had provided for the protection of water catchment areas, wetlands, rangeland resources management and land degradation neglecting groundwater resources. These policies should have considered incorporating groundwater management aspect to achieve holistic environmental management.

Finally, Water Resources Management Authority formulated a Proposal for a Policy for Protection of Groundwater (PPPG) Paper in 2006, to discuss conservation of groundwater resources by balancing sustainable use and national development and protection of groundwater quality by minimizing the risks posed by pollution. This important discussion only remained at a proposal stage, never to be implemented.

To address these challenges the following existing opportunities ought to be adopted; i) integration of surface water and groundwater resource management in order to reduce pressure on a single resource; ii) managing aquifer recharge through sand dams and adopting water and soil conservation structures; iii) guiding future land use planning base on the vulnerability maps; iv) creating awareness and improving knowledge on the dangers of groundwater mismanagement; and v) enforcing and implementing the provisions of existing laws and regulations.

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