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ASSESSMENT OF POLLUTION STATUS AND GROUNDWATER VULNERABILITY MAPPING OF THEADDIS ABABA WATER SUPPLY AQUIFERS, ETHIOPIA

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INTRODUCTION

Water Pollution is a global problem and has been evident for a long period of time. The impact of human population on surface and groundwater is increasing with the development of industry and population size in the city of Addis Ababa. Water quality degradation is one of the major environmental problems of these days. This is due to its unique characteristics that make it crucial for the existence of life and an important factor in many physical and biochemical processes. The physical, chemical and biological quality degradation can limit the intended use of water.

The state of groundwater pollution in the city of Addis Ababa is similar with the reality in most developing countries. The level of water pollution tends to rise with increasing human population and low level of economic development in the city. Consequently contamination of surface and groundwater is one of the most serious problems affecting the health of the population.

The fast population growth, uncontrolled urbanization and industrialization, poor sanitation situation, uncontrolled waste disposal etc. causes serious quality degradation of surface and groundwater in particular. Currently water quality degradation in Addis Ababa becomes main threat to the health of the population specially those living in the down stream and in area where there is shortage of municipal water supply.

In recent years, there is a growing awareness of environmental degradation problem as a consequence of our day-to-day activities. That is why in order to live in harmony with the environment; the city council has currently implemented policy that integrates economic development with environmental protection.

OBJECTIVES

Currently the available water resource for the city is from surface water reservoirs (Gefersa, LegeDadi and Dire), shallow and deep bore holes, hand-dug wells and springs. However, there is shortage of municipal water supply in different parts of the city particularly during the dry season. Consequently most of the industries, some residential houses, and governmental and non-governmental organizations have water wells in their premises to alleviate the problem. Moreover, in the peripheral parts of the city, where there is a serious shortage of municipal water supply, the problem is being overcome by using water from the springs. Most of the springs are not developed and are vulnerable to different types of pollutants. These rivers are the confluence points of all streams crossing the city from different directions. Besides, large number of private septic tanks in the city is directly connected with the nearby streams/rivers.

The improvement of general living conditions, high population growth, increase in the rate of migration and greatly accelerated industrial and residential expansion rapidly raises the demand of water supplies. These may also have an impact not only on the social and economical situations but also on the situation of surface and ground water resources of the city. Thus, the ultimate objective of this research is to produce aquifer vulnerability map for the water supply aquifer of Addis Ababa.

Therefore, the main objectives of the project are to assess the risk for groundwater pollution through DRASTIC mapping of water supply aquifers.

HYDROGEOLOGY

The Addis Ababa area is made up of Oligocene-Miocene and Quaternary volcanic rocks. The rock chemistry ranges from basic to acidic. The northern part of the city is made of rhyolites and trachytes of older age than the basaltic rocks of the southern sector. The main volcanic centers are Entoto, Yerer, Furi and Wachacha.

The groundwater circulation and the dispersion of pollutants depend on the hydrogeological characteristics of the material more specifically hydraulic properties such as porosity, permeability, transmissivity etc. The origin, flow and chemical constituent of groundwater is controlled by the type of lithology, distribution, thickness and structure of hydrogeological units through which it moves. Moreover, the stresses due to tectonism and weathering govern the hydrogeochemical characteristics of earth materials. Volcanic rocks mainly basalts, rhyolites, trachytes, scoria, trachy-basalts, welded and unwelded tuffs are the dominant rock outcrops in the area. Besides, unconsolidated materials of different origin also occurred in the study area. These rocks are the major groundwater supply for large parts of Addis Ababa. Hydrogeological investigation in volcanic terrain needs emphasis in re-construction of the geologic and geomorphologic history of the area. Thus, the geomorphologic setup of the area can be deduced based on previous work conducted in the area, lithological log obtained from boreholes and data collected during the fieldwork. There fore, the project area is characterized by alternate eruption of basic and acidic lava flows from different centers. In between successive lava flows physical disintegration and chemical decomposition of rocks exposed at the surface; subsequent erosion and deposition; and tectonic activity taken place that has modified significantly the geomorphologic set up of the area. The main porosity groups identified are fracture porosity and interstitial porosity.

The main aquifers in the project area can be categorized into three groups:

1. Shallow aquifer: made of weathered volcanic rocks and alluvial sediments along the river valleys.
2. Deep aquifers: made of fractured volcanic rocks that tap fresh ground water.
3. Thermal aquifer: that is located at depth greater than 300m.

HYDROCHEMISTRY

The chemical composition of natural water is the results of natural processes and cultural effects as a consequence of man's activities. Climate, structure and position of rock strata and biochemical effects associated with life cycle of plants and animals are the main environmental factors that control the amount of solutes present in the natural water. Accordingly in the present study area, occurrence of basic and acidic volcanic rocks, major tectonic discontinuity and topography are the major water quality controlling factors. Besides urbanization and associated development features for more than a century in the city significantly change the chemical and biological constituents of surface and groundwater.

Water entering the subsurface from different sources may remain temporary as a continuous body or in several distinct water-bearing zones. The resulting physical and chemical properties of groundwater are related to its relationship with the media, which the water encountered, and its residence time. In addition to the natural factors a major changes in the constituents of groundwater in the study area is resulted from the activities of man. On the other hand, the type and concentration of dissolved constituents governs the usefulness of groundwater from various purposes. Therefore, it is necessary to determine the composition of groundwater before the water can be used for the intended purpose.

Four kinds of water can be identified in Addis Ababa: Na-HCO_3, Na-Ca-HCO_3, Ca-Mg-HCO_3 and Ca-Mg- Cl.

Most of the river water belongs to Na-HCO_3 and Na-Ca-HCO_3 types. The relative abundance of the ions can be related to geochemical reactions taken place as the water comes in contact with different minerals. Moreover, there is also significant contribution of elements due to pollution of the river water. As a result some scattered water points are observed in the diagram. Therefore, the river water chemical composition represents the product of natural as well as artificially induced materials.

The chemistry of spring water becomes a Ca-Mg-Cl and Ca-Mg- HCO_3 type. A shift of the water chemistry towards SO_4+ Cl is mostly related to the infiltration of contaminants into the subsurface rather than natural dissolution processes. This is due to the fact that most of the springs located in the up stream parts (less vulnerable to pollution) are characterized by high bicarbonate concentration instead of chloride.

The plots of existing groundwater points in the tri-liner diagram shows the dominance of bicarbonate ions, with variation in composition of Ca and Na. The resulting water types also vary from Ca-HCO_3 to Na-HCO_3. The relative abundance of the cations indicates the dissolution of minerals that constitute either basic or acidic volcanic rocks.

Chemical analysis of water samples collected from rivers, springs and bore holes revealed that sodium and calcium are the dominant cations. The major sources of calcium and sodium are the minerals that constitute basic and acidic volcanic rocks. Rocks containing sodium and calcium are more or less susceptible and upon weathering yield the metal cation and silica in solution. The resulting water from basic volcanic rocks tends to be a Ca-Mg-HCO_3 and becomes Na-HCO_3 water in the case of acidic volcanic rocks, with relatively large amounts of silica.

SURFACE WATER AND GROUNDWATER INTERACTION

Traditionally, management of water resources has focused on surface or groundwater as if they were separate entities. However, it is apparent that the movement of water between surface and groundwater provides a major pathway for chemical transfer between terrestrial and aquatic systems. This transfer of chemicals affects the supply of carbon, oxygen, nutrients such as nitrogen and phosphorus and other chemical constituents that enhance biogeochemical processes on both side of the interface. Nearly all-surface water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with groundwater. This interaction takes different forms. In many situations, surface water bodies gain water and solute from groundwater systems while in others surface water is a source of groundwater recharge and causes change in groundwater quality.

Pollution of surface water can cause degradation of groundwater quality and conversely pollution of groundwater can degrade surface water. Thus, effective water management requires a clear understanding of the linkage between surface and groundwater as it applies to any given hydrogeological setting.

This interaction takes place in three basic ways. Streams gain water from groundwater through the streambed when the level of water Table adjacent to the streambed is higher than the water level in the stream. A second possibility is that streams may lose water to groundwater by outflow through the streambed when the level of the water Table is lower than its level in the stream, or they do both, gaining in some reaches and losing in other reaches. Although these basic interactions are the same for lakes as they are for streams, the interactions differ in several ways. The main difference is that lakes have a much larger surface water and bed area with water level that does not change as rapidly as the water level of streams. Furthermore, the slower through flow rates in a lake often result in accumulations of low permeability sediments in the lake floor, which can affect the distribution of seepage. As a result, the rate of seepage is often greatest around the lake margin where wave action may restrict the deposition of finer sediments.

The interaction between surface and groundwater can be determined from water Table contour maps. In addition to this, environmental tracers such as naturally occurring dissolved constituents; isotopes and physicochemical properties of water are used to track the movement of water through the watersheds. Moreover, environmental tracers can be used to calculate hydrologic and chemical fluxes between surface and groundwater.

Shallow local patterns of groundwater flow near surface water are emphasized in this study, as shallow aquifers are more susceptible to contamination from human sources. Hydrochemical data was used as tracers in studying the interaction between surface and groundwater.

Groundwater flow direction is essential in identification of the movement of contaminants, once they enter the groundwater from high grounds. The elevation of water level in boreholes was used to determine the general direction of groundwater flow in the study area. However, occurrence of fractured and intergranular porosity and complexity of multilayer aquifers system in the area make the actual groundwater flow more complex than shown in the groundwater level contour map.

Surface water commonly is hydraulically connected to groundwater, but the interactions area difficult to observe and measure and have been ignored in water management considerations and polices. Streams interact with groundwater in all types of landscapes as loosing or gaining streams or both. The environments in which polluted Akaki river interacts with the underlying groundwater vary from place to place. The water level in the Akaki river is located at higher elevation than the water level in the aquifer and hence is acting as a loosing river by releasing water in to the near by alluvial and volcanic aquifer. The subsurface zone where the river water flows through short segment of its adjacent bed and bank is marked as hyporheic zone. After the river water crosses this zone it directly migrate towards the water table.

POSSIBLE SOURCES OF POLLUTANTS

Like in many other sectors of the developing countries of the world, economic development usually does not take into consideration the possible impact it has on the environment. On the other hand, absence of proper environmental management practice paralleling economic development may lead to an irrecoverable environmental degradation.

There are numerous sources of pollutants that could deteriorate the quality of water resources. In developing countries sources of pollution from domestic, agricultural, industrial activities are unregulated. Like wise in Addis Ababa, where there is no as such environmental protection practice there are a number of pollutant sources that continuously deteriorate the quality of surface and ground water since the foundation of the city. Based on obtained information, observation made during site visit and analytical results, the following hazard centers have been considered as major category of sources of pollutants in the project area. These are industrial establishment, agricultural activities, municipal wastes, fuel stations, garages and health centers. Meanwhile in the project area numerous graveyard and market areas contribute to the deterioration of water environment.

The number, distribution and major activities of hazard centers are summarized below so as to give a better understanding of the magnitude and possible pollutant types.

The main sources of pollution are:

AGRICULTURAL POLLUTION

PETROL STATIONS

MUNCIPAL SOLID WASTE

SEWAGE

INDUSTRIAL POLLUTION

GARAGES

HEALTH CENTERS

GRAVE YARDS

AQUIFER VULNERABILITY ASSESSMENT

Assessments of the groundwater resources involves an appreciation of the magnitude and quality of the resources, its recharge and discharge zones, its interaction with surface water and groundwater resources, environmental links and demands and present and future consumptive demands on the resources by all consumer groups.

In the last decades, groundwater vulnerability assessments have been conducted in many countries as a part of comprehensive groundwater protection strategies. The vulnerability concept is obviously attractive to decision makers, physical planners and groundwater managers. The objective in the evaluation of aquifers vulnerability is directed at the study in space and time of the phenomena of pollution of underground water bodies. Adopted approaches for vulnerability assessment range from empirical classifications of key properties to process based simulation models. The former category includes stratigraphic zoning and different index methods. Process based simulation models have mainly been applied in pollutant specific vulnerability assessments for diffusive sources. Statistical methods, where groundwater quality data are coupled to hydrogeological data, land use etc constitutes a further possible approach to vulnerability assessment. Since vulnerability of an aquifer is a function of a number of parameters, it is necessary to adopt aquifer vulnerability assessment to the intended use and local conditions.

Water pollutants do not have always the possibility to enter the groundwater system, instead the pollutant tends to be removed or reduced in concentration with time and distance traveled. The rate of pollution attenuation depends on the type of pollutants and on the local hydrogeological situations. Moreover, mechanism of pollution attenuation includes filtration, sorption, chemical processes, microbiological decomposition and dilution. The soil/overburden and unsaturated zone as the first and the second defense line. Thus, an important element in assessing groundwater resources is investigation of aquifer exposure to contamination. The evaluation of the potential exposure of groundwater resources to contamination is termed as vulnerability. Thus the preparation of aquifer vulnerability map is a key consideration and becomes a forecasting tool and via the planning processes a prevention tool and an identifier of action priority list. A valid point count system model (DRASTIC) was built up to assess aquifer vulnerability by USEPA, which directly derived from LeGrand ideas, despite several efforts have been made since the early seventies. It was noticed that LeGrand developed an empirical point count system to evaluate the potential pollution from a given sources. As an aftermath many countries adopted aquifer vulnerability mapping techniques with the local conditions for the protection of groundwater quality deterioration. A case in point is the new point count system called SINTACS that was developed in Italy in accordance with local conditions modified from DRASTIC.

The general objective of the study is to identify and map the groundwater aquifers vulnerability to pollution in the Akaki River Catchment by using the system known as *DRASTIC* **with model builder of ESRI-ARCVIEW-GIS there by to prepare vulnerability map. The hydro geological factors defined in the DRASTIC system are:**

D= ***D***epth to water,

R= net ***R***echarge,

A= ***A***quifer media,

S= ***S***oil media,

T= ***T***opography/slope,

I= ***I***mpact of vadose zone media,

C= hydraulic ***C***onductivity.

To meet the above-specified objectives of the research project the **DRASTIC** model developed by United States Environmental Protection Agency (Aller et. al, 1987) to assess relative groundwater pollution susceptibility using hydrogeological factors was adopted. DRASTIC Index (D_I) was computed using the assigned rates and weights for each DRASTIC factors or parameters as follows:

DI =DrDw+ RrRw+ ArAw+ SrSw+ TrTw+
IrIw+ CrCw

Where: D, R, A, S, T, I and C are the parameters, and r = rating value and w = weight strings

SUMMARY

Water quality degradation is one of the major environmental problems in Addis Ababa and its environs. Hence, determination of the degree of vulnerability to pollution based on hydrogeological factors is important for policy and decision makers. Therefore, the primary goal of this study was to perform an aquifer vulnerability assessment of the water supply aquifers of Addis Ababa using a DRASTIC approach assisted by GIS software. To apply the DRASTIC system, hydrometeorology, topography, drainage, borehole, geology, soil, land use and lineament databases were constructed. Using the database, hydrogeological factors such as depth to water Table, net recharge, aquifer media, soil media, slope, and hydraulic conductivity were extracted. Using the database, the DRASTIC system was applied. The results suggest that this method can assesses the pollution potential of the project area and generate information that is readily usable by agencies that are involved in groundwater protection and evaluation.

The groundwater pollution vulnerability map is ideal for use in future land-use planning studies, where potential contamination may occur. It also helps in avoiding future contamination of the groundwater by considering the vulnerability of an area before high-risk activities were allowed to take place. Information of non-point and point sources of potential pollutants, including population, livestock, and industries, will be needed for the risk analysis of groundwater pollution.

The main sources of pollutants that deteriorate the quality of water in the project area are wastes generated from industries, domestic activities, garages, health centers and fuel stations. The pollutants identified in surface and ground water bodies include organic wastes, nutrients, inorganic constituents and microorganisms. Moreover river water in Addis Ababa is characterized by objectionable physical properties offensive odor, and colored water. There is seasonal variation in EC, TDS and PH more rapidly in surface waters (rivers and streams) attributed to the type of wastes and industrial effluents. It is worthwhile to note the high EC values as compared with groundwater. Boreholes also indicate rapid change in EC and TDS based on the contaminant input. Groundwater that has more or less stable EC and TDS like wells Akaki well field portrays variation in pH, which indicates contaminant input (an open system). The intrinsic vulnerability mapping for the water supply aquifers of Addis Ababa revealed that major part (central) of the city lies on medium risk area while the southern aquifer is highly vulnerable to pollution. Low vulnerable areas are aerially quite small. Thick clay deposits around lake Aba Samuel fall in medium vulnerability category and the southern industrial area is situated in high vulnerability zone. Industries located on high-risk area are advised to control their effluent at source.

Intrinsic vulnerability map represents the distribution and the extent of groundwater that are potentially sensitive to pollution. The validity of the map depends upon the accuracy of the database and respective interpretation. Recent international interest, governmental and NGO, in environmental protection has given emphasis to groundwater protection from pollution. For proper evaluation of pollution problems, aquifer vulnerability mapping is an ultimate solution. The map is useful in:

1. Land use planning and land use decisions
2. Policy analysis and development processes to identify potential for groundwater pollution
3. Improving general awareness of an environment.