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Clarion University of Pennsylvania, Clarion, Pennsylvania

MILLENNIUM DEVELOPMENT GOAL ON WATER SUPPLY AND THE CHALLENGES OF HEADWATERS QUALITY IN NIGERIA: EXAMPLE FROM A SMALL COMMUNITY IN SOUTHWEST NIGERIA

By

Eludoyin, A. O

Department of Geography, Obafemi Awolowo University, Nigeria

Akinbode, O. M.

Department of Geography and Planning Sciences, Adekunle Ajasin University, Nigeria

ABSTRACT

The water chemistry of some headwaters of the Southwestern Nigeria was investigated in line with the requirements of the MDGs for the development of appropriate management strategy for headwaters in developing countries. To exemplify this, about 60 water samples (50 streams and 10 bulk precipitation) were collected from the headwater regions and investigated for the major ions, pH and conductivity. About 64 soil samples (16 from each region) were also obtained from the 0 - 45 cm depth in the headwater regions. The results of the statistical analyses showed that Ca^{2+} *was the least abundant cation (≤ 0.01* $MeqL^{-1}$*) and* NO_3^- *was the least abundant anion (≤ 0.06* $MeqL^{-1}$*) in all the headwaters;* Cl^- *and* SO_4^{2-} *were the most abundant cations and anions, respectively, in one of the headwaters close to a dumpsite. Most of the investigated ions were significantly higher in this stream than the concentrations in other headwaters that are more sterile. The study showed that the contributions of the rainwater to* *the chemical quality of the headwaters were rather low, while the rock and land use were more important contributors. The significance of the contribution of the dumpsite was associated with high* Cl^- *and* SO_4^{2-}*. The study concluded many developing countries may not meet the water quality/supply requirement of the MDGs if appropriate policy, such as the headwater control policy is not enacted.*

Keywords: headwaters; headwater control policy; millennium development goals; pollution; and water quality.

INTRODUCTION

One of the most potent ways of increasing qualitative and quantitative water supply in a community is to improve its headwaters. Headwaters are the first- and zero-order basins, and the region of their existence is defined as the place where water flow-lines originate and where groundwater recharge occurs. They have been regarded as the ultimate source of terrestrial fresh water (Haigh et al, 2005). The importance of water management at this scale cannot be over emphasized as it could offer potential for maximizing the delivery of contamination to the downstream (Burt and Johnes, 1997).

Headwater sources are often associated with areas of low levels of human occupation and isolation from major industrial and economic processes (Haigh et al, 2005). They could also be found in mountainous areas, and most peripheral parts of a drainage basin where they provide valuable fresh water supply to the ecosystems and human communities in the extended basins. However, with the rate of development globally in the recent times, the supply and quality of water produced by these headwater regions have declined. Many of the headwater regions have subsequently become used for agriculture, logging, mining, road construction, tourism, hydropower generation, and water supply in the bid to acquire land for urban growth. These activities have been shown to interfere with water availability and quality, and consequently affecting the downstream uses (Maybeck et al, 1996; Adewale and Ikeola, 2005).

For example, the Smithsonian Environmental Research Centre (SERC), USA has documented a number of research findings on the Rhode River to show the impact of land use on the nutrient composition of the receiving waters, especially due to industrialization and urbanization (Jordan et al, 1997). Also, Hecky (1993) and Bootsma and Hecky (1993) attributed the increase in eutropication in Lake Victoria to nutrient enrichments from agricultural, industrial, and combustion activities in the headwater environment. A number of cases of pollution of downstream were also attributed to human activities within the headwater environment (Weijden and Middelburg, 1989; Painchaud, 1997; Peters et al, 2007).

Attempts have, however, been made to protect the headwaters, especially with the formation of the Headwater Control Movement (Haigh et al, 2005), based on the principles that headwater environments are threatened by environmental changes due to human action; direct intervention can secure environmental quality and solutions to the degradation of the headwater environment demands the practical application of coordinated and integrated environmental management. And in realization of an important agenda of the Millennium Development Goals (MDGs), i.e. commitments to improve water security and ensure environmental sustainability (World Bank Group, 2003), the human dimension of headwater management has become an issue to the modern world.

Despite the importance of the headwater to the global community, many developing countries, including Nigeria, are yet to arise to the challenges of MDGs. Most of these countries neither possess acceptable country specific guidelines or standards for drinking water (UNEP/GEMS/WP, 2006) nor a coherent policy for water resources management and development (Okoye and Achakpa, 2007) required for the achievement of the MDSs on water resources and sanitation.

Problem

Since the quality of headwaters usually contributes to that of the downstream and could be undesirable for several uses, it is not only vital to ascertain the physical and chemical quality of the headwaters. It is also necessary to elucidate the sources of identified pollution and contamination. Knowledge of the potential effect of land uses on the chemical quality of headwaters is required to guide all activities towards meeting the challenge of the MDGs on water resources and bridge the gap of scarce information in a developing country in Tropical Africa.

This study was carried out to investigate the chemical quality of four headwaters of the Opa Reservoir, which is an important source of water supply in the Southwestern Nigeria; the Reservoir supplies potable water to more than 20, 000 people. It is also used for study in hydrobiological researches (Akinbuwa and Adeniyi, 1996). Previous study of receiving Opa Reservoir has shown that the sources of organic contamination of the reservoir were both variable and diversified. For example, Alagbe (2000) concluded that the bacteriological quality of the reservoir is low, although the report did not identify sources of the bacteriological pollution. Furthermore, Olowoyo (2001) reported that agricultural effluents were contributing significantly to organic pollution in Opa Reservoir but did not identify the sources. Later, Eludoyin et al (2004) explained that effluent through point source pollution, the Oja titun market, situated within the River Ogboku, is a contributor to the contamination of water in the Reservoir. The study indicated that while the market effluent is contributing to organic pollution in the reservoir, there are, probably, many other important sources, which must be identified before the dynamics of pollution in Opa River is understood and before any remedial intervention could be sustained

Objectives and Hypothesis

The general consensus, as aptly reflected in the Kyoto agreement, is that environmental pollution in the less developed nations, such as Nigeria, is rather minimal. While this is true to a large extent, this argument underestimates the effect of primary land use activities (such as farming, waste disposal, etc.) on the chemical pollution of the environment, especially the headwater environment. In developing societies, many headwaters have suffered through colonization by peasant farmers. Agricultural modernization has also caused an increase in the chemical input in the headwaters, while some communities have turned headwater regions to dumpsite and incinerating sites.

In many rural communities in developing countries, the struggle for immediate survival has higher priority than any concern for the future or the surrounding environment, even where the skills and resources needed for its management exist. In such cases, the problems of environmental degradation rarely remain in the headwaters. Regions downstream suffer through water and sediment pollution, changes in the hydrological regime, and reduced natural resource supply, which may also lead to social stress and livelihood disruption.

Apart from the fact that the ability to properly track progress toward minimizing impacts on natural environments and improving access of humans to safe water depends on the availability of data that document trends in both space and time – a phenomenon has mandated monitoring of both water quality and quantity in surface and ground water resources all governing levels: local, national, and international (UNEP/GEMS/WP, 2006), the impact of such land use on pollution of headwaters in many developing tropical countries is not well documented, especially in Nigeria. As a result, they are rarely taken into consideration in environmental and water resources management. The objective of this investigation is, therefore, to determine the specific and general environmental consequences on headwaters of land uses from one of such tropical countries. All conclusions on the effects of the land use were based on the hypothesis that the quality of any body of surface or ground water is a function of either or both natural influences and human activities (Stark et al., 2000).

Study Area

The four headwaters (Asunle, Agbogbo, Awosun, and Amuta) are tributaries of River Opa, one of the main regional rivers of southwestern Nigeria. They are located between $7^0$21'N $4^0$31'E and $7^0$35'N $4^0$39'E (Figure 1). The basin area of Agbogbo is 0.44km^2 while those of Asunle, Awosun, and Amuta are 0.23, 0.15, and 0.35, respectively. Amuta, however, dries up in the dry season.

The annual rainfall averaged 1,413 in a 3–year survey (2005-2007) and showed two peaks; one in July and the other in September. The mean temperature ranges from 22.5^{o}C to 31.4^{o}C. Figure 2 summarizes the geology of the headwater basins. The Agbogbo largely comprises granite gneiss; Amuta contains rock of mica schist composition, while Asunle and Awosun are underlain by granite gneiss. The soils in Agbogbo generally belong to the Typic Rhodulstults group (Ogunkoya, 2000); soils in Amuta River are ferruginous tropical soils, generally described as Tropudalf and Paleustult (Amusan et al, 2005). Asunle and Awosun were also covered by soils of the Iwo series (Smyth and Montgomery, 1962).

Figure 3 summarizes the land use characteristics of the headwater region. These values were determined by traverse surveys across the headwater regions. The University incinerator is located in Asunle, making it the most vulnerable basin to receiving effluent from the surrounding dumpsite. Others are dominated by secondary vegetation interspersed with cultivated patches and fallow species, namely Chromolaena adorata Imperata cylindrical and Elusine indica. Annual crops, such as maize and cassava, are the common crops, while trees crops (e.g. cocoa and kola) are restricted to some accessible portions in Agbogbo and Awosun. Also, while Amuta is cultivated by mechanized farming, others are purely by indigenous practices.

MATERIALS AND METHODS

Instrumentation

All of the headwater regions, except one (Asunle, due to insecurity of the equipment), were equipped with rain gauges and bulk precipitation collector to monitor rainfall intensity and collect rain samples for chemical analysis, respectively. The bulk precipitator is made up of continuously opened 31 cm plastic funnel draining into a 4L container. The container and the lower part of the funnel are encased in a fitted metal rod to stabilize the funnel in a vertical position. A staff gauge was also constructed in each basin to monitor the stage of the stream at different periods of sampling and stream flow determination.

Velocity of the stream for discharge measurement was determined for different periods with an OTT model of a propeller type current meter.

Sampling Design, Collection, and Field Observations

The headwaters were surveyed for information about the land uses to determine the land use composition. The soil characteristics within the headwater regions were also determined using soil samples obtained from three areas within 100 m of each of the basins. The sampled soils, which were collected between August and December 2007, were dug with a soil urger, to 0 – 15, 15 – 30, 30 – 45 cm and below, and samples were collected in black polyethene containers. The samples were later taken to the Soil Science Laboratory, Obafemi Awolowo University, Ile-Ife, Nigeria for the determination of the soils' pH, PO_4-P, Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-} and particle distribution.

In addition, about 50 depth-integrated grab water samples (event and nonevent) were collected from each headwater between April 2005 and July 2007 in the wet and the early dry periods, using 1L plastic bottles. Rain samples were also collected from the bulk precipitation collectors located in three of the catchments, in 2L plastic containers. Samples were analyzed for pH, electrical conductivity, K^+, Ca^{2+}, Fe^{2+}, Mg^{2+}, Na^+, SO_4^{2-}, PO_4^{3-}, Cl^-, and NO_3^- at the 'Water Quality Section' of the Centre for Energy and Research Development and Department of Chemistry, Obafemi Awolowo University Campus, Ile-Ife.

Laboratory Analyses

pH of the soil samples was determined after 1: 2 (H_2O: $CaCl_2$) dilution of 10g of samples using pH meter (pHep – 1 model). The concentrations of Na, Ca, and K were determined by extraction with a solution of Ammonium Acetate and the supernatant read with a flame analyzer (Model 2655 – 00). Mg was, however, read with Atomic Absorption Spectroctrophotometer (ALPHA 4 model). The concentrations of Na^+, K^+, Ca^{2+}, Fe^{2+}, and Mg^{2+} in water samples were, however, determined using AAS (ALPHA 4 model) at their characteristic wavelengths of 589, 766, 422.7, 248.8, 285.2 nm, respectively.

SO_4^{2-} and PO_4^{3-} in both soil and water samples were determined using the colorimetric method (Spectronic 20D+ model). Cl^- was determined by argentiometric titration. NO_3^- was, however, only determined in water samples, because the requirements for its extraction in soil could not be met by the laboratory.

Statistical Analysis

The mean values of the variables and their standard deviations were computed for each basin. This was done to account for variability in the data obtained for each station. Comparison of the basins was performed using the Analysis of Variance (ANOVA) statistic. ANOVA is an accepted method of testing the null hypothesis that several group means are equal in the population, by comparing the sample variance estimated from the group means to that estimated within the groups (Zar, 1992; SPSS Help file). Individual sites were compared with others using the Scheffee Multiple Comparison (SMC). SMC is one of the post hoc pair-wise multiple comparison tests that are often used to determine the differences between each pair of means. Significant differences were obtained at $p \leq 0.05$.

The principal component analysis (PCA), using the Varimax rotation technique, was used to identify how much of the variance is accounted by the differences in the basins. PCA is concerned with explaining the variance – covariance structure through a few linear combinations of the original variables, i.e. the eigenvectors of variance – covariance matrix (Daves, 1973). It is used to interpret the structure within a correlation (or variance – covariance) matrix of a multivariate data (Gregory, 1973). Keiser (1958)'s Varimax rotation model was used to maximally group the factor variables into distinct clusters their sites.

RESULTS AND DISCUSSION

Major Ion Distribution

The mean values of all variables investigated in the rain, stream, and soils are presented in Table 1. The peak value of each variable, except Mg^{2+} and PO_4^{3-} was recorded at Asunle headwater region. In general, Na^+ was the most abundant ion, except in Asunle, which were Cl^- rich. Ca^{2+} was the least solute in all the headwaters. The difference in the ionic balance (i.e. % difference between cation and anion) was highest in Awosun (56.8%) and lowest in Asunle (1.5%). One-way ANOVA showed that the distribution of all variables (except PO_4^{3-}, Mg^{2+}, Fe^{2+}, and Ca^{2+}) were significantly different between the headwaters (Table 2). The Scheffe multiple comparison tests showed that the value of each variable (except PO_4^{3-}, Mg^{2+}, Fe^{2+}, and Ca^{2+}) was significantly higher at Asunle than at each other site, while the values of most variables at Agbogbo, Amuta, and Awosun were comparable (i.e. Agbogbo = Amuta = Awosun). On the other hand, PO_4^{3-}, Mg^{2+}, Fe^{2+}, and Ca^{2+} were comparable in all sites, including Asunle.

Ionic concentration was generally high, but both cation and anion sums were lowest in Asunle and increased from Amuta through Agbogbo to Awosun. Among the major cations, all the headwaters were dominated by sodium (59.93 – 81.01%) followed by potassium (37.86%) in Asunle and iron (20.2 – 22.72%) in the other headwaters. Calcium was the least important cation in all the sites. In the case of the anions, all the waters were chloride dominated (48.48 – 79. 30%), except the rainwater, which was dominated by phosphate (42.63%), iron (72.09%), and sodium (10.93%). The soils in Asunle and Agbogbo were, however, dominated by magnesium (49.59%), followed by calcium (38.02%), while Awosun was dominated by calcium (53.44%), and followed by potassium (31.30%). Potassium dominated Amuta (44.04%), followed by magnesium (31.61%). The dominant ion was chloride in all the soils (about 50% in each). Thus, while the soils were typically of the magnesium chloride type, the headwaters were sodium chloride waters, and rainwater was iron phosphate.

Variability in Spatial Distribution

A discriminant analysis performed to determine the importance of differences in the values of the various variables between headwater regions showed that 94.7% of original grouped cases were correctly classified according to regions (i.e. Asunle, Amuta, Agbogbo, and Awosun). Therefore, spatial variability was probably high, although the variables were not completely classified correctly. As a result, the PCA was performed separately on the spatial data. Results of the spatial data analysis revealed that the first two factors accounted for 51.2% of the total variance in Asunle; 60.8% in Agbogbo; 49.8% in Awosun; and 54.1% in Amuta. Factor 1 in Asunle (33.1% of total variance), Amuta (32.2% of total variance), and factor 2 in Amuta (22.0% of total variance) are all related to variables that change with pollution (SO_4^{2-}, K^+, PO_4^{3-}, Cl^-) (Figure 4), suggesting that these headwaters were relatively contaminated and could have potential impact on the water quality of Opa Reservoir, downstream. Factor 1 in Agbogbo (41.1% of the total variance) was most accounted for by Ca^{2+}, Na^+, Fe^{2+}, and Mg^{2+}, which are associated with weathering of alumino–silicate minerals of crystalline rocks (Bartarya, 1993).

DISCUSSION

The objective of this study was to determine the water quality of selected headwaters of the Obudu River section of the Opa basin. According to Stark et al (2000), the quality of any body of surface or ground water is a function of either or both natural influences and human activities. The results of this investigation showed that (with the exception of pH, PO_4^{3-}, Cl^-, Fe^{2+}, and Mg^{2+}) the values of all other variables were significantly higher in Asunle than the other headwaters. For instance, variables Na^+, K^+, and Cl^- were more than twice as high in the Asunle as in the other headwaters, while PO_4^{3-}, Ca^{2+}, K^+, and Cl^- were significantly more enriched in the soils in Amuta. In general, precipitation input into the freshwater system is low in the major ions, except perhaps PO_4^{3-}, which accounted for about 12% or less, but was not found in higher concentrations in the streams (Table 3). The contribution of the base flow was significant for all of the variables (except Na^+, K^+, and Cl^-) in Asunle and Na^+ and K^+ in other headwaters. Basic cations (such as Mg^{2+}, Ca^{2+}, etc.) may have, therefore, been released into streams through the mineral weathering of the bedrock, their main sources (Anderson and Burt, 1982; Jenkins, 1989). Excess of Na^+ in all of the waters and Cl^- in Asunle, in particular, were not likely fed through either the base flow or rain. The streams may have been fed through overland flow from Na^+ and Cl^- rich land surfaces, respectively. Both ions are related to salinity of waters, and can enrich from municipal, agricultural, and industrial discharges (UNEP/GEMS/WP, 2006). Saline toxicity in the headwaters can cause loss of biodiversity, affecting invertebrates, vertebrates, aquatic plants, and riparian vegetation alike (Goodfellow et al., 2000; Williams, 2001).

Both ions (Na^+ and Cl^-) have also been identified as a conserved solute in some systems. The high degree of conservation is due to the low anion exchangeability of the ion and the high solubility of its compounds (Eugster and Jones, 1979). The fact that most Na^+ concentrations at the streams are higher than the combined inputs from soils and rains, suggests that there is substantial gain from within the headwater regions. An alternative explanation could be that the headwater regions are a substantial source of the solute. However, it is unlikely that large amounts of chloride or sodium would be retained in the system due to the highly soluble nature of their compounds. As a result, chloride and sodium are widely recognized as conserved solutes during evaporation and/or transpiration of surface waters (McCarthy et al., 1993), and their increased concentration in the headwaters could be related to the incidence of pollution of the streams.

The results presented in Table 1 also presented a picture of the lowest concentrations of chemical constituents in precipitation and the highest in stream water (Bruijnzeel, 1983; Elsenbeer et al., 1995). However, some of the results deviate from the usual. For instance, PO_4^{3-} concentrations in all of the headwaters and SO_4^{2-} at Awosun were lower than in precipitation. This could have been caused by their preferential uptake by the vegetation (Jordan, 1985). In addition, the nutrients' concentrations in precipitation are likely to vary more in time than those in the stream water. In addition, stream water samples collected by the depth integrated sample technique often 'integrate' the inputs of a number of sources due to mixing and dispersion. Because PO_4^{3-} and SO_4^{2-} concentrations are strongly governed by the contact of the water with the wastes from industry, agriculture, medical, and household activities (UNEP/GEMS/WP, 2006) it can be used to indicate the relative residence times of the respective land use types (Bruijnzeel, 1983). As such, runoff can be expected to have the highest PO_4^{3-} and SO_4^{2-} concentrations. However, as none of the runoff sources that were sampled had the percentage of Ca^{2+} and Mg^{2+} concentrations that resembled those of the stream flow (Table 3), it may be concluded that the actual source of the these elements (base flow) was not sampled. Brouwer (1996) reported enhanced elemental concentrations in matrix soil water flowing down the soil depth along the different soil profiles. A similar mechanism may be at work at the headwater regions in this study. Based on the geochemical evidence, it may be assumed that some of the precipitation percolates through the different soil profile during saturation overland flow (SOF). SOF may have enhanced the chances for water to come into contact with the K^+ from the agricultural and domestic wastes in the study area. On a related note, Moughalu et al (1993) showed that Ca^{2+} is often associated with high litter falls in the forest region; hence, the total absence of forest in the basin may have accounted for the general low in the concentration of the ion in the headwater regions in the present study (Figure 5).

These findings are in agreement with those of Meybeck (1989) that sodium, chloride, potassium, phosphates, and suphate were observed in high concentration in streams that have been fed by leachates from domestic wastes and increasing sewerage inputs. Few studies have been undertaken in tropical and developing countries, and strong correlations between land use and most water chemistry parameters were observed, probably due to the strong contrasts between headwaters in urban versus nonurban areas (Baker, 2005). Biggs et al (2002) investigated part of the Amazon basin where 22% has been deforested with about 50% of deforested area currently in re-growth and observed that sodium, chloride, and sulphate were all observed to increase with urbanization.

CONCLUSIONS

This study has assessed the water quality in some headwaters in southwestern Nigeria. It was the purpose of the study to contribute to the scanty information on the water quality of headwaters in tropical areas. The study has used results of analysis of water samples from precipitation, streams, and soils sampled at various layers between April 2005 and July 2007.

The study has shown that some water quality determinants and land use do show reproducible trends. Human influence, in general, often determines chloride concentration (Herlihy et al, 1998; Baker, 2005). Agricultural land use may also often determine nutrient concentrations in intensive (commercial) agricultural headwater regions. Understanding human land use and natural water resources' response are essential, because land use is forever changing, and future land use changes will be driven by the interplay between population growth, climate change, and policy makers, which will vary in different parts of the world. In general, the land use–water quality relationship in a headwater region has been observed to be complex, associating the components of the hydrological cycle. Observations in one headwater may also be site or region specific (Baker, 2005). One could, therefore, agree with Langley (2004) that water quality of the headwater regions should be widely repeated in multiple areas to allow relevant governing bodies determine how universal or case-specific land management policies must be in order to preserve the integrity of freshwater sources.

In many developing societies, many headwaters have suffered through colonization by peasant farmers who have been displaced from better-quality agricultural lands (Haigh et al, 2005). Agricultural modernization and communal crises have launched waves of economic migrants into the cultivation of unfamiliar and often unsuitable terrain. In such communities, the struggle for immediate survival has higher priority than any concern for the future or the surrounding environment, even where the skills and resources needed for its management exist. In such cases, the problems of environmental degradation rarely remain in the headwaters. Regions downstream suffer through water changes in the hydrological regime and reduced natural resource supply, which may also lead to social stress and livelihood disruption.

One option for curbing this problem in the headwater regions in the study area is to embark on the headwater control policies. The headwater control policy should aim at aiding local communities to build self-sustaining local systems for the management of their own livelihoods and environment, including biodiversity, natural resources, cultural icons, and the services their lands provide to outside communities and habitats. This will be achieved through education of the settlers around the headwater regions on the principles of the MDGs on water resources, which will further reduce the prospect of pollution of the headwaters. A similar intervention in all the headwaters of the Opa Reservoir will, no doubt, improve the overall quality of water in the Reservoir. In the long run, this will prove more proactive and cost-effective, as both the intensity and cost of treatment would be reduced substantially.

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