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Coefficient of Sustainable in Water Resources Exploitation and Utilization

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Abstract
The concept of radial Venn was employed in constructing the relationship between the per capita groundwater exploitable and the per capita water available to any given territory as to model natures' water budget for a given territory. Elements considered include precipitation, infiltration, aquifer's material volume and its volumetric specific yield. These factors were resolved into a linear regression equation expressed as X = E - U. Where X is the unit of groundwater budget in the area, U is the value of the difference of the discharge and the recharge. E is the coefficient of sustainability for the available groundwater resource (which is a constant for any given country/area).
Key words: radial venn, groundwater, water budget, aquifer, linear regression,

Introduction

Freshwater is a critical and scarce resource which is not just expensive but rarely renewable. Owing to this fact, the use of water in a territory should be planned. In planning, absorption capacity of the available freshwater resources for nutrients dispersion and aquifer's capacity for recharge should be considered.
This is because both quantity and quality of freshwater are interrelated and important in water resources evaluation and management. Freshwater stock are steadily depleted through pollution (quality wise) and overdraft (quantity). Having precipitation is not the issue, but the real issue is the extent to which the rainwater can result to infiltration judging the ratio of paved surface to the recharge compatible land use [14]. Impeded infiltration caused by paved surfaces (which is a common place in today's developmental design), implies uncertain.
The work centered on establishing a working plan in the form of a mathematical model that tried to resolve the cause, effect and management issues that are associated with water resources exploitation and utilization in a given area. It targets to strike a balance between a territory's aquifer volumetric yield capacity and the actual water draft in dealing with the population dynamics. It has a view to arrive at the coefficient required to attain sustainability in the resources exploitation and utilization. It is so because the amount of fresh water that is available to any country on a long-term basis is nearly constant for all practical purposes [3]. This means that very high percentage of water will continue to be under-developed because of adverse economic conditions and environmental constrains [2], [23]. Population increase presents with attendant increase in water requirements which exacerbates water resources planning problems. This problem borders on meeting the portability requirements for the populations' water needs. This work attempted to prescribe a benchmark upon which water resources planning and development could be based. It is believed that the prescription struck a balance between man's developmental design and natures' water budget. It is a quest directed towards content with a view to establishing the coefficient of sustainability in water resources exploitation and utilization. Achieving this, involved making efforts to obtain information on the following:

- the level of satisfaction of the water requirements
- the human impact on freshwater quantity in a built environment
- the level of influence of standard of living on water-use in an area
- identification of the major activities requiring water and the sources of water supply
- collection of information on water demand and supply situation, regional water requirement and consumption
- obtaining information on recharge, precipitation, infiltration and pumping were obtained from various sources, existing literature etc

Some of the data set were obtained using structured survey questionnaires, direct interview and review of existing literature.

Water is essentially required for all human activities including but not limited to drinking, agricultural production, industrial development, all forms of large-scale energy generation, navigation, recreation and general sanitation. As population increases, the water required for the said uses also increases. Water management process is therefore complicated by the steady increase in water requirements by man due to higher levels of human activities and per capita water availability declines steadily since the amount of fresh water that is available is limited [3], [12] and [19]. Climate change is known to cause considerable changes in water supply due to increase in temperature, sea level rise and variable precipitation and the semi-arid regions are faced with fresh water scarcity [20]. It is established that the higher water temperatures, increased precipitation intensity, and longer periods of low flows exacerbate many forms of water pollution with impacts on ecosystems, human health, water system reliability and operation costs [20].

For sustainable water management in an area to attain the acceptable level of service required for sustainable utilization (of water to secure its availability and quality), an efficient method of estimating the following: the level of service, daily per capita water requirement and consumption, the dynamics of ratio of water consumption to the available water stock, and the expected increase in total water-use in future should be considered. The equation as developed has practical application in on the following:

* Water resources evaluation and management
* Water resources planning and development
* Water resources monitoring and conservation for sustainable water-use for the security of water stock and water quality for future use. The figure below illustrates the relationship between the parameters under consideration in a radial Venn.

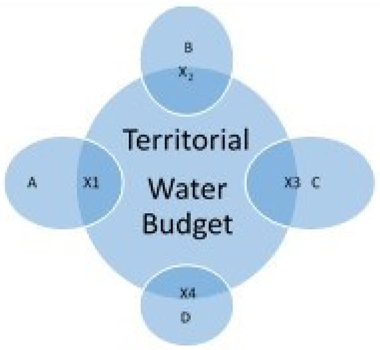

Fig. 1. Radial Venn showing the relationship between the elements of territorial water budget

Where;

A = Rainfall amount (the total) and x_1 = the per capita content of precipitation
B = Volumetric yield of the aquifer in a given area x_2 = its per capita value
C = Material volume of the aquifer, x_3 = its per capita allowance
D = Infiltration capacity and x_4 = its per capita content

This relationship was translated into a linear regression equation as follows;

$A + x_1 = A^1$ ….. (1)
$B + x_2 = B^1$ ….. (2)
$C + x_3 = C^1$ ….. (3)
$D + x_4 = D^1$ ….. (4)
$E = x_1 + x_2 + X_3 + x_4 + x$ ….. (5)

Solving for x_1, x_2, x_3, x_4, x you have

$x_1 = E - (x_2 + X_3 + x_4 + x)$ ….. (6)
$x_2 = E - (x_1 + X_3 + x_4 + x)$ ….. (7)
$x_3 = E - (x_1 + x_2 + x_4 + x)$ ….. (8)
$x_4 = E - (x_1 + x_2 + x_3 + x)$ ….. (9)
$x = E - (x_1 + x_2 + x_3 + x_4)$ ….. (10)

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Substituting the values of $x_1, x_2, x_3, x_4, \ldots$ for x in equations (1) - (4)

$$A + E = (x_2 + x_3 + x_4 + x) = A^1 \quad \ldots\ldots \quad (11)$$
$$B + E = (x_1 + x_3 + x_4 + x) = B^1 \quad \ldots\ldots \quad (12)$$
$$C + E = (x_1 + x_2 + x_4 + x) = C^1 \quad \ldots\ldots \quad (13)$$
$$D + E = (x_1 + x_2 + x_3 + x) = D^1 \quad \ldots\ldots \quad (14)$$

Adding equations (11) – (14)

$$A + E - x_2 - x_3 - x_4 - x) = A^1$$
$$+ B + E - x_1 - x_3 - x_4 - x) = B^1$$
$$+ C + E - x_1 - x_2 - x_4 - x) = C^1$$
$$+ D + E - x_1 - x_2 - x_3 - x) = D^1$$
$$A + B + C + D + 4E - 3x_1 - 3x_2 - 3x_3 - 3x_4 - 4x$$
$$A + B + C + D + 4E - 3(x_1 + x_2 + x_3 + x_4 + x) - x$$

But equation (5)

And $E = x + x_1 - x_2 - x_3 - x_4$

Substituting the value of E, the equation becomes

$$A + B + C + D + 4E - 3E - x = A^1 + B^1 + C^1 + D^1$$
$$A + B + C + D + E - x = A^1 + B^1 + C^1 + D^1$$

let $A + B + C + D = V$ and

$A^1 + B^1 + C^1 + D^1 = W$

then the equation becomes

$$V + E - x = W \quad \ldots\ldots \quad (15)$$
$$X = E + (V - W) \quad \ldots\ldots \quad (16)$$

Let $V - W = U$

So that $X = E - U \quad \ldots\ldots \quad (17)$

Equation (17) is a linear regression equation.

Where X defines the index of groundwater budget in the area, U is the value of the difference of the discharge and the recharge.

E defines the coefficient of sustainability for the available groundwater resource which is the amount of water that is available to any country. According to [4], it is constant for any given country for any practical purpose and it is a function of the aquifers capacity for recharge. This in turn will determine its sustainability coefficient when groundwater exploitation and utilization is to be considered. Also in surface water, source water potentials for quick or slow recovery should be determined when water draft from the river or lake becomes an option for a territory's water supply. This information will also help establish the coefficient for river recovery and the pace at which it is expected to occur in order to attain sustainability in the water body's exploitation and utilization. Generally, establishing the natural resources impact index and modeling it so as to integrate it in an area's developmental plan will answer most questions on Strategic Asset Management.

$x_1 - x_2 - x_3 - x_4$ are the intercepts that accounts for the population, that lives or which should live in a territory in terms of nature's water budget where X is the actual index of groundwater budget and $X = E - U$ tends to express that there is a balance point between the available groundwater if the per capita natures water budget is considered. Then, $E - U = 0$; implies a balance or equilibrium and $E - U$ = positive value indicates underutilization while negative value indicates over exploitation.

Rainfall amount (A) can be obtained from the average of rainfall total for the territory under consideration and the per capita content of this can be determined.

The volumetric specific yield (B) for a territory is that amount of water that is accessible from the aquifer and it is a function of aquifer characteristics and its per capita allowance can also be determined.

The territory's aquifer storage capacity or rather the material volume of the aquifer (C) refers to its capacity to take water into storage (in terms of size as storage cannot take place in a vacuum).

The territory's infiltration capacity refers to the surface mechanism, inter - and intra - pore spaces relations as it affects the mechanics of infiltration. Hence the intended rainfall for recharge should be conducted through these pores to the groundwater flow system. This is in turn controlled by two factors:

- nature – geologic structures porosity etc
- man's developmental design- recharge compatible or incompatible surfaces.

These tend to cause much of these rainfalls to either become absorbed or abstracted due to pavements and pore characteristics. These factors when empirically considered gives the nature's water budget for a territory and its per capita content.

Hence, land use planners can estimate a territory's population based on carrying capacity in terms of its ability to sustain them judging the natural water budget and can hence construct water requirement budget that will be attainable and sustainable.

Discussion and Application of the Equation

In the analysis, Onitsha was used as a model city and it is one such urban center where water service is a very big problem. This problem borders on the spatial aspects of human activities, the demographic characteristics of the resident population and their socio-cultural orientation also play a role in either enhancing or compounding the service delivery. With water consumption pattern designate in the study area where over 85% of the studied population do not only rely on groundwater (even for activities that does not require high quality water) but are also self-supplied. The need however arises for the establishment of a bench mark for making estimations for groundwater exploitation as to ensure groundwater balance.

Considering land use allocation and the space allowed for infiltration or recharge and the infiltration rate, owing to the fact that these properties – rainfall characteristics, infiltration capacity and the actual size and nature of the catchments (watershed) tend to determine the value of recharge. Just as population and land use tend to determine water requirement/demand amount. The groundwater budget index has practical application in making water demand model attainable. Recall that water supply in the study area is neither metered, billed nor regulated making over exploitation inevitable. Diffuse pumping of groundwater from an aquifer at a rate difficult to fathom by any regulatory body is rather unsustainable and the risk of over draft is high. This is because sustainable groundwater development is that which meets today's needs without compromising that of the future generation. The author in [16] had submitted that sustainability in hydrology implies that rate of pumping from an aquifer, must be in line with the storage or recharge. But how would this be achieved in the study area, where pumping rate is unknown, no regulation exists for groundwater development. Also groundwater resource is privately owned under Nigerian riparian rights which ceded the groundwater beneath any landed property to the land owner. Yet intensive groundwater use is feared for its ability to induce significant changes on natural aquifer dynamics [7]. Aquifer over exploitation causes changes in flow patterns and directions (groundwater quality or interferences from surface water bodies depending on the relative positions of the water table in the groundwater regime and that of the surface water and the flow would be down the hydraulic gradient). Lower water table in the groundwater regime makes it liable to lateral invasion by poor quality surface water with higher water table.

One would also recall that Agenda 21 in its publication on the tenets of blue revolution as prescribed by the author in [18] did insist that blue revolution be established to parallel the massive freshwater use in productivity or ensure efficient allocation of freshwater; and to inculcate attitudinal changes towards freshwater consumption. This is believed will make way for a sustainable exploitation of an ever increasing scarce resource.

The study area may claim it is lavished with recharge from the great River Niger and the heavy rainfall peculiar to rainforests, but the River Niger faces water losses through numerous dams on the upstream area and have lost large volumes of its water. Therefore, it may not present the same hope as before judging the width of the water column. The ten year annual and monthly average raindrops in Onitsha showed that there is serious fluctuation in rainfall characteristics for the months and years covered. The quantities of rainfall and the amounts may not equate the recharge required to keep up with the 1700cm^3 per capita freshwater prescribed for water shortage to be ruled out in any territory. It has been established that water shortages occur when freshwater availability falls below 1700cm^3 per capita per year [18]. Also forecasts estimates that 2025 will see 65 countries face water shortages and that 65% of the then world population as projected would be affected and mostly from the developing countries, Agenda 21.

Result on both per capita and per household water use in the study area showed that, of the average of 5 persons per house hold, that the 600-800 liters of water required is not attainable; as much as about 52% of the respondents use below 400 liters of water per day at every point of water use. About 37% barely use water volumes greater than 400 liters and this is still inadequate by all standards. The per capita water use placed 65% of respondent users far below the amount of water required, while about 24% use water greater than 100 liters per person per day, an amount still less than required. The fact remains that water use is low among respondents; but reliance on groundwater is very high while management is completely lacking. This is in line with the findings submitted in [10].

Groundwater over exploitation due to increasing demand is the direct consequences of increased human activities in a given area; and there is the attendant pollution impact on water resources and the groundwater in the study area are faced with quality problems from pollution due to incompatible land use just as [15] asserted in an earlier work. The author in [21] had submitted that many large cities are dangerously depleting their groundwater resources and that the ground surface tend to sink due to groundwater over pumping. So the concept held by some authors that pumping in excess of aquifer recharge is sustainable is rather misleading, [22], [6] and [1]

Demand Burden on Water Resources

As it is with most developing countries [26] estimated that about 2 billion persons lack basic sanitation. The situation they say ranges from no access to toilets, open drainages (that are highly infested by disease causing organisms) and solid wastes accumulation. This situation is unacceptable as it compounds the incidences of vector borne diseases in urban centers. Another set of problems are linked to the environments contaminated with human feaces through open defecation, contaminated water supplies and untreated sewage fallouts. In some parts of the study area pit latrines and faulty sewers were sited close to water supply sources. Solid wastes contribute to diseases carried by mosquitoes, rodents and other vectors causing as much diseases as deaths. So that sanitation coverage can barely keep up with population growth, and World Bank in an earlier work had asserted that it will remain so in the next 30years [25].

In places where demographic shifts towards urbanization is not regulated with respect to basic resources and infrastructure capacity, like the study area, the population will suffer health effects from poor sanitation and will be at higher risk of sanitation-related diseases epidemics. It is estimated that 45% of the world's total population as at 1996 live in cities, and that approximately 37% of these urban dwellers are without sanitation [27]. These are said to be mainly poor people living in crowded conditions with high risk of diseases epidemics [5].

Quality requirements for the intended uses of water should be considered from the sources and supply points so that no one source of water is over exploited like the situation in the study area. Greater percentage of water users rely on groundwater for all their water needs and the rest are restricted to use less water and other sources because of their current socio-economic status. The remnant as soon as things improve economically will sink their own boreholes and use water as they wish. The owner developer attitude toward groundwater development have restricted greater percentage of the respondents to use less water than is required for adequate sanitation, so that toilets may be left un-flushed all day to allow for more than a user even before a flush.

However, leaving the public to fend for their water supply presents them with many problems; notable among these are: (i) Moderating the quantity of water in use would be difficult, as their supply is not metered (ii) Quality of water in use could be compromised as the syndrome of making do with what is available may prevail (iii) Proper inventory of freshwater development, exploitation, pumping rate, overuse and tariff-the very instruments required for effective management of the freshwater stock would be difficult to come by (iv) Lack of centralized water resources development, allocation and management will eventually lead to overexploitation as earlier submitted by [24]; a situation already observed in one of the sedimentary basins in northern Nigeria.

Landuse Issues

The ratio of the total impervious area to the total areas of watershed is a factor that characterize the various abstractive processes and that alter the distribution of rainfall and the total volume of rainfall excess. Among the different land uses, open spaces are considered under pervious land use and aquifer depletion is feared as pumping rate is unknown.

The heavy rains would have ensured adequate groundwater recharge but cemented surfaces tend to impede recharge resulting in heavy floods. Available literature gave the gradient of the regressed line of infiltration rate (amount in time) as 36mm per minute for the study area [11]. The rate at which water penetrates the soil is a function of porosity, permeability and catchment surface area for the entire soil. Hence urban land use determines the magnitude of runoff [13]. Onitsha in terms of water balance has greater than 45% of its water shed impervious since its pervious land use (open spaces) is just 5.48%. So if recharge compatible land use is 5.48%, and the land use incompatible with recharge is 86.52%, it follows that recharge is abstracted by far and this space is far too small compared to the minimum requirements to rule out water scarcity or aquifer depletion.

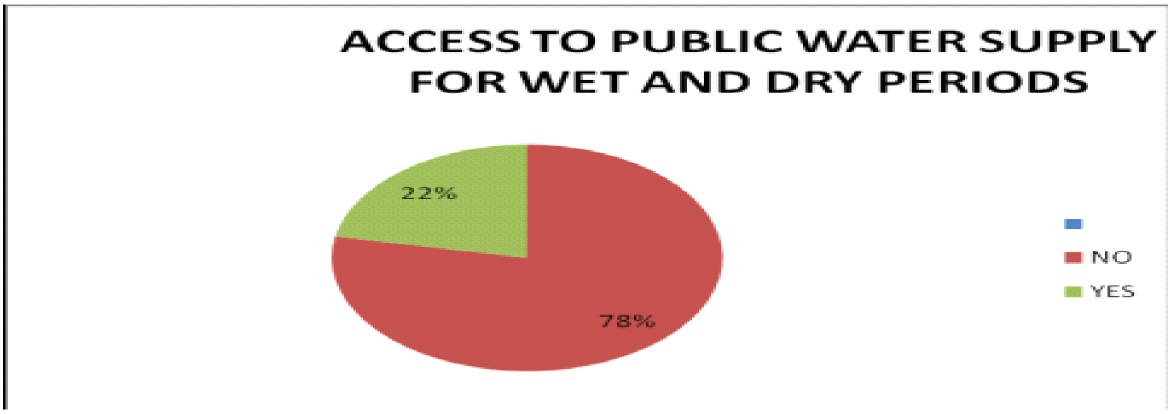

Fig. 2. Pie chart access to public water supply

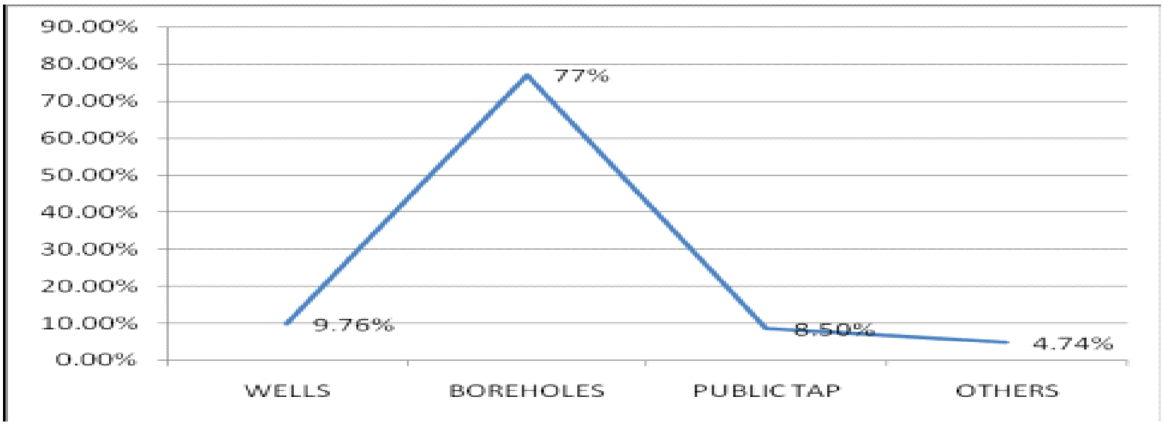

Fig. 3. Graph of sources of water supply

Summary

The result of the analysis and previous works reveled that there is strong relationship between water problems (quality and quantity) with the spatial aspects of human activities (hygiene and environmental pollution and sanitation). This makes a case for integrated management of land and water use in regulating human use of both resources for a sustainable future with such vital resources. Natural resources management will have to strike a balance with land use and water use, while controlling environmental pollution as this will positively impact water quality viz-a-viz water quantity. Water use problems in the study area can rightly be attributed to the absence of centralized water resources exploitation and sharing. Perhaps, this gave room to the unsustainable practice of diffuse pumping at a rate unknown and characterizing the risk of water- over draft from the aquifer becomes uncertain. There is massive groundwater development in the study area, but owing to the decentralized exploitation and allocation of water in the area; water use is low and inefficient and lacks pattern. This implies that water development and tariff or cost of water development projects places the commercial water users- the small scale industries at lower GDPs. This is because with more water, they would have done better since they are willing to pay more for sustained, adequate and portable water service.

Recommendations

Balancing water ethics with human ethics remains a viable panacea to water resources management problems if sustainability will be attained in the water sector [8], [9] and [22]. Hydrological education is necessary for all both users and developers of land and water [17]. Centralizing water development, allocation and management is imperative for proper audit and record. Reconsidering the freshwater treaty will be of great help in saving the freshwater resources from the hydrocidal attitudes of man. Water efficient appliances are a handy alternative to saving freshwater from vanishing due to over use. Developing other sources of water to augment groundwater sources will help save the groundwater from over-draft and depletion. Rainwater should be banked in large reservoirs at convenient places to store as much water as is possible - for public distribution during dry spells. Surface water sources for instance, the Nkisi River served as intake to the Anambra State Water Board when it was still functional and the dream of expanding this river to a greater water supply scheme for Onitsha and environs should be realized. If this is done, the groundwater can be made to provide 1/3 at least for drinking water supply.
The surface water can serve commercial water line for commercial purposes other than direct consumption. The banked rainwater can serve both purposes but as the quality requirement entails for the intended use. Pay as you go policy will enhance demand management; ensure conservation and efficiency in water use. Proper inventory of wells and boreholes should be done periodically to ascertain the level of groundwater development and pumping should be monitored through metering and billed accordingly and aquifer potential should be taking into account.

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