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The Transformation of Kostiakov's (1932)Infiltration Equation on theInfiltration Rate of Forest Land Cover in Biase, Cross River State, Nigeria

Samuel Uka Ukata[1], OluyemiAyorindeAkintoye[2],Opaminola Nicholas Digha[3], AdesojiAlade [4], Adeniyi Asiyanbi[5]

1,2,3Dept. of Geography and Environmental Science, University of Calabar, Cross River State, Nigeria
4,Office of Surveyor-General of the Federation, Federal Secretariat, Port Harcourt, Nigeria
5, Department of Geography , School of Social Sciences and Policy , Kings College , London , United Kingdom

Abstract: *This paper examined the structural stability of forest soil by applying Kostiakov's (1932) infiltration equation on measured infiltration values from the fieldin Abine, Biase, Cross River State in Nigeria. The behavior of soil structure or profile condition is paramount for scientific investigations, which is needful in the construction industry, agricultural land use and solid mineral resources inventory. Very often environmental hazards as landslide, flooding, building collapse and decline in crop yield emanate from the inadequate assessment and evaluation of soil's physical properties, before the commencement of human activities on a given land. Adopting this equation in this study, was an attempt to evaluate the structural conditions of forest soils of the region, under different hydrological regime prior to decision making on landuse and management to satisfy various stakeholders' interests. Data for the study were generated through field measurements of infiltration rates of soils using a cylinder (flooding) infiltrometer designed by Hills (1970) in both rainy (September to October) and dry (December to January) seasons in rural watershed under forest land cover. The mean values used for logarithm transformation in Kostiakov's equation of* $\log i = \log c + \alpha \log^t$*produced a straight line graph, whose slope value (a) ranged between 0.5 and 1. These values revealed that the soil is structurally very stableto support human activities in the construction and agricultural industries. The study recommends the application of the equation for empirical evaluation of land-uses for sustainable landuse and development by man.*

Keywords:*Kostakiov's equation, Structural condition of soils, Sustainable land-use, Infiltration values.*

I. Introduction

Infiltration is one of the most important processes in the soil phase of the hydrologic cycle since it determines to a large extent the amount of water intake by a soil profile beyond which over land flow, runoff and erosion are initiated. Very often, the two important parameters for characterizing the infiltration of water into the soil profile are the rate and the cumulative amount. According to Rawls, Gish and Brankensick (1991), measurements and numerical solutions have shown that, the rate, in a uniform, initially dry soil when rainfall does not limit infiltration, decrease with time and approaches an asymptotic minimum rate until a final equilibrium stage is reached. But soil profiles are seldom uniform with depth and the water content distribution is not uniform at the initiation of infiltration (Antigha, 2007). Notably, knowledge acquired in infiltration studies have applicability in the field of agriculture, engineering and industry

Empirical studies have proved variations in the infiltration rate and capacities of soil arising from differentials in their physical properties such as texture, structure, and profile compositions (Amalu and Antigha, 1999, Temple, 2002, Shukia, Owen and Unkefer, 2003). Measurements in the field have also shown that, infiltration rates of forested areas are higher than those of other land uses during experimental runs (Akintola, 1974, Zake, 200, Tilman, 2001, Weather Land, 2009). It implies that the influence of vegetal cover increases water absorption capacity of soils in forested areas in the event of heavy storm.Akintoye,Ukata andEsomonye (2012) have also examined the effects of land-use on the infiltration capacity of coastal plain soils of Calabar in Nigeria. Also,Ukataet al (2014) carried out a study on seasonal variations of infiltration rates of forest land cover in utisols soils of Abini in Biase, within Cross River Stateof Nigeria.The result indicated that there is seasonal changes in the equilibrium rates of infiltration from 9.6cm/hrt (rainy season) to 8.4cm/hrt (dry season). This was indeed a hypothetical contrast from the expected ideal situation among infiltration experts, since infiltration values are supposed to soar in dry season, higher than in rainy season within the tropics. The factors of soil pore compaction and decline in the rates of biological activities accounted for this. Soil compaction reduces the rate of soil water loss through evaporation. This enhances ground water conservation and stabilizes the soil structure for diverse benefits to man.

Kostiakov (1932) developed a physically based infiltration model used extensively because of its simplicity and accuracy in fitting experimental data and for determining the point at which equilibrium is reached as a function of soil structural stability or resistance to wetting front. The application of kostiakov's model in evaluating soil stability is of utmost importance to soil scientist seeking the determination of soil fitness or shear strength required in construction industry prior to the erection of buildings for various human purposes.

The model is given thus:

$1=ct^{\alpha}$

Where 1; is the cumulative infiltration after time t, and C and α are constants. Parameter c is a measure of the initial rate of infiltration of water into the soil which relates to a measure of the structural condition of the soil; the value α is an index of soil structural stability and also an index which the infiltration decreases as a result of breakdown of soil structure. It assumes that as the wetting front penetrates soil layer downward, cumulative values of infiltration decrease as a result of the breakdown of soil structure.

Kostiakov's model has found wide application by different authors during infiltration studies. For instance, Viessman (1989) in Australia, Don-Scott (2000) in New York and Amalu and Antigha(1999) in Calabar Nigeria employed it in their studies.

The authors found out that the equation fits very well in characterizing moisture retention curves and evaluating infiltration data. Although many researchers are of the opinion that the parameter αis between O and 1, Gosh (1983) subscribed to the fact that α is ≥ under in some situations. He adduced that thepossible reason for higher values of (α) could be due to soils being layered or heterogeneous or that the flow of water might not be truly one dimensional.

Gosh (1983) maintained that in unstable soils due to swelling of colloidal particles or when there is a breakdown of soil particles, the α value becomes very low. It varies between 0.5 and 1 for very stable soils. The value of C is equally high in soils having earthworms or termites. Employing Kostiakov's equation involves logarithm transformation (Babalola, 1977).

This is given in the form.

$1 = ct^{\alpha}$

$\text{Log } 1 = \log C + a \log t$

A graph of log 1 versus lag t gives a straight line, whose slope is the α value while the intercept on log 1 axis gives the C value. The emphasis was to ascertain the structural condition of soils under forest cover as water infiltrate down the wetting front of the soil profile.

II. Study Area

The study area is Abini, in Biase, Cross River State of Nigeria. It is located between longitude $8^{0}06$ and $8^{0}10$'E and latitudes $5^{0}00$N and $5^{0}38$N. The area is characterized by humid tropical climate with distinct wet and dry seasons. Rainfall amount ranges from 3,500mm to 4,000mm per annum. The rainy season falls between April and October with a short dry spell usually referred to as August break during the month of August (NIMEST, 2009).It also has a relative humidity of between 80 and 90 per cent (NAA, 2006). The temperature is moderately hot and does not fluctuate greatly with a mean range of 27^{0}C to 33^{0}C (Ayoade, 2004). The geologic environment comprise of phyllites, schists with structural features as foliation, joints, fold intrusion, pegmatite and barite. The rocks are unconformable overlain by sedimentary sequence of calcareous sandstones with mineral contents of quartz clay, calcite and fossils occurring as ridges (Ekwueme, 2004). The soils are mostly derived from cretaceous sediments of Eze-Aku group (Amajor, 1987) and are mostly lateritic in the upland area as essential residue products (deposits) formed under distinctive climatic conditions in tropical and subtropical regions. There are also calcareous soils containing quartz, calcite and fossils as dominant minerals. Being acted upon by human induced and natural processes, the soils occur in separate but close ranges as silt loam, silt day, loamy, sand loam and clay loam with varying textural characteristics of coarse gritty, powdery smooth to sticky and plastic feel.The forest land cover is made up of woody and non woody plants (parasitic, saprophytic and epiphytic chambers) which constitutes luxuriant and dense tree canopy, shading the soils from the vagaries of nature across seasons. This, in conjunction with other environmental variables highlighted, influence the infiltration rates of regional soils at different scales which can either be detrimental or beneficial to the local land resources.

III. Method Of Study

A cylinder (flooding) infiltrometer designed by Hills (1970) was used for field measurements in both rainy (September –October) and dry (December-January) seasons in rural watershed under forest land cover. A metal tube was driven into the ground to depth of 10cm with a sledge hammer to avoid lateral flow of water during experiment. Care was taken to prevent damage to the soil structure in the process (Ukata, 2002).

As a rule, a constant ponding level of 5cm was maintained in the metal tube (ring) throughout the experimental runs. Using a timer, readings were taken at various time interval until a state of equilibrium, which is usually 180 minutes was reached. The experiment was replicated in rainy and dry seasons on the same land cover to determine seasonal variations in the infiltration capacity of the soils.

IV. Result and Conclusion

The values of infiltration time (t) and rate (i) in Table I were used for the graphical logarithmic transformation of the equation of log i=log C +α log t to produce a straight line whose slope is the α value, an index of soil structural stability at which the infiltration decreases as a result of the breakdown of soil structure, while the intercept on log i axis gives the C value (cumulative water intake) by the soil.

Table 1: The transformation of Kostiakov's (1932) infiltration equation of $I=ct^{\alpha}$ on forest landcover

Infiltration time (t) in mins	Mean infiltration rate (i) cm/mins	Log i	Log t
5	0.74	-0.1307	0.6990
10	0.98	-0.0088	1.0000
15	0.41	0-3872	1.1761
20	0.37	-0.4318	1.3010
25	0.37	-0.4815	1.3979
30	0.30	-0.5229	1.4771
40	0.26	-0.5850	1.6021
50	0.24	-0.6198	1.6990
60	0.22	-0.6576	1.7782
75	0.18	-0.7447	1.8751
90	0.17	-0.7696	1.9542
120	0.15	-0.8239	2.0792
150	0.15	-0.8239	2.1761
180	0.15	-0.8239	2.2553

Source Authors fieldwork, 2013

From the graph (FIG.I) the slope value (α) ranged between 0.5 and 1 implying that the soil is structurally very stableand with good infiltration rate. According to Gosh (1983) such soil equally has earthworm and organic matter content which facilitate the rate of biological activity to keep it well aerated. Antigha (2007) observed that, soils under this condition are less prone to over land flow, runoff and erosion, since the rate of water absorption to cause profile saturation is always high.

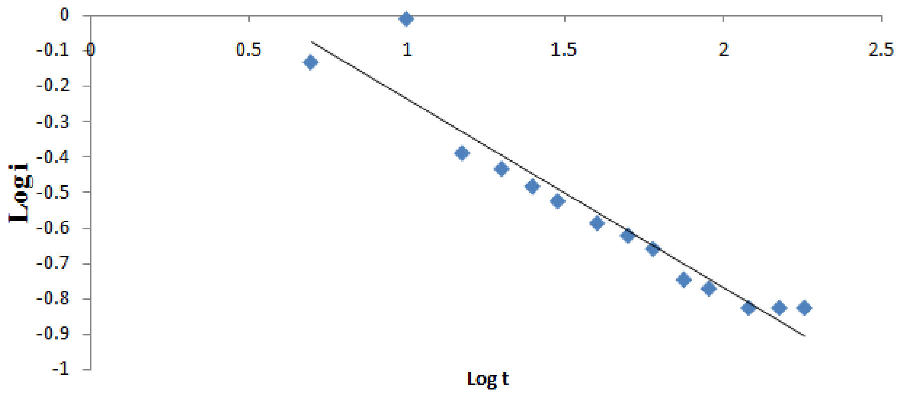

FIG 1 : Relationship between log i and log t for forest

V. Conclusion

Kostiakov's equation fitted very well in determining the structural condition of soil under forest cover during infiltration experiment. The findings may have far reaching implications on human decision in landuse and management at given time and place. It is imperative to apply the equation to related infiltration data to yield empirical result for sustainable land utilization and for ecosystems protection.

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