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Relation between water availability and human population of an area, by taking water pollution into account

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Abstract
The population of a human settlement in an area depends on the water availability and water pollution of that area. The paper aims to explain the relationship among them with a new law and give a mathematical formula for calculating the relation. The range of physico-chemical parameters of the water bodies are temperature (14.8 °C-17 °C), pH (6.05-7.4), alkalinity (115.5 mg/L-122.5 mg/L), total hardness (40 mg/L-167 mg/L), chloride (23.5 mg/L-118 mg/L), DO (4.6 mg/L-17.2 mg/L), TDS (49 mg/L-580 mg/L). The study revealed that parameters of water samples from uninhabited areas were within the permissible limit given by BIS (2012) and WHO (2017). But the pH, DO and TDS values of the water samples from inhabited areas were not within the permissible limit.

Keywords: water pollution, human settlement, population, water availability, kikon equation, klopp threshold, kikon law

Introduction
The feasibility and survivability of human settlement in an area depend on the water available in that area. There are about two billion people in the world who do not have access to clean drinking water [4]. The availability of water, dictate the number of the human population that can settle and survive in that area. While the human population, in turn, causes water pollution thereby decreasing water availability. This in turn decreases the capacity of the area to sustain the human population, a cyclic relation thus occurs. An increase or decrease in the human population will have varied effects on the water availability and thereby the status of the human settlement. If the human population or water pollution of an area goes on increasing, a limit will be reached when the area will not be able to support the human settlement leading to its disintegration.

A physico-chemical analysis of water bodies in uninhabited and habited areas of Wokha Town was done to understand this relation. The results were compared with the drinking water permissible limit given by BIS (2012) [2] and WHO (2017) [10]. Wokha Town is the Headquarter of Wokha District, Nagaland, and is located about 80 km north of the state capital Kohima [9].

By taking into account the water pollution along with water availability and the human population of the area, a new law and a mathematical equation have been given.

Materials and Method
Sampling and Analysis
Eight samples were collected from four rivulets/streams inside and outside the settlements of Wokha Town. From the two streams inside the town three samples; Upstream (uninhabited, located beyond any human settlements), Midstream (inhabited, located at highly concentrated human settlements.), Downstream (after it had flown through the densely inhabited Town); each were collected along their route of flow. And one sample each from the two streams on the opposite ends of the town (uninhabited area), away from any human settlement.

The water samples were collected in 2L polyethylene bottles and were analyzed for pH and Temperature by using a digital pH and Temperature meter; alkalinity by titrimetry; total hardness by EDTA –Titrimetry; Chloride was determined by using Argentometric method, Dissolved Oxygen by Winklers titrimetric method, TDS was determined using gravimetric method

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Table 1: Sampling Sites

Sites	Location/Name	Code
1	Near Vankhosüng	Van
2	Upstream of Dr. Jükha	Doc1
3	Midstream of Dr. Jükha	Doc2
4	Downstream of Dr. Jükha	Doc3
5	Upstream of Niropen	Nir1
6	Midstream of Niropen	Nir2
7	Downstream of Niropen	Nir3
8	Santsüphen	Sat

Results and Discussion

Table 2: Physico-chemical parameters of the water bodies in Wokha Town

Location	Temperature (in °C)	pH	Alkalinity (mg/L)	Total Hardness (mg/L)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	TDS (mg/L)
Van	14.8	7.02	115.5	42	23.5	17.2	49
Doc1	16.7	7.33	116.5	53	26.7	16.3	52
Doc2	15.8	6.22	120.3	160	102	5.3	531.2
Doc3	15.6	6.05	122.5	167	116.2	4.6	570
Nir1	16.4	7.4	117	45.6	36.26	16.9	56
Nir2	17	6.42	119.2	149	114	5.5	545
Nir3	16.8	6.2	121	156.8	118	4.8	580
Sat	16.5	7.34	116.8	40	26.8	17	53.5

Temperature

The temperatures of the water samples ranged from 14.8 °C at site Van to 17 °C at site Nir2. There is no permissible limit given by BIS (2012) [2] and WHO (2017) [10] for temperature. Temperature is important for aquatic life and affects the chemical and biological reaction taking place in water [7].

pH

The pH of the water samples ranged from 6.05 at site Doc3 to 7.4 at site Nir1. Sites that were located in uninhabited areas had pH values within the permissible limit given by BIS (2012) [2] and WHO (2017) [10] while the sites in uninhabited areas do not fall under the permissible limit.

Alkalinity

The alkalinity of the water samples ranged from 115.5 mg/L at site Van to 122.5 mg/L at site Doc3. The alkalinity of all the water samples is within the permissible limit given by BIS (2012) [2] and WHO (2017) [10]. There is an increase in alkalinity in the mid-stream and down-stream of the rivulets; this indicates that pollutants were added when it flowed through the human settlements.

Total hardness

Total hardness is due to the presence of divalent metallic cations such as calcium, magnesium, strontium, ferrous ions, and manganese ions [1]. Total hardness of the water samples ranged from 40 mg/L at site Sat to 167 mg/L at site Doc3. The Total hardness of all the water samples is within the permissible limit given by BIS (2012) [2] and WHO (2017) [10]. There is an increase in total hardness in the mid-stream and down-stream of the rivulets; this can be due to domestic sewage [5] added when it flowed through the human settlements.

Chloride

Chloride present in the water samples ranged from 23.5 mg/L at site Van to 118 mg/L at site Nir3. The chloride value of all the water samples is within the permissible limit given by BIS (2012) [2] and WHO (2017) [10]. There is an increase in chloride value in the mid-stream and down-stream of the rivulets; the increase in chloride is due to municipal and domestic sewage [8] This indicates that pollutants were added when it flowed through the human settlements.

Dissolved Oxygen (DO)

DO is essential for the survival of fishes and other aquatic life [3]. The DO present in the water samples ranged from 4.6 mg/L at site Doc3 to 17.2 mg/L at site Van. Sites located far from any human settlements, have DO values within the permissible limit given by BIS (2012) [2] and WHO (2017) [10]. But DO values in the mid-stream and down-stream of the rivulets decreases below the permissible limit. Oxygen in water is reduced by decomposition of organic matter, presence of oxygen demanding waste, and inorganic reductant [6]; this indicates that pollutants were added when it flowed through the human settlements.

Total dissolved solids (TDS)

TDS present in the water samples ranged from 49 mg/L at site Van to 580 mg/L at Nir3 site. Sites located far from any human settlements have TDS values within the permissible limit given by BIS (2012) [2] and WHO (2017) [10]. But TDS values in the mid-stream and down-stream of the rivulets increases above the permissible limit; this indicates that pollutants were added when it flowed through the human settlements.

From the result, we can see that the water samples from uninhabited areas were within the permissible limit given by BIS (2012) [2] and WHO (2017) [10]. But the water sample from the mid-stream and down-stream of the rivulets flowing through the densely populated town showed deteriorating water quality compared to their respective up-streams, their TDS, DO and pH values were beyond/below the permissible limit; and although the alkalinity, total hardness, and chlorides values were within the permissible limits, there was an increase in their values as the rivulets flowed through the densely populated human settlements. This shows that the

population of a human settlement is responsible for water pollution which in turn affects the water available to the human population of that area. To explain the relationship between water availability and the human population of an area, by taking water pollution into account; a new mathematical equation and a law are given.

Mathematical equation

$$\text{Kikon equation} = \left[\frac{(\psi T - \psi P)}{(\Phi \times N)} - 1\right] \times 100$$

$$\text{Or} = \left[\frac{(\Delta\psi)}{(\Phi \times N)} - 1\right] \times 100$$

Where, ψ_T = Total water available in the area for the period under study.
ψ_P = Polluted water in the area for the period under study.
Φ = Water requirement per person for the period under study.
N = Total number of person/ population in the area under study.
$\Delta\psi$ = Total water available for use for the period under study.
Three scenarios arise from this equation:

1. When the value of the equation is positive
This indicates that the area has excess water than required. There is no water deficit in the area.

2. When the value of the equation is zero
This represents an ideal situation in which the water requirement of the population is equal to the usable water present in the area. There is no water deficit in the area.

3. When the value of the equation is negative
This indicates that the area has less water than required. There is a water deficit in the area.
The value of the equation "v" also corresponds to the percentage of population "v" % of N.
A positive value "+v" will indicate the percentage of population "v" % of N that can be added to the settlement without causing a water crisis in that area.
A negative value "-v" will indicate the percentage of population "v" % of N that is more than the population that can be sustained by the water available in the area.

Law
From the mathematical equation a new law is given; Kikon Law. This states that "An area will not be able to sustain a human settlement if the water deficit is equal to or greater than the water required by 10% of the population. In other words for an area to sustain a given population of a human settlement with the water available in that area, it should give a value of greater than -10 in the Kikon's equation i.e. it should not reach the Klopp Threshold "
The Kikon equation value of -10 is known as the "Klopp Threshold", and is defined as the limit at and beyond which human settlement is not possible in an area.
When the value of the equation is greater than or equal to $\geq$ -10 it indicates an excess population of $\geq$ 10 % of N that cannot be sustained by the water available in the area. In this case, the water available cannot support the human population of the area and it will lead to the disintegration of the human settlement of the area.

Mathematical proof
Hypothetical Case I: The period under study is one day, for an area with 14,000,000 liters of total water available (ψ_T), 365,000 liters of polluted water (ψ_P), and a population (N) of 1 lakh. Taking water requirement per person (Φ) as 135 liters.

$$\text{We have, Kikon equation} = \left[\frac{(\psi T - \psi P)}{(\Phi \times N)} - 1\right] \times 100$$
$$= \left[\frac{14,000,000 - 365,000}{100,000 \times 135} - 1\right] \times 100$$
$$= 1$$

Inference
1. The positive value indicates that there is no water deficit or there is a water surplus.
2. "1" indicates that "1" % of N (population of the area) can be added to the settlement without causing a water crisis in that area.

i.e 1% of 100,000 = 1000.

Therefore 1000 people can be added to the human settlement according to the water available in the area.
Hypothetical Case II: The period under study is one day, for an area with 13,000,000 liters of total water available (ψ_T), 850,000 liters of polluted water (ψ_P), and a population (N) of 1 lakh. Taking water requirement per person (Φ) as 135 liters.

$$\text{We have, Kikon equation} = \left[\frac{(\psi T - \psi P)}{(\Phi \times N)} - 1\right] \times 100$$
$$= \left[\frac{13,000,000 - 850,000}{100,000 \times 135} - 1\right] \times 100$$
$$= -10$$

Inference
1. The negative value indicates that there is a water deficit.
2. "-10" indicates that "10" % of N (population of the area) is more than the population that can be sustained by the water available in the area.

i.e. 10 % of 100,000 = 10,000 (people).

As the value has reached the Klopp threshold ($\geq$ -10); therefore according to Kikon law, the area will not be able to sustain a human population and will lead to the disintegration of the human settlement.

Conclusion
The study revealed that there is a stark contrast in the water quality of the rivulets before and after flowing through densely populated human settlements. It showed that human activities were responsible for degrading the water, establishing the cyclic relationship among water pollution, human populations, and water availability; the water available in an area determine the human population that can settle in that area while the human population is responsible for water pollution which in turn impacts the water available to the human population of that area. The Kikon equation can be used to assess the real-time impact of polluted water on human settlements. And help in taking necessary actions to check water pollution and excess population than that is permitted by the water availability of that area. A new human settlement can be modeled using this equation, to assess if the water available will support the human population and keep the

water pollution at a level permitted by the Kikon law. This equation can be used to create a study model of an extra-terrestrial human settlement based on the water need of such a human population; to calculate how much water will be needed by such a human population in the short run and long run.

Acknowledgement

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