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Modelling Livestock Activities and Environmental Sustainability: The African Case

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ABSTRACT

This paper develops a dynamic model of grazing land degradation. The model illustrates the relationship between livestock levels and grazing land degradation over time. It identifies the mechanisms by which the factors internal to the livestock local production system and those drawn from the larger economic context of livestock marketing influence livestock-grazing land relationship. The paper shows that overstocking leads to degradation which leads to declining relative prices of livestock as quality declines and mortality increases. As relative price of livestock falls, consumption increases. The increased consumption and mortality ultimately leads to lower livestock population, which leads to decreased degradation. The model results show that medium term dynamics of grazing land degradation are quite different from long term dynamics. It is shown that although grazing land sustainability situation is adverse in the medium term, yet it is favourable in the long term. The livestock system is dynamic and can adjust when longer term system dynamics are allowed to play out. Part of the adjustment mechanism is built in the livestock system and the other part comes from the economic system. The built-in adjustment mechanism works through the two-way relationship between the stock and degradation. The external adjustment mechanism, originating from the economic system, works through economic growth, relative prices and foreign trade. In the medium term, opportunistic management strategy and policies that facilitate access to grazing land and water are crucial for mitigating degradation. The results suggest that the views of the mainstream range management paradigm and the new thinking of range ecology can be reconciled.

Keywords: *Livestock, Grazing Land, Degradation, Models*

1. Introduction

There are complex relationships between livestock grazing and production on the one hand, and environment conservation and degradation costs on the other hand. In the context of the interaction between livestock and the environment in developing countries, several studies have underlined the tendency of overstocking of grazing land resulting in land degradation, see [1–4].

The degradation of grazing land adversely affects the natural growth rate of the livestock and its quality. When grazing land is degraded, the stock fertility rate falls and mortality rate rises, the weight of animals in terms of kilograms is less and the quality of their product is low, as compared to the situation where there is no degradation. Also, when grazing land is degraded its value falls. Furthermore, the decline in the livestock, both in quantity and quality, and the fall of the value of grazed land, lead to the decline of the capital wealth of the livestock sector [5–8].

The empirical literature on the analysis of the trade-off between livestock and environment and its economic implications is very sporadic. There is no more than a handful quantitative models that have addressed related issues. Wilcox and Thomas [9] used for Australia a model to examine the relationship between cost of production and range conditions under long term steady-state conditions. Braat and Opschoor [10] developed for Botswana a simulation model that focused on the role of rainfall and the stocking rate in determining the quality of the range and herd development. Berrings and Stern [11] using the cattle-rangeland system in the semi-arid rangelands of Botswana, followed a dynamic econometric approach for modelling the loss of resilience in an ecological-economic system.

None of the above quoted research encroached on formalising and modelling the complex relationship between the various aspects of livestock activities and the varied dimensions of environmental degradation. In this paper, we develop a simple and at the same time a comprehensive model in nine equations, that examines the medium and long terms dynamics of grazing and degradation in an African country, *i.e.* Sudan, where in relative terms, livestock activities take significant proportions. The importance of the model is that it synthesizes the views of the mainstream range management paradigm with the new range ecology thinking. The pursued model integrates the ecological and economic dimensions of the livestock system and the ecological system; these are elements that are mostly missing in the literature. Empirical data from Sudan are employed to operationalise the model, and investigate the complex relationships and their analytical and policy implications.

The paper proceeds as follows. Section 2 specifies the model. Section 3 discusses its structure. Section 4 deals with estimation and solution. Section 5 discusses the model results for the medium term scenario over the period 1990–2000, when livestock prices tended to fall in relative terms. Section 6 discusses model results for a long term scenario extending to 2030, where livestock prices are assumed to remain stable in relative terms. Section 7 examines sensitivity results, and Section 8 concludes.

2. Model Specification

We formulate a determinate model of nine equations that focuses on giving solutions to nine crucial variables that link livestock activities and land degradation to each other.

To start with, we denote the actual number of animal stock that grazes on the available grazed land, by *L*. Next to the actual grazing capacity, any grazing land can be said to have an optimal carrying capacity for animals. The optimal carrying capacity refers to the number of animals that grazing land can support without being degraded. The word ‘optimal’ is used here in the agronomical sense of the word. The optimal carrying capacity of grazing land is determined by its size, *N*[1], its annual vegetation yield per unit of land, *V*, and the vegetation requirement per animal unit, *H*. When the actual capacity exceeds the optimal capacity, land degradation sets in. This idea is formalised in Equation (1), where the numerator gives the actual capacity, *i.e.* actual stock of animals, and the denominator gives the optimal capacity, *i.e.* desirable stock of animals on grazing land.

$$Q = \left[\frac{L}{(V\ N)/H} \right]_{t-1} \qquad Q \geq 1 \qquad (1)$$

In Equation (1), the ratio of the actual capacity to the optimal one is used as an indicator of the prevailing conditions on grazing land. This ratio is a degradation index denoted by *Q*. The one-year lag of the variables is justified on the ground that it is the cumulative degradation from last year that adversely affects the current year variables.

[1]The land unit used here is the *feddan* which is a measure of area and it is equivalent to 4200 square metres or 0.42 acre.

When the actual capacity exceeds the optimal one, the degradation index exceeds unity. Ideally, the actual capacity should approach the optimal one. The situation when this is reached, *i.e.* $Q = 1$, will be seen that the structure of the model will have to undergo changes that will be treated in a later section. The situation where *Q* is below unity, a process of grazing land and livestock regeneration sets in, is not a focus of the paper.

According to Scoones [4] an effective management strategy of *Q* can be achieved in four ways: 1) increasing available fodder by enhancing its production or importing feed from elsewhere; 2) moving livestock to where fodder is available; 3) reducing animal feed intake during drought through shifts in watering regimes; 4) destocking animals through sales during drought. It can be seen from Equation (1) that effective tracking is a good strategy that can pre-empt or reduce grazing land degradation. This is because increasing availability of fodder means increasing *V*; moving animals to where fodder exists means effectively expanding *N*; reducing animal feed intake means decreasing *H*; and destocking animals means reducing *L*. All these four options lead to lower *Q*, or in other words, less grazing land degradation.

Two of the four variables in the equation defining *Q* are exogenously given; these are land *N* and vegetation requirements *H*. The other two variables of *V* and *L* are endogenous and their determination is displayed below in additional equations.

The development of the vegetation yield of grazing land, *V*, depends on three main factors: rainfall water, Wrain, irrigation water[2], Wirr, and degradation of grazing land, *Q*. The influence of the abovementioned three factors on vegetation yield is formalised in Equation (2). *V* is positively related to the first two factors and inversely related to the third one. Given availability of rain and irrigation water, the expected vegetation yield will depend on the base year vegetation yield, v_0, and on the level of degradation of grazing land, as indicated by the ratio of the degradation index in the base year Q_0 to that of the current year *Q*, and an elasticity parameter η.

$$V = \frac{v_0}{(Q/Q_0)^{\eta}} (W_{rain})^{\alpha} (W_{irr})^{\beta} \qquad (2)$$

The other variable to model is the size of the animal stock on grazing land[3] in the current year, *L*. This is determined by last year’s stock, L_{t-1}, the natural growth rate, g, and the slaughter from the stock, which is equivalent to sale of livestock units of standard weight and quality at a given price. *X* denotes the monetary value of live-

[2]The term “irrigation water” is used here in its broad sense to refer to underground water from dug wells as well as water from irrigation canals.

[3]Consideration is given here to four types of animals, namely, goats, sheep, cattle and camels. This is because mainly these animals are consumed and exported. Then, these animals are converted into livestock units (LSU) using the following livestock unit conversion factors: sheep and goats at 0.12, cattle at 0.75 and camels at 1.00 [12].

stock slaughter or output and P is the price per unit of livestock. P is constructed in such a way that it consists of the absolute price level per unit of livestock in the base year multiplied by the relative price index of livestock product to that of the alternative agricultural product[4].

Not only the natural growth rate but also the weight and the quality of livestock units are influenced by the prevailing conditions on grazing land. Therefore, both the growth rate of the stock and the price of livestock units have to be adjusted to reflect the condition prevailing on grazing land. This is formalised in Equation (3). The growth rate of the stock is adjusted for the prevailing conditions on grazing land by the ratio of the degradation index in the base year Q_0 to that of the current year Q, with elasticity parameter η. The price per unit of livestock P is adjusted to reflect the prevailing conditions on grazing land by the ratio Q_0/Q. The idea is that in any given year a degradation level which is more (less) than that of the base year level means lower (higher) weight and quality of the sold livestock units in that year as compared to the base year. Therefore, the price of livestock units is adjusted accordingly, downward when there is more degradation and upward when there is less degradation relative to that of the base year.

$$L = L_{t-1}\left[1 + g\left(\frac{Q_0}{Q}\right)^{\eta}\right] - \left[\frac{X}{(Q_0/Q)\,P}\right]$$

$$0 < g,\ \eta < 1 \tag{3}$$

The slaughter, *i.e.* the value of livestock output, is used for intermediate consumption and domestic final consumption, and is exported[5]. This is formalised in the sectotal balance Equation (4), where the left hand side of the equation gives the supply side and the right hand side gives demand side, both in monetary value. The intermediate deliveries are a proportion, $a1$, of the country's gross domestic product, GDP. The final consumption demand for livestock product is a function of the GDP, and the relative price index of livestock product to that of the alternative agricultural product, denoted by P_{index}, where ε, γ, δ are parameters describing the final consumption demand. The livestock net exports, denoted by E, are fixed exogenously through the world demand and they are assumed to grow annually by a constant rate.

$$X = a1(GDP) + \varepsilon\left(GDP\right)^{\gamma}\left(P_{index}\right)^{\delta} + E$$

$$0 < \varepsilon,\ \gamma < 1,\ \delta < 0 \tag{4}$$

In Equation (5), the gross value added of the livestock sector, denoted by Y, is the value of the livestock off-take or output X less the value of the intermediate inputs used for producing this output, assumed as a proportion $a2$ of X.

$$Y = \left(1 - a2\right)X \tag{5}$$

In Equation (6), livestock output per unit of land in volume terms, O, is defined as total value of output X, divided by the price per unit of output and land, P and N respectively.

$$O = \frac{X}{\left(PN\right)} \tag{6}$$

In Equation (7), the value of a piece of land in the livestock sector Z is derived from the return to that land. The return to a unit of grazing land is its share b, in the value of output $P\ O$, adjusted for the level of grazing land degradation by the factor Q_0/Q. The adjustment factor Q_0/Q reflects the adverse impact of degradation on the value of land, and the effect is assumed to be proportionate.[6]

$$Z = b\ P\ O\left(\frac{Q_0}{Q}\right) \qquad 0 < b < 1 \tag{7}$$

In Equation (8), the wealth value of the livestock sector, R, is defined to comprise the total value of grazed land, that is the grazed land N multiplied by the unit value of grazed land, Z, and the value of the stock of animals on that land. Degradation will affect the wealth of the sector R not only via a diminished land price Z as occurs in the previous equation, but also via a diminished livestock price P as in the current equation. To allow for the degradation effects on P, Q/Q_0 is incorporated as an adjustment factor that reflects the prevailing conditions on grazing land. A proportionate effect of degradation on price is assumed.

$$R = Z\,N + L\left(\frac{Q_0}{Q}\right)P \tag{8}$$

Finally, returning to the degradation index, any rise in Q implies additional degradation costs. When grazing land is degraded, it has to be reclaimed if production is to be sustained into the future. The reclamation cost of degraded grazing land can be thought of as the depreciation cost of production in the livestock sector. Being as such, a depreciation allowance should be set aside for financing the reclamation of degraded land. This is called here degradation cost, and is denoted by D. It is defined in relation to the desirable value of Q=1, where there is no grazing land degradation. The average reclamation cost for a piece of land, denoted by c, has been estimated at ten per cent of the foregone output of that land as a result

[4]The price per unit of livestock P can be written as $P_0\ P_{index}$, where P_0 is the absolute price level per unit of livestock in the base year and P_{index} is the relative price index of the livestock product to that of the alternative agricultural product.

[5]Meat is the only product of the livestock sector that is considered here. Other products that are not directly relevant to the problem at hand, such as milk and hides, are not treated in this model.

[6]It is noted that whether land is allocated to grazing or other alternative uses such cultivation or forestry, depends on the relative value of land in its different uses, but since these alternative uses are not modelled here it is assumed that land allocated to grazing is fixed exogenously.

of its degradation [13]. The foregone output of land is the lost output share of the factor of production land, *b O*, valued at the price *P*. The output loss is dependent on the degradation level (1-1/*Q*). Degradation cost per unit of land is then multiplied by N to give *D*, as formalised in Equation (9).

$$D = c\left(b\,P\,O\right)\left(1 - \frac{1}{Q}\right)N \tag{9}$$

If *Q* is at its desirable level of 1, *i.e.* when the actual stock of animals is commensurate with the grazing land carrying capacity, the degradation cost becomes zero. See Section 6 for treating the model under the situation when *Q* =1.

3. Model Structure

Causal ordering (or recursivity) is used to understand the structure of the model. Causal ordering has been mainly elaborated in Simon [14]. As shown in **Table 1**, the livestock model has a simple diagonal structure containing four orders, and a total of nine equations that are solved for nine endogenous variables. These endogenous variables are *D*, *L*, *O*, *Q*, *R*, *V*, *X*, *Y*, *Z*. In the 1st order, which contains Equations (1) and (4), two endogenous variables are determined. These are grazing land degradation index *Q* and output value of the livestock sector *X*. In the 2nd order, which contains Equations (2), (3), (5) and (6), four endogenous variables are determined. These are vegetation yield per unit of grazing land *V*, stock of animals *L*, income of livestock sector *Y* and output per unit of grazing land *O*. In the 3rd order, which contains Equation (7), the per unit value of land *Z* is determined. In the 4th order, which contains Equations (8) and (9), two endogenous variables are determined, these are wealth *R* and degradation cost *D*. Note furthermore in **Table 1**, that Equations (2), (3), (5) and (6) are in a higher order than Equations (1) and (4), but they are in a lower order than Equations (7), (8) and (9).

As it is clear from the model structure, the most crucial variable in the model is the degradation index *Q*. The degradation index influences the vegetation yield per unit of land *V*, stock of animals *L*, value per unit of land *Z*, wealth *R*, and depreciation cost *D* in livestock sector.

4. Estimation and Solutions of the Model

The model is calibrated for Sudan for the base year 1990. This year is chosen as the base year because it has marked the beginning of a major economic reform programme in the country. Several sources are used in estimation of the parameters, see appendix **Table 3**. Estimates of most behaviourally oriented parameters, denoted by small Greek letters, were calibrated from the Social Accounting Matrix (SAM) of Sudan [15]. Estimates of most physically oriented parameters, denoted by small Latin letters, came from livestock literature. The exogenous variables are taken from publications of the Ministry of Agriculture, Ministry Finance and the Department of Statistics of Sudan; see appendix **Table 4**.

Estimates of parameters and exogenous variables for the base year are fed into the model and solved to reproduce the observed values of the endogenous variables in 1990. The model is then solved under varying assumptions for two scenarios: a) the medium term of 1990–2000 with falling relative livestock price, reflecting the actual past developments, and (b) the long term, extended from 1990 to 2030, with stable relative livestock prices.

As the model contains mechanisms with time lags, the model results can be expected to show up recurring cycles over time for the crucial variables of the size of livestock, *L*, measured in ten millions of equivalent animal units, and the index of degradation, *Q*. Indeed, these cycles occur, as is shown in **Figure 1** below.

As the recurring cycles occur already within the ten year period of 1990–2000, it becomes interesting to examine in the long term scenario the characteristic properties of the relationship between livestock and

Table 1. Model structure

Equation No.	Predetermined variables	Endogenous variables								
(1)	L_{t-1}, V_{t-1}, N_{t-1}, H	*Q*								
(4)	GDP, P_{index}, E		*X*							
(2)	W_{rain}, W_{irr}	*Q*		*V*						
(3)	L_{t-1}, P	*Q*	*X*		*L*					
(5)			*X*			*Y*				
(6)	*P*, *N*		*X*				*O*			
(7)	*P*	*Q*					*O*	*Z*		
(8)	*N*, *P*	*Q*			*L*			*Z*	*R*	
(9)	*N*, *P*	*Q*					*O*			*D*

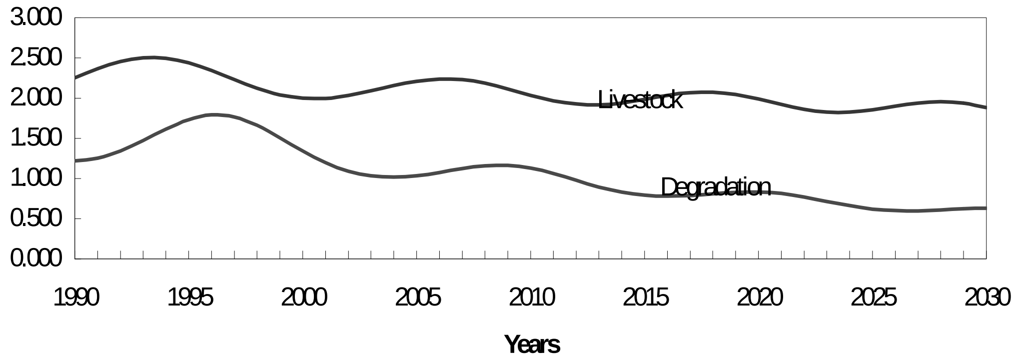

Figure 1. Livestock in ten millions of equivalent units, and degradation index, 1990–2030

Table 2. Projected scenarios of the model: Medium term and long term

Symbol	Description	Measurement	Value 1990	Medium term: Falling relative price of livestock		Long term: Stable relative price of livestock , *i.e.* $P_{index} = 1.0$			
				Growth % p.a	Value 2000	Growth % p.a	Value 2000	Value 2012	Value 2030
D	Degradation cost	Billion Ls	0.105	3.078	0.142	4.502	0.163	0.000	0.000
L	Livestock in equivalent units	Ten Million	2.2524	–1.338	1.9686	–1.192	1.9978	1.9255	1.8831
O	Output per feddan	LSU [(c)]	0.033	0.976	0.037	0.952	0.037	0.061	0.060
V	Vegetation yield	Metric Ton	1.067	–0.412	1.024	–0.760	0.989	1.275	1.275
Q	Degradation index	Index	1.220	0.518	1.285	0.958	1.342	1.000	1.000
R	Total wealth	Billions Ls	88.426	–1.679	74.651	–1.977	72.421	81.298	79.505
X	Total output	Billion Ls	9.409	0.976	10.369	0.952	10.344	17.287	16.906
Y	Sectoral GDP	Billion Ls	7.762	0.976	8.554	0.952	8.534	14.262	13.948
Z	Land value	Thousand Ls	0.075	0.456	0.079	–0.006	0.075	0.139	0.135
E	Exports value (a)	Billion Ls						4.642	–12.647
Sustainability indicators									
D/X	Deg. per unit of *X*	Ls	0.011	2.081	0.014	3.517	0.016	0.000	0.000
D/Y	Deg. per unit of *Y*	Ls	0.013	2.081	0.017	3.517	0.019	0.000	0.000
Y–D	Green GDP	Billion Ls	7.657	0.945	8.413	0.895	8.371	14.262	13.948

(a) Exports, *E*, is exogenous in the original structure of the model, and that is why no value is entered for *E* for the years 1990 and 2000 in **Table 2**, but the exogenous value for *E* is provided in the appendix **Table 4**. However, in the long term (*i.e.* from the year 2012 and on) the model structure is changed so that exports, *E*, become endogenous. For more elaboration of this point see Section 6.

degradation over a longer period up to 2030. Running the long term scenario will also highlight the long range future outlook for the livestock sector and its environmental repercussions, which are relevant for policy making.

It is worth mentioning that the model is more analytical than predictive. Therefore, the focus is more on trends and tendencies in the medium and long runs, rather than on exact magnitudes of the modelled variables. Therefore, the results should be read in that light. The next sections will analyse the results of the medium and long term scenarios, which are summarized in **Table 2**.

[7]It is estimated that the price of livestock product is growing by an annual rate of 4.2% while that of the alternative agricultural product by 4.8%. Therefore, the relative price of livestock product is falling by an annual rate of 0.6%.

5. The Medium Term Scenario: Falling Relative Livestock Prices

In the medium term scenario, a period of ten years until 2000, it is assumed that the gross domestic product, GDP, and intermediate deliveries from livestock sector to the rest of the economy, grow annually by 5%, livestock exports *E* to grow annually by 3%, and the relative price index of livestock product P_{index} to fall annually by –0.6%[7]. These are the average growth rates of these variables during the period of 1990–2000.

Table 2 gives the results for the medium term scenario. The fall of the relative price of livestock product leads to more consumption of livestock product and hence livestock *L* falls by 1.338% annually. This compares to a fall of 1.192% in the second scenario. The difference is due to the falling price of livestock product relative to that of the alternative agricultural product. With the relative price of livestock product falling, more livestock product is consumed and therefore livestock is relatively falling faster than when its relative price is unchanging.

As a result, degradation index Q rises by 0.518% in the first scenario as compared to 0.958% in the second scenario. Correspondingly, vegetation yield V falls annually by 0.412% in the first scenario and by 0.760% in the second scenario. Both output X and income Y grow by 0.976% in the first scenario and by 0.952% in the second scenario. The value of land Z grows by 0.456% in the first scenario, but declines marginally by 0.006% in the second one. Regarding degradation cost D, it rises at a rate of 3.078% under the first scenario, but at a rate of 4.502% under the second one.

The above brief discussion of the model medium term results show that grazing land sustainability situation is adverse in the medium term. But as we will see in the next section, this situation is quite favourable in the long term. This is because the livestock system has sufficient time to adjust when longer term livestock system dynamics are allowed to play out.

6. The Long Term Scenario: Stable Relative Livestock Price

In the long term scenario, the same assumption of 5% growth of GDP and intermediate deliveries are held, livestock exports E are endogenized after 2000, and most importantly, we assume an unchanging relative price of livestock products. This is justified by 1) the uncertainty about the trends of relative prices over such a long period of time, and 2) a stable price represents a conservative prospects for the sector whose achievement can be seen to be always more plausible than that of a rising price and a booming prospects.

The results for the long term scenario, **Table 2**, show falling livestock L and declining degradation Q. These occur in more or less equivalent waves of ups and downs in the direction approximately indicated by a ten-year period[8]. The long term falling trend of livestock is explained by the outcome that both the slaughter from the stock and the cyclical rise of grazing land degradation are favouring the reduction of the stock. The long term declining trend of grazing land degradation is caused by the falling trend of livestock. The sequence of causation, in this two-way relationship between the stock and degradation, runs from the stock to degradation and then from degradation to the stock. This can be seen from **Figure 1**, where the peak of the stock precedes that of the degradation.

The figure shows that the long term declining trend of livestock is less pronounced than its medium term declining trend. Note that while degradation is rising in the medium term when compared to the base year level, yet it is falling in the long term. This is because the impact of the forces at work in the model is not fully realised in the medium term. In the long term, the impact of these forces is fully realised since there is sufficient time for the livestock system to adjust.

The sustainability situation of grazing land is favourable as degradation is declining. This is because the off-take from the stock is increasing. This increase in the off-take is due to economic growth, rising income and livestock exports, which all favour increased demand for livestock product.

Equation (1) of the model has the restriction that $Q \geq 1$. This is because once Q falls blow 1 the livestock sector will be operating under grazing land conditions where there is no degradation and theoretically speaking a process of grazing land and livestock regeneration sets in, but this possibility is not discussed in this paper. In the long term projection of the model, Q falls below unity starting in the year 2012. Therefore, Q is kept at 1 during the period 2012–2030 according to the restriction of Equation (1).

When Q reaches 1, the original structure of the model is bound to change into a new structure. With two variables Q and V becoming by definition exogenous, Equations (1) and (2) are practically dropped from the model.

In the absence of degradation, a very plausible scenario for livestock development, which at the same time gives justice to economic and socio-cultural considerations[9], is to assume that livestock owners would like to maintain a stable balance between the off-take and the stock. In this way, slaughter as a proportion of the stock assumes a certain ratio ψ, see Equation (10) below. This ratio can be fixed at the point where the livestock is operating under the grazing land conditions where there is no degradation, which is when Q reaches 1. This occurs in the year 2012 and at this point the ratio of slaughter to stock, ψ, is about 0.245.[10]

$$\left(\frac{X}{P}\right)\Big/L = \psi \tag{10}$$

With this one additional equation, the solution of the model requires that one additional variable should become endogenous. In the new model structure, it is proposed that net exports of livestock, E, which is exogenous in the original structure of the model, becomes endogenous.

The three main equations of the restructured model (3), (4) and (10) contain three endogenous variables,

[8]Such cycles in livestock dynamics are also confirmed by Fafchamps. According to Fafchamps "Although the timing of cycles depends on exogenous rainfall shocks, it fundamentally results from the accumulation of animals beyond the carrying capacity of the range", [16].

[9]For nomadic livestock owners in Sudan, animals are a store of food and wealth in addition to their socio-cultural role. Therefore, they would not allow this joint store of food and wealth, and socio-cultural symbol, to fall below a certain level [12].

[10]It is interesting to note that in Western Australia, [9] found that this ratio, which they called the ratio of turnoff to herd size, is more than 0.200 in areas where the range conditions are good.

namely L, X and E. These equations are solved simultaneously and the results are used for solving the rest of the model.

The solution of the endogenous variables under the new structure of the model for the year 2012 and the year 2030 are presented in the last two columns of **Table 2**. Note that livestock exports E are added to **Table 2** as an endogenous variable for the years 2012 and 2030. But before the year 2012, E was exogenous and that is why it is not shown in **Table 2** before 2012. As can be seen from the table, degradation cost D is zero in 2012 and 2030, since degradation index Q is unity in these two years. The output X in 2030 is somewhat less than that in 2012. Therefore, the domestic output, which is used to meet domestic consumption demand, is supplemented in later years by imports of livestock product, *i.e.* net exports $E < 0$, see **Table 2**. This is explained by the outcome that our assumption of unchanging relative price of livestock product has ruled out any price adjustment mechanism. Therefore, a quantity adjustment mechanism has to adjust supply to rising demand, and the net exports of livestock product E has to bear the burden of this adjustment, see Equation (4) of the model.

The above analysis shows that there are two adjustment mechanisms at work in the long term. The first one is internal to the livestock sector and the second one is external. The internal one shows that the livestock system is self-regulatory in the sense that it has a built-in adjustment mechanism. This mechanism works through the two-way relationship between the stock and degradation. When the stock of grazing animals exceeds grazing land carrying capacity degradation sets in. Due to degradation the stock does not continue to grow steadily and sustainably, since degradation adversely affects the growth of the stock. After a certain point in time, the stock is adjusted downward to the prevailing degradation conditions on grazing land. The end result is that the downward adjustment of the stock eases the pressure on grazing land and hence degradation is mitigated.

The external adjustment mechanism originates from the economic system and it works through economic growth, foreign trade and relative prices. We have seen the last one in the medium term analysis and in principle it applies also for the long term[11]. Rising income, falling relative price of livestock product and more livestock exports lead to increasing off-take from the stock which eases pressure on grazing land and ultimately reduces degradation.

The results of the model suggest that it is possible to reconcile the new range ecology thinking [4,17,19] with that of the mainstream range management paradigm. The latter, which assumes equilibrium[12] environment, argues that the number of animal population is limited by availability of vegetation and the existence of excessive number of animals on the range adversely affect vegetation and this leads in the long run to rangeland degradation. The former, which assumes disequilibrium environment, argue that both animal population and vegetation are dominated by external factors such as rainfall and animal population are kept low by events such as drought and therefore animal population cannot have long run adverse impact on rangeland. The model results in the medium term seem to confirm the mainstream range management thinking while the model results in the long term seem to confirm the new range ecology thinking. Thus, whether range ecology is in equilibrium or disequilibrium is not a permanent situation but a situation that varies over time. Therefore, it appears that both paradigms, equilibrium and disequilibrium, have a grain of truth in their views regarding the issue of land degradation.

7. More Discussion of Results

The lower part of **Table 2** sums up several sustainability indicators for the livestock sector. The sustainability situation is relatively encouraging under the scenario of changing relative prices as compared to the unchanging one. Under the first scenario, degradation cost per unit of output and value added, D/X and D/Y respectively, grow by 2.081% per annum, compared to 3.517% under the second scenario. Regarding the sectoral green GDP, (Y–D), it grows by 0.945% under the first scenario and by 0.895% under second scenario. The concept of green GDP here refers to the livestock sectoral GDP, Y, after the deduction of the degradation cost of grazing land, D. The degradation cost is supposed to be deposited in separate fund for financing the reclamation of the degraded land in the livestock sector, if production is to be sustained into the future.

One important policy lesson which emerges from this discussion is that a falling relative price of livestock product encourages more consumption from the stock, thereby eases the pressure on grazing land and ultimately grazing land degradation is mitigated[13]. In other words, subsidising the price of livestock product can be a policy option for achieving sustainability in the livestock sector, but this needs to be weighed against any distortionary effects or fiscal problems that the subsidy may cause.

As an exercise in sensitivity analysis, the parameter γ

[11]In the long term solution of the model and under changing relative prices scenario (not reported here), the livestock system reaches the point of no degradation, *i.e.* Q =1, in much earlier time than under the unchanging relative prices scenario, which we have seen here.

[12]The term (dis) equilibrium is used in ecology to refer to an ecosystem where populations are in long term (im) balance with other elements of the system [17].

[13]An IMF working paper shows that lower price of meat in Sudan leads to more off-take from the stock since livestock owners want to supplement their income and smooth consumption [18].

that describes the final demand function for livestock product has been increased by 5%. For some variables such as the stock L and degradation index Q, the projected trend has changed resulting in improved sustainability of grazing land. This indicates that a shift in consumers' preferences towards more consumption of livestock product promotes environmental sustainability in the livestock sector.

Furthermore, an opportunistic management strategy that involves an increase of vegetation yield V; effective expansion of grazing land N; reduction of animals vegetation intake H; and reduction of the stock L can preempt or reduce grazing land degradation, that is resulting in lower Q.

8. Conclusions

Some important conclusions have emerged from the analysis. First, the livestock system is dynamic and can adjust when longer term system dynamics are allowed to play out. Part of the adjustment mechanism is built in the livestock system and the other part comes from the economic system. The built-in adjustment mechanism works through the two-way relationship between the stock and degradation. The external adjustment mechanism, originating from the economic system, works through economic growth, relative prices and foreign trade. Second, although grazing land sustainability situation is favourable in the long term, yet it is adverse in the medium term. Therefore, an external intervention in the form of appropriate policies, that facilitate access to grazing land and water, is needed to help the livestock system adjust in the medium term and mitigate degradation. Also, opportunistic management strategy on the part of pastoralists is an effective way of pre-empting and/or reducing grazing land degradation. The model results seem to suggest a reasonable synthesis of the traditional mainstream range management approach with the new range ecology thinking.

It is important to be reminded that the model is more analytical than predictive. Its focus is more on medium and long term trends rather than exact mangnitudes. Therefore its results should be understood in that light.

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Appendix

Table 3. Parameters estimates

Symbol	Description	Value
α	Effect of rainfall water on vegetation yield	0.500
β	Effect of irrigation water on vegetation yield	0.500
γ	Effect of GDP on consumption demand for livestock	0.950
δ	Effect of price on consumption demand for livestock	–0.100
ε	Average propensity of consumption demand for livestock	0.029
η	Effect of degradation on livestock and vegetation	0.800
$a1$	Coefficient of intermediate deliveries by livestock sector to whole economy	0.0073
$a2$	Coefficient of intermediate deliveries received by livestock sector	0.175
b	Share of factor land in value added of livestock sector	0.617
c	Reclamation cost as a proportion of foregone output	0.100
g	Average gross annual growth rate of the stock	0.142

Table 4. Exogenous variables (Ls=Sudanese pound)

Symbol	Description	Measurement	1990	Growth p. a.
E	Value of livestock exports	Billion Ls	2.352	0.030
N	Total grazing land	Million feddan	77.000	
P	Price per livestock unit in the base year	Thousand Ls	3.668	
P_{index}	Relative price index of livestock product	Index	1.000	–0.006 (a)
H	Vegetation requirement per livestock unit	Metric ton	4.562	
W_{rain}	Rainfall index	Index	1.000	
W_{irr}	Irrigation index	Index	1.000	
GDP	Gross domestic product of the whole economy	Billion Ls	192.660	0.050

(a) The model is also simulated assuming that P_{index} is not changing, *i.e.* $P_{index} = 1.0$

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Assessment of Radiological Contamination of Soils Due to Shipbreaking Using HPGe Digital Gamma-Ray Spectrometry System

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ABSTRACT

A systematic study of the distribution of the Naturally Occurring Radioactive Materials as well as the anthropogenic radionuclide in the working environment of the Shipbreaking yards of Sitakunda, Chittagong, Bangladesh, has been carried out with an objective of establishing reliable base line data on the radiation level and hence to measure the radiation dose expose to the workers and to the inhabitants of the studied area. Fifteen Soil samples have been collected from five different Shipbreaking yards. Three sampling spots in each yard have been selected for having representative samples for the assessment of radioactivity releasing from ^{226}Ra (^{238}U), ^{232}Th *and their daughters and* ^{40}K *using the Digital Gamma-ray Spectrometry system coupled with a High Purity Germanium (HPGe; Canberra, 40% relative efficiency, 1.8 keV resolution at 1332 keV of* ^{60}Co) *detector and PC based Multichannel Analyzer (MCA, upto 16k channel). The software Genie 2000 (Canberra) and Hypermet PC have been used for data acquisition and gamma peak analysis, respectively. Each of fifteen soils (~200g) and two standards (IAEA-Soil-6 and 800Bq liquid* ^{226}Ra *sprayed in* Al_2O_3) *were counted in cylindrical plastic pot using gamma spectrometry system for 20000 sec for the determination of activity concentrations of the radionuclides. The samples and standards were kept in air tied condition at least for 4 weeks before gamma counting to attain the radioactive equilibrium between daughters and parents of* ^{226}Ra (^{238}U) *and* ^{232}Th *decay series. The* Al_2O_3 *based* ^{226}Ra *standard was used for the construction of efficiency curve covering the wide gamma energy range. The IAEA-Soil-6 was used for quality control (QC) of the analysis. The homogeneity test and density corrections of* Al_2O_3 *based* ^{226}Ra *standard were performed and implemented for the analysis. The results of activity concentrations have been used to assess the radium equivalent activities* (Ra_{eq}) *and the representative level index* ($I_{\gamma r}$) *values in the experimental soil samples. The results have been compared with other global radioactivity measurements and evaluations.*

Keywords: *Shipbreaking Yards, HPGe Detector, Radionuclides, Activity Concentrations, Dose Rates, Radium Equivalent Activity, Representative Level Index*

1. Introduction

The world is naturally radioactive and hence human being on earth evolved in a radioactive environment. About 90% of the human radiation exposure arises from natural sources such as terrestrial radiation, cosmic radiation, and radon gas. Natural radionuclides of concern are thorium (^{232}Th) and uranium (^{238}U) with their radioactive decay chains and potassium (^{40}K). Emanation of radon gas (^{222}Rn and ^{220}Rn) into air occurs as a product of uranium (^{238}U) and thorium (^{232}Th) decay chain respectively. Like all other materials soil can also be the source of radon gas [1].

Assessment of any release of radioactivity to the environment is important for the protection of public health; especially if the released radioactivity is a matter of direct population exposure and can enter into the food chain [2], which is a matter of indirect exposure. In the case of the workers of the shipbreaking yards and the peoples living round the yards, peoples are subjected to both direct and indirect radiation exposures.

The whole activities of shipbreaking in Bangladesh are done in an unhygienic environment with the violation of the safety regulations. During the dismantling of the ships different chemicals, gases, oils, ballast water, etc., fall in the sea water which pollute the marine environment. Also after dismantling of the ships the scraps carrying the poisonous materials like chemicals, gases, oils etc., radioactive materials, and heavy metals in its paints and electric equipments-pollute the soil and the surrounding environment where they are stored. As a result of these, today, shipbreaking becomes a threat to the environment and hence to human health.

Now from the point of view of natural risk, it is necessary to measure the environmental radiation level for the estimation of the exposures of natural radiation sources and to know the dose limit of public exposure. Therefore the main object of this study is to assess the environmental radioactive contamination in the working environment of the shipbreaking yards of Sitakunda, Chittagong, Bangladesh, through finding out the types and concentrations of the radionuclides in the soil of the yards. With the above considerations and with a view to ensure the significant contribution of the shipbreaking to the national economy of Bangladesh, fifteen (15) soil samples have been collected from 5 different shipbreaking yards of Sitakunda, Chittagong, with 3 samples from each. The samples were analyzed by the HPGe detector coupled with computer based digital gamma spectrometry system and sophisticated data acquisition and gamma peak analysis software in the NAA laboratory of the Institute of Nuclear Science & Technology (INST), Atomic Energy Research Establishment (AERE), Savar, Dhaka, Bangladesh.

2. Materials and Methods

2.1 Sample Collection and Processes

Most of the shipbreaking yards of Bangladesh are situated in different locations (Fultola, Baro Awlia, Kadam rasul, Jahanabad, Kumira, Kattoli, etc.) under Sitakunda thana of Chittagong District. That is why for the present research five different shipbreaking yards of Sitakunda, Chittagong, Bangladesh are selected as sites for sample collection.

After cleaning the surface, soil was collected from 0-30 cm depth by auguring. Three soil samples were collected in cleaned polyethylene bag from each of five shipbreaking yards. The samples were marked separately by giving the identification (ID) number carefully. The name and addresses of the shipyards with soils identity are quoted in **Table 1**. It is noted that in the **Table 1** the letters A, B, C are given for three different locations of each yard.

The collected soil samples were taken in a pre-cleaned pyrex beaker and then allowed to dry in the oven at 70°C until having constant weight. The dried soil samples were taken then powdered by the use of an agate mortar. Fifteen (15) cleaned cylindrical plastic pots having the same geometry were filled with about 200g dried powered samples and kept in air tied condition. All the air tied pots were remained undisturb at least for 4 weeks before counting to attain parents-daughter equilibrium in the ^{238}U and ^{232}Th decay series. For example, the ^{222}Rn from ^{238}U decay series can easily be escaped by diffusion from the samples during preparation. As the half-life of ^{222}Rn is 3.84 days, once the ^{222}Rn escaped from the sample it is needed at least 7 half-lives to attain equilibrium.

For measuring the natural radioactivity two standards were used. One was IAEA Soil-6 and the other was ^{226}Ra (liquid) sprayed into Al_2O_3. The Al_2O_3 standard was prepared in the INST laboratory. For the preparation of Al_2O_3 standard ^{226}Ra liquid having an initial activity 800 Bq was sprayed into the Al_2O_3 powder. The liquid was sprayed carefully and mixed homogeneously. The homogeneity test of Al_2O_3 standard was performed by splitting it into 6 equal folds and measured them in the sample geometry of HPGe_detector. Both the standards were also packed in the plastic pots having the same geometry and height as that of samples. The IAEA-Soil-6 and samples have almost the same packing density, whereas has lower packing density. The density corrections were performed and taken into account for the calculation.

The accuracy of any experimental analysis depends mainly on the performance of the detection system. On the other, the performance of any detection system depends on some parameters of the experimental set up. Therefore in the present experiment some useful parameters of the HPGe detector were determined to ensure the accuracy of the analysis. We have performed energy calibration, resolution, counting efficiencies of the HPGe detector, Quality Control Chart (QC) for Instrumental Quality, etc. and details of these parameters analyses techniques are almost same as on Reference [3].

Table 1. Name and addresses of investigated shipyards with soils identity

Name and Address of the yard	Sample ID
Rising Steel Ltd. (Ship Breaking Unit) Fultola, Baro Aulia, Sitakunda, Chittagong.	S-1A S-1B S-1C
Ziri Subader Steel Re-Rolling Mills (Ship Breaking Unit), BaroAulia, Sitakunda, Chittagong.	S-2A S-2B S-2C
Muhib & Sakib Steel Industries (Ship Breaking Unit), Kadam Rasul, Vatiary, Sitakunda, Chittagong.	S-3A S-3B S-3C
M/S. Sultana Ship Breaking Yard, Kadam Rasul, Vatiary, Sitakunda, Chittagong.	S-4A S-4B S-4C
M/S. Six Star Corporation (Ship Breaking Yard), Jahanabad, Sitakunda, Chittagong.	S-5A S-5B S-5C

2.2 Counting of the Samples and Standards

In counting system a count was taken for 20000 seconds for each of the samples and standards of interest. The standards for homogeneity testing were counted for 7200 second each. The spectra in all cases were saved in the PC. A background count for the time 20000 seconds was taken to get the background contribution in the samples and standards.

2.3 Analysis of the Spectra

The spectra collected for the samples and standards were analyzed in two ways: manually and by the use of analyzing software Hypermet PC version –5.12. The area under the peak of a certain gamma ray energy spectrum represents the number of counts collected only for that gamma ray energy. For the manual evaluation of the peak area, equal numbers of channels were taken on each side of the peak. Hypermet PC version –5.12 gave the area automatically. Both the peak analysis methods yielded almost consistent peak area for the interested radionuclide.

2.4 Interference Correction

The interference corrections have been performed in some cases. ^{232}Th and ^{226}Ra have gamma peaks at 240.98 keV and at 241.98 keV energies, respectively. It is difficult for any detector to show the peaks separately, so there is always a spectral interference between them. Hence to calculate the correct peak area from the interfered peaks, interference correction was made in the current experiment.

The conversion of the measured to the correct peak area [Np] is performed as:

$$[N_{p,a}]_{Correct} = [N_{p,a+b}] - [N_{p,ref}]\frac{\left[I_{\gamma}\times\varepsilon_{P}\right]_{b}}{\left[I_{\gamma}\times\varepsilon_{P}\right]_{ref}} \quad (1)$$

where I_{γ} is the gamma ray intensity, "*a*" denotes the interfered peak, "*b*" the interfering peak, "*ref*" is an undisturbed peak from the interfering radionuclide and "ε" the efficiency.

2.5 Density Corrections

In the present work density correction was made to determine how the gamma rays are affected by the density and composition of the samples & standards. For this, IAEA-Soil-6, Al_2O_3 standards and gamma emitting point sources of ^{60}Co, ^{133}Ba, ^{137}Cs and ^{152}Eu covering the low and high energies were used. The CPS ratio of various gamma energies emitting from point sources and passing through both the standards were determined and plotted as in **Figure 1**.

It is seen that at very low energy (80.99 keV) the gamma-rays passing through the IAEA soil-6 standard is 10% affected compared to that through the Al_2O_3 standard. But at high energies there was no effect at all; the CPS ratio is around 1.

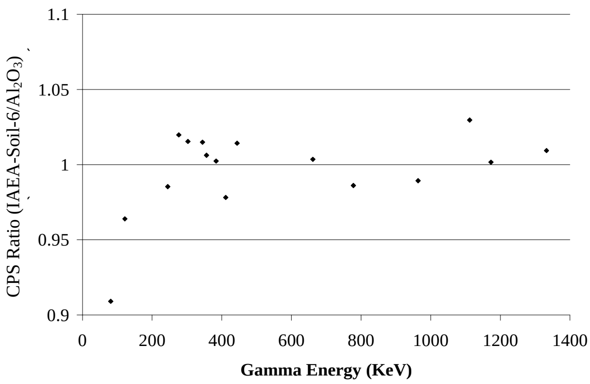

Figure 1. The effect of packing density and composition of the sample on gamma ray energies

2.6 Homogeneity Testing

The homogeneity of the Al_2O_3 (^{226}Ra) standard was tested by measuring the specific count rate (CPS/g) for six folds for particular gamma energy. It was found that the CPS's were the same at 768.36 keV of ^{226}Ra. This confirmed the homogeneity of the Al_2O_3 standard (**Figure 2**).

3. Calculations of Activity Concentrations, Dose Rate, Radium Equivalent Activity and Representative Index

Soil samples were collected to determine the activity concentrations, their corresponding dose rates and other radioactivity indices e.g., radium equivalent activity and representative level index, etc. The activity concentrations were measured from the following relation:

$$A = \frac{CPS \times 1000}{\varepsilon(abs)\times I_{\gamma}(abs)\times W} \quad (2)$$

where A is the activity in Bq.kg^{-1}, CPS is the net counts per second of the experimental sample, W is the weight of the sample in gm, ε (*abs*) is the absolute gamma peak detection efficiency, $I_{\gamma}(abs)$ is the absolute gamma intensity of the corresponding gamma ray energy.

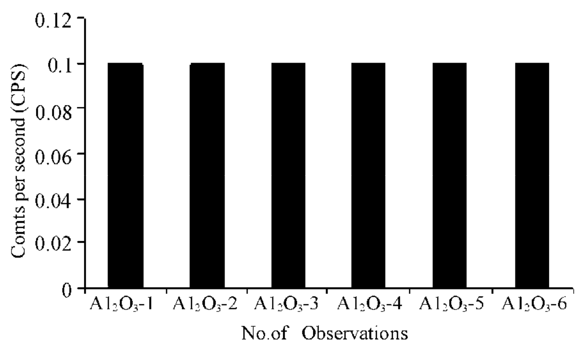

Figure 2. Homogeneity testing of the Al_2O_3 standard

To determine the activity concentrations of ^{226}Ra (^{238}U), the γ-ray lines 295.21, 351.92 keV (^{214}Pb); 609.31 and 1120.29 keV (^{214}Bi) were used. To determine the activity concentrations of ^{232}Th, the γ-ray lines 911.07, 969.11 keV (^{228}Ac); 238.63 keV (^{212}Pb); 583, 2614.66 keV (^{208}Tl) were used.

The dose rate in the studied area was calculated from the formula reported in Reference [2] as:

$$D=(0.0427)\, C_{Ra\text{-}226} + 0.0662\, C_{Th\text{-}232} + 0.00432\, C_{K\text{-}40}) \times (10^{-8}\text{Gy.h}^{-1}) \quad (3)$$

where, D-the dose rate (equivalent to the external dose rate), $C_{Ra\text{-}226}$, $C_{Th\text{-}232}$ and $C_{K\text{-}40}$ are the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K contents respectively in the experimental soil.

The internal dose rate is assumed to be 1.2 times higher than the external dose rate [4]

$$D_{internal} = D_{external} \times 1.2 \ (\text{nGy.h}^{-1}) \quad (4)$$

The transformation of activity into the radium equivalent activity, Ra_{eq}, was performed according to Reference [5] as:

$$Ra_{eq} = C_{Ra} + (10/7)C_{Th} + (10/130)C_K \quad (5)$$

Another radiation index, named representative level index can be defined as per recommendations of Reference [6],

as: $$I_{\gamma r} = (1/150)C_{Ra} + (1/100)C_{Th} + (1/1500)C_K \quad (6)$$

where in both cases C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1}, respectively.

4. Results

The range and mean values of activity concentration, dose rates, Radium Equivalent Activities (Ra_{eq}), Representative Level Index ($I_{\gamma r}$) and a comparative study are shown in the **Tables (2–4)**, respectively:

The quoted uncertainties were calculated based on the total uncertainty budget considering 1 σ. A comparative study was performed for the activity concentrations and the corresponding dose rates obtained in the present work with other previous measurements (**Table 5**).

The mean activity of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K in fifteen soils samples were found to be 31.39 ± 1.77, 63.34 ± 3.27 and 364.47 ± 15.32 Bq.kg^{-1}, dry weight, respectively, which contributes to an average gamma dose of 71.08 ± 3.64 nGy.h^{-1}, in air, at a height of one meter above the ground surface of the yards. The activity concentration of the anthropogenic radionuclide ^{137}Cs was below the detection limit. The results of activity concentrations have been used to assess the radium equivalent activities (Ra_{eq}) and the representative level index ($I_{\gamma r}$) values in the experimental soil samples. The observed mean value of Ra_{eq} and $I_{\gamma r}$ in soil is found to be 149.91 ± 7.62 and 1.09 ± 0.05 Bq.kg^{-1}, respectively.

Table 2. The range and average values of the activity concentrations

Radio-nuclides	Activity Concentrations in Bq.kg^{-1}		
	Minimum	Maximum	Average
^{226}Ra	9.88±0.86	86.95±3.47	31.39±1.77
^{232}Th	24.07±1.69	178.07±6.57	63.34±3.27
^{40}K	68.01±4.80	792.68±29.80	364.47±15.32
^{137}Cs	ND	ND	ND

Table 3. The range and average values of the dose rate

Dose Rates	In nGy.h^{-1}		
	Minimum	Maximum	Average
External (D_{ex})	26.06±1.81	159.79±7.00	71.08±3.64
Internal (D_{in})	31.27±2.17	191.75±8.40	85.30±4.37

Table 4. The range and average values of the Radium Equivalent Activities (Ra_{eq}) and Representative Level Index ($I_{\gamma r}$)

Index	Minimum	Maximum	Average
Ra_{eq}	55.91±3.89	349.85±13.33	149.91±7.62
$I_{\gamma r}$	0.40±0.03	2.43±0.09	1.09±0.05

Table 5. Comparisons of the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and the corresponding dose rates

Country	Mean Activity Concentrations in Bq.kg^{-1}			Mean Dose Rate in nGy.h^{-1}	Reference
	^{226}Ra	^{232}Th	^{40}K	D	
Bangladesh (Ship yards)	**31.39**	**63.34**	**364.47**	**71.08**	**Present study**
Bangladesh(Dhaka)	33.00	016.00	574.00	81.0	[7]
India(Kotagiri)	41.00	102.00	229.00	86.0	[8]
USA (California)	39.40	045.60	420.00	23.0	[9]
Greece	49.00	024.00	760.00	42.0	[10]
Taiwan	30.00	044.00	653.00	56.6	[11]
World Average	25.00	025.00	370.00	55.0	[12]

5. Conclusions

For the radiation protection, the accumulation of information on natural radiation is of great importance. Therefore the present work may be important to carry out an approximately designed program on environmental radioactivity monitoring-aimed at minimizing population exposure which will ensure a proper working environment in the ship breaking yards and also help to save peoples inside and outside the yards.

Comparison of activity concentrations of different radionuclides and their corresponding dose rates with world wide references revealed that there is no anomaly observed in Chittagong Shipbreaking yard in radiological point of view. However, the created baseline data in the present work will help to assess any radiological contamination due to ship breaking activities in the study area in future.

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Environmental Consequences of Rapid Urbanisation: Bamenda City, Cameroon

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ABSTRACT

Human settlement conditions in many parts of the world, particularly the developing countries, are deteriorating. Natural hazards now occur right at our door steps and the frequency of occurrence and magnitude of damages that they cause is seen to be on an increase especially in poor urban communities. The natural environment is deteriorating at a rate faster than the rate at which natural occurring processes and resources available within the environment can replenish. If left unabated, landslides, flooding, sporadic fire outbreaks, collapse of major road axis, houses and bridges have the potential of plunging urban centre's into an abyss of environmental chaos. This paper chooses Bamenda city-Cameroon, a rapidly expanding city in the third world as an example. The paper therefore assesses the overall situation of deteriorating urban quality by randomly selecting some of the quarters within Bamenda city that are generally considered as hazard prone. It was noticed that deteriorating urban quality stems from the phenomenon of rural exodus. The situation is further exacerbated by inappropriate systems of land administration, poverty and an overall anarchy and ignorance in the handling of environmental issues. This paper therefore calls for a multidisciplinary and holistic range of approaches to solving present day environmental hazards of Bamenda. It calls for the adoption of modern technology and the systematization of the processes of land acquisition and registration especially at state and local government levels.

Keywords*: *Bamenda City, Hazards, Environment, Flooding, Landslide

1. Introduction

The word "urbanization" refers to an increase in the proportion of national or regional population living in cities [1]. For the first six thousand years of urban life, no society was long able to maintain an urban percentage greater than from 5 to 10 percent. Starting in late eighteenth-century England, however, one nation after another experienced an accelerating shift from rural to urban population. After several generations of rapid urbanization, the process leveled off toward a new equilibrium in which about three-quarters of the population lived in cities and many of the rest pursued city-related activities in smaller towns.

Chapter 7 of **Agenda 21** acknowledges the fact that human settlement conditions in many parts of the world, particularly the developing countries, are deteriorating mainly as a result of the low levels of investment in the sector attributable to the overall resource constraints in these countries. The natural environment of Bamenda is deteriorating at a rate faster than the rate at which natural occurring processes and resources available within the environment can replenish.

Emerging as a city in the colonial days of the British, French and Germans from around 19th century, Bamenda has transcended from being a traditional monoculture village to becoming a complex heterogeneous city offering many services to its inhabitants as well as to its hinterland. Besides hosting the headquarters of the North West region and thereby serving as the socioeconomic nerve wire of the region, it serves as a pivot to major political, religious and cultural happenings in Cameroon. Bamenda is located at a cross route linking cities in neighboring Nigeria such as Enugu and Calabar to the economic and capital cities of Douala and Yaounde respectively.

The numerous services offered in Bamenda have somehow encouraged rural exodus and accelerated the urbanization process of Bamenda. People; especially the youthful folk migrate into Bamenda in search of jobs and scholarly pursue. This net flow of population within the recent past has not been compensated for by an increase of or improvement in social infrastructure. The demand for low cost housing and social amenities such as roads, waste disposal sites, water as well as landed property has noticed an exponential increase since the 1980s. Varied forms of housing developments that are dependent on miniature, inaccessible and undulating footpaths have led to a situation of urban sprawl and an overall deterioration in the scenic beauty of Bamenda city. The devaluation of the CFA currency by 50% in the 1990s, increase in the price of building materials and a general increase in cost of a square foot of land have led to a situation of uncontrolled and illegal occupancy and an overall disorderliness in civil life as people are now seen to occupy high risk hill slope systems and swampy valleys more than ever before.

The gradual but steady encroachment of population onto high risk soon is characterized by the erection of unplanned buildings (no building permits) of very low quality standards. Such lands are known to be about 300 times cheaper than properly located pieces of land within the city. The acquisition of such land is usually through mere land agreement and not through the complicated, expensive, bureaucratic and time consuming land title acquisition procedure whose cost could well be more than a hundred times higher than the value of land in such unstable zones. As a consequence to the above, the city of Bamenda is witnessing an ever increasing high in the number of natural hazards, which very often claim lives; a situation which if left unabated could plunge the city into an abyss of widening urban instability and decay.

The situation of urban hazard within this millennium appears to be different in scope and magnitude. Not only do such hazards occur frequently, but they are seen to occur with even greater intensity and at threatening scales seen to be dangerous to the very existence of man and to the disruption of a onetime ecologically balanced complex. The situation within the city of Bamenda is that which beck for an answer as the incidence of flash flooding, mudflow, landslides, fire disasters, and sheet and gulley erosion are on a disheartening increase in the phase of a rapidly expanding human numbers. Ensuing natural hazards that occur due to man's disruption of the geomorphic processes are that which man himself can't prevent from occurring. They are certainly inevitable and man has a price to pay.

The one time physical environment of Bamenda that knew little or no stress in the 60's has seen the progressive replacement of pre-existing vegetation with buildings and pavements of varying degree and quality. In as much as this change is seen as man's quest to improve on his immediate environment with the desire to lead a more comfortable life, there is need for such change to follow a planned and comprehensive pattern that can still stand the taste of time in generations to come. This paper calls for the adoption of a multidisciplinary approach in the planning of present day Bamenda. Bamenda, the metropolitan centre of the North West Region has a panoramic and well-drained natural site. In spite of the existing largely unplanned urban development, it could be replanned, upgraded and systematically extended to offer a beautiful, healthy, safe, secured, comfortable, convenient and functional living environment which provides equitable opportunities to all its inhabitants. To do this, the current situation where private interest over land completely dominates public interest has to be reversed without necessarily undermining the former.

2. Objectives and Hypothesis of the Study

The aim of this study is to point out the peculiarities about urban catastrophe in Bamenda. The main objectives that this research aimed to achieve were the following:

- To show the extent to which haphazard urban development planning provokes and is prone to the occurrence and effects of urban environmental hazards.
- To make an assessment of peoples perception of urban environmental hazards in Bamenda
- To propose appropriate ways in which urban environmental hazards in Bamenda could be checked.

3. Hypothesis

Rapid urbanization does not lead to urban environmental problems

4. Statement of the Problem

Bamenda city has seen the progressive deterioration in its environmental quality as a result of rapid and unplanned urbanization that took off since the early 80's. There has thus been an upwards surge in the frequency of occurrence of natural hazards within the environment which if left unabated have the potential of plunging Bamenda into an abyss of environmental chaos. Landslides, flooding, sporadic fire outbreaks, collapse of major road axis, houses and bridges are thus on an ever increasing high.

There is thus a rising need for concrete environmental management plans that can meet the taste of time in the short, medium and long term for present day Bamenda. At the same time the environmental implications of urban development should be recognized and addressed in an integrated fashion by all countries, with high priority being given to the needs of the urban and rural poor, the unemployed and the growing number of people without any source of income [2].

5. Conceptual Framework

In the developing world most especially, high birth rate within the surrounding hinterland and within an urban sector leads to deterioration in living condition and pressure on rural resources. In a quest to find a way out of this dilemma people often migrate to the cities where they hope to better their living conditions. This more often than not leads to overcrowding and the development of shanks and squatters within the urban built with attendant deterioration in urban environmental quality. **Figure 1** below shows the intricate link between rising urban population and urban environmental quality problems.

6. Methodology

6.1 Primary Data

Questionnaires, historical linings, interview, visual appreciation through pictures were used to collect raw data from the field. The city of Bamenda was classified into highly prone, moderately prone and least prone quarters with respect to the occurrence of natural hazards following some critical satellite interpretation exercise. Flood prone areas were digitized using Arc View GIS 3.2. For the purpose of sustainable management of the built environment, the researcher saw the need to concentrate more on four quarters classified as highly prone- Abangoh, Sisia, New layout Nkwen, Ngohmgham and Mulang. These quarters were further broken down into two categories. Category one quarters relate to quarters that have been earmarked for demolition and rehabilitation by the state. These include part of Abangoh, Sisia and New layout Nkwen. These quarters have sudden and localized hazards whose occurrence more often than not provokes the attention of public authority. Category two quarters refers to quarters whose hazards though recurrent appear to vary in nature and are delocalised (Ngohmgham and Mulang). Digitised data of habitat swamps and contour lines were superimposed using geo-informatics layering concept to further concretize this categorization.

Twenty questionnaires were administered to each of the quarters that make up the respective categories. The questionnaires comprised of short structured questions to which respondents were asked to make a choice between “Yes” or “No”. Respondents equally had to provide short answers in some cases for clarification. The responses that ensued were then coded and introduced into statistical packages such as excel and SPSS. In this way some results were obtained, presented in the form of graph; reflecting the actual situation on the ground. From this some recommendations that to lead to an amelioration of the existing situation were given.

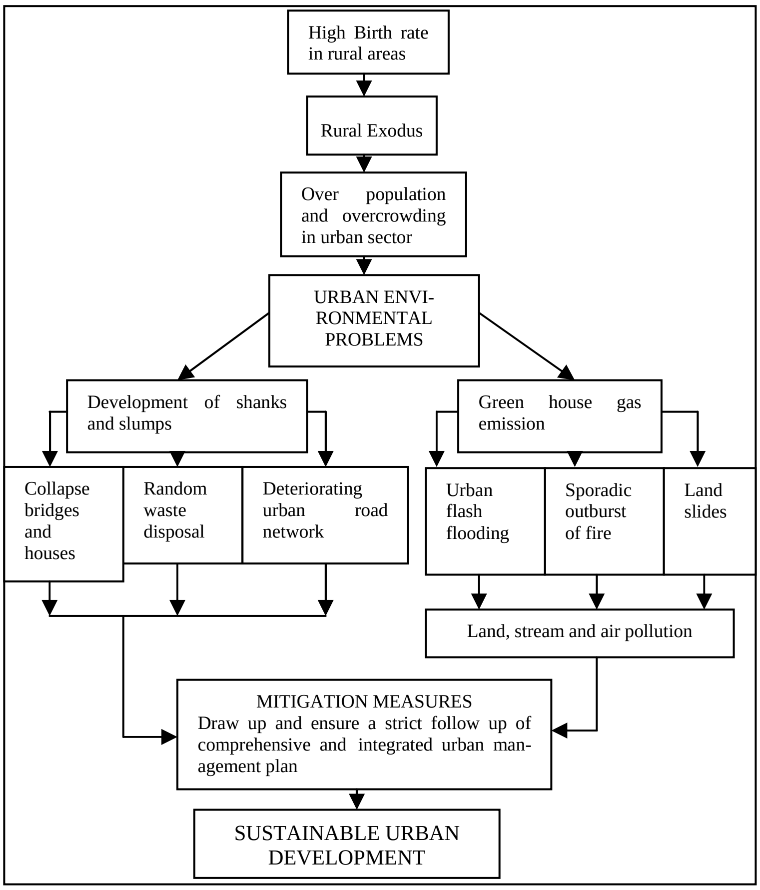


Figure 1. Urbanization and urban environmental problems

Two interviews were held with the indigenes selected from the aging and young folks. This was recorded on a tape recorder with the prime objective of gathering cross generational perspectives about prevailing environmental problems in Bamenda.

6.2 Secondary Sources of Data

Secondary data was gathered through literature review and from data obtained from ministerial delegations operating within the city of Bamenda. Some materials were equally downloaded from the "web of knowledge" data base of Vrije Universiteit Brussels http://www.vub.ac.be/BIBLIO/ubwebsite_database_alpha_en.html#W by using key words such as urban environmental problems and causes of urban growth. The Human Ecology library of Vrije Universiteit Brussels was equally used to collect some information from books.

7. Urban Growth Patterns

7.1 Global Pattern

The 21st century is the Century of the City. Half of the world's population already lives in urban areas and by the middle of this century; most regions of the developing world will be predominantly urban [3]. Cities are perhaps one of humanity's most complex creations, never finished, never definitive. They are like a journey that never ends [3]. Cities drive national economies by creating wealth, enhancing social development and providing employment but they can also be the breeding grounds for poverty, exclusion and environmental degradation.

In some regions of the world, the urban transition occurred decades ago, in the 1950s and 1960s, if not earlier. More than 70 per cent of the populations of Europe, North America and Latin America are already urban; Asia and Africa remain predominately rural, with 40 per cent and 38 per cent of their populations living in urban areas, respectively. However, if current trends continue, half of Africa's population will be urban by 2050. In Asia, the urban transition will occur even earlier, owing to rapid urban growth rates in China, a country that is expected to be more than 70 per cent urban by 2050. Urban growth rates in India will be slower; by 2050, 55 per cent of its population, or 900 million people, will live in cities. Globally, urbanization levels will rise dramatically in the next 40 years to 70 per cent by 2050.

Every day, 193,107 new city dwellers are added to the world's urban population, which translates to slightly more than two people every second [3]. But not all regions are affected by this growth in the same way or on the same scale. In developed nations, the total increase in urban population per month is 500,000, compared to 5 million in the developing world. In terms of absolute numbers, the growth of cities in the developing world is ten times that of cities in the global North. Annually, cities in the developing world grew at a rate of 2.5 per cent in the 1990s, compared to an annual growth rate of 0.3 per cent in the developed world [3].

Harmony in cities cannot be achieved if the price of urban living is paid by the environment. Harmony within cities hinges not only on prosperity and its attendant benefits, but on two pillars that make harmony possible: equity and sustainability.

Migration is necessary for the growth and development of nowadays societies, but also detrimental when rural-urban flows exceed the absorptive capacity of towns, leading to a degraded kind of human settlement called "slum",. Urban growth rates are thus highest in the developing world, which absorbs an average of 5 million new urban residents every month and is responsible for 95 per cent of the world's urban population growth [3]. The problems of poverty and deprivation in rural areas and their spill-over into urban areas cannot be solved by preventing urbanization and keeping rural people confined to rural areas-which would be impossible in any event [4].

7.2 Socio Demographic Characteristic and Spatial Evolution of Bamenda

Bamenda center already stretched beyond Old Town in the early 1980's. This area also known by the name Ntambag II and III experienced a high population bump as was the case with quarters like Azire, Musang, Mougheb and Bayel. GRA was moderately inhabited. The newly occupied areas were amongst others Ntarikon, Nitop, Atuakom, Ngomgham, Ntambesi and Mendankwe. The development of Bamenda happened very quickly over the last two decades. This growth was in every sense profoundly alters the cityscape. From 1982 to 1992, the spatial evolution was in the low density neighbourhoods inhabited in 1982. Accessibility has also played an important role in extending the city Opening Many secondary roads has encouraged the extension of linear habitat around these roads. Since 1992, the urban area of Bamenda has continued to spread in all directions: the north-west it extends to Alamatu, crossing the north-east to Mulanga and Ntenefor to six Nkwen Mile. Ntatru, Atuakom, high Ngomgham, bayel III, IV and Sisia Abangoh. The area now known GRA extension, with part of Mendankwe now incorporated in the urban space.

Table 1. Evolution of population – Bamenda

Years	Population	Growth rate
1976	47.955	
1987	110.692	7.9
1992	148.812	6.04
1997	199.496	4.67
2003	249.489	
2005	298.300	**Projections**
2007	302749	

Source: Adapted from MINDU Bamenda (2007).
P2007 =P97 (1-r/100) n-1, P2005= Population in 2005, P97= Population in 1997, n = number of years in between 1997-2007, r = Population growth rate

8. The Natural Environment of Bamenda

The city of Bamenda was chosen for this study because of the peculiarity of its physical environment on the one hand and its susceptibility to natural hazards on the other. The Bamenda station escarpment has an imposing characteristic has transformed the morphology of Bamenda city. Bamenda could be divided into an upper and lower half. The upper half known as Up-station lies at 1455m above sea level and is host of the administrative and government residential area (GRA). The lower half of Bamenda lies between 1330m above sea level around Sisia quarter to a height of 1200m around Lower Ngomgham quarter. Up-station is separated from down town Bamenda by an abrupt escarpment. This abrupt gradient difference of 255m between Up-station and Lower Ngomgham could permit an easy and steady discharge of runoff into river courses under natural conditions should the natural ecology be left undisturbed by human activities.

9. Results and Discussion

9.1 Land Tenure System

The present state of urban development in Bamenda could best be understood with recur to land administration practices that transcend to colonial days. Most land in sub-Saharan Africa has no registration of who owns it or has rights to use it. Various new initiatives are underway to address this, in the belief that land registration and titling can promote investment, reduce poverty and encourage better natural-resource management [5].

The rapid and unplanned growth of the Bamenda urban space is having huge repercussions on the environment and resource processes in the rural hinterland and on the regional economy in general. Bamenda region provides a good illustration of the impact that urbanization can have on the rural landscape and economy [6].

9.2 Environmental Problems Emanating from Rapid Urbanization

9.2.1 Floods

Natural hazards in the form of flash floods are very common within Bamenda. Given the increased rate at which surfaces are being paved, new houses constructed and stream channels distorted and reduced in width span, flooding now features top on the list of natural hazards within Bamenda. There are a total of 48.8km of tarred primary and secondary roads in Bamenda. In the recent past, floods has taken away scores of souls, damaged roads and buildings and above all other properties of economic value have been reduced to bear zero within the twinkle of an eye.

Although one might argue that from the point of view of earthquake building risk, the system is relatively good, unfortunately it must be noted that there is hardly any building regulation which applies to floods [7]. Inhabitants in certain quarters in Bamenda are beginning to notice failures in their architectural design of their houses.

These areas are built along and across the confluence of a centripetal drainage network that drains all the flood waters generated over the entire city of Bamenda. More than 90% of respondent living within flood affected area declared that they are always afraid of heavy rains and are very willing to quit their present residence for a new one should the government provide them necessary finance and site for them to relocate. Inhabitants are aware of the dangers that come with their living in such flood prone areas but lack the financial and material means to afford for a new site elsewhere. As a coping strategy to the floods in Bamenda, more than 70% of inhabitants within these flood areas have resorted to the putting sand in bags to block advancing water during floods, others use buckets to send out water from homes after flooding while the well to do afford to raise their foundations to an appreciable height that “might” not be attained by flood waters. Some of them even declare: “flood has caused a lot of destruction to our properties, making life a living hell in Bamenda”. The table below shows some of the losses incurred through urban environmental hazards in Bamenda in the recent past.

There were plans by the Bamenda city authority to rehabilitate and raise the height of bridges along major roads axis that are prone to flooding after heavy rains. As if to make things worse, bridges constructed are just a miniature and are still unable handle huge volumes of water after heavy rains. The reasons to this dilemma could be twofold: misappropriation of funds allocated for engineering projects by unscrupulous contractors or an increase tendency of the population to deposit waste into river courses resulting in heavy river load after rains.

Table 2. Impact of environmental hazards emanating from rapid urbanisation: Bamenda

Landslide and mud flow		
Quarters	**Damages**	**Year**
Up-Station	Traffic arrest on major high way for about 24 hours	4th/08/2009
Sisia	One death, two seriously injured	4th/08/2009
Abangoh	Three deaths	2007
Subsidence		
Anindoh	Collapse of bridge on major national highway	7th/08/2009
Floods		
Mulang	Two death	2006
Ngomgham	Houses and properties	Annual
Nitop I	Houses and properties	Annual
Ntamulung, II and III	Houses and properties	Annual
Ntaturu	One death	2007
Mougheb	Swept away 700 bags of 50 kg rice, One death	2007
Azire	Houses and properties	Annual

Source: Field data, 2009

As a consequence of the above, bridges still under rehabilitation are already proving their incapacity to be able to retain the vast volume of water generated from paved surface and roof of buildings after heavy rains.

9.2.2 Subsidence/Collapse of Bridges

Subsidence is very common within quarters like Atuazire. Since 2004, most residents of Atuazire have noticed a progressive up serge of water in the form of spring from underneath their foundations. It has now done on this group of people that the onetime stable pond ecosystem whose bed was filled with soil and rocks of varied texture and resistance could pose as potential hazards during present day more than it was about 20 years ago when this area began noticing a progressive encroachment man and his construction works on this ecologically fragile environment. During a field survey and interview session the researcher could notice tilted imposing cracked walls. Many a building have been brought down as a result of the inability of the underlying clay and cretaceous soil materials that once was under pond conditions to resist huge masses of blocks pilled to appreciable heights.

It has been estimated from field survey that if something is not done and done fast, the number of houses that shall continue to suffer from subsidence within Atu-Azire quarter shall keep increasing with increase rainfall and wetness of the basement rocks.

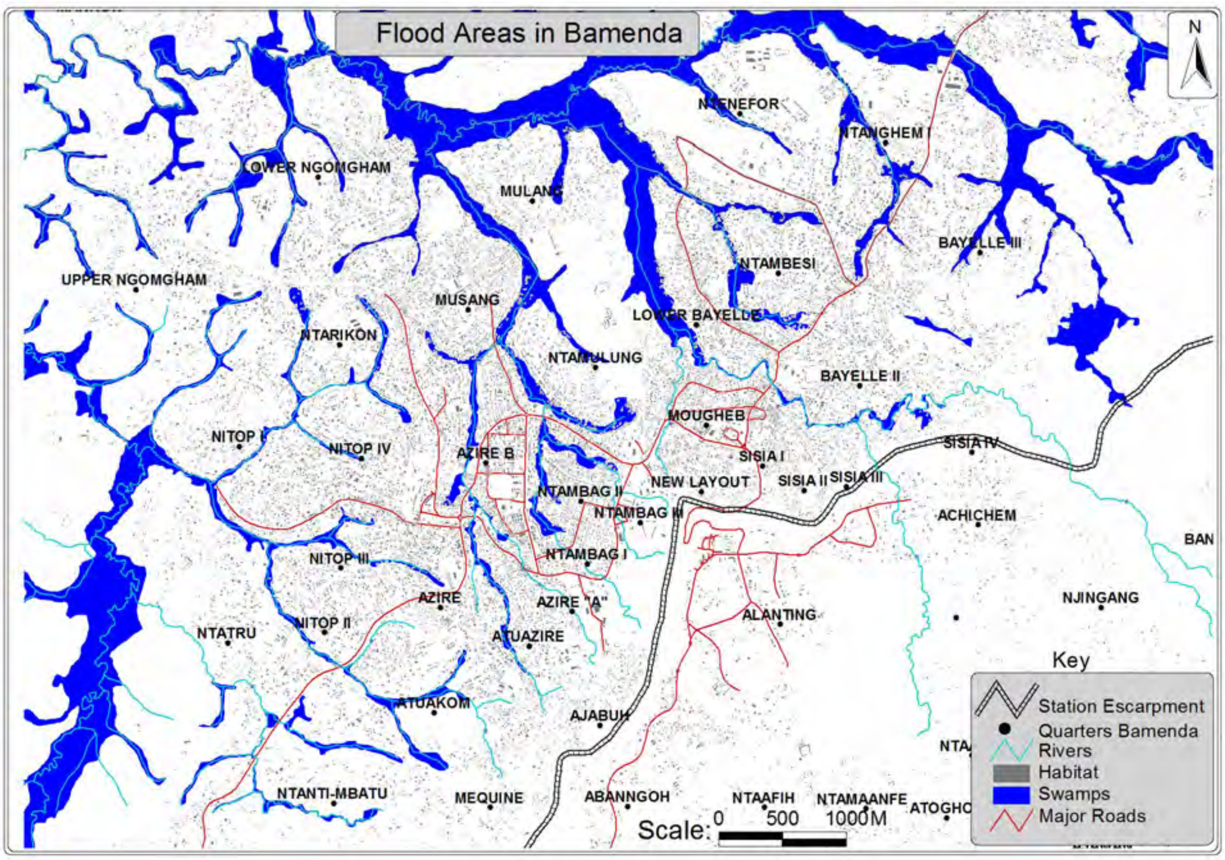


Figure 2. Floods areas in Bamenda

9.2.3 Landslides

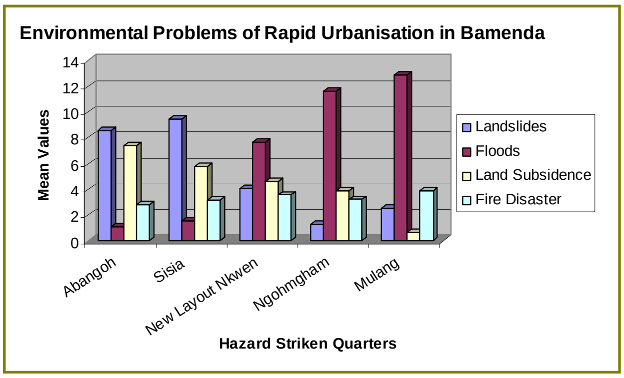
Landslide is fast becoming one of the major environmental problems in Bamenda that come about as a result of the rapid urbanization. Landslide is seen to occur in the heart of the rainy season *i.e.* between the months of July and September with rainfall varying between 340 mm and 450 mm. Landslide in Bamenda is thus provoked by rapid urban development resulting from progressive occupancy of steeper slopes adapted by cutting terrace-like areas and re-distributing materials in order to provide building sites. Heavy rains have the tendency to soak and dislodge large rock masses sometimes resulting in the complete crushing or burial of an entire housing unit.

Mean values were used to represent the results obtained from the questionnaires that were administered to twenty randomly selected respondents in each of the quarters sampled. Respondent identified landslide and land subsidence to be more common in Abangoh and Sisia quarters while flooding was seen to be more common with New Layout Nkwen, Ngohmgham and Mulang quarters (**Figure 3**). In the same vein, fire disaster was identified as an emerging urban hazard in Bamenda with its occurrence more rampant during the dry season periods.

9.2.4 Fire Disaster

Sporadic outbreak of fire especially during the dry season is fast gaining grounds to becoming a very serious environmental problem emanating from rapid urbanization. Statistics from the army rescue unit indicated that the number of fire outbreaks per year has passed from 10 in 2006 to 59 in 2008 (**Table 3** below).

The Kyoto Protocol, the international climate change agreement finalized in Marrakech in 2001 lists six greenhouse gases (or groups of gases) whose emissions signatories to the Protocol agree to reduce. These gases include: Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Fluorocarbons (including hydro fluorocarbons (HFCs) and perfluorocarbons (PFCs)), Sulfur hexafluoride (**SF_6**).



Source: Field data

Figure 3. Urban natural hazards – Bamenda

Table 3. Fire disaster and other urbanization problems

Activity	Years		
	2006	2007	2008
False calls	4	14	12
Fire	10	34	59
Relief victims	24	51	114
Traffic accidents	2	15	19
Assistance to people	4	13	14
Water, gas, and electricity	0	1	0
Protection of property	0	0	3
Drowning	2	4	3

Source: Army rescue unit – Bamenda.

Many of these gases come from natural sources. When fire out breaks thus occurs, there is the release of an appreciable quantity of green house gases into the atmosphere further compounding the phenomenon of climate change which is already being felt within and around Bamenda. CO_2 and other green house gases such as methane and N_2O are released in vast proportions during such incidence.

9.3 The Mystery behind Natural Hazards

The natural environment of Bamenda has been overstressed as a result of high population pressure on land. Environmental hazards provoked by rapid urbanization don't show signs of warning before their outburst. They are all too sudden and their impact on the inhabitants living within and without its area of occurrence cannot be underestimated. The first few days of the month of August *i.e.* 4^{th}–10^{th} August 2009 were characterized by sporadic outburst of natural environmental hazards within the city of Bamenda. Environmental experts will be quick to say Bamenda had exceeded its carrying capacity. Geologists and Geographers will definitely have their own site of the story: there has been the percolation and progressive upwelling of soil top layer due to water accumulation from heavy rains.

Given the uncertainty that looms, we must not forget the fact that the indigenes have their own part of the story. To this effect therefore:

- Major road in the heart of the city linking the Central.
- Business District (CBD) to the administrative centre was attacked by landslide (4^{th} August 2009, **Figure 4**), few day later and about 4 km away from the landslide area, Major bridge linking the North West region to the rest of the country collapsed, 7^{th}

August 2009.

- Within the same days, at the foot of the Bamenda station escarpment, a major landslide occurred killing a child and completely engulfing a housing unit into its bosom.
- As if that were not enough, some major incidence of flooding and destruction of properties were reported in many parts of the city.

The bridge collapse and landslide along the major road axis brought untold suffering to people travelling into and out of the city of Bamenda. This saw the transportation of corpses over and across the natural barriers by porters, people trekked in mud, commercial and private vehicles were grounded because of lack of fuel supply and above all people missed their appointments. These natural environmental hazards drew the attention of both national and international press organs. It then began to done on the people of Bamenda that "*the God's have forgotten them*".

Indigenous people put the blame on engineers for failing to respect and apiece the "Gods" of the land before and after major construction works. In the construction of the backward retaining wall, two anonymous indigenes recounted:

Anonymous indigene aged 29 years:
"Look at that forest over there. That is where the "God's" of this quarter reside. The time has come for the engineers who constructed this backward retaining wall (*Figure* 7) *to know that our God is not someone you can joke with and go scotch free. Before the engineers could begin working on that site we advised them to bring some money and drinks and food for our Gods to be apiece. They hesitated now look at what this is costing them and the government. To site you an example, that this black forest is not a forest to joke with. Some few years back, I was doing laundry in this same stream that has swept away the bridge. I suddenly noticed a sound in the forest. It appeared as if there was something in the forest moving slowly but steadily towards my direction. Little did I know what was happening? I suddenly saw a huge volume of water rushing towards me. That was floods waters from coming from no where since there were no signs of rains around Bamenda on that faithful day. So I think it's high time these engineers involved the local community in the planning of their projects".*

Anonymous indigene aged 71 years:
"I was born in this town and have lived here all my live. The magnitude of the environmental hazards that have occurred during the past couple of days in this city hasn't been equaled by any since I was born. Perhaps it could be because of the high population in this city these days. But all the same we must not forget the fact that the "Gods" of the land need to always be apiece"

If one were to go by the fact that the frequency of environmental hazards in present day Bamenda is on an increase and hasn't been equaled by any in the history of Bamenda, and also by the fact that the population of Bamenda has increased from 110.692 people in 1987 to a projected high of 302749 people by 2007, then one might be tempted to believe that rapid urbanization stimulates the occurrence of environmental hazards. With this in mind therefore the null hypothesis is accepted.

10. Sustainable Cities: Meeting the Millennium Development Goal

The lack of improved sanitation and water facilities are two of the four defining characteristics of urban slums. The others are durable housing and sufficient living area. In 2005, slightly more than one third of the urban population in developing regions lived in slum conditions; in sub-Saharan Africa, the proportion was over 60 per cent [8]. It is particularly ironic that the battle to save the world's remaining healthy ecosystems will be won or lost not in tropical forests or coral reefs that are threatened but on the streets of the most unnatural landscapes on the planet [9]. In today's risk adverse society, communities are expected to identify geo-hazards that affect their existing and planned developments and infrastructure and prepare zoning maps based on these geo-hazards, as part of their infrastructure risk management and emergency response planning [10].

Simple, low-cost interventions to correct these specific

Source: Field data 2009

Figure 4. Landslide on the Bamenda station escarpment

deficiencies would go a long way towards improving the lives of many slums dwellers.

11. Recommendation

Culshaw [11] calls for an enhanced understanding of ground conditions to better define hazard zoning in urban environments, linking hazard, infrastructure and risk, and an improved recognition where mitigation is required. The following key point need to be taken into consideration when drawing up urban management plans in an effort to eradicate the environmental consequences of urbanization in a third world city like Bamenda.

- Develop building and population risk zonation.
- This building risk map from the point of view of reduction, the building risk map highlights the areas where building re-strengthening or demolition works are necessary.
- A system that combines economic incentives (e.g. Lower construction permit fees or annual property taxes) to develop medium-rise housing using particular structural systems together with educational campaigns.
- Government institutions should ensure that the population understands that they are both victims and contributors of environmental problems.
- Architects, urban planners and engineers need to cooperate in order to develop projects that not only fulfill its objectives in terms of flood levels [12] reduction but also consider other needs of local communities and the urban poor.
- Since urban flash flooding is one of the most pressing environmental problems in Bamenda, canals and bridges should be constructed with widening ends and not with tapering ends. Such is an application of urban geomorphology and hydrology to city engineering practice.

The use of distributed storage and on-site control techniques are usually cheaper than traditional approaches of enlargement of the drainage net [13]. In this way, developing countries, where significant investment capability restrictions is a reality, should make an effort to use these kind of solutions more frequently in post-event engineering constructions. One of the proposed actions consists in the possibility of re-urbanization of public squares to work as temporary detention reservoirs. Maps therefore seem to be the chosen interface for transferring information from geomorphologists to engineers and planners [13].

A combination of indigenous approaches to hazard management and technical appraisal by engineers is therefore necessary in the analysis and mitigation of hazards within Bamenda. There is need for a multidisciplinary research and action into the current problems of Bamenda.

12. Conclusions

At the confluence of high birth rate and unplanned/rapid urban development lie the devastating consequences of urban environmental hazards. Such hazards have been seen to be on an increase and the degree and losses both of life and property increase with increase in the proportion of the rural poor who flood the town each day in quest for a better living. There is need for a change of mentality of the Bamenda man towards an awareness that the environment has its carrying capacity and when over stretched could lead devastating respond in an undesirable manner. The time to re-planning and reshaping the urban spatial structures of Bamenda is now if this city is to evade greater catastrophe in the pipeline.

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Comparative Performance and Computational Approach of Humic Acid Removal by Clay Adsorption

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ABSTRACT

The effective removal of humic acid is an important factor influencing the quality of treated waters. Adsorption is one of major techniques used for the removal of humic acid. This study demonstrated that modified clays could be used as alternatives to activated carbons for adsorbing humic acid. Both Al-Fe modified and Fe modified clays had high affinity to humic acid and then high removal efficiency. Al-modified clay had less removal capacity for adsorbing humic acid. Mathematics formulas were developed to predict the adsorption performance of modified clays for the humic acid removal via the parameters of UV_{254} absorbance and DOC concentrations. The optimal clay dose could be predicted using the developed model. The F test was used to validate the model developed by examining if it fells into the reject field. The reject field varied according to each F test. The results showed that the model developed was 99% *confident and can be used to perform the simulation.*

Keywords**:** *Adsorption, Clay, Humic Aid (HA), Mathematics Approach, Modification, Water Treatment*

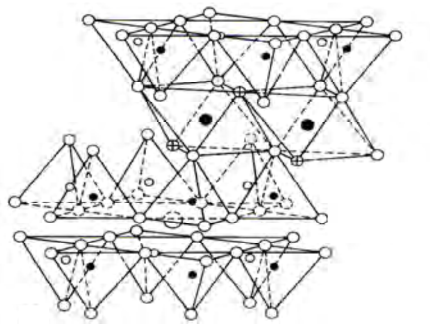
1. Introduction

Humic acid in surface water causes a lot of problems such as colour, taste, odour and lower efficiency in water treatment process. In addition to this, in the chlorination process, humic acid reacts with chlorine and produces disinfection-by-products (DBPs) [1]. The World Health Organization (WHO) has recommended the maximum concentrations of the DBPs and these parameters have been regulated in most countries' environmental agencies. The effective removal of humic acid is thus an important factor influencing the quality of treated waters. Among techniques used for the removal of humic acid, coagulation, adsorption and membrane processes are widely adapted.

Clay is one of the most common earth's minerals, which are the residue of weathering or hypothermal action. The classification and origin of clay depends on particle size, physical characteristics, chemical compositions and common crystal structural characteristics. Clay's size is less than 2 micrometers with plastic properties when moist. Fundamentally, clay exhibits a layered structure and itself can be subdivided into groups according to its underlying structure and layer's charge. An ideal structure of the most rigid clays is the 2:1-layered silicates which can be seen in **Figure 1**. The 2:1 notation means that the host layers consist of two tetrahedral silicate sheets sandwiching one octahedral sheet. The two other subclasses of clays have a 1:1 layer type and a 2:1 inverted ribbon structure, respectively [2]. At the central of the tetrahedral layers are silicon or aluminium ions, while the number of A1 ions in tetrahedral sites determines the net negative charge of the host layer. Those oxygens forming the tetrahedral bases border the interlamellar gallery and are arranged in hexagonal rings that form a kagom´e lattice.

The approximate chemical formula for the verminculites is $(Mg_3(Si_3Al)O_{10}(OH)_2)(Mg_{0.5}(H_2O)_y)$; where the first set of brackets denotes the host layer, the second set denotes the guest layer, and the hydration state is variable. The host layers in clays can adopt a number of interesting stacking arrangements to form ordered, partially ordered, or disordered three-dimensional structures. Particular clays are prone to form poly-types in which different stacking sequences are associated with lateral layer-to-layer shifts.

Overall, natural mineral clays possess specific surface chemical properties, e.g., cation exchange capacity, and adsorptive affinity for some organic and inorganic compounds, and then have attracted research interesting to investigate the potential use of clays as adsorbents for treating heavy metals and organic pollutants, or as coagulant aids for improving the settling performance in coagulating low particle content water. By replacing the



○ Oxygens ● Aluminum ⊕ Hydroxyls
• Silicons replaced by aluminums

Figure 1. Diagrammatic illustration of 2:1 layer lattice (after [2])

natural inorganic exchange cations with alkylammonium ions, clay surfaces are converted from being primarily hydrophilic to hydrophobic, which enable them to interact strongly with organic vapours and organic compounds dissolved in water [3]. Previous studies [4,5] have demonstrated that the polymeric Al/Fe species are the most efficient coagulating/adsorbing chemicals for removing natural and synthetic organic impurities in potable water treatment. The combination of the natural mineral clays with polymeric Al/Fe species may produce somewhat optimal properties and enhance the adsorption of metal and organic compounds from the solution. The feasibility of this idea has been confirmed by preceding work [6–10], where, modified clays had comparatively great affinities for the heavy metals, and phenol and dye structured pollutants.

The aim of this paper is to use modified clays for humic substances removal and to develop a model to forecast the operating conditions based on the experimental results of using modified clay to adsorb humic acid. It is expected that using the developed model, the most efficient outcome of adsorption of humic acid could be predicted.

2. Materials and Methods

2.1 Modifying and Characterising Clays

The raw clay used in this study, montmorillonites KSF, and the other chemicals were supplied by Sigma-Aldrich Chemicals Corporation UK. The modification of clays was following an established procedure [7]. The modification involved with the mixing of the given amount of clays with polymeric metal species for four hours at 55℃ and then the mixtures were separated by filtration to obtain the solid phase of the modified clays. The resulting clays were dried using a freeze dryer (Dry Winner3, HETO Ltd., UK) operating at –0.5MPa and –52℃. The chemical composition of the modified clays were analysed using X-ray Fluorescence (XRF), and the XRF data was collected on a Philips PW1480 XRF Spectrometer.

The clays used in the study were raw montmorillonites KSF (termed as raw clay), poly-aluminium modified montmorillonites KSF (Al-clay), poly-iron modified montmorillonites KSF (Fe-clay) and poly-aluminium and iron modified montmorillonites KSF (Al-Fe-clay).

2.2 Procedures of Adsorption Experiments and Water Quality Measurement

The model water containing humic acid (HA) was prepared using a commercial HA (Fisher, UK), and the HA concentration was 6.5 mg/L, giving UV_{254} abs of 15 1/m and dissolved organic carbon (DOC) concentration 3.2 mg/L as C.

The adsorption experiments were carried out using the batch equilibration technique. For each isotherm, given amount of clay was weighed into 40 mL polypropylene centrifuge tubes, and 30 mL of the above stated HA solution were added. The pH value of HA solution was pre-adjusted to 5. The suspensions were mixed on a rotary tumbler for 4 hours, which has been tested to be sufficient to reach the equilibrium status under the study conditions. After phase separation by centrifugation, the concentration of HA in the supernatant was determined by UV- absorbance at wavelength of 254 nm and DOC analysis. The analytical procedures were following the AWWA standard methods [11]. The adsorbed HA quantities were then determined using the mass balance equation:

$$C_s\, m = V\,(C_0 - C_e)$$

where, C_s is sorbed HA concentration on clay (mg/g), m is the weight of clay used (g), V is volume of HA solution (L), C_0 is HA initial concentration (here expressed as DOC mg/L), and C_e is HA equilibrium concentration (DOC mg/L). Percentage removal of humic acid was calculated based on the original and treated DOC concentrations.

2.3 Mathematical Approach

The regression procedures and the least square method were used to set up a model and to analyze the data. In terms of the experimental results of humic acid removed by clays, a model was developed to forecast humic acid removal efficiency by adsorption with clays. Finnaly, the F test was used to validate the model developed.

3. Results and Discussion

3.1 Characterisation of the Modified Clays

Figure 2 shows an example XRD traces for the modified montmorillonites. The peaks marked by (x) are the d001 reflections indicative of 2:1 swelling clays. The other peaks are impurities corresponding to quartz, plagioclase feldspar, illite and mica. Illite is a non-swelling 2:1 clay, mica is a non-swelling 2:1 phyllosilicate (sheet silicate) mineral and plagioclase is tectosilicate (three dimensional structure similar to zeolite framework).

The XRD results also demonstrated that increase in basal spacing (which is an indication of expanding clay's inter-layers; a high basal spacing value means more inter-layer volume) occurs in the modified montmorillonites but the extents of changes are very different (**Table 1**). The values of d001 basal spacing of Al- or Fe-clays only slightly increased or was different from that of the raw clay but d001 basal spacing of Al-Fe-clay increased markedly. The possible reason for this could be that the single Al or Fe polymeric species have probably undergone subsequent hydrolysis prior to XRD analysis, resulting in partial collapse of the interlayer spacing back to near the original value. However, polymeric aluminium-iron species probably are stable, which results in the larger spacing being retained. However, the d001 basal spacing values alone cannot explain the modification mechanism, which is the exchange of the interlayer Ca^{2+} ions for the polymeric Al or Fe species in solution. The XRF analysis revealed that Ca^{2+} content in the treated clays signifycantly decreased and which is equivalent to 99.5% for the Al- or Fe-clays, and 98.6% for the Al-Fe-clay, indicating that the polymeric Fe or Al species are definitely entering the internal structure of the clays.

3.2 Adsorption of Humic Acid

Tables 2 and **3** show the adsorption of humic acid vs. doses of clays. Al-Fe- and Fe-clays demonstrated superior humic acid removal efficiency when doses were above 400 mg/L. whilst Al-clay did not show good adsorption performance under study conditions. It is well documented that the interaction of iron (III) with humic acid involves complexing, charge neutralization, precipitation and adsorption [12]. Most common pH used for removing humic acid is 4-6 and complexing species is Fe(III), therefore, both Al-Fe-clay and Fe- clay performed superior to Al-clay. The best performance was achieved by Al-Fe clay since the modifier used in this clay is polymeric alumino-iron species, which has been demonstrated to have the highest cationic charge in comparison with other Al/Fe metal species [13].

The superior adsorption performance of modified clays could be attributed to their specific properties; *i.e.*, high hydrophobicity and specific chemical complexation. After modification, the modified clays either became more hydrophobic in nature or increased interactions with functional groups of the humic acid (e.g., carboxyl, hydroxyl and carbonyl). Most possibly, the combination of two mentioned mechanisms can be used to explain the enhanced humic acid adsorption with Al-Fe-clays.

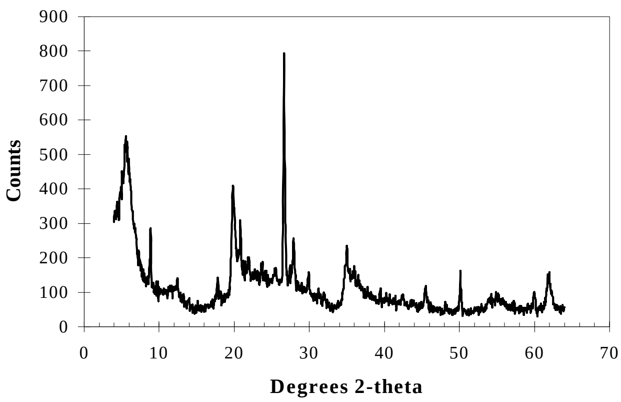


Figure 2. XRD trace of Al_{13}-polycation modified montmorillonite

Table 1. Basal spacing for modified montmorillonites KSF clays

Type of clay	Basal spacing (d001)/Å
Raw clay	15.5
Al-clay	15.3
Fe-clay	15.9
Al-Fe clay	17.8

3.3 Development of Mathematics Models

The following formula (Equation 1) was set up to be fitted with the adsorption operating conditions stated pre-

Table 2. DOC adsorption vs. clay dose

Clay dose (mg/L)	Clay/DOC		
	Al-Fe-	Al-	Fe-
0	3.1	3.2	3.2
200	2.85	2.86	3.47
400	0.16	2.44	0.16
600	0.09	2.30	0.09
800	0.08	2.11	0.09
1000	0.09	1.93	0.10

Table 3. UV_{254} adsorption vs. clay dose

Clay dose (mg/L)	Clay/ $UV_{254\ (m-1)}$		
	Al-Fe-	Al-	Fe-
0	0.252	0.257	0.260
200	0.232	0.230	0.282
400	0.013	0.196	0.013
600	0.007	0.185	0.007
800	0.006	0.169	0.007
1000	0.007	0.155	0.008

viously, *i.e.*, that the Al and Fe have an equally fixed ratio towards clay when they were modified, Al, Fe and clay are independent variables, *i.e.* they won't interfere with each other when performing as adsorbents.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \quad (1)$$

where y represents the remaining DOC or UV_{254} treated by Al-Fe-clay; x1, x2, and x3 represent the remaining DOC or UV_{254} treated by Al-, Fe- and raw clay respectively; β_i are unknown parameters (i=0,1,2,3); ε is the random error item which satisfy:

$$E(\varepsilon) = 0 \text{ and } Var(\varepsilon) = \sigma^2$$

The purpose of the above model is to predict the adsorption performance of either Al-Fe-clay (y) or other clays (x_i). The influence of three factors were considered: Al content, Fe content and raw clay. And the least square method was used to obtain β_i. Take the form

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \varepsilon_i , i = 1,2,3...,n$$

where, $n \geq 3$.

A matrix form was written as follows:

$$Y = (y_1, y_2, ..., y_n)^T$$

$$X = \begin{pmatrix} 1 & x_{11} & x_{12} & x_{13} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & x_{n3} \end{pmatrix}_{n\times 4}$$

$$\beta = (\beta_0, \beta_1, \beta_2, \beta_3)^T$$

$$\varepsilon = (\varepsilon_1, \varepsilon_2, ..., \varepsilon_n)^T$$

Thus, the original equation was written as:

$$Y = X\beta + \varepsilon$$

Compute the parameters. According to the least square method, the estimated vector $\hat{\beta}$ was found which should satisfy:

$$Q(\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2) = \sum_{i=1}^{n}(y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} - \hat{\beta}_2 x_{i2} - \hat{\beta}_3 x_{i3})^2$$

$$= \min_{\beta_0,\beta_1,\beta_2} \sum_{i=1}^{n}(y_i - \beta_0 - \beta_1 x_{i1} - \beta_2 x_{i2} - \beta_3 x_{i3})^2$$

The parameters were then computed by using method from multivariable calculus and were written in the matrix form:

$$X^T(Y - X\hat{\beta}) = 0$$

Since $X^T X$ is a non-singular matrix, thus the formula was obtained to compute β

$$\hat{\beta} = (X^T X)^{-1} X^T Y$$

In real practice, Matlab could be used to compute the above calculation.

For the DOC value,

$\hat{\beta}$ = (-0.1813, 0.0833, 0.8057, 0.1391)^T, and then Equation 2 was obtained,

$$\hat{y}_{DOC} = -0.1813 + 0.0833x_1 + 0.8075x_2 + 0.1391x_3 \quad (2)$$

Similar procedures were applied to UV_{254}-abs removal prediction, or, Equation 3:

$$\hat{y}_{UV} = -0.013 + 0.073x_1 + 0.8072x_2 + 0.1448x_3 \quad (3)$$

Figures 3 and **4** show the remaining DOC concentrations and UV_{254} abs. after clay adsorption via either the experimental and the model simulated data. Both approaches deliver significantly consistent results indicating that the developed model could be used to predict the humic acid adsorption performance by clays.

3.4 Hypothesis Test

The F test was used to validate the model developed, which determines whether y and x_1, x_2 and x_3 are linear correlated at a significant level (alpha equals to 0.01), *i.e.*, whether it is appropriate to represent y with $beta_0$ +

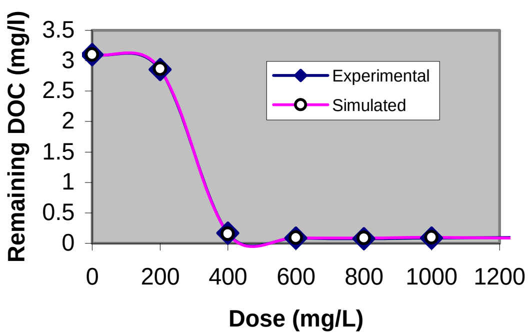


Figure 3. Model simulated and experimental remaining DOC

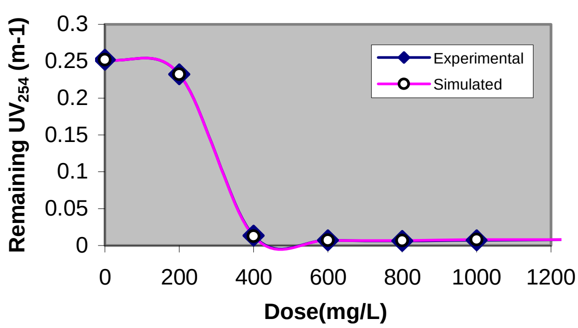


Figure 4. Model simulated and experimental remaining UV_{254}

$beta_1*x_1 + beta_2*x_2 + beta_3*x_3$ with the confidence level of 99%. The F value is examined to see if it fells into the reject field. If it is, the developed model is wrong, and has to be reconstructed. The reject field varies according to each F test.

As shown in the following equations, that the F test needs three components to locate, which are 0.01, 4 and 3, respectively. The 0.01 means the confident level (equals to 99%), 4 and 3 are the degree of freedom which are set due to the data numbers. 16.69 stands for the reject field (obtainable from the table provided with statistics books). If the F value computed is less than 16.69, then the hypothesis that original model is correct would be rejected. As the F value in this case is greater than 16.69 (Equations 4 and 5), it means that the developed model was 99% in confidence (with the coefficients $beta_0$ - $beta_3$ are not all zero) for its accuracy, and can be used to simulate and predict the adsorption performance.

$$H_0 : \beta_0 = \beta_1 = \beta_2 = \beta_3 = 0 \quad \text{Versus}$$
$$H_1 : (\beta_0, \beta_1, \beta_2, \beta_3) \neq (0,0,0,0)$$

$$S_T = l_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2 = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 + \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$
$$= S_R + S_E$$

$$F = \frac{\frac{S_R}{4}}{\frac{S_E}{n-4-1}} \sim F(4, n-4-1)$$

$$F_{UV_{254}} = 26322.29 > F_{0.01}(4,3) = 16.69 \tag{4}$$

$$F_{DOC} = 7748.875 > F_{0.01}(4,3) = 16.69 \tag{5}$$

So H_0, was rejected and the parameters can be fit to the model significantly at the 99% confidence.

The developed models were verified, and then they can be used to predict that when the clays' doses are about 400~600 mg l^{-1}, the overall adsorption of UV_{254} and DOC could reach to the maximum. Furthermore, if the remaining UV_{254} or DOC could be known, the outcome of Al-Fe modified clay at the same dose level could be forecasted.

4. Conclusions

This study demonstrated that modified clays could be used as alternatives to activated carbons for humic acid removal. Both Al-Fe modified and Fe modified clays have high affinity to humic acid and then high removal efficiency. Al-modified clay has less removal capacity for adsorbing humic acid. Higher d-spacing values of Al-Fe modified and Fe modified clays could explain such phenomena.

Mathematics formulas were developed to predict the adsorption performance of modified clays for the humic acid removal via the parameters of UV254 absorbance and DOC concentrations. The optimal clay dose could be predicted using the developed models.

The F test was used to validate the model developed by examining if it fells into the reject field. The reject field varied according to each F test. The results showed that the model developed was 99% confident and can be used to perform the simulation.

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Assessment of Groundwater Quality and its Suitability for Drinking and Agricultural Uses in the Oshnavieh Area, Northwest of Iran

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ABSTRACT

The Oshnavieh plain is part of the West Azarbaijan province, which is located; 100 *km south of Urmia City, northwestern of Iran, and its groundwater resources are developed for water supply and irrigation purposes. In order to evaluate the quality of groundwater in study area,* 31 *groundwater samples were collected and analyzed for various parameters. Physical and chemical parameters of groundwater such as electrical conductivity, pH, total dissolved solids, Na, K, Ca, Mg, Cl,* HCO_3, CO_3, SO_4, NO_3, NH_3, PO_4, *Fe, F were determined. Chemical index like percentage of sodium, sodium adsorption ratio, and residual sodium carbonated, permeability index (PI) and chloroalkaline indices were calculated. Based on the analytical results, groundwater in the area is generally fresh and hard to very hard. The abundance of the major ions is as follows:* $HCO_3 > SO_4 > Cl$ *and* $Ca > Mg > Na > K$. *The dominant hydrochemical facieses of groundwater is* Ca-HCO_3 *and* Ca-Mg-HCO_3 *type. According to Gibbs diagrams samples fall in the rock dominance field and the chemical quality of groundwater is related to the lithology of the area. The results of calculation saturation index by computer program PHREEQC shows that the nearly all of the water samples were saturated to undersaturated with respect to carbonate minerals and undersaturated with respect to sulfate minerals. Assessment of water samples from various methods indicated that groundwater in study area is chemically suitable for drinking and agricultural uses. Fluoride and nitrate are within the permissible limits for human consumption and crops as per the international standards.*

Keywords**:** *Groundwater Quality, Hydrochemistry, Hydrogeology, Oshnavieh Plain, Water Type*

1. Introduction

Understanding the aquifer hydraulic properties and hydrochemical characteristics of water is crucial for groundwater planning and management in the study area. Generally, the motion of groundwater along its flow paths below the ground surface increases the concentration of the chem. ical species [1–3]. Hence, the groundwater chemistry could reveal important information on the geological history of the aquifers and the suitability of groundwater for domestic, industrial and agricultural purposes. Moreover, pumping tests with the drilling results are the most important information available for the groundwater investigations, as they are the only methods that provide information on the hydraulic behavior of wells and reservoir boundaries [4,5].

Hydrochemical evaluation of groundwater systems is usually based on the availability of a large amount of information concerning groundwater chemistry [6,7]. Quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes [8,9]. Groundwater chemistry, in turn, depends on a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water and inputs from sources other than water-rock interaction. Such factors and their interactions result in a complex groundwater quality [1,10,11]. The rapid increase in the population of the country has led to large scale groundwater developments in some areas. Intense agricultural and urban development has caused a high demand on groundwater resources in arid and semi-arid regions of Iran while putting these resources at greater risk to contamination [12–14]. Groundwater is an important water resource for drinking, agriculture and industrial uses in study area. In this study, physical, hydrogeologic, and hydrochemical data from the groundwater system will be integrated and used to determine the main factors and mechanisms controlling the chemistry of groundwater in the area. The relationship between groundwater flow, hydrogeologic properties and hydrochemistry has been studied by many researchers [2,15, 16]. The chemical quality of groundwater is related to the lithology of the area.

The Oshnavieh aquifer is part of the Gedar river drainage basin and lies between latitudes 36°,57′ to 37°,05′ N and longitudes 45°,01′, to 45°,15′ E. Oshnavieh plain covers an area of 120 km^2 and average elevation is 1450 m a.s.l. (**Figure 1**). The Gedar river basin covers approximately 2010 km^2 and river flow direction is almost west-east with utmost discharges into the Urmia lake. The most important drainage feature of the study area is the Oshnavieh, Nilvan and Sheykhan rivers. The area has a cold temperate climate and the air temperature is highest in August (26.7℃) and lowest in January (–1℃) with an annual average of 13.3℃. The climate of the study area is semi-arid and it's average annual rainfall is about 422 mm, which 70% of it falls during the spring and winter seasons. The most important economic activity in the area is agriculture, with the chief crops being beet, wheat and pea.

2. Materials and Methods

Groundwater samples were collected from 31 shallow and deep wells and springs of the area during May 2006. The location of sampling points is shown in **Figure 4**. The pH and electrical conductivity (EC) were measured using digital conductivity meters immediately after sampling. Water sample collected in the field were analyzed in the laboratory for the major ions (Ca, Mg, Na, K, HCO_3, CO_3, SO_4, Cl), nitrate, phosphate, ammonia, iron and fluorine using the standard methods as suggested by the American Public Health Association [17]. Sodium (Na) and Potassium (K) were determined by flame photometer. Total hardness (TH) as $CaCO_3$, Calcium (Ca^{2+}), carbonate (CO_3), bicarbonate (HCO_3) and chloride (Cl) were analyzed by volumetric methods. Magnesium (Mg) was calculated from TH and Ca contents. Sulfates (SO_4) were estimated using the colorimetric technique. Nitrate (NO_3), phosphate (PO_4), ammonia (NH_3), iron (Fe) and fluorine (F) were determined by spectrophotometer. The saturation indexes were determined using the hydrogeochemical equilibrium model, Phreeqc for Windows [18].

3. Results and Discussion

3.1 Geological and Hydrogeological Stting

From a geological point of view, the investigated area is located in the Khoy-Mahabad zone of the Iran [19]. Igneous, metamorphic and sedimentary rocks of different age's crop out in the basin and range in age from Percambrian to Quaternary. Precambrian sedimentary rocks consist of green to grey shale and siltstone. Cambrian formations in study area chiefly comprise crystalline limestone, siltstone, sandstone and dolomite in alternation with dark shale. The Ophiolite formation consists of crystallized limestone and shale with serpentinized ultramafic rocks, spite and some schist [20]. Igneous rocks of late Cretaceous age outcrop in many mountain and

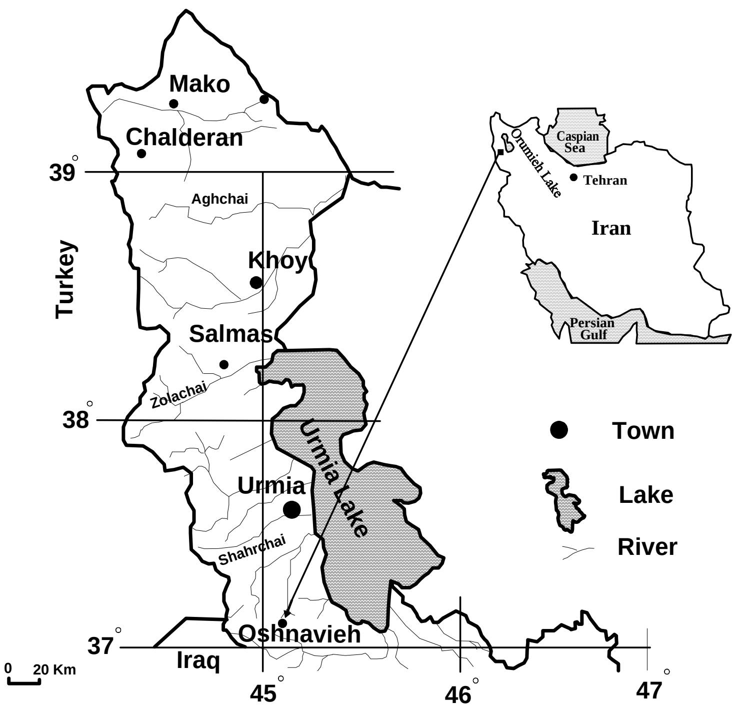

Figure 1. Location of study area in iran

including biotite granite, muscovite garnet granite, diorite, monzodiorite and granodiorite. The Quaternary sediments consist of alluvial sandy gravel, alluvial fan consists of a clay, silt, sand, gravel and clearly sand. The thickness of this major aquifer increases from the fan deposits in the west towards the middle and southeast side of plain. **Figure 2** shows the distribution of the outcropping rock formations in the study area. The basin is tectonically active and the most important structure that affected the geology of the Oshnavieh basin was the Aghbolag, Kandvola and Shivehbro fault system. The exposed lithological units of the Oshnavieh plain range in age from Precambrian to Quaternary and have different hydrogeological characteristics (**Figure 2**). The stratigraphic succession of study area shows in **Table 1**. The units of similar hydrogeological characteristics are summarized in **Table 1** and qualitatively grouped as impermeable, semi-permeable and permeable.

In the study area, the Eocene Formations and intrusive rocks are impermeable, and the Cambrian formations (Zaigun, Lalum and Barut Formation) and Precambrian Formations (Kahar Formation) are semi-permeable. The Ruteh Formation, alluvium and old terraces are permeable [21].

Table 1. Stratigraphic relations of the geologic units in the study area showing hydrogeologic properties

Age	Unit	Lithology	Hydrogeologic properties
Cenozoic	Recent alluvium Young alluvium Old terraces	Gravel, Sand, Clay, Sandy clay and clearly sand	Permeable
Eocene	Ophiolite	Limestone, Shale, Spilite, Schist and Serpentinite	impermeable
Permian	Ruteh Formation	Limestone and Shale	Permeable
Cambrian	Zaigun, Lalum and Barut Formation	Siltstone, Sandstone, Shale, Limestone and dolomite	semipermeable
Precambrian	Kahar Formation	Schist, shale and siltstone	semipermeable
		Granite, Grano diorite, Amphibolite and diabaz	impermeable

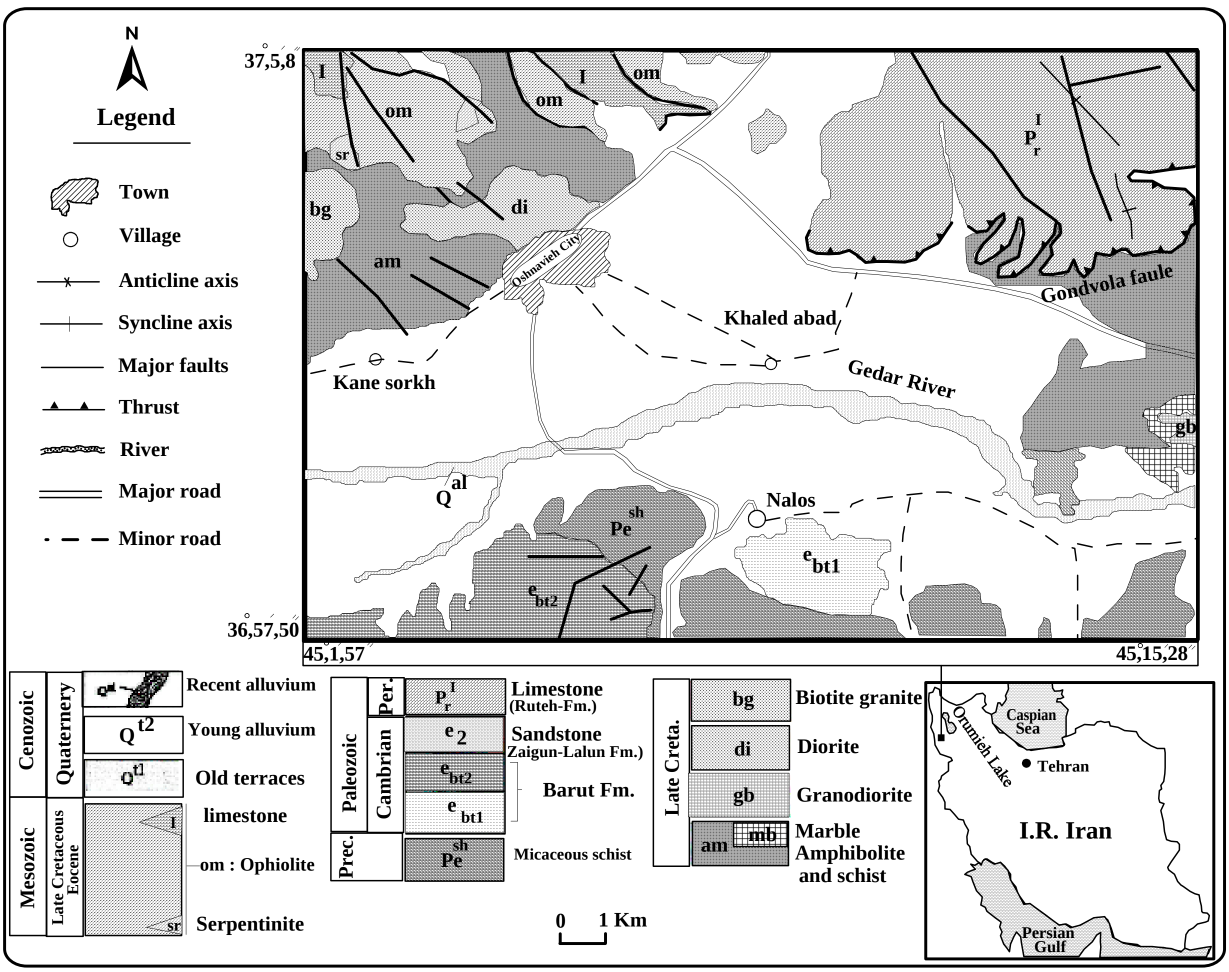

Figure 2. Location of study area showing geology and hydrogeology units

Oshnavieh aquifer is occurred in Quaternary sediments, which are distinguished by horizontal and vertical exchange of various lithological units. It is composed of Pleistocene and Holocene gravel-sand sediments and with silt-clay interbreeds. From field work and observations, groundwater occurs in the study area in two main water-bearing layers, a lower confined aquifer and an upper unconfined aquifer. Groundwater recharge is from rainfall. In the study area groundwater is an important source for domestic water supply. Groundwater and surface water of Gedar rivers use for agriculture uses. According to Azarbaijan Regional Water Authority [22], 122 deep and 253 shallow active pumping wells operate in the aquifer. The water abstraction from the Oshnavieh aquifer during the 2003-2004 is about 30.738 million m^3 and presented in **Table 2**. The hydraulic properties of Oshnavieh aquifer was determined using pumping tests data. The Oshnavieh aquifer is characterized by transmissivity that varies from 500-3000 m^2/day and specific yield of about 3×10^{-2} [22]. One of the main imperative approaches for the identification of groundwater flow directions is the water level contour map, which has been used as a basis for evaluating groundwater recharge. Hence, water heads in meters above sea level (a.s.l.) in each piezometr were used to construct the piezometric surface contour map using the Surfer Software. The groundwater level contour map shown on **Figure 3** summarizes the distribution of piezometric head in the aquifer system within the study area. The general groundwater flow direction in the aquifer is from W to E, and depth to water table varies from 1.8 to 24.75 m below ground level (**Figure 4**). Seasonal groundwater level fluctuations indicate that the water table tends to rise during November and April to reach peak in May and declines from January onwards to reach minimum in September [21].

3.2 Groundwater Chemistry

The chemical composition of groundwater results from the geochemical processes occurring as water reacts with the geologic materials which it flows [23]. The water quality analyses included all major anions, cations, nitrate, phosphate, ammonia, iron and fluorine. The allover groundwater pH and electrical conductivity (EC) values of the study area are ranging from 7.1 to 8.4 and 290 to 990 μS cm^{-1}, respectively. Total dissolved solids (TDS) in the study area vary between 182 to 582 mg/l. The groundwater in the study area falls under fresh (TDS < 1, 000 mg/l) types of water [2]. The total hardness (as $CaCO_3$) ranges from 125 to 448 mg/l.

Table 2. Total Abstraction from Groundwater and springs during 2004

Water Resource	Num.	Min.Discharge(lit/s)	Max.Discharge(lit/s)	Annual Discharge(MCM)	Agricultural uses (MCM)	Drinking uses (MCM)
Springs	23	1.5	35	6.927	6.341	0.585
Wells	375	2.4	44	23.811	19.26	4.55
Total	893	-	-	30.738	25.601	5.135

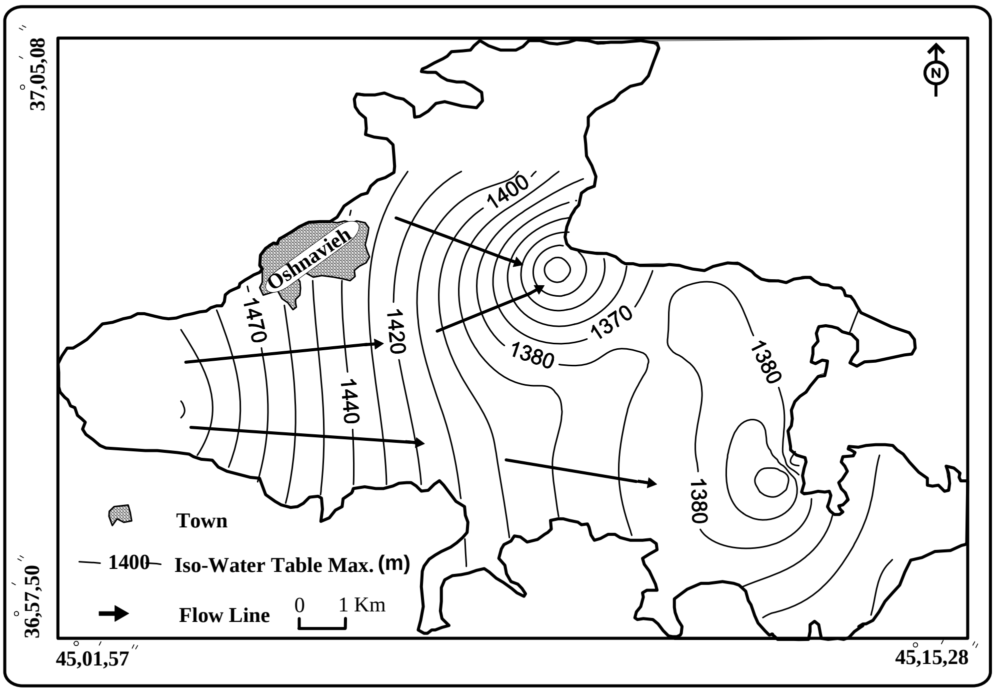

Figure 3. Groundwater level contour map of the aquifer system in the Oshnavieh plain (in meters above mean sea level)

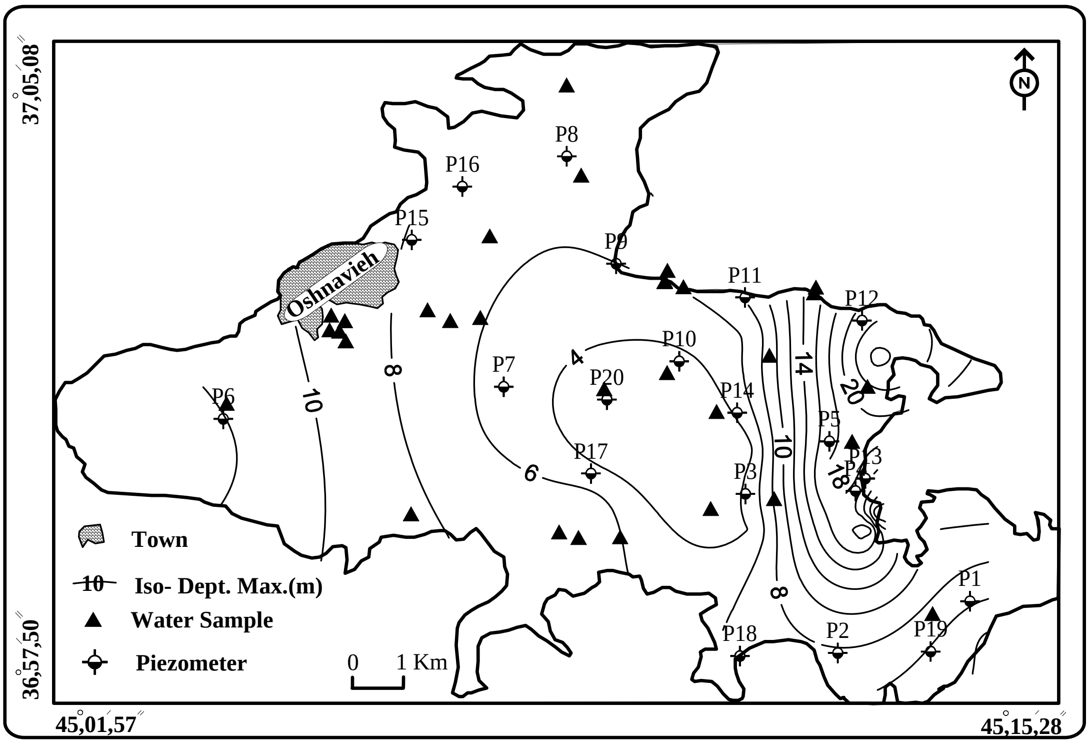

Figure 4. Depth groundwater contour map of the aquifer system in the Oshnavieh plain (in meters below ground level) and location of groundwater samples

In the study area, the Na and K concentrations in groundwater range from 2 to 52 and 0 to 11.7 mg/l, respectively. The concentrations of calcium range from 20 to 142 mg/l, which is derived from calcium rich minerals like feldspars, pyroxenes and amphiboles. The major source of magnesium (Mg) in the groundwater is due to ion exchange of minerals in rocks and soils by water. The concentrations of Mg and HCO_3 ions found in the groundwater samples of study area are ranged from 12–51 and 140 to 506 mg/l respectively. The concentration of chloride ranges from 3.5 to 43 mg/l and increases from the recharge to discharge area. Sulfate varies from 8 to 48 mg/l. The nitrate concentration in May 2006 groundwater samples range from 8 mg/l to 62 mg/l with an average value of 16.6 mg/l. The source of nitrate in area is N fertilizers (commonly urea, nitrate or ammonium compounds) that are used for agricultural practices. Fluoride is one of main trace elements in groundwater, which generally occurs as a natural constituent. Bedrock containing fluoride minerals is generally responsible for high concentration of this ion in groundwater [24,25]. The concentration of fluoride in groundwater of the study area varies between 0.11-0.42 mg/l during May 2006 with an average value of 0.22 mg/l and all samples groundwater in study area are suitability for drinking. **Figure 5** shows that Ca, Mg and HCO_3 are dominant cations and anion, respectively. A further illustration of this is shown in **Figure 5** where the median values of HCO_3 exceeded 50% of total anions in milli-equivalent unit. The abundance of the major ions in groundwater is in following order: Ca > Mg > Na > K and $HCO_3 > SO_4 > Cl > NO_3 > CO_3$. Minimum, maximum and average values of physical and chemical parameters of groundwater samples are presented in **Table 3**. The concentration of dissolved ions in groundwater samples are generally governed by lithology, nature of geochemical reactions and solubility of interaction rocks. The functional sources of dissolved ions can be broadly assessed by plotting the samples, according to the variation in the ratio of Na/(Na+Ca) and $Cl/(Cl+HCO_3)$ as a function of TDS [26]. The Gibbs plot of data from study area (**Figure 6**) indicates that rock is the dominant processes controlling the major ion composition of groundwater.

3.3 Saturation Index

Saturation indexes are used to evaluate the degree of equilibrium between water and minerals. Changes in saturation state are useful to distinguish different stages of hydrochemical evolution and help identify which geochemical reactions are important in controlling water chemistry [27–29]. The saturation index of a mineral is obtained from Equation (1) [30].

Table 3. Minimum, maximum and average values of physical and chemical parameters of groundwater samples

Parameters	Units	Minimum	Maximum	Average
pH	-	7.1	8.4	7.52
EC	S/cmμ	290	910	592
TDS	mg/l	182	582	374
Na	mg/l	2.63	34.78	7.14
K	mg/l	0	11.7	1.91
Ca	mg/l	20	142	45.16
Mg	mg/l	12	51	25.9
Cl	mg/l	3.5	43	17.97
HCO_3	mg/l	140	506	297.6
CO_3	mg/l	0	60	2.1
SO_4	mg/l	8	48	23.75
TH	mg/l	125	448	294
SAR	-	0.074	1.8	1.25
%Na	%	2.63	34.78	7.14
RSC	meq/l	–2.93	2.3	–1.01
PI	%	30	66	42.9
CAI,1	meq/l	–0.7	0.64	–0.33
CAI,2	meq/l	–0.44	0.37	–0.18
$SI_{calcite}$	-	–0.82	0.12	–0.24
$SI_{dolomite}$	-	–1.84.	–0.12	–0.62
SI_{gypsum}	-	–2.82	–1.77	–2.26
$SI_{anhydrate}$	-			

EC: Electrical conductivity
TDS: Total dissolved solids
TH: Total hardness
SAR: Sodium adsorption ratio
RSC: Residual sodium carbonate
PI: Permeability index
CAI: Chloro alkaline index
SI: Saturation index

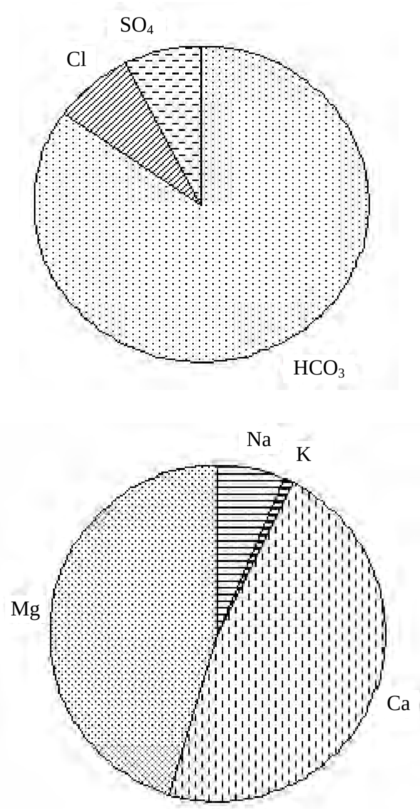

Figure 5. Pie diagram of median values of major ions

$$SI = \log (IAP/Kt) \quad (1)$$

where IAP is the ion activity product of the dissociated chemical species in solution, Kt is the equilibrium solubility product for the chemical involved at the sample temperature. An index (SI), less than zero, indicate that the groundwater is undersaturated with respect to that particular mineral. Such a value could reflect the character of water from a formation with insufficient amount of the mineral for solution or short residence time. An index (SI), greater than zero, specifies that the groundwater being supersaturated with respect to the particular mineral phase and therefore incapable of dissolving more of the mineral. Such an index value reflects groundwater discharging from an aquifer containing ample amount of the mineral with sufficient resident time to reach equilibrium. Nonetheless, super saturation can also be produced by other factors that include incongruent dissolution, common ion effect, and evaporation, rapid increase in temperature and CO_2 exsolution [23,29]. In **Table 2** the SI for calcite, dolomite, anhydrate and gypsum are shown. **Figure 7** shows the plots of SI against TDS for all the investigated water. Nearly all water samples were saturated to undersaturate with respect to calcite, dolomite and aragonite and all samples undersaturated with respect to gypsum and anhydrite, suggesting that these carbonate mineral phases may have influenced the chemical composition of the study area. In Ca-HCO_3 water type the

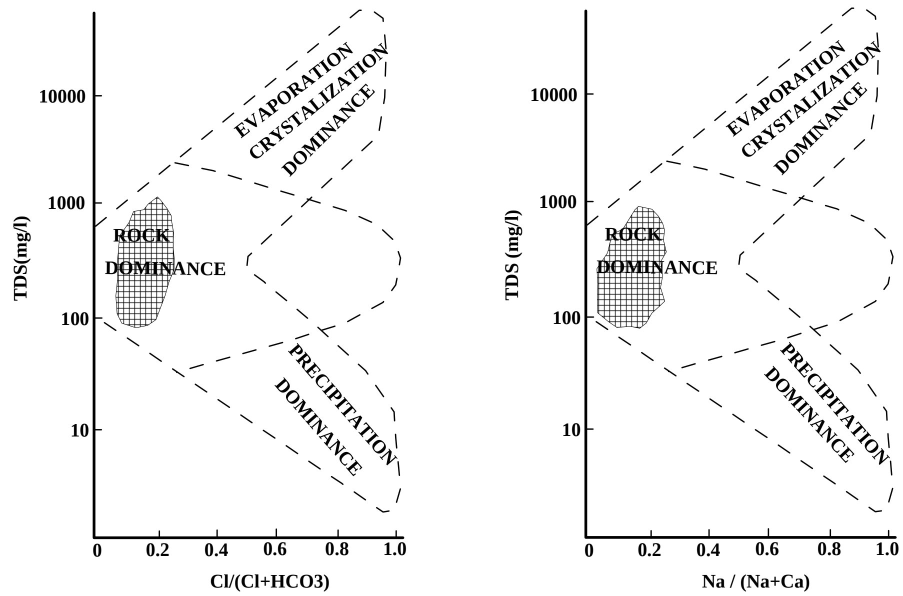

Figure 6. Mechanisms governing groundwater chemistry (after gibbs, 1970)

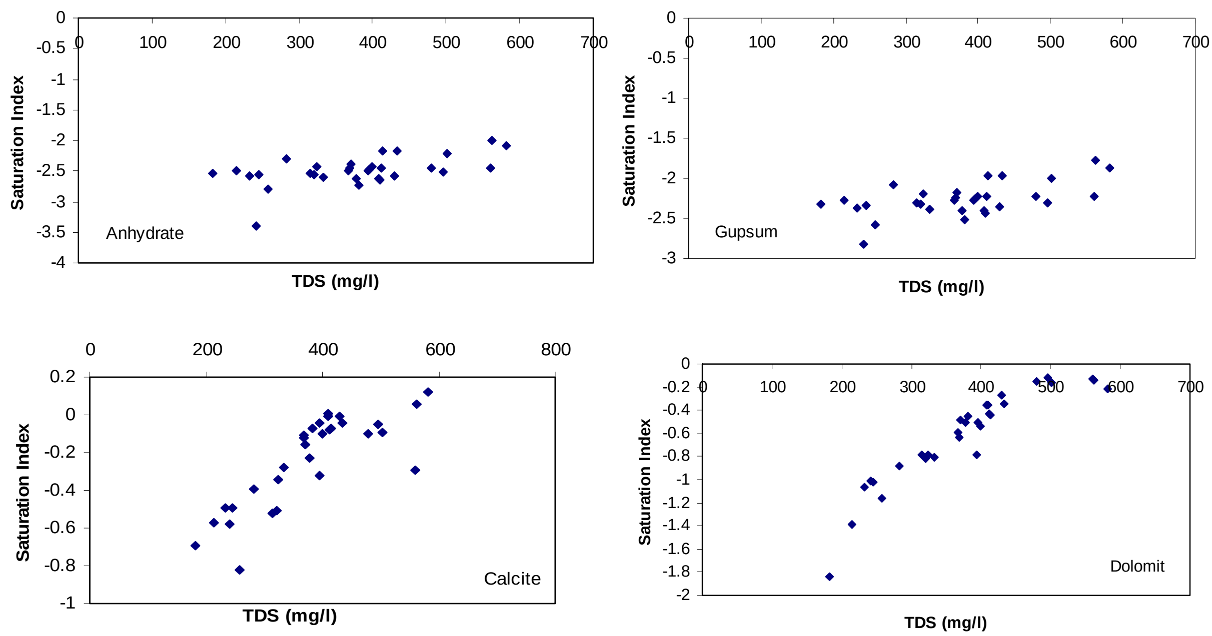

Figure 7. Plots of saturation indexes with respect to some carbonate minerals against total dissolved solids (TDS)

mean values of SI_{cal} , SI_{dol} , SI_{gyp}, SI_{anhy} are –0.24, –0.617, –2.26 and –2.49, respectively.

3.4 Hydrochemical Facies

The values obtained from the groundwater samples analyzing, and their plot on the Piper's diagrams [31] reveal that the dominant cation is Ca and the anion is HCO_3. In the study area, the major groundwater type is Ca-HCO_3 and Ca-Mg-HCO_3 (**Figure 8**). Chadha [32] has proposed new diagram for geochemical data presentations. The proposed diagram is a modification of Piper diagram with a view to extend its applicability in representing water analysis in the possible simplest way. Results of analyses were plotted on the proposed diagram to test its applicability for geochemical classification of groundwater and to study hydrochemical processes (**Figure 9**). The plot shows that all of the groundwater samples fall under the subdivision of alkaline earths exceeds alkali metals and weak acidic anions exceed strong acidic anions (Ca-Mg-HCO_3water type).

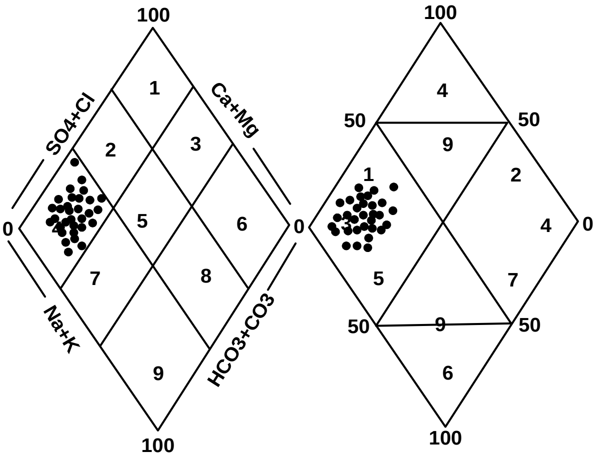

Figure 8. Chemical facies of groundwater in piper diagram

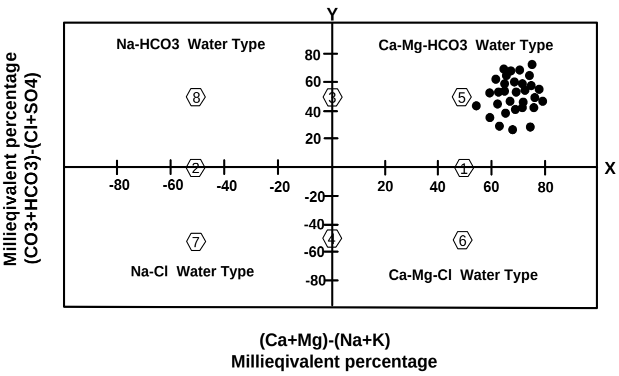

Figure 9. Diagram showing geochemical classification and hydrochemical parameters of groundwater (after chadha, 1999)

3.5 Drinking and Irrigation Water Quality

The analytical results have been evaluated to ascertain the suitability of groundwater of the study area for drinking and agricultural uses. The drinking water quality is evaluated by comparing with the specifications of TH and TDS set by the World Health Organization [33,34]. According to WHO specification TDS up to 500 mg/l is the highest desirable and up to 1500 mg/l is maximum permissible (**Table 4**). Based on this classification, 87% of samples are belonging to highest desirable category and remaining samples are belonging to maximum permissible category. The hardness values range from 125 to 448 mg/l during May 2006. The classification of groundwater based on total hardness [35] (**Table 5**) shows that 59% of the groundwater samples fall in the very hard water category, 35% hard category and remaining samples fall in moderately hard category(**Table 5**). Maximum allowable limit of TH for drinking is 500 mg/l and the most desirable limit is 100 mg/l as per the WHO international standard. Based on this classification it indicates that all of the groundwater samples are not exceed the maximum allowable limits.

Table 4. Groundwater samples of the study area exceeding the permissible limits prescribed by WHO for drinking purposes

Parameters	WHO international standard (1971, 1983)		
	Most desirable limits	Maximum Allowable limits	Amount in Groundwater samples
PH	7–8.5	9.2	7.1–8.4
TDS(mg/l)	500	1500	182–582
TH(mg/l)	100	500	125–448
Na(mg/l)	-	200	2–52
Ca(mg/l)	75	200	20–142
Mg(mg/l)	50	150	12–51
Cl(mg/l)	200	600	3.5–43
SO_4(mg/l)	200	400	8–48
NO_3(mg/l)	45	-	8–62
NH_3(mg/l)	0.05	0.5	0–0.05
F(mg/l)	-	1.5	0.115–0.425
Fe(mg/l)	0.1	1	0–0.141

Table 5. Suitability of groundwater based on hardness

Total hardness as $CaCO_3$(mg/l)	Water class
<75	Soft
75–150	Moderately hard
150–300	Hard
>300	Very hard

Salinity and indices such as, sodium absorption ratio (SAR), sodium percentage (Na %), residual sodium carbonate (RSC), and permeability index (PI) are important parameters for determining the suitability of groundwater for agricultural uses [36,37]. Electrical conductivity is a good measure of salinity hazard to crops as it reflects the TDS in groundwater. The US Salinity Laboratory [38] classified ground waters on the basis of electrical conductivity (**Table 6**). Based on this classification, 16% of samples are belonging to the doubtful category and 84% to good category. Sodium adsorption ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops [9]. SAR is defined by

Table 6. Classification of groundwater for irrigation based on EC, SAR

Quality of water	Electrical conductivity (S/cm)	Sodium adsorption ratio(SAR)
Excellent	<250	<10
Good	250–750	10–18
Doubtful	750–2250	18–26
Unsuitable	>2250	>26

Karanth [39] as Equation (2).

$$SAR = Na/[(Ca+Mg)/2]^{1/2} \quad (2)$$

where all ionic concentrations are expressed in meq/l. The SAR values range from 0.074 to 1.84 and according to the Richards [40] classification based on SAR values (**Table 6**), all of samples are belong to the excellent category. SAR can indicate the degree to which irrigation water tends to enter into cation-exchange reactions in soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure and becomes compact and impervious [37]. The analytical data plotted on the US salinity diagram [40] illustrates that 77% of the groundwater samples fall in the field of C2S1, indicating medium salinity and low sodium water, which can be used for irrigation on all types of soil without danger of exchangeable sodium (**Figure 10**). The sodium percent (%Na) is obtained by the Equation (3).

$$\%Na = [Nark] \times 100/[Ca+Mg+Na+K] \quad (3)$$

where all ionic concentrations are expressed in meq/l.

The Wilcox [41] diagram relating sodium percentage and total concentration shows that %26 of the groundwater samples fall in the field of good to permissible and 74% of the groundwater samples fall in the field of excellent to good for irrigation (**Figure 11**).

Residual sodium carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose and has been determined by the Equation (4).

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad (4)$$

where all ionic concentrations are expressed in meq/l [42]. The classification of irrigation water according to the RSC values is waters containing more than 2.5 meq/l

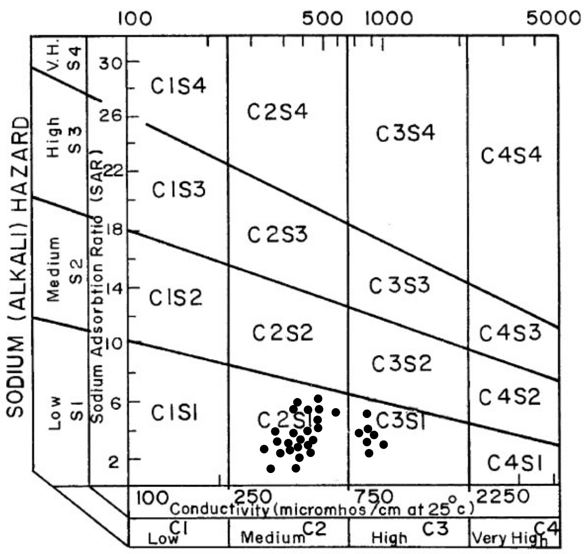

Figure 10. Rating of groundwater samples in relation to salinity and sodium hazard

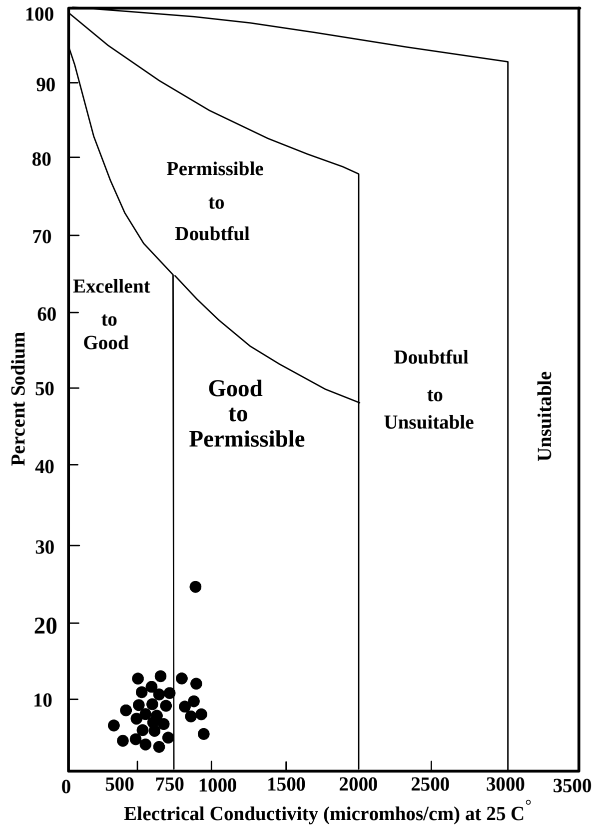

Figure 11. Rating of groundwater samples on the basis of electrical conductivity and percent sodium (after wilcox, 1955)

of RSC are not suitable for irrigation, while those having –2.93 to 2.3meq/l are doubtful and those with less than 1.25 meq/l are good for irrigation. Based on this classification, all of groundwater samples belong to the good category except one sample. The permeability index (PI) values also indicate that the groundwater is suitable for irrigation. It is defined as follows (Equation (5))

$$PI = 100 \times [([Na]+[HCO_3]^{1/2})/[Na]+[Ca]+[Mg] \quad (5)$$

where all the ions are expressed in meq/l [44]. WHO [45] uses a criterion for assessing the suitability of water for irrigation based on permeability index. The PI range from 30% to 66% and the average value is about 43% during May 2006. According to PI values, the groundwater of in the study area can be designated as class II (25–75%) that shows the groundwater in study area is suitable for irrigation purposes.

3.6 Chloroalkaline Indices (CAI)

It is essential to know the changes in chemical composition of groundwater during its travel in the sub-surface [45]. The Chloro-alkaline indices CAI 1, 2 are suggested by Schoeller [46], which indicate the ion exchange between the groundwater and its host environment. The

Chloro-alkaline indices used in the evaluation of Base Exchange are calculated using the Equations (6,7).

1) Chloro Alkaline Indices

$$1 = [Cl–(Na+K)] / Cl \quad (6)$$

2) Chloro Alkaline Indices

$$2 = [Cl–(Na+K)]/(SO_4+HCO_3+CO_3+NO_3) \quad (7)$$

If there is ion exchange of Na and K from water with magnesium and calcium in the rock, the exchange is known as direct when the indices are positive. If the exchange is reverse then the exchange is indirect and the indices are found to be negative. The CAI 1, 2 are calculated for the waters of the study area as given in **Table 2**. Chloro Alkaline Indices 1, 2 calculations shows that 26% of the groundwater sample is negative and 74% positive ratios.

4. Conclusions

Interpretation of hydrochemical analysis reveals that the groundwater in study area is fresh, hard to very hard. The sequence of the abundance of the major ions is in the following order: Ca > Mg > Na > K and HCO_3 > SO_4 > Cl. Alkali earths slightly exceed alkalis and weak acids exceed strong acids. Falling of water samples in the rock dominance area in Gibbs plot indicates the interaction between rock chemistry and the chemistry of the percolating precipitation waters in the sub-surface. The results of calculation saturation index show that the nearly all of the water samples were saturated to undersaturated with respect to carbonate minerals (calcite, dolomite and aragonite) and undersaturated with respect to sulfate minerals (gypsum and anhydrite). In the study area, the dominant hydrochemical facieses of groundwater is Ca- HCO_3 and Ca-Mg-HCO_3. Distribution of the groundwater samples in rectangular diagram reveals that all of the groundwater samples fall under the calcium-magnesium-bicarbonate category. According to classification of water based on TDS, 87% of samples are belonging to highest desirable category and remaining samples are belonging to maximum permissible category. Irrigation waters classified based on SAR has indicated that 83% of samples belong to the excellent, 11% samples good and remaining samples belong to doubtful category. The Wilcox diagram relating sodium percentage and total concentration shows that 26% of the groundwater samples fall in the field of good to permissible and 74% of the groundwater samples fall in the field of excellent to good for irrigation. The analytical data plotted on the US salinity diagram illustrates that 77% of the groundwater samples fall in the field of C2S1, indicating medium salinity and low sodium water. Base on the classification of irrigation water according to the RSC values, all of groundwater samples belongs to the good category. According to PI values, the groundwater of in the study area can be designated as class II (25 – 75%) that shows the groundwater in study area is suitable for irrigation purposes. Assessment of water samples from various methods indicated that groundwater in study area is chemically suitable for drinking and agricultural uses. Chloroalkaline Indices 1, 2 calculations shows that 26% of the groundwater sample is negative and 74% positive ratios. The positive values indicate absence of base-exchange reaction.

5. Acknowledgements

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Modeling of Climatic Parameters and Determination of Climatic Differences in the City of Elazig-Turkey and its Close Regions

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ABSTRACT

This study deals with the climatic parameters and the climatic differences in Elazig and its close regions (*cities of Malatya, Tunceli, Bingöl, Erzincan*). *Data on mean monthly temperature, daily maximum-minimum temperature, relative humidity, pressure, wind speed, rainfall, solar radiation and sunshine duration were analyzed and modeled for* 10-*year period, from* 1994 *to* 2003. *Malatya city was the hottest area whole period, while the Erzincan city was the coldest area. Maximum temperatures were at highest values in Tunceli. Minimum temperatures reached the warmest values in the Malatya. Erzincan city was the most humid area almost throughout the period while Malatya was the least humid area. Wind speed reached the highest values in the Elazig and the lowest values in the Tunceli. Pressure reached the highest values in the Malatya and the lowest values in the Erzincan. Direct solar radiation reached the highest values in the Tunceli and the lowest values in the Erzincan. Sunshine duration reached the highest values in the Malatya and the lowest values in the Erzincan. A regression analysis was carried out by using the linear regression technique to model the climatic parameters. The models developed can be used in any study related to climatic and its effect on the environment and energy. The models developed in this study can be used for future predictions of the climatic parameters and analysing the environmental and energy related issues in Elazig and its close regions* (*cities of Malatya, Tunceli, Bingöl, Erzincan*).

Keywords*: *Energy, Environment, Elazig, Erzincan, Malatya, Tunceli, Bingöl-Turkey, Relative Humidity, Solar Radiation, Sunshine Duration, Temperature, Weather Parameters, Wind Speed

1. Introduction

Energy is one of the precious resources in the world. Energy conservation becomes a hot topic around people, not just for deferring the depletion date of fossil fuel but also concerning the environmental impact due to energy consumption [1]. Performance of environment-related systems, such as heating, cooling, ventilating and air-conditioning of buildings (HVAC systems), solar collectors, solar cells, greenhouses, power plants and cooling towers, are dependent on weather variables like solar radiation, dry-bulb temperature, wet-bulb temperature, humidity, wind speed, etc. In order to calculate the performance of an existing system or to predict the energy consumption of a system in design step, the researcher/designer needs appropriate weather data [2].

A number of studies are found in the literature dealing with the weather characteristics, solar and wind energy related issues for different region of the World. Global solar irradiation (GSI) had been estimated in a number of studies by the known climatic parameters of bright sunshine duration [3,4], cloud fraction [5,6], air temperature range [7], precipitation status [8], both temperature and rainfall [9] and both sunshine duration and cloud [10,11], trends to years of the weather parameters such as temperature, relative humidity, wind speed, dust and fog [12]. Climatic differences between urban and suburban have been studied by many other authors [13–19].

The main objective of the present study is

1) to investigate the climatic differences between Elazig city and its close regions, cities of Malatya, Tunceli, Bingöl, Erzincan, for 10-year period, from 1994 to 2003.

2) to discuss the climatic parameters (such as temperature, relative humidity, wind speed, pressure, solar radiation, and sunshine duration) in the Elazig city and its close regions using the linear regression model.

2. Material and Methods

2.1 Features of Study Area

City of Elazig (longitude; 38º 40’, latitude; 39º 14’, elevation of 991 m), Malatya (longitude; 38º 21’, latitude; 38º 19’, elevation of 898 m), Tunceli (longitude; 39º 07’, latitude; 39º 33' elevation of 980 m), Bingöl (longitude; 38º 53', latitude; 40º 29', elevation of 1177 m) and Erzincan (longitude; 39º 45', latitude; 39º 30', elevation of 1218 m) is situated in east Anatolia region of Turkey. City of Elazig, Malatya, Tunceli, Bingöl and Erzincan has a typical highland climate, in that it is generally cold in winter and hot in summer and there are considerable temperature differences between day and night. Location of Elazig, Malatya, Tunceli, Bingöl and Erzincan city can be shown from **Figure 1**. The mean monthly temperature, daily maximum–minimum temperature, relative humidity, pressure, wind speed, solar radiation and sunshine duration were the measured meteorological parameters of this research. The measurements have been carried out by conventional meteorological instruments by the Turkish Meteorological State Department (TMSD).

2.2 Modelling of Climatic Parameters

Statistical techniques of regression models are frequently used to study a set of experimental data. Adequacy and validity of the model is performed to determine if the model will function in a successful manner in its intended operating field.

Linear regression analysis is a statistical tool by which a line is fitted through a set of experimental data using the least-squares method. Regression is used in a wide variety of applications in order to analyze how a single dependent variable is affected by the values of one or more independent variables. In this study, temperature, relative humidity, wind speed, pressure, solar radiation and sunshine duration collected for a period of 10 years (1994–2003) is modelled using linear regression analysis with 95% confidence level.

For the purpose of checking the adequacy of the models developed in this study, residual analysis was adopted. It is important to examine plots of residuals versus the corresponding predicted values of weather parameters to detect common patterns such as horizontal bands, outward openings, double bows, and curved bands [12]. The desirable pattern for a good model is one in which the residuals are contained within a horizontal band. Model validation is also essential for model building, since a model that fits the data well may not work well for predictions.

Figure 1. Location of city of Elazig, Erzincan, Tunceli, Malatya and Bingöl in Turkey

3. Results

From the data obtained over a 10-year period between 1994 and 2003, the results of study were summarized at **Table 1**, results are as following:

3.1 The Differences in the Mean Monthly Temperatures

From **Figure 2**, it can be seen that there was an evident difference at mean monthly temperatures between the investigated cities. Mean monthly temperatures was showed changing between 0.6 and 27.5°C for Elazig city, –0.9 and 24.7°C for Erzincan city, 0.3 and 27.8°C for Tunceli city, 1.6 and 27.9°C for Malatya city, –0.7 and 27.1°C for Bingöl city. The overall average temperature for 10 years was found to be about 13.19°C for Elazig, 11.50°C for Erzincan, 13.75°C for Tunceli, 14.14°C for Malatya, 12.56°C for Bingöl. While the Erzincan city was the coldest area whole period, Malatya city was the hottest area whole period. However, Malatya was warmer than Tunceli, Elazig and Bingöl in terms of averages, respectively. Mean monthly temperatures of city of Elazig, Tunceli and Bingöl were showed changing at the close values to each other for month of April, May, June, July, August, September, October, November. The highest difference in mean temperature between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 1.5°C at September, –0.6°C at December, –1.6 °C at February and –2.8°C at July, respectively. The lowest difference in mean temperature between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 0.3°C at December, 0.1°C at March and April, –0.1°C at August, September, November, May, June and –0.6°C at April, respectively. There was a mean temperature difference of 0.96, 0.083, –0.63 and –1.56°C between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**). These data can be seen that mean monthly temperatures of Elazig was about equal to mean monthly temperatures of Tunceli.

3.2 The Differences in Maximum Temperatures

From **Figure 3**, maximum temperatures were at highest values in Tunceli, followed by Malatya, Elazig, Bingöl and Erzincan. Mean maximum monthly temperatures was showed changing between 4.3 and 34.8°C for Elazig city, 3.9 and 32.4 °C for Erzincan city, 4.8 and 35.3°C for Tunceli city, 5.2 and 34.4°C for Malatya city, 3.7 and 35.1°C for Bingöl city. While maximum temperatures

Table 1. Differences in the climatic elements between cities

Parameters	Elazig-Malatya	Elazig-Tunceli	Elazig-Bingöl	Elazig-Erzincan
Mean temperature (°C)	0.96	0.083	–0.63	–1.56
Maximum temperature (°C)	0.26	0.34	–0.40	–1.30
Minimum temperature (°C)	1.60	0.16	0.066	–1.35
Relative humidity (%)	–5	–0.083	–1.083	5.91
Wind speed (m/s)	–0.9	–1.55	–1.40	–1.19
Pressure (mbar)	4.41	1.1	–16.2	–24.61
Direct solar radiation (cal/cm^2)	19.29	24.17	9.93	–6.30
Sunshine duration (min)	12.08	–22.58	–72.58	–92.25

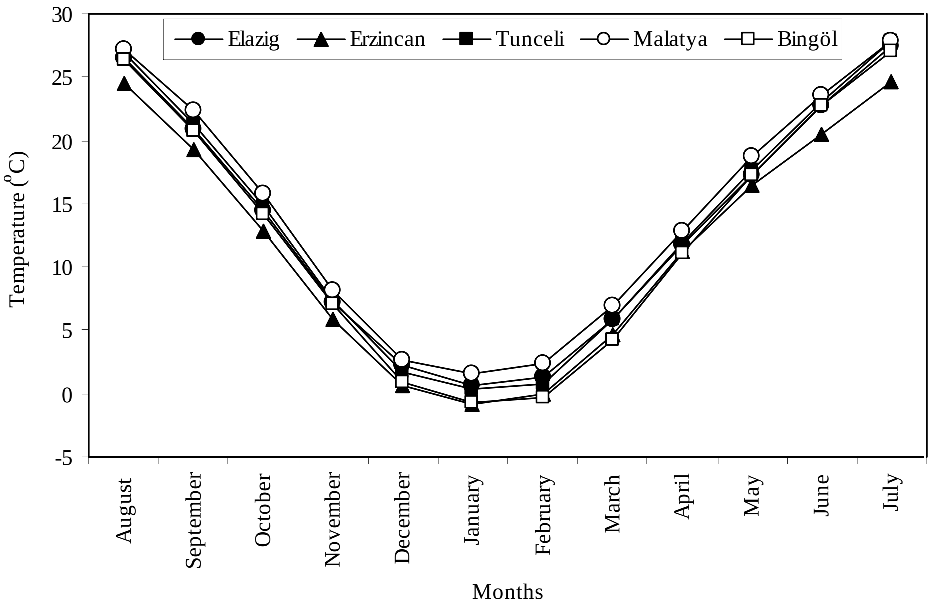

Figure 2. Monthly mean temperatures during the years 1994–2003 for the cities

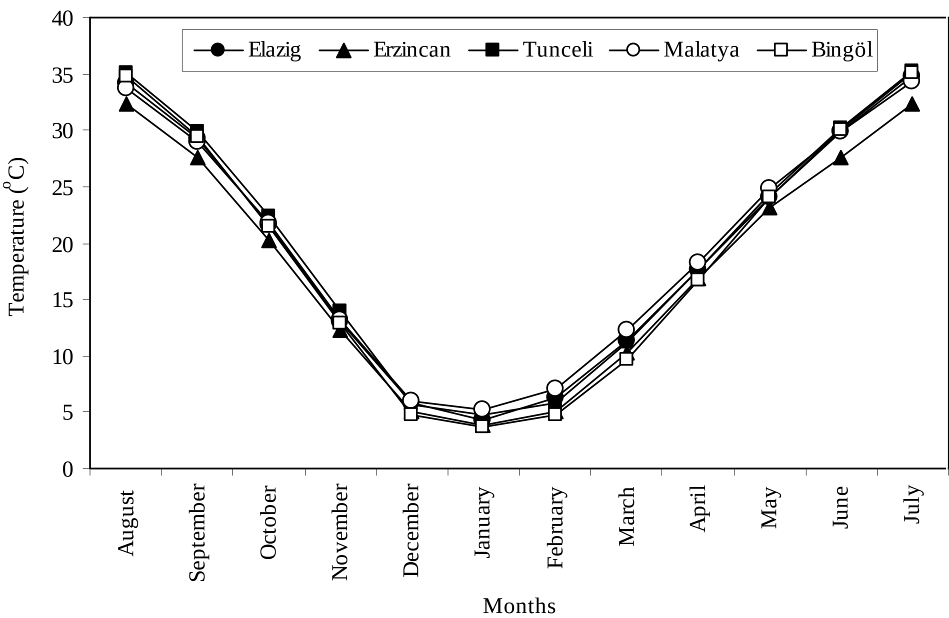

Figure 3. Monthly mean maximum temperatures during the years 1994–2003 for the cities

were at highest values in August and July, at lowest values in January. The highest difference in maximum mean temperature between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 0.9°C at January, 0.9°C at August and November, –1.7°C at March and –2.5°C at July, respectively. The lowest difference in maximum temperature between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 0°C at June, 0°C at April, –0.1°C at October and May and –0.4°C at January, respectively. There was a mean maximum temperature difference of 0.26, 0.34, –0.40 and –1.30°C between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**). While Erzincan was coldest city whole period, Tunceli was warmest city. Malatya was warmer than cities of Elazig and Bingöl. Values of maximum temperature of Elazig were close to values of maximum temperature of Malatya and Tunceli.

3.3 The Differences in Minimum Temperatures

Mean minimum monthly temperatures was showed changing between –3 and 18.7°C for Elazig city, –4.8 and 16.6°C for Erzincan city, –3.5 and 19.5°C for Tunceli city, –1.5 and 20.3°C for Malatya city, –4.2 and 19.7°C for Bingöl city (**Figure 4**). While minimum temperatures were at highest values in July, at lowest values in January and February. The highest difference in minimum mean temperature between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 2.3°C at September and May, 0.8°C at June, July and January, –1.4°C at December and June and –2.1°C at December, January and July, respectively. The lowest difference in minimum mean temperature between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 0.4°C at December, 0.2°C at October, 0.1°C at November and –0.3°C at April and May, respectively. There was a mean minimum temperature difference of 1.60, 0.16, 0.066 and –1.35°C between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**). Minimum temperatures reached the warmest values in the Malatya. Malatya was followed by Tunceli, Bingöl, Elazig and Erzincan. Minimum temperatures were at lowest values in Erzincan. However, values of mean minimum temperature of Elazig were almost equal to values of mean minimum temperature of Bingöl and Tunceli.

3.4 The Differences in Relative Humidity

Erzincan city was the most humid area almost throughout the period while Malatya was the least humid area. However, values of mean relative humidity of Elazig were almost equal to values of mean relative humidity of Tunceli. Bingöl was less humid than Elazig and Tunceli. Mean monthly relative humidity was showed changing between 36 and 74% for Elazig city, 51 and 76% for Erzincan city, 37 and 74% for Tunceli city, 31 and 74% for Malatya city, 37 and 74% for Bingöl city (**Figure 5**). The overall average humidity ratio was found to be about 57.69% for Elazig, 63.52% for Erzincan, 57.40% for Tunceli, 52.76% for Malatya 56.59% for Bingol. While relative humidity was at highest values in December and

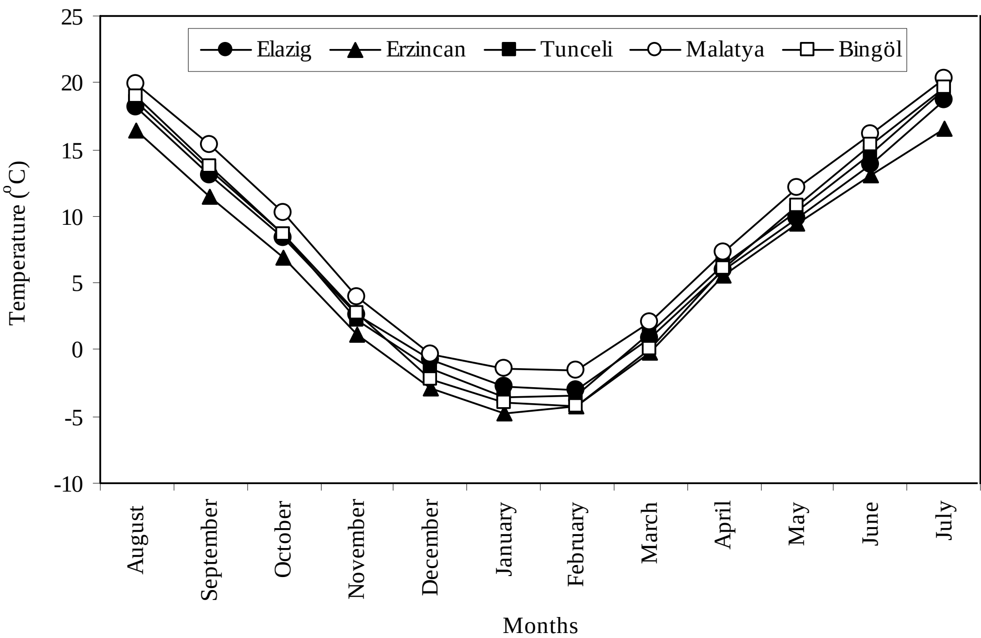

Figure 4. Monthly mean minimum temperatures during the years 1994–2003 for the cities

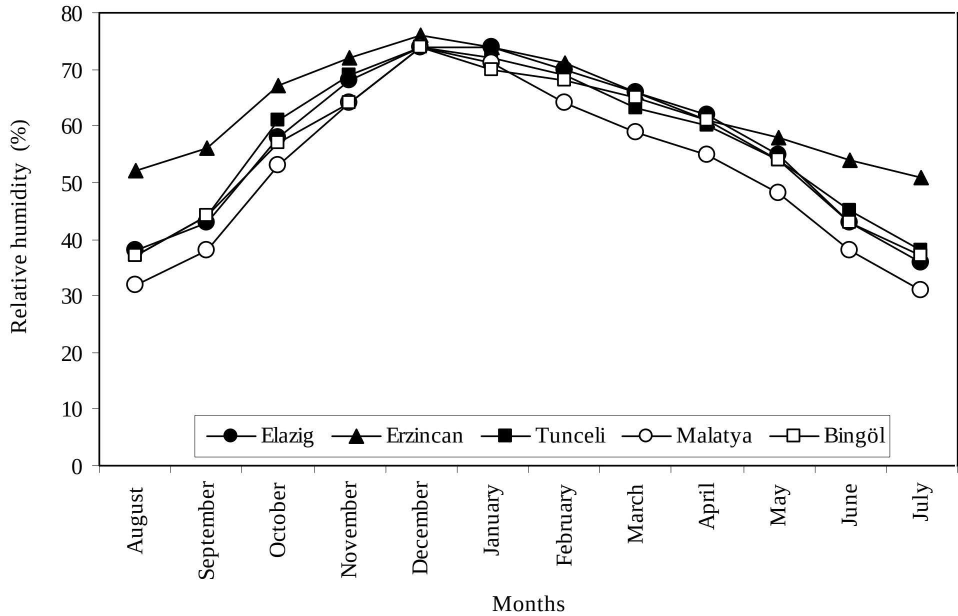

Figure 5. Monthly mean relative humidity values during the years 1994–2003 for the cities

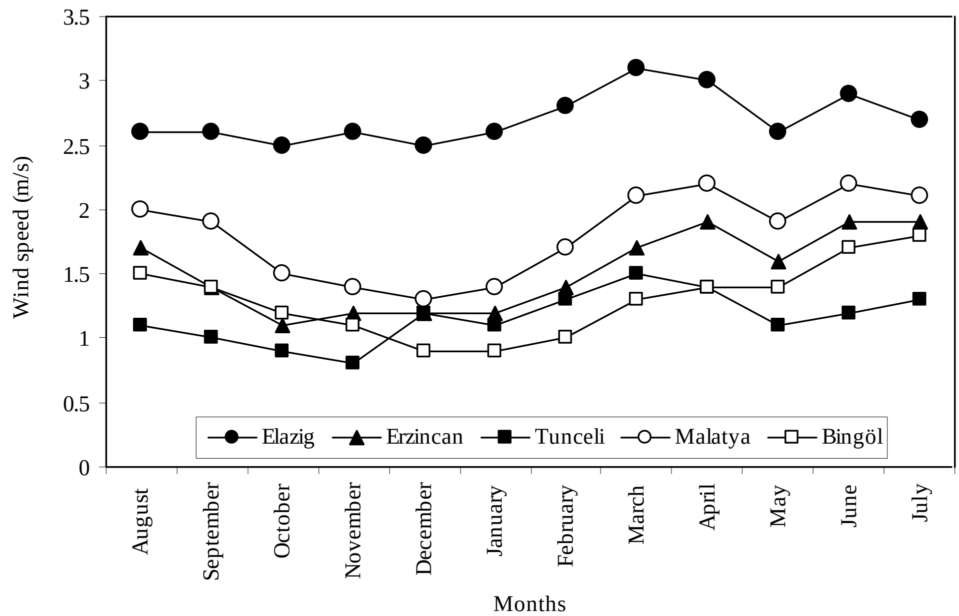

Figure 6. Monthly mean wind speed values during the years 1994–2003 for the cities

January, at lowest values in July and August. The highest difference in mean relative humidity between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was –7% at March, April and May, 3% at October and May, 4% at November and January and 15 % at July, respectively. The lowest difference in mean relative humidity between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 0% at December, 0% at December, 0% at December and June and 0% at January and March, respectively. There was a mean relative humidity difference of –5%, –0.083%, –1.083% and 5.91% between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**).

3.5 Differences in Wind Speed

While the windiest city was Elazig, it was followed by Malatya, Erzincan, Bingöl and Tunceli (**Figure 6**). Mean monthly wind speed was showed changing between 2.5 and 3.1 m/s for Elazig city, 1.1 and 1.9 m/s for Erzincan city, 0.8 and 1.5 m/s for Tunceli city, 1.3 and 2.2 m/s for Malatya city, 0.9 and 1.8 m/s for Bingöl city (**Figure 6**).

The overall average of wind speed for the same period was obtained to be approximately 2.69 m/s for Elazig, 1.47 m/s for Erzincan, 1.21 m/s for Tunceli, 1.79 m/s for Malatya, 1.3 m/s for Bingol. The highest difference in the mean wind speed between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was –1.2 m/s at November, December and January, –1.8 m/s at November, –1.8 m/s at February and March and –1.4 m/s at October, November, January, February and March, respectively. The lowest difference in mean wind speed between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was –0.6 m/s at August and July, –1.3 m/s at December, –0.9 m/s at July and –0.8 m/s at July, respectively. There was a mean wind speed difference of –0.9 m/s, –1.55 m/s, –1.40 m/s and –1.19 m/s between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**).

3.6 The Differences in Mean Pressure

Mean monthly pressure was showed changing between 896.7 and 907.3 mbar for Elazig city, 874.2 and 881.6 mbar for Erzincan city, 898.3 and 908.1 mbar for Tunceli city, 901.5 and 911.6 mbar for Malatya city, 881 and 890.7 mbar for Bingöl city (**Figure 7**). The overall pressure was found to be about 902.74 mbar for Elazig, 878.03 mbar for Erzincan, 903.79 mbar for Tunceli, 907.19 mbar for Malatya, 886.50 mbar for Bingol. While pressure values were at highest values in November and December, at lowest values in July. The highest difference in mean pressure between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 4.9 mbar at June, 1.8 mbar at May, –16.9 mbar at January and –26.1 mbar at December, respectively. The lowest difference in mean pressure between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 4 mbar at October, 0.3 mbar at October, –15.5 mbar at June and –22.5 mbar at July, respectively. There was a mean pressure difference of 4.41, 1.1, –16.2 and –24.61 mbar between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**). Pressure reached the highest values in the Malatya. Malatya was followed by Tunceli, Elazig, Bingöl, and Erzincan. Pressure values were at lowest values in Erzincan. However, values of mean pressure of Elazig were close to values of mean pressure of Tunceli.

3.7 The Differences in Mean Direct Solar Radiation

Mean monthly direct solar radiation was showed changing between 125.58 cal/cm^2 and 592.18 cal/cm^2 for Elazig city, 145.06 and 554.45 cal/cm^2 for Erzincan city, 139.78 and 628.3 cal/cm^2 for Tunceli city, 138.28 and 599.1 cal/cm^2 for Malatya city, 132.73 and 621.44 cal/cm^2 for Bingöl city (**Figure 8**). The overall average of solar radiation for the same period was obtained to be approximately 363.06 cal/cm^2 for Elazig, 356.69 cal/cm^2 for Erzincan, 385.6 cal/cm^2 for Tunceli, 382.38 cal/cm^2 for Malatya, 373.15 cal/cm^2 for Bingol. While direct solar radiation values were at highest values in June and July, at lowest values in December. The highest difference in direct solar radiation between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 36.5 cal/cm^2 at August, 45.23 cal/cm^2 at August,

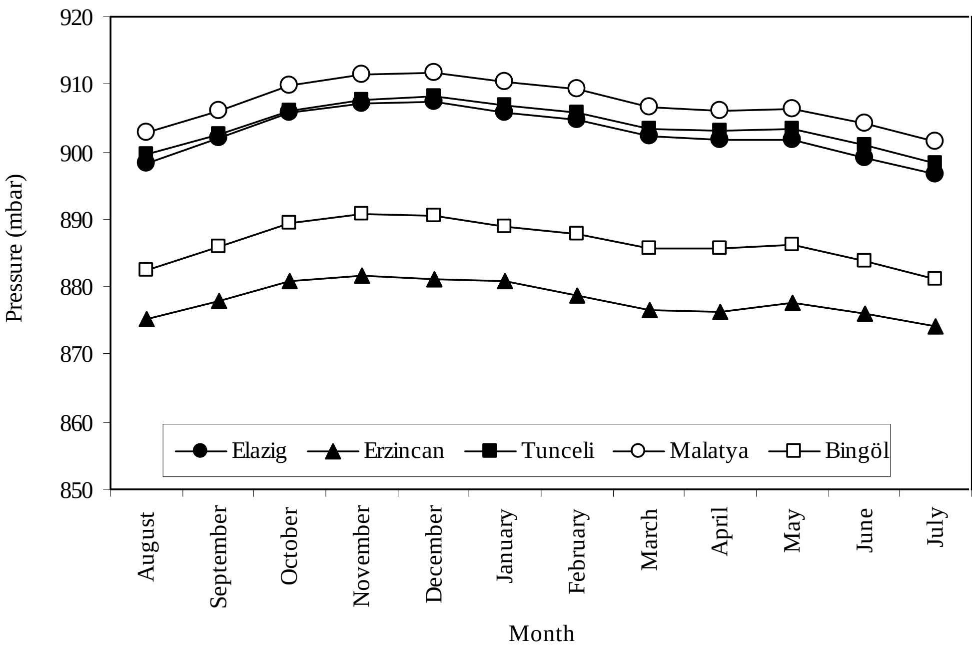

Figure 7. Monthly mean pressure values during the years 1994–2003 for the cities

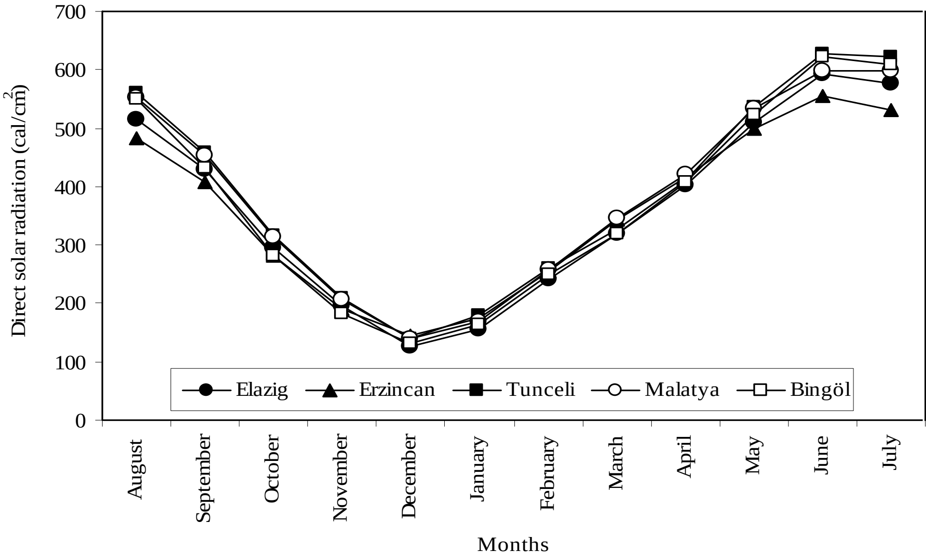

Figure 8. Monthly mean solar radiation values during the years 1994–2003 for the cities

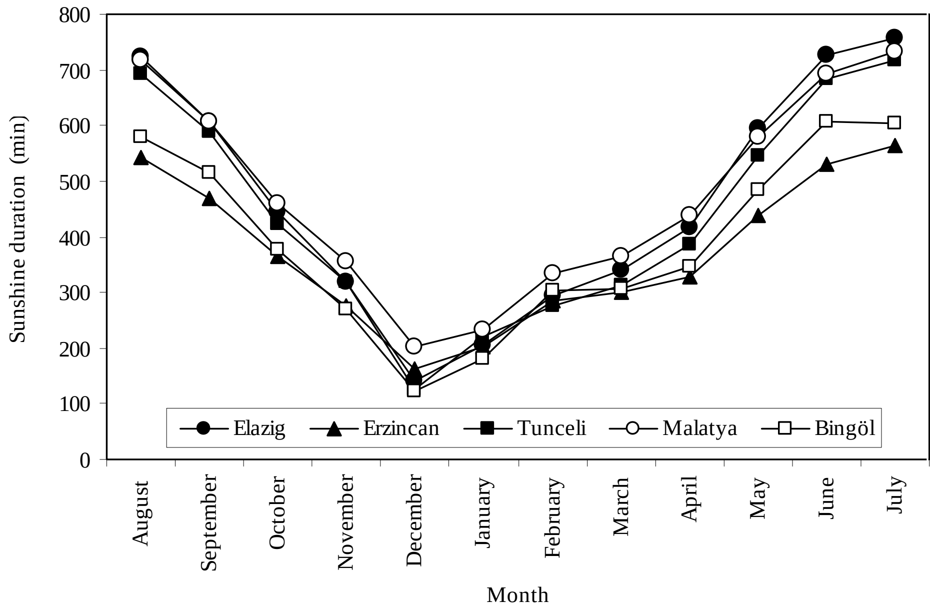

Figure 9. Monthly mean sunshine duration values during the years 1994–2003 for the cities

34.29 cal/cm^2 at August and –45.24 cal/cm^2 at July, respectively. The lowest difference in mean direct solar radiation between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 6.06 cal/cm^2 at June, 8.75 cal/cm^2 at April, 1.21 cal/cm^2 at March and –4.66 cal/cm^2 at November, respectively. There was a mean solar radiation difference of 19.29, 24.17, 9.93 and –6.30 cal/cm^2 between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**). Direct solar radiation reached the highest values in the Tunceli. Tunceli was followed by Malatya, Bingöl, Elazig and Erzincan. Direct solar radiation values were at lowest values in Erzincan. However, values of mean direct solar radiation of Elazig were very close to values of mean direct solar radiation of Erzincan.

3.8 The Differences in Mean Sunshine Duration

Mean monthly sunshine duration was showed changing between 142 and 757 min for Elazig city, 161 and 565 min for Erzincan city, 125 and 718 min for Tunceli city, 201 and 732 min for Malatya city, 124 and 607 min for

Bingöl city (**Figure 9**). The overall average sunshine duration for 10 years was found to be about 464.76 min for Elazig, 369.48 min for Erzincan, 445.74 min for Tunceli, 476.4 min for Malatya, 396 min for Bingol. While sunshine duration values were at highest values in August and July, at lowest values in December. The highest difference in sunshine duration between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was 59 min at December, –47 min at May, –154 min at July and –195 min at June, respectively. The lowest difference in mean sunshine duration between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan was –1 min at September, 1 min at November, 9 min at February and –4 min at January, respectively. There was a mean sunshine duration difference of 12.08, –22.58, –72.58 and –92.25 min between Elazig and Malatya, Elazig and Tunceli, Elazig and Bingol, Elazig and Erzincan, respectively (**Table 1**). Sunshine duration reached the highest values in the Malatya. Malatya was followed by Elazig, Tunceli, Bingöl and Erzincan. Sunshine duration values were at lowest values in Erzincan. However, values of mean sunshine duration of Elazig were very close to values of mean sunshine duration of Malatya.

4. Regression Analysis of Climatic Parameters

Figures **10–14** show the linear regression results for the temperature, relative humidity, wind speed, pressure, solar radiation and sunshine duration respectively, for the period of 10 years. The linear regression correlations for these data were obtained for forecasting purposes (**Table 2**).

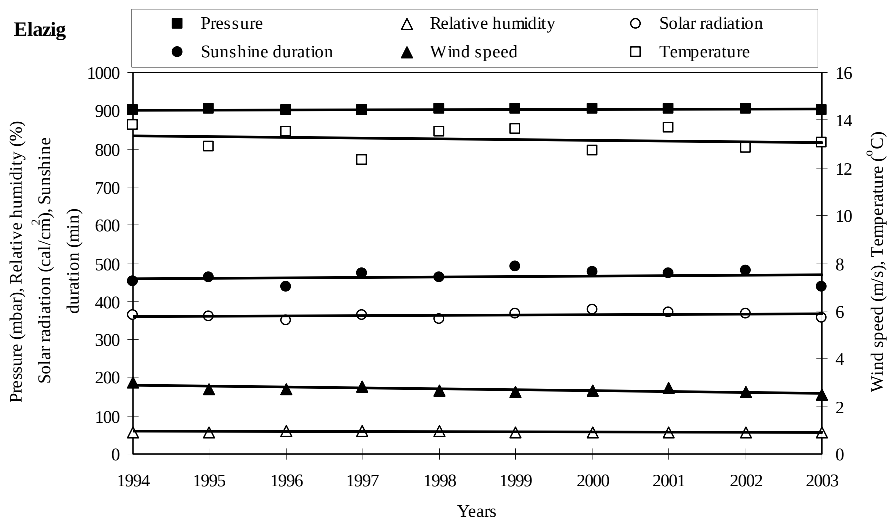

Figure 10. Linear regression and variations of annual average climatic conditions in Elazig city during the years 1994–2003

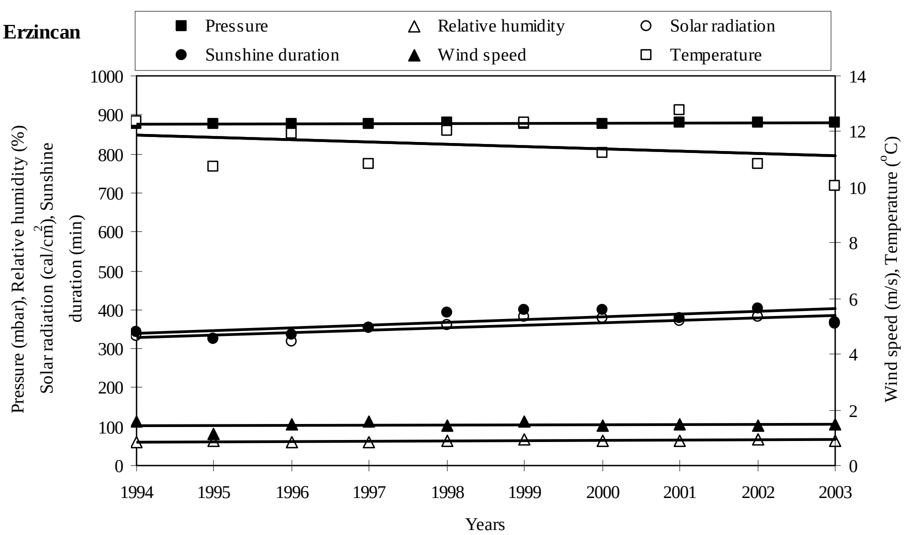

Figure 11. Linear regression and variations of annual average climatic conditions in Erzincan city during the years 1994–2003

Table 2. Linear regression correlations

Parameters	Correlations
Elazig	
Temperature, (°C)	= –0.0272*Y + 13.347
Relative humidity, (%)	= –0.1864*Y + 58.72
Wind speed, (m/s)	= –0.0351*Y + 2.892
Pressure, (mbar)	= 0.0424*Y x + 902.51
Solar radiation, (cal/cm^2)	= 0.9449*Y + 357.87
Sunshine duration, (min)	= 1.2436*Y + 457.92
Erzincan	
Temperature, (°C)	= –0.0866*Y + 11.984
Relative humidity, (%)	= 0.5283*Y + 60.618
Wind speed, (m/s)	= 0.0057*Y + 1.44
Pressure, (mbar)	= 0.0589*Y + 877.71
Solar radiation, (cal/cm^2)	= 6.2399*Y + 322.38
Sunshine duration, (min)	= 7.0618*Y + 330.64
Tunceli	
Temperature, (°C)	= 0.2259*Y + 12.509
Relative humidity, (%)	= –0.2733*Y + 58.904
Wind speed, (m/s)	= –0.0013*Y + 1.22
Pressure, (mbar)	= 0.0112*Y + 903.73
Solar radiation, (cal/cm^2)	= 2.0678*Y + 374.23
Sunshine duration, (min)	= 1.6182*Y + 436.84
Malatya	
Temperature, (°C)	= 0.0084*Y + 14.097
Relative humidity, (%)	= –0.045*Y + 53.013
Wind speed, (m/s)	= –0.0373*Y + 2.0028
Pressure, (mbar)	= –0.0045*Y + 907.22
Solar radiation, (cal/cm^2)	= –0.045*Y + 53.013
Sunshine duration, (min)	= –2.6909*Y + 491.2
Bingöl	
Temperature, (°C)	= 0.0485*Y + 12.293
Relative humidity, (%)	= 0.4321*Y + 54.213
Wind speed, (m/s)	= –0.0411*Y + 1.526
Pressure, (mbar)	= 0.2158*Y + 885.32
Solar radiation, (cal/cm^2)	= 3.6787*Y + 352.92
Sunshine duration, (min)	= 1.9636*Y + 385.2

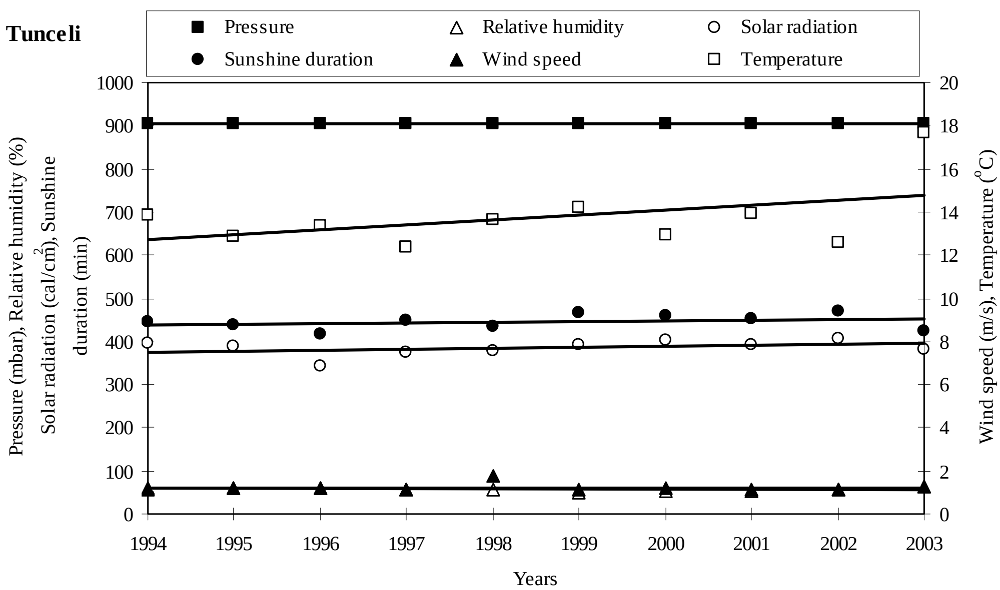

Figure 12. Linear regression and variations of annual average climatic conditions in Tunceli city during the years 1994–2003

Linear regression models indicate that the pressure remains almost invariant throughout the years considered for all cities. The temperature showed a slight decrease with a negative slope for Elazig and Erzincan, a slight increase with a positive slope for Malatya, Tunceli and Bingöl. The relative humidity showed a slight decrease with a negative slope for Elazig, Tunceli and Malatya, a slight increase with a positive slope for Erzincan and

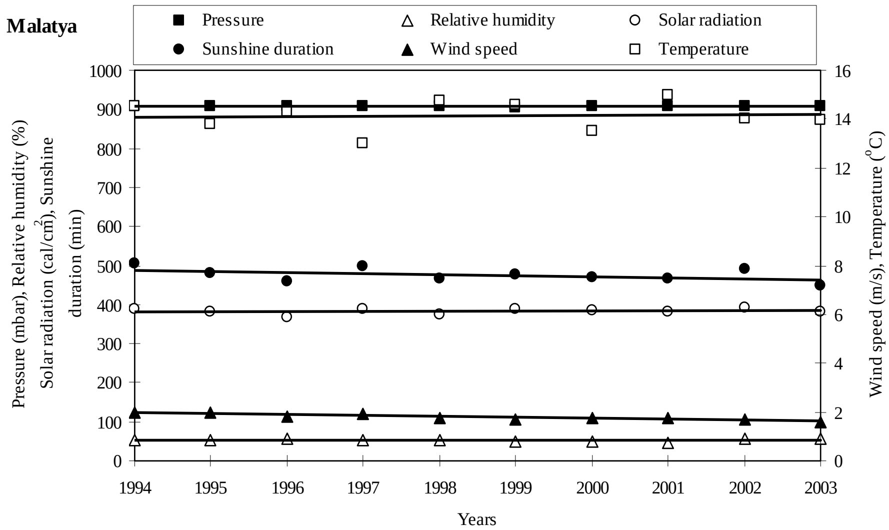

Figure 13. Linear regression and variations of annual average climatic conditions in Malatya city during the years 1994–2003

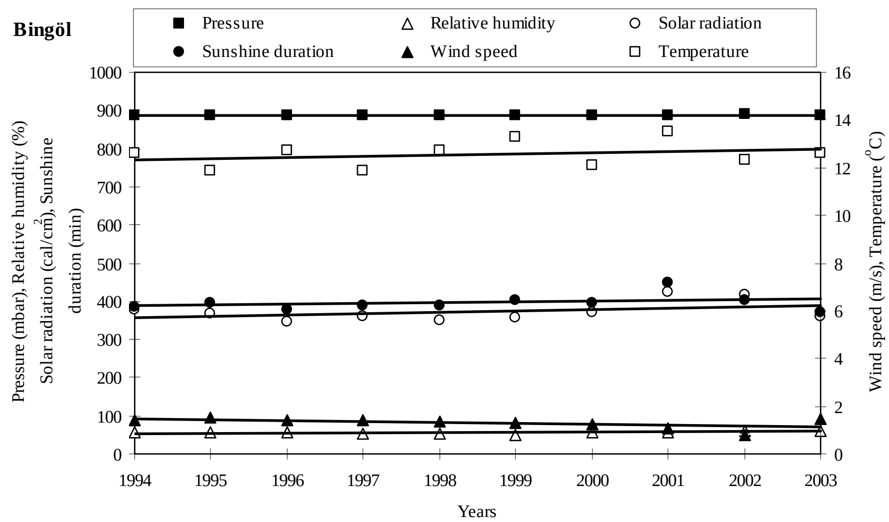

Figure 14. Linear regression and variations of annual average climatic conditions in Bingöl city during the years 1994–2003

Bingöl. The wind speed slightly decreased with a negative slope for Elazig, Tunceli Malatya and Bingöl, and increased with a positive slope for Erzincan. The solar radiation and sunshine duration increased with a positive slope for Elazig, Erzincan, Tunceli and Bingöl, and decreased with a negative slope for Malatya.

Analysis of the residuals is frequently helpful in checking the assumption that the errors were approximately normally distributed with constant variance, as well as in determining whether linear regression model would be adequate. **Figure 15** shows the residual plots for the temperature, relative humidity, wind speed, pressure, solar radiation and sunshine duration. As was obvious from this figure there were no serious model inadequacies. A general overview of the weather characteristics for the past 10 years indicated that some of the essential characteristics of weather such as temperature, relative humidity, wind speed, pressure, solar radiation and sunshine duration can be modelled and, thus, future forecasting of such characteristics are possible.

5. Conclusions

In the study, firstly, it was attempted to determine how much the climatic elements between Elazig and its close regions (cities of Malatya, Tunceli, Bingöl, Erzincan) may differ and obtain concrete values. Secondly, linear regression models was investigated to present climatic data collected in Elazig and its close regions for a period of 10 years. These data can be seen that

1) Values of mean monthly temperature, relative humidity

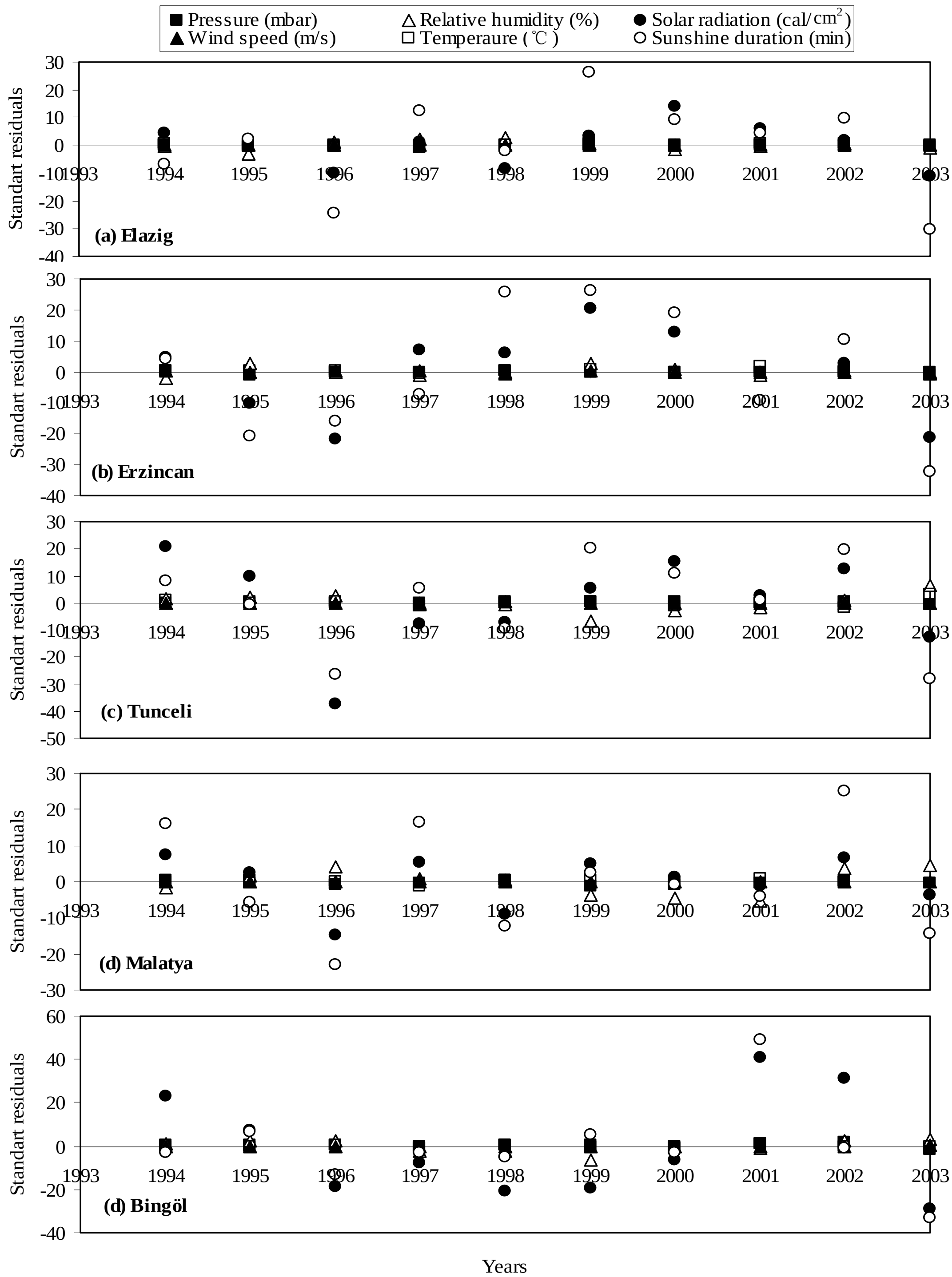

Figure 15. Standard residual plots of temperature, relative humidity, wind speed, pressure, solar radiation and sunshine duration for the investigated cities

and pressure of Elazig were about equal to values of Tunceli.

2) Values of maximum temperature of Elazig were close to values of maximum temperature of Malatya and Tunceli.

3) Values of mean minimum temperature of Elazig were almost equal to values of mean minimum temperature of Bingöl and Tunceli.

4) Values of mean solar radiation of Elazig were very

close to values of mean solar radiation of Erzincan.

5) Values of mean sunshine duration of Elazig were very close to values of mean sunshine duration of Malatya.

6) Malatya city was the hottest area whole period, while the Erzincan city was the coldest area. Maximum temperatures were at highest values in Tunceli. Minimum temperatures reached the warmest values in the Malatya. Erzincan city was the most humid area almost throughout the period while Malatya was the least humid area. Wind speed reached the highest values in the Elazig and the lowest values in the Tunceli. Pressure reached the highest values in the Malatya and the lowest values in the Erzincan. Direct solar radiation reached the highest values in the Tunceli and the lowest values in the Erzincan. Sunshine duration reached the highest values in the Malatya and the lowest values in the Erzincan. The factors thought to be effective on the climatic differences mentioned above may result from the features of the investigated cities. The factors thought to be effective on the differences determined in the present study are briefly canopy and evapo-transpiration effects, elevation difference between the areas and surface roughness, radiation and reflection factors, smoke and dust, the duration and color of snow cover on the ground, wind direction and other anthropogenic effects of the invest-tigated city. Depending on the location of the city center, prevalent easterly and northerly winds in this area is effective on temperatures and humidity, which can de-crease temperatures and increase humidity. As is known, there is a true relationship between the population and temperature in a city center. This effect may be smaller compared to those aforementioned, because of the rela-tively low population and the city lacks of any industrial facilities that may influence the temperature in the city.

7) The models were reviewed for the statistical ade-quacy, *i.e.* the normality assumption is satisfied and the residual versus the predicted and regressed variables are contained within a horizontal band. There was little va-riation between the observed and predicted values of climatic data, *i.e.* temperature, relative humidity, wind speed pressure, solar radiation and sunshine duration. The models developed in this study can be used for future pre-dictions of the climatic parameters and analysing the en-vironmental and energy related issues in Elazig and its close regions (cities of Malatya, Tunceli, Bingöl, Erzincan).

Nomenclature

Y the year according to the Gregorian calendar

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Impacts of Chromium from Tannery Effluent and Evaluation of Alternative Treatment Options

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ABSTRACT

The paper has focused on the challenges/impacts of tannery effluent and evaluates the alternative treatment options used to treat, recover or recycle chromium from the waste water. The paper was done entirely on secondary data by consulting literature sources including scientific journals, chapters of books, conference report papers and websites. The results of this review paper indicated that chromium is highly toxic and carcinogenic to human beings, animals, plants and the general environment (*soil and water sediment*)*. It is found out that chrome is the primary threat when ever tanning industry comes in to practice. Though many treatment options were evaluated to prevent its consequence on the environment, neither of them could achieve to treat or recover chrome* 100%*. Treatment options are either; inefficient, complicated, energy demanding, costly or applicable to a certain parts of the world due to technology or skilled man power demand. Therefore, to tackle this serious challenge stringent environmental regulation with law enforcement has to be exercised to use better treatment system which is widely applicable. Polluters must also know the environmental cost of their industry and treated according to polluter pay or precautionary principles. Moreover, the general public has to be aware of it and all concerned organizations and governments has to work hand in hand to reach zero discharge level or at least to attain the EPA chrome discharge limit.*

Keywords**:** *Chromium Toxicity, Environmental Impact, Chromium Recovery and Recycling, Chromium Treatment Option, Tannery Effluent*

1. Introduction

All sectors of our society generate waste: industry, agriculture, mining, energy, transportation, construction and consumers. Waste contains pollutants which are discarded materials, process materials or chemicals. Pollution could be caused by these pollutants when they are released beyond the assimilation capacity of the environment. Industrial wastes are generated from different processes and the amount and toxicity of waste released varies with its own specific industrial processes [1]. Tannery effluents are ranked as the highest pollutants among all industrial wastes. They are especially large contributors of chromium pollution. For instance, in India alone about 2000–3000 tone of chromium escapes into the environment annually from tannery industries, with chromium concentrations ranging between 2000 and 5000 mg/l in the aqueous effluent compared to the recommended permissible discharge limits of 2 mg/l [2].

There are two types of tanning systems which are vegetable tanning, which does not contain chromium, and chrome tanning. However, due to the high pollution load and low treatability, conventional vegetable tanning can't be considered more environmentally friendly than chrome tanning. Moreover, vegetable tanned leathers have different physical properties and specific applications, but is biodegradable [3]. Currently more than 90% of global leather production of 18 billion sq. ft is through chrome-tanning process [4]. Chromium salts (particularly chromium sulphate) are the most widely used tanning substances today. Hides tanned with chromium salts have a good mechanical resistance, an extraordinary dyeing suitability and a better hydrothermic resistance in comparison with hides treated with vegetable substances. Unfortunately only a fraction of the chromium salts used in the tanning process react with the skins. The rest of the salts remain in the tanning exhaust bath and are subsequently sent to a depuration plant where the chromium salts end up in the sludge [5]. One of the major emerging environmental problems in the tanning industry is the disposal of chromium contaminated sludge produced as a by-product of wastewater treatment. Tannery effluents severely affect the mitotic process and reduce seed germination in extensively cultivated pulse crops [2].

At high concentrations chromium is toxic, mutagenic, carcinogenic, and teratogenic. Chromium exists in oxidation states of +2, +3, and +6. The trivalent oxidation state is the most stable form of chromium and is essential to mammals in trace concentration and relatively immobile in the aquatic system due to its low water solubility. The hexavalent chromium is much more toxic to many plants, animals, and bacteria inhabiting aquatic environments. Most micro-organisms are sensitive to Cr (VI) toxicity but some groups possess resistance mechanisms to tolerate high levels. A relationship was found between the total chromium content of soil and the presence of metal tolerant/resistant bacteria [2]. In natural waters two stable oxidation states of Cr persist (III and VI), which have contrasting toxicities, motilities, and bioavailability. Cr (VI) is motile and highly toxic and soluble in water and it is a strong oxidizing agent that causes severe damage to cell membranes [6].

Worldwide chromium contamination of soils has arisen predominantly from the common practice of land-based disposal of tannery wastes under the assumption that the dominant species in the tannery waste would be the thermodynamically stable Cr (III) species. However, recent detection of significant levels of toxic Cr (VI) in surface water and groundwater in different part of the world raise critical questions relating to current disposal of Cr-containing wastes. Despite the thermodynamic stability of Cr (III), the presence of certain naturally occurring minerals, especially MnO_2 oxides, can enhance oxidation of Cr (III) to Cr (VI) in the soil environment. This factor is of public concern because at high pH, Cr (VI) is bio available, and it is this form that is highly mobile and therefore poses the greatest risk of groundwater contamination [7].

Cleaner technologies used to reduce chromium in waste water such as high exhaustion process, direct or indirect chromium recycling cannot eliminate completely from effluent coming from post tanning section. In response to this challenge, replacement of chromium with combinations of metallic cat ions, for example titanium, magnesium, aluminium and zirconium, was tried but the results obtained at the moment are not completely satisfying for all types of leather. Synthetic organic tanning agents, alone or in combination with a metallic cat ion can be considered as a substitute for chromium in some types of leather, provided that environmental and workers health regulations are complied with [3].

Although Cr III is an essential nutrient for human beings, there is no doubt that Cr (VI) compounds are both acutely and chronically toxic. The dose threshold effect for this element has not yet been determined accurately enough to allow regulations to be defined. However some risk assessment analysis is currently being undertaken. Cr III is less toxic than some other elements (Hg, Cd, Pb, Ni and Zn) to mammalian and aquatic organism, probably due to the low solubility of this element in its trivalent form. Cr III compounds also have a very low mobility in soils and are thus relatively unavailable to plants [ibid]. The direct discharge of effluents from tanneries in to water bodies has become a growing environmental problem in these days. Most of these waste waters are extremely complex mixtures containing inorganic and organic compounds that make the tanning industry potentially a pollution-intensive sector [8].

In general chrome waste from leather processing poses a significant disposal problem to human health and the environment. Today, all tanneries must thoroughly check their waste streams. Chrome discharge into those streams is one of the components that have to be strictly controlled. The environmental impact of chrome waste from tanneries has been a subject of extensive scientific and technical dispute. Statutory limits have since been set for chrome discharge and disposal, and relevant guidelines have been drawn up throughout the world. Due to high correlation between chrome tanning and its environmental impact, checking of the efficiency of processing operations and treatment plant takes on prime importance. Therefore, the objective of this paper is to describe potential impact of tannery waste, evaluate the different chrome treatment methods and to discuss the challenges faced to chrome removal technologies.

2. Chromium Toxicity and its Accumulation

Industrial activities like electro plating, metal cleaning and dyeing processing, cement, and leather tanning are the major sectors that play role in releasing chromium into the environment. Chrome in the hexa-valent form is very toxic. It is quite intriguing that contaminated field by industrial effluent show a mobilization ration of less than 5 (potentially toxic) for selected plant specious. Surprisingly, the mobilization ratios for weeds become greater than 5, which have healthy morphology in the early flowering stage [9].

A study done by Marchese *et al*, 2008 about the rate of accumulation of chromium in four fresh water plant species, clams, crabs, and fishes showed that, all the four fresh water species and animals were found with high concentration of chromium which is an indication of its high accumulation potential. This clearly indicates that this problem become more serious and toxic to human beings which are found at the top of the food web due to its toxicity and bio accumulation effect.

In the tanning industry leather processing involves conversion of put rescible hide or skin into leather. Tanning agents could help permanent stabilization of the skin matrix against biodegradation. This industry has gained a negative image in society with respect to its pollution potential and therefore is facing a severe challenge. The unit processes that cause tanneries the most difficult with regard to perceived environmental impact are unharing and chrome tanning. Basic chromium sulfate (BCS) is a tanning agent, which is employed by 90%

of the tanning industry. Conventional chrome tanning results in wastewater containing as high as 1500−3000 ppm (parts per million) of chromium; however, the present day high-exhaust chrome tanning methods lead to a wastewater containing 500−1000 ppm of chromium [10]. But, the discharge limits for trivalent chromium vary broadly ranging from 1 to 5 mg/l in the case of direct discharge into water bodies and 1 to 20 mg/l in the case of discharge into the public sewer system. Therefore, the treatment plant used by the tanning industry needs to treat the influent by 200 fold to send to water bodies, which is not practical in most of the cases [11].

3. Chrome Recovery and Recycling

Conventional chrome tanning in leather production produces spent liquors containing significant amounts of chromium and other polluting substances, both organic and inorganic. From the total chromium used for tanning only 60% to 70% is utilized, while the rest 30 to 40% remains in the spent tanning liquor, which is normally sent to a wastewater treatment plant. This inefficient use of chromium and its release to the environment has to be compensated by designing a good recovery and recycling scheme. The recovery of chromium from spent tanning and re-tanning baths provides a significant economic advantage in terms of both its reuse and the simplification of the processing of global wastewaters [12].

Several recovery techniques such as chemical precipitation, membrane processes, adsorption, redox adsorption, and ion exchange have been proposed for this purpose. Among these membrane process offer very interesting opportunities for the recovery and recycling of primary resources from spent liquors of unit operations such as soaking, unhairing, degreasing, pickling, dyeing, and chromium tannage. Studies showed that the application of nanofiltration (NF) and reverse osmosis (RO) in combination can provide better recovery of unreacted chromium from high concentrated spent tanning effluent. However, this technique is being challenged by the presence of considerable biological oxygen demand (BOD) and proteins, which can cause fouling and subsequent system failure, either temporarily or permanently [12].

In practice, there are two ways of chrome recycling methods which are widely practiced: these are direct and indirect recycling. The direct form entails spent float being recycled direct to the chrome tanning processing for re-use. While, the indirect form entails precipitating and separating the chrome from the float containing residual chrome, and then re-dissolving it in acid for re-use. The efficiency of both methods can be very high (more than 90%); it depends on the effectiveness of the float collection process and the recycling/reusing technique. Of the two approaches, chrome recovery is more widely used than chrome precipitation. However, it is mandatory to adopt and practice the new technologies which are more efficient in recovering this chemical, which is a big challenge to tanning industry [13].

Use of chemical compounds for chrome treatment is not a new phenomenon. A study conducted by M. ali awan *et al*., 2003 identified three aqueous oxidants, namely; Hydrogen peroxide, Sodium Hypochlorite and Calcium Hypochlorite independently in oxidizing Chromium (III) containing tannery wastewaters to soluble chromate (CrO_4^{2-}) under alkaline conditions. Among those, Hydrogen peroxide was potentially a suitable oxidant as it could recover chromate (CrO_4^{2-}) up to 98% (from synthetic Cr^{3+} solution) and 88% (from effluent I). Despite the different experimental conditions (temperatures and oxidation time) for all the three oxidants complete (100%) recovery could not be achieved. The recovery of chromium could help in reducing the possibility of oxidizing Cr III to Cr VI (carcinogenic) compound and helps to rescue the financial and environmental cost occurred as a result of its discharge [14]. Other kinds of methods like combined system have to be also tested since it might improve the efficiency of recovering chromium from tanning process. In fact experimental conditions like, temperature, PH, time, need to be controlled to have more efficient recovery.

4. Treatment Medias Used for Chromium Removal

A wide range of physical and chemical processes are available for the removal of Cr (VI) from effluents. A major drawback with those treatment systems is sludge production, and, high operational cost and some of them are complicated for management. This actually makes the application of these technologies to be limited only in developed countries. In response to this challenge a different attempt were undertaken to produce a media which was feasible and cost effective to use by the majority. A research was done S. M. Nomanbhay and K. Palanisamy, 2005 by preparing a new composite bio sorbent which has been done by coating chitosan onto acid treated oil palm shell charcoal (CCAB). It is an attractive option because of its cost effective treatment system. Among other low cost absorbent identified chitosan has the highest sorption capacity for several metal ions including Chrome. Chromium adsorption was influenced by initial PH, agitation, dose of adsorbent and contact time. For instance at a PH of 5 the media managed to treat 92 % of chromium, which is significant. Further control of these environmental conditions in the laboratory may improve its treatment capacity [15].

A comparison study also conducted by leaching raw tannery effluent through mono and mixed columns (different grades) of vermiculite to evaluate their removal efficiency of chromium. The mixed column of vermiculite has the highest chromium removal (74.6%) while the mono vermiculite achieved 63.6%. This improvement in chrome removal efficiency is brought by the use of combined medias which increase its adsorption capacity. It was also found out that, it could remove cat ions like Ca, Na, Mg and K. of course high cat ion exchange helps to make the system more efficient [16].

Recently different studies are concentrating use of combined medias under the control of laboratory environment and the results seem promising. A research has been done in Ethiopia by Tadesse *et al*, 2005 to check the removal efficiency of chromium from tannery effluent in a horizontal settling tanks and subsequent Advanced Integrated Wastewater Pond System (AIWPS) reactors. The raw combined effluent from the tannery had a different PH and its removal efficiency was measured in detention time and PH to come up with the best chrome removal efficacy. After a one day detention time 58-95% of trivalent chromium has been removed in the primary settling tank when the PH is approached to 8, which is the optimum precipitation PH for trivalent chromium.

A significant amount of chromium has also removed in the secondary facultative pond and maturation pond. The presence of sulphide plays a role in the overall removal of chromium. It has some coagulating effect besides maintaining a conducive pH for the formation of $Cr(OH)_3$ precipitate. However, since chromium doesn't make any stable precipitate with sulphide, it has no any effect in the chromium removal chemically. With Cr (III) concentration of 0.2–0.8 mg/l in the final treated effluent, the AIWPS preceded by horizontal settling tanks produced effluent that could easily meet most of the current Cr (III) discharge limits. This study is prominent in finding ways to achieve the maximum removal of chromium and producing an effluent that meet the standard criteria to discharge to water bodies. This technique needs get attention to be considered and applied in the conventional tannery treatment system to improve its efficiency and prevent the alleged environmental consequence due to the toxic effluent discharge [11].

The ever increasing concern about the deterioration of the environmental condition could be a driving force to assess and remediate pollutant from the ecosystem. On this regard the use of plant species especially algae become acknowledged in indicating and managing metal pollution. Despite the fact that a large scale study and experience has been developed in different countries to use algal ponds as effective means of sewage treatment system the accumulation potential of algal species and seasonal variation of tolerance is not exhaustively addressed. Rai *et al*., 2005 did a study on seasonal variation of algal growth in tannery effluent and metal accumulation potential for chromium removal scheme. It has been noticed that different algal species found with accumulated chromium in their tissue, which could be used in developing bioremediation strategy for pollution abatement. Of course, factors like population density, volume of effluent, the nature of mixing with effluent and optimum algal biomass should be considered and well examined before promoting for wide application [17].

Wastewater characterization is an important step in designing effective treatment facilities for industrial wastewaters. This is especially true for tanneries which exhibit significant differences in their production processes that generate effluents of unique and complex nature. Characterization is also needed for assessing the performance of individual unit operations and processes. Most pollutants in wastewaters appear to exist either in particulate form or are associated with particulates. This understanding led to the wastewater treatment strategy of removing particulate and colloidal matter in the primary step using suitable coagulants. A study investigated about chemically enhanced primary treatment (CEPT) technology that uses different coagulants for enhanced pollutants removal at the primary stage of the wastewater treatment. Among those coagulants used, alum has been found to be the suitable coagulant for tannery wastewater in a dose range of 200–240 mg/L as $Al_2(SO_4)^3$ and it has removed 98.7–99.8% of chromium. The final effluent also met the national effluent quality standards for chromium and total suspended solids. However other COD content needs secondary treatment for the tannery effluent. Therefore, CEPT technique offers almost complete removal of chromium and produces an effluent that will no more affect the receiving water bodies [18].

5. Process Modification

Commercial conventional chrome tanning has poor chromium uptake, only about 55–60% (average). So, constant innovative process modifications for cleaner technology have been of the utmost importance in the leather-processing sector to safeguard our environment. The method employed in the leather processing industry subjects the hides and skins to treatment with a wide variety of chemicals and passage through various unit operations. All this involves an enormous amount of time and they contribute to an increase in chromium, COD, chlorides, sulfates and other mineral salts, which end up as effluent. But, perhaps more alarmingly, the process uses profuse quantities of water in areas where there is rapid depletion of ground water. Very provoking research paper was presented by Mukherjee, 2006 in the international union of leather technologies and chemist societies (IULTCS) Congress to overcome this great challenge. This study explored a process to reduce water usage, vis-a-vis deliming, pickle and basification-free chrome tanning [19].

This leads to a substantial decrease in chemical consumption by 20% for chrome tanning alone. Consumption of water can be cut by 37–40%. It is also an energy efficient technology. This exceptional approach is very appealing to tanning companies, environmentalist and also invites other researchers to do some job for possible improvement or it guides somehow to a new direction. There are some key words frequently used by scientists like pollution prevention, waste minimization, product empowerment and process innovation. However, these approaches are very much confined within recycling of wastewater to a maximum number of cycles followed by discharging or use of environmentally-friendly chemicals. In principle discharge of minimum pollution loads or a zero-discharge concept should be the topic of the day to prevent pollution completely [19].

From this intensive review of literature it is evident that chromium is very toxic to human health, animals and the environments (soil, water, sediments plants and etc). There are many options of treating chromium from tannery effluent and some treatment techniques managed nearly 99% of removal of chromium from the spent liquor. Usually, these kind of technologies are complicated, expensive, energy intensive, can be applied on a specific region, others need skilled personnel and some technologies not yet commercialised. However, technology like electro coagulation could give very high removal of chromium (98%) and reproducibility to developing countries due to its low cost. Despite all these scientific attempts tanning industry is still one of the major polluter of the environment worldwide. Therefore, to prevent the public health and environmental impact of tannery waste in general and chromium in particular the environmental regulation like effluent discharge limit has to be stringent and organization should be powerful to the extent to take measure by applying polluter principle or precautionary principle to avoid the effect of toxicity and bioaccumulation.

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A Review of the Climate-Change-Impacts' Rates of Change in the Arctic*

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ABSTRACT

Climate Change is a global phenomenon that has a global scale impact. The current trend of climate change towards the warming of the globe has resulted in various changes in the geological, climatology, social, economical, and biological processes worldwide. Temperature of the globe has increased due to various factors, but anthropogenic plays a major contribution through the heavy input of Greenhouse gases. One of the world's most remote regions that have been affected by most of the anthropogenic stresses on environmental services is the Arctic Region. The Arctic Region has shown various drastic changes and has shown to be effected by various anthropogenic activities that take place elsewhere. These changes include the ozone hole (resulting from ozone degrading compound emitted heavily by anthropogenic demands), the accumulation of various persistent and volatile pollutants (i.e. POPs), and the meltdown of the polar ice (among others). These drastic changes are well perceived and well projected for future preparations. However, the question still remains if these impacts would only accelerate change. This paper aims to discuss if these changes are accelerating or happening at a constant rate. In addition, this paper aims to only focus on changes due to global warming and climate changes phenomenon.

Keywords*: *Climate Change Impacts, Rates of Change, Causal Network, Arctic Ecosystems

1. Introduction

Climate Change is one of the biggest threats to the nature and humanity in the 21st century, influenced by both anthropogenic activities and natural phenomenon. It was calculated that the increase fossil fuel use with enhancement global warming will lead to the extinction of civilizations as time increases [1]. Hence the problems associated with Climate Change are one of the major obstacle to Sustainable Development. With an increasing release of Green house gases (GHG), which is the major cause of global warming and a key role in regulating Earth's temperature, it is vital to respond by achieving greater understandings on the impacts of climate change.

The impacts of Climate Change have been widely acknowledged to be deteriorating ecosystems services. Coral Reefs have been found to degrade due to increasing oceanic temperatures [2], while melting ice sheets caused problems for Arctic organisms [3]. Although several studies have been made on the opportunities and adaptations required meeting climate change challenges [4,5], however, the question remains whether the rates of change caused by climate-change led impacts will be constant or accelerating. Acknowledging the rates of change of the effects resulted from climate change led impacts is vital towards setting goals for sustainable development. Since if the rates are accelerating, it may require leading agencies to contribute to reducing the effects of Climate Change while combating Climate Change itself. Hence the aim of this paper is to review the impacts of climate change to glimpse the prospects of the rates of change that may result.

The Arctic Region is one of current most remote places on the planet. However, due to the effects of vorticity, the location, the Arctic Oscillation, and various other factors that made the Arctic vulnerable to change. The characteristics of the Arctic Ocean are similar to that of the Mediterranean Sea, where it is heavily influenced by "land-ocean interactions with restricted exchange with other oceans" [6]. It is the Arctic region's vulnerability to change that has given the Arctic a reputation for being the global health meter. Hence the aim of this paper is to determine whether changes caused by climate-change led impacts will be accelerating or not in the Arctic regions. To do so, this paper will explore the climate change im-

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pacts on the Arctic Ecosystem through literature studies. A prognosis of the rates of change resulted from the impacts incurred by climate change will then be determined by performing a causal network assessment of the climate change impacts, where a cause-effect diagram will be constructed. By understanding the impacts and the rates of change associated with climate change in the Arctic regions, future paradigm of the global climate change impacts can then be perceived which would allow a greater possibility to move towards sustainability.

In order to assess the rates of change, it is required to understand the relationships that exist between climate change and its impacted entities. One common technique is to apply Causal Networks. Causal Networks are a diagrammatic representation of relationships demonstrating the causality in relationships. There are a number of ways of performing a causal network analysis. It can be as simple as constructing a form of Directed Graphs or as complex as performing systems dynamics and data mining tasks. However, since this paper will require not only the understanding of the impacts from climate change, but how the impacts are interrelated, where the more related they are the more probable that the rates of change will not be constant. Meanwhile, there is limited resource in terms of time and data availability. Thus, for this paper, a Cause and Effect diagram will be conducted. A Cause and Effect Diagram is a type of Directed Graphs where elements are textually stated and with their relationships represented using arrows, often without quantitative data [7]. The Cause and Effect diagram does not give a lot of information but it does present a general idea of the problems, which would allow a first stance perception of an issue – in this case climate change impacts.

In order to assess and construct a Cause and Effect Diagram, it is mandatory to understand the impacts of climate change on the Arctic ecosystem. Hence the impacts of climate change on the indigenous people and the society, biodiversity and biological processes, the Arctic climate and physical geography, and the Arctic economical trends and transitions are reviewed.

2. Climate Change Effects on Indigenous People and the Human Health

The situation is the same across the North for indigenous people from Canada's Arctic to Siberia. The Polar Regions are experiencing some of Earth's most rapid climate change, even though they have contributed the least to the world's greenhouse gas emissions and have the smallest ecological footprint on earth. Indigenous people are affected by climate change and the effects varying depending on different locations and ecosystems in which they live, because their culture and the whole ecosystem that they interact is dependent on the cold and the conditions of the Arctic region. For example, the ice is diminishing and animal migration routes in the Arctic are changing. Indigenous people depend on natural resources for their livelihood and they often inhabit diverse but fragile ecosystems. For indigenous peoples around the world, climate change brings different kinds of risks, to cultural survival and undermines indigenous human rights [8].

Climate change also increased health risk and contributed to increase mortality in many regions of the world. Many present human diseases are linked to climate fluctuations. Some evidence is mounting that the changed in the broad-scale climate system may already be affecting human health, including mortality and morbidity from extreme heat, cold, drought or storms, changes in air and water quality and so on. Changes in climate would also create new challenges for community health. Drier summer conditions and the projected increase in forest fire incidence would likely lead to increased lofting of dust and dust-borne organisms and an increase in forest fire incidence. The poorer air quality resulting from increases in smoke and dust would likely increase respiratory illnesses such as asthma [9]. Impacts on the health are not only due to climate change, but may also be due to releases of greenhouse gases, *i.e.* incomplete combustion emissions from internal combustion engines [10] which can cause various health problems under specific environmental conditions [11].

The other aspects influenced the indigenous people is that climate change induced the culture transformed. For example, people live Arctic has already adapted to the environmental but as the weather gets warmer, the people are becoming stressed. The routes across the ice become dangerous when the ice thins [3].

3. Effects of Climate Change on Biodiversity and Biological Processes

Climate change is expected to increase during the next hundreds of years, contributing to many changes such as physical, ecological, economical and social but many of them are already taking place. The increase on precipitation, shorter and warmer winters, decreases in snow and ice cover, rising of the sea levels are projected changes that will likely persist in the long term (see section 4).

Changes related to climate change or the Arctic may cause "cascade-impacts", therefore involving many species of animals and plants. Comparing with other warmer regions, the systems in the arctic have generally less species, but such species develop important and similar roles, so if the species are displaced, there can be terrible consequences for other species that depend upon them [12].

3.1 Changes in Habitat and Distribution

Annual average temperature in the Arctic has increased almost twice the rates as that the rest of the world on the past years, with many variation between different regions.

Because of such warming environment, increased atmospheric CO_2 concentrations and other green house gases due to human activities, mainly the burning of fossil fuels and increased UV irradiance the temperature is projected to increase. It is assumed that the distribution of species or the habitat in the Arctic will move towards the north and that local species will migrate [13] which leads to the gretest impact of climate change; the dominance of species that favours the changed environment [14]. Many ecosystems and species have been recently affected on its distribution, for example the Marine Environment which is a highly climate-dependant system; therefore, climate variations are having important consequences on marine species [15,16].

Polar bears population which is very dependent on sea ice has decreased around 15% in both average weight and number of cubs during recent years [3]. The increased temperatures and increased rains of spring cause the collapse of dens resulting in the death of cubs and females. Also the early break-up of the ice in the spring separate the den sites from feeding areas so the young cubs can't swim long distances from dens to the feeding areas. Polar bears cannot survive if there is a big loss of the ice cover during the summer, so their only option would in a nearly future will be to change to a land – based lifestyle during the summer which means competition with brown and grizzly bears, resulting as an additional threat to their survival. The loss of polar bears is very likely to have fast consequences for the ecosystem that they are currently occupying.

3.2 Changes in Abundance

Climate change is projected to affect individual organisms' size, structure and abundance. Organisms' physiological responses and depend upon the dynamics of the populations and competitiveness between species. Physiology and Biochemistry are very important because they are key elements for the response of the organisms to changes in environment.

Phenology studies the relation between climate factors and life cycle of organisms, and it is also crucial for the diversity of the Arctic, unexpected events in climate will also affect the size of populations. The most important impacts related to such issue consist on how changes will affect interaction between pairs of species, and if one of the species changes its phenology more than others, this will probably increase the effects of competition [17].

3.3 Changes in Migratory Habits

The climate affects the migration and survival of animals that are an important source of native diets, the ability of goods to arrive from the south, the stability of homes on the permafrost and the ice-thickness to make travel over land and sea safe [3].

Climate change is expected to cause the northward expansion of forests into the Arctic tundra, and of tundra into polar deserts. Such changes are likely to take place this century in areas where suitable soils and other conditions exist. This is expected to result in the area of tundra becoming smaller than it has ever been during the past 21 000 years, reducing the breeding area for many birds and the grazing areas for certain land animals [3]. However, the possibility of migration is dependent on various factors. According to [14] insects and birds will be able to migrate but would have been a challenge for flightless species.

The total number of species in the Arctic is projected to increase under a warmer climate due to migration of species from the south. Many of the adaptations that enable plants and animals to survive in the Arctic environment also limit their ability to compete with species that move in from the south. Moreover, Arctic species are limited in their northward migration by the Arctic Ocean, which enhances the likelihood of bioinvasive success. These northern species may be reproducing less successfully due to temperature-induced habitat changes, while changes affecting breeding grounds and access to food may cause seasonal migrations to take place earlier in spring and later in autumn. Changes in the ranges of certain bird [18], amphibians, and invertebrate species have been observed [13]. At present, there are more varieties of moss and lichens in the Arctic than anywhere else in the world. This type of vegetation is particularly likely to decline as the Arctic [3]. Under a CO_2-doubled climatic forcing, migration fates of vegetation have also predicted in a variety of scenarios [19].

The geographical spread of animals can generally shift much faster than that of plants, and large migratory animals such as caribou can move much more readily than small animals such as lemmings. In addition to mobility, the availability of food sources is another factor that influences the pace at which different species will shift northward. All of these differences will result in the break-up of currently interdependent communities and ecosystems and the formation of new ones, with unknown consequences [3,13].

3.4 Problems with Bioinvasion

Invasion of non-indigenous species have caused important problems during the past years. With a changing climate in terrestrial ecosystems, species seem to be more likely to survive in the Arctic and therefore new species will probably arrive, and some of them will establish and form reproducing populations. There is not yet a clear establishment of classifying such new species as "native" or "non-native" when the reason of a rapid change in climate is driven anthropogenically, but it stills need to be remembered that at least 1% of the species that are introduced into the Arctic environment are likely to become "invasive species" [3]. An example of this has been portrayed in British Columbia where invasive species that are often aggressive and highly adaptable, have been continually introduced in low elevation protions of British Columbia; most of which are plants and noxious weeds [14]. Such introduction can lead to resource competence and disease spreading, for wildlife and people.

On the aquatic environment one of the major problems is caused because of the thinning of the sea ice and the opening up of the Arctic Ocean to more shipping so the possibility of introducing non-native species through ballast has increased and for that reason environmental risks. It is under great concern not only because of the problems that it creates, but also because 80% of the worlds total cargo is transported by ships [20], while many thousands of marine species are being transported through ballast water [21]. Ballast water becomes a problem when organisms that came with the ballast water survived the journey and started dominating in the new habitat [20]. In addition various kinds of bacteria and viruses may spread due to the results of the depletion of the Oxygen in the water, allowing them to grow during the journey [22]. In fact, it was said that most of the aquatic species do not survive the voyage, which is often shorter than the long voyages at sea [20]. Despite this fact, if the water quality remains favorable, towards certain species, for the whole voyage and at the destination, this may give the higher possibility for success in bioinvasion, since its success would require the organism to stay alive during the voyage, to be able to adapt to the new environment and to out compete the local species [23].

4. Arctic Climate and Geographical Impacts due to Global Warming

It is believed by various scientists that global warming will be manifested through Arctic's regional changes. There have been various climate models predicting temperature changes in the Arctic regions. R. W. Mcdonald R. W. *et al* (2005) stated that in the 20th century, the Arctic has been at its warmest comparably to the temperatures of the past 400 years, where there would be an approximate increase of 5^{o}C or more at the pole and 2–3^{o}C increase at the arctic margins, whilst decreasing the temperature contrast between the Arctic and the equator. [24] have used various global climate models to predict scenarios of climate changes in the Arctic region and suggests that there will be a 5^{o}C increase during the spring (Mar – May), 1–2^{o}C during summer (Jun – Aug), 7 –8^{o}C during autumn (Sept – Nov) and 8–9^{o}C during winter for the 2030 AD–2060 AD period. In addition, some studies suggest temperature change is greater over land than the ocean [25], while some suggest a similar trend. According to [6] the Eastern Arctic Ocean's temperature in spring indicates a warming of 2^{o}C per decade while the Arctic land mass indicates a warming of 2^{o}C per decade in winter and spring.

The changes in temperature have caused changes in the pressure over the Arctic Region. [24] suggested that there will be a decrease in 1–2 mb of sea level pressure in the Arctic region where these projected decreases of pressure are in the autumn and winter. Studies on the Arctic Oscillation have also shown anomalies in the pressure of the Arctic region. Arctic Oscillation is a climatic index which indicates atmospheric circulation over the Arctic, taking considerations of various factors including pressure and vorticity, among several others [26]. The Arctic Oscillation index has been found to be gaining a positive shift since the 1980s and especially in the 1990s, indicating increasingly lower sea-level pressure. These values have been found to be distributed symmetrically over the pole while higher pressures are evident over the North Atlantic and North Pacific during the winter and over Siberia and Europe during the summers. Normally the Arctic Oscillation index value would be shifting between positive and negative values, but some research studies suggest that GHG warming is the culprit for locking the Arctic Oscillation index value to a positive position [6]. In addition, it is also suggested that the temperature changes in association with the Arctic Oscillation is large enough to effect the polar circulation. The changes in Arctic Oscillation, especially on the average sea level pressure, have allowed increase in precipitation, including increase cyclonic activities. [25] discussed models for projecting climate change scenarios for global impact studies and projected that during winters there would be increases in precipitation in middle and high northern latitudes. In addition, there would also be large precipitation increases in the northwest of North America. [24] suggested that polar low pressure systems would be more common, causing an increase in mixed phase precipitation, while warmer temperatures may contribute towards enhanced hydrological cycles over the arctic, increasing the stratification of the upper ocean. It had been projected that precipitation during 2030–2060 are generally higher that present by 1 cm per month. The changes in the Arctic Oscillation would allow the Arctic region to become wetter and in combination with warming of the Arctic atmosphere, freezing mist and drizzle generation would increase. In addition, current trends in the Arctic Oscillation Index indicate a greater tendency for cyclonic activity and the poleward-propagating extratropical cyclones will have fewer tendencies to decay. [6] suggest that, under the condition of 1% CO_2 concentration increase per annum for 80 years, precipitation would increase by 0.5–1 m per annum for Arctic and subpolar regions.

Other geographical impacts of climate change on the Arctic region include the decrease in ice volume and extent, decrease in permafrost areas, fresh water discharge, among others. [6] suggests that the mean annual river discharge will increase by 20% for the Yenisei, Lena and Mackenzie rivers with 12% decrease for the Ob River, where Yensei, Lena, Mackenzie, and Ob are the 4 many other major rivers that discharges to the Arctic Ocean. In addition the amplitude and seasonality of flow will change due to decrease snow fall and earlier spring melt. There is also glacial ice mass loss in the Arctic region. Ice mass in Greenland are decreasing at the rate of 53 km^3/layer. [24] have used 4 global climate models to project scenarios of sea ice in the Arctic and resulted in reductions in ice extent and thickness in the Arctic region. It is estimated that by 2050, ice extent will decline by 30% and the ice volume 40%. Data recorded by ships and settlements suggested that the ice extent decline have fall below pre-1950 minima after 1975. Satellites records show that for the past 20 years, the rate of decline of ice extent is at 3% per decade. It is projected with satellites' records' extrapolation that in 2050, the trend of summer minimum ice extent reduction will be at 15% and the volume will be decreased by 40%. [6] suggests that by 2100 permafrost area could be reduced by 12–22%. Approximately 25% of the land in the Northern Hemisphere and under sediments of the continental shelves is permafrost, where discontinuous permafrost regions of the Arctic are the most vulnerable to change.

From these changes of the geographical and climatic changes of the Arctic region, we can see the magnitude of impacts due to climate change on the Arctic regions. It is these changes that will impact the global environment at all scales.

5. Economical Trends due Impacts of the Arctic Region due to Climate Change

Sub-regional impacts: In a region as large and diverse as the Arctic, there are significant sub-regional variations in climate and the warming is more dramatic in some areas than others. For example in some regions such as parts of Canada and Greenland (near the Labrador Sea), have not yet experienced the tangible warming of the rest of the region. Regional variations in future climate change are also projected. In fact the local characteristics of the nature and societies also create differences in types of impacts and the importance of them in each sub-region. This makes the discussion of economic impacts more specific, regional, and controversial because of the interconnections between these regions. As an intuition into the different regional impacts, just some general properties of different arctic sub-regions are presented and the economical impacts will be discussed in general, while different economical impacts can be inspired from different climate characteristics. The regions and their specific changes due to global warming can be classified as follows [27]:

1) East Greenland, Iceland, Norway, Sweden, Finland, Northwest Russia, and adjacent seas: The marine access to oil, gas, and mineral resources is likely to improve as sea ice retreats. A general increase in North Atlantic and Arctic fisheries is likely, based on traditional species as well as the influx of more southerly species.

2) Siberia and adjacent seas: Sea-ice retreat is very likely to increase the navigation season through the Northern Sea Route, presenting economic opportunities as well as pollution risks. Access to offshore oil and gas is likely to improve but some activities could be limited by increased wave action.

3) Chukotka, Alaska, Western Canadian Arctic, and nearby regions: Damage to infrastructure will result from permafrost thawing and coastal erosion. Reduced sea ice will enhance ocean access to northern coastlines. Thawing may cause problems for land transport in winter. Traditional local economies based on resources that are vulnerable to climate change (such as polar bears and ringed seals), are very likely to be disrupted by warming.

4) Central Eastern Canadian Arctic, West Greenland, and adjacent seas: Sea-ice retreat is likely to increase shipping through the Northwest Passage, providing economic opportunities with increasing the risks of pollution due to oil spills and other accidents. More southerly marine fish species such as haddock, herring, and blue fin tuna could move into the region. Lake trout and other freshwater fish will decline, with impacts on local food supplies as well as sport fishing and tourism.

5.1 Major Potential Economical Impacts:

Climate change would have a wide range of impacts on the Arctic Economy. Although it is probably that this would have led to the tradgedy of the commons [28] but may also have led to developmental impacts. The significant economical impacts of the climate change to the arctic regions are being discussed as follows.

5.2 Agriculture and Forestry Development

Treeline is expected to move northward and to higher elevations, with forests replacing a significant fraction of existing tundra, and tundra vegetation moving into polar deserts, thus as potential areas for food and wood production expand northward due to a longer and warmer growing season and increasing precipitation, where suitable soils exist, agriculture and forestry will have the potential to expand northward due to a longer and warmer growing season. More-productive vegetation is likely to increase carbon uptake, although reduced reflectivity of the land surface is likely to outweigh this, causing further warming. The consequent impacts such as emissions from transportation of the agriculture and forestry products and machinery used to handle the related cultivation and process industries may also become of more importance as contributors to speed up the climate change rate.

5.3 Expanding Marine Shipping and Access to Resources

The continuing reduction of sea ice is very likely to lengthen the navigation season and increase marine access to the Arctic's natural resources, though increasing ice movement in some channels of the Northwest Passage could initially make shipping more difficult. Shipping through key marine routes, including the Northern Sea Route and the Northwest Passage, is likely to increase. The summer navigation season is projected to lengthen considerably due to the decline of sea ice. Expansion of tourism and marine transport of goods are likely outcomes that this may result in increased rate of released emissions of GHG and other pollutants to the arctic areas.

5.4 Changes in Fisheries

Some major arctic marine fisheries, including those for herring and cod, are likely to become more productive as climate warms. Ranges and migration patterns of many fish species are very likely to change. Also decreased abundance and local and global extinctions of freshwater fisheries are projected for this century. Arctic char, broad whitefish, and Arctic cisco, which are major contributors to the diets of local people, are among the species threatened by a warming climate.

5.5 Indigenous Communities are Facing Major Economic Impacts

Many Indigenous People depend on hunting polar bear, walrus, seals, and caribou, herding reindeer, fish, etc. that lots of these species are likely to be seriously damaged by climate warming. This results to a shifting towards food imports and the necessity to have an industrialized style of living to be able to earn the related income. It will result in a total change in the economy structure of the region and style of living of the indigenous people.

5.6 Thawing Ground will Disrupt Transportation, Buildings, and Other Infrastructure

Northern communities that rely on frozen roadways to truck in supplies are somehow affected now and may be affected more. Transportation and industry on land, including oil and gas extraction and forestry, will increasingly be disrupted by the shortening of the periods during which ice roads and tundra are frozen enough to permit travel. As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are likely to be destabilized, requiring substantial rebuilding, maintenance, and investment. Future development will require new design elements to account for ongoing warming that will add to construction, maintenance costs, and probably the new materials production emissions.

5.7 Increasing Access to Resources, Industrialization, and Appearance of Sovereignty Claims

Marine access to some arctic resources, including offshore oil and gas and some minerals, is likely to be enhanced by the reduction in sea ice, bringing new opportunities as well as environmental concerns, though increased ice movement could initially make some operations more difficult. As a result, industrialization in the arctic areas is inevitable due to the access to the extracted resources and the high transportation costs to other parts of the world. This will result in a higher rate of release of GHG emissions and other pollutants to the ecosystems nearby and contribute to the rate of climate changes. Also due to resource extraction and the industrialization and the related economic benefits, sovereignty, security, and safety issues, as well as social, cultural, and environmental concerns are likely to arise.

6. Prognostic Overview of the Rates of Change

Climate change will definitely have impacts on the global scale. As illustrated previously, various factors of the Arctic will be affected by the current rising trend of global warming. However, these changes are not happening at the constant rate, and many are influencing acceleration in the rates of change.

If we observed the sea level rise, we can see that estimates of the rise in sea level have been changing by various models over the years. Although it is arguable there may have been a lack of accuracy in these models, however, readings of models recently shows a similar trend. In addition, Recent studies from the department of Meteorology, University of Utah, suggests that efforts in developing climate models in the United States have paid off in climate models with much greater accuracy than before [29]. [25] analyzed 3 different models and projected various changes over a 30 year period with respect to 1961–1990 data. The projection showed varying figures in rise; 12–20 cm in 2020s, 24–38 cm in 2050s and 40–58 cm in 2080s. [6] suggested that they may be an additional of 50 cm in sea level rise to the already estimated rise of 10–25 cm in the past century. One of the Chief of the Arctic Climate Impact Assessment (ACIA), Dr. Robert Corell, stated that "Greenland contains enough water to raise the sea by seven meters" and that the "sea could under these projections rise a meter every 50 years", where this can cause great impacts on many parts of the world as stated by Dr. Robert Corell that "Bangladesh will lose 40% of its land mass." It is also noted that the total Greenland ice can be melted overtime by 3^{o}C increase.

The raise in sea level is attributed to many factors, among them, the increasing rate of ice cover, extent, and volume decline. The current rate minimum ice extent reduction would lead to ice free areas. The Sea of Okhotsk, the Sea of Japan, the Northwest Passage through the Canadian archipelago, and the coast of Alaska will be ice free. The central Arctic Ocean, Greenland Sea, Bering Sea, and Gulf of St. Lawrence will maintain ice cover but there will be a reduction in thickness, estimated at 1.5 m with less compact properties. It is also predicted that marginal ice zone will migrate pole-wards under a warmer climate [24]. Thus due to more exposed oceanic areas and the disappearance of former ice, any newly ice formed would disappear faster due to the salinity content of the ice. [6] suggested that the Arctic Oscillation also contributes towards the variation of the Arctic sea ice distribution. A study of stable isotope data from the Beaufort Sea dating from 1987 to 1997 show a correlation between the increase of ice melt amounts within the water column and the increase in the Arctic Oscillation index. [6] explained that "cyclonic circulation leads to greater ice divergence, new ice leads, enhanced heat flux, reduced ridging", which these factors lead to thinning. Although, there have been discussion of whether the influence of the Arctic Oscillation is significant in terms of thickness distribution change but may not be as significant for ice volume change, but it is also suggested that the sea-ice thinning and the Arctic Oscillation correlation is strong (approximately 80%), due to various dynamic effects. As mentioned previously, the Arctic Oscillation index increase implies lower sea level pressure and increase in cyclonic activity. The increase of Cyclonic activities would further enhance the effectiveness of ice thinning. The Arctic Oscillation index is said to be locked in the positive position partly due to GHG warming. Thus, a continuation of rapid global warming would further imply the enhancement of ice thinning efficiency, which would cause the global albedo capacity reduction and resulting with an accelerated warming. Furthermore, it is suggested by [6] that the change in ice cover would alter the levels of light penetration, mixing levels, the degree of primary production, and the amount of carbon flux.

The Degree of mixing is affected by various factors, including the thermocline and the halocline of the water column. Prof. Terry Callaghan from the Alaska Scientific Research Station stated in an interview that the Arctic region cools the rest of the world through capturing and storing Greenhouse Gases, high albedo, and the cooling of the world's ocean currents. The cooling of oceanic currents relies on the mixing of the oceanic water column that is affected by the stratification. The level of stratification is influenced by thermocline and the halocline of the water column. However, due to the warming of the climate, these stratifications and the hydrology of the Arctic region have been changing recently. The level of stratification and the efficiency at which it is forming is still a scientific controversial discussion due to the variances in the halocline within the Arctic region [6,30]. The increase in glacial melts, increased precipitation, a decline in permafrost, and enhance from the Atlantic lowers the salinity, whereas in some areas the salinity is increasing due to the change in freshwater flow of rivers, e.g. the enhancement of salinification of the Eurasian Basin due to the diversion of river inflow [6]. From these findings, we can say that the general salinity balance has been greatly disturbed by impacts of climate change. These changes will affect the general mixing of the Arctic, which would affect the efficiency of the Arctic to cool down the global oceanic currents. According to [31], the upper oceanic layers of the Siberian coast have shown a decrease in salinity and have been suggested to prevent mixing and preventing the warmer oceanic waters from reaching the surface through the increase in stratification. The effect of oceanic currents and hydrology in general of the Arctic region will also increase the transportation of contaminants towards the Arctic region. This leads to increase in the accumulation of contaminants in the Arctic region and thus threatened various biological species in the region.

The other major impact of climate change that accelerates the changes in the Arctic region is the decreasing permafrost within the region. Permafrost degradation would lead to the increase of the active layer of the soil and hence causing further knock-on effects. The degradation of permafrost would lead to a change in vegetation pattern and other biological processes, while allowing the soil to become drier due to the degrading frozen soil which keeps the moisture to remain within the soil. The dryness, in addition to change in vegetation pattern changes, can lead to increase forest fires risks. In addition, the expansion of forests poleward would decrease the albedo levels and reducing the global cooling trend. Other problems of Permafrost degradation may also include increase sediment loading of water systems and risks of problems associated with waste management, *i.e.* landfills.

The biological importance in the marine environment of the arctic can be sometimes underestimated. Species from the arctic are very dependant to the sea ice. The loss of the cover or increase stratification are results of the rapid temperature increase in the arctic due to climate change and it has the potential to alter the amount of available food in many habitats. The alteration of the primary production either on amounts or in its distribution will decrease the food availability for aquatic biota such as fishes, whales, seals, walrus, etc. leading to population depletion, migration or even redistribution through the food webs. Regional variations in distribution and abundance of sea ice already have significant effects on the reproduction and survival of some species such as polar bear populations.

The increased warming and precipitation are very likely to increase the amount of persistent organic pollutants and mercury that are deposited on the Arctic. As temperatures raise, snow, ice and permafrost which contain contaminants will melt, leading to the release of these contaminants. The resulting increase in the concentrations of contaminants in ponds and rivers may have harmful effects on aquatic plants and animals and can also contaminate sea waters. Such impacts will be amplified and the levels of contaminants on the Arctic lakes will be accumulated and transferred up to the food web even endangering humans health by bioaccumulation that later can lead to other problems.

There are also important indicators that climate change affected radically terrestrial species. The climate change also had very strong impacts on habitat loss, diversity and migration, indicating that climate change can increase significantly extinction rates and modify the ecosystem in all levels, (global, regional and local) changes in biota and animal migration routes are also very sensitive to climate changes and will also be associated in response to warming. Thawing permafrost, changes in land use, habitat fragmentation are also some important changes that can affect animal success in reproduction, survival and dispersal, leading to specie losses in the Arctic.

By now there is no doubt that natural systems in arctic are changing and the most important thing that we should take into account is to have the adequate knowledge in order to know when keystone species begin to cause collapses of ecosystems and reductions in the ecosystem services. Therefore the monitoring is important for understanding how the biodiversity in the Arctic is changing and whether actions to take in order to understand the complex system responses to impacts of the climate change.

Growing evidence suggests that increases in global temperatures may lead to more rapid and irreversible shifts in the climate system. These could produce large changes in global systems. Since the early 1800's, the human activities have helped to increase concentrations of carbon dioxide by 30%, and methane, a greenhouse gas with 22 times the global warming potential of carbon dioxide, by 140%. And the rising greenhouse gas emissions will lead to changes in other parts of the earth's life support system. The number of people in the world has grown from 2.5 billion to more than 6.2 billion since 1950.The potential impacts of these events are too high to ignore. Human population growth and climate change are critically linked. The size of the population and its activities will be major factors in the extent of warming. And the population size will very much determine the effects on that population of climate change.

Climate change cause many social problems. The number of refugees and displaced people has increased markedly. Refugees represent a vulnerable population with health problems, and large-scale migration because of flooding, drought and other natural disasters. In addition to these factors, the increasing population will put greater stresses on the environmental services, which are being impacted from the global warming phenomenon and thus increase the rate of change. The rate of change in environmental services is further enhanced due to the possibilities of the generation of new ports and cities due to possible increase in the shipping and transportation industry.

In terms of economical effects, there are too many issues that would need discussing, so in this paper the effort is to stick to the side of most important and too concise rather than lots of details. As discussed in the paper, the development of agriculture and forestry and also expanding Marine Shipping and easier access to the natural resources, makes the rate of the changes accelerating, it means day by day the global warming effects such as thawing of sea-ice results in comfortability and feasibility of transportation, agriculture, etc. and the related developments (rebound effect) that helps to much easier further developments and also more GHG emissions. So this cycle is an important issue to consider in this area.

The assessment performed in this section, hence, shows the effects of the impacts in the Arctic regions that are caused by Climate Change and how they are related. From the discussions above, a causal network can be formed as a Cause and Effect Diagram (See **Figure 1**).

Figure 1 shows the causal network that represents the effects of climate-change led impacts and how they are interrelated. The reinforcing cycle of the climate change effect is visualized with the significant factors. This cycle is a growing cycle and can result in an irreversibility point.

The most important contributing factors in this worsening cycle can be counted as follow:

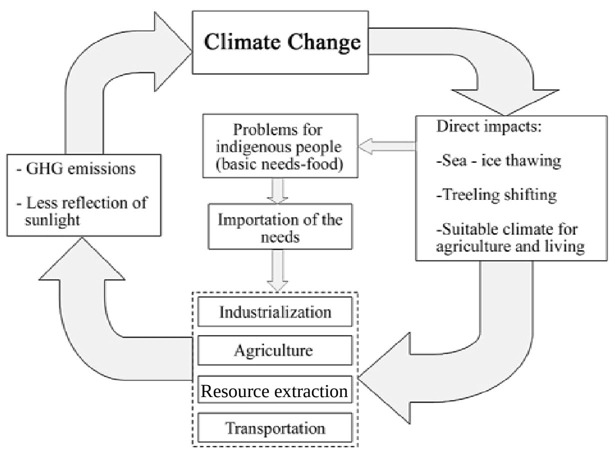

Figure 1. Cause and effect diagram, a form or causal network, showing the relativity between the effects led by climate change impacts

The development of agriculture and forestry in the arctic region may contribute to the absorption of CO_2 at the first glance, but the reduced reflectivity of the land surface is likely to outweigh this, causing further warming. Also impacts of emissions from transportation of the agriculture and forestry products and machinery used to handle the related cultivation and the related process industries are contributors to speed up the climate change rate towards the irreversibility point.

Easiness of direct-route marine transportations across the arctic zone which means less transportation costs and less emission from transporting of merchandize at first which might be a preventive agent for climate change rate, but this means less costs and an incentive for more transportation and therefore more emissions in total (the rebound effect).

Increasing access to resources makes industrialization rate faster and creates a competitive environment through the region. Also the proximity of the arctic with developed countries such as Canada, Sweden, Norway, and Finland makes the change faster and the multinational companies will start their business there leading to more resource consumption etc. and all these comes in the form of a accelerating cycle contributing to both global warming and the appearance of sovereignty claims for the region. So in case of having no international treaties and protocols, we may consider the trend of industrial revolution infect the arctic region.

From these findings and discussions as demonstrated above, we can see that most impacts of climate change on the Arctic region are bound to increase at an accelerating rate of change. Thus the accelerating contribution towards the climate change (the growing effect) can be qualitatively visualized in **Figure 2**.

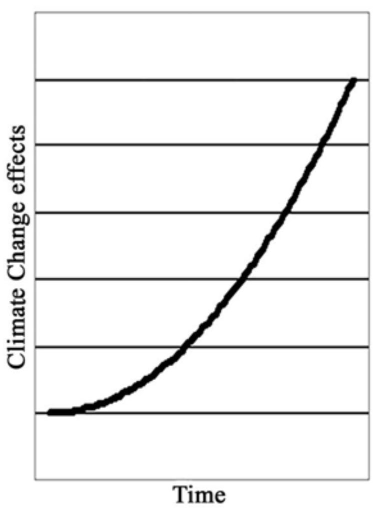

Figure 2. Accelerating rates of change as a result of increasing climate change effects with respect to time

7. Discussions

This paper semi-qualitatively assesses the effects of the climate change impacts in Arctic regions and portrays how the rates of change inflicted by climate change impacts will accelerate in the years to come. However, several human activities that may lower the rates of change have not been discussed. For example, the economical transitions may include more environmental strict abiding laws and well committed emissions cut by the industries. Although, this is not such a strong case in the past, but commitment to respond to the climate change phenomenon is increasing, as has been witnessed in the 2009 Copenhagen Climate Change Summit. Hence further evaluations of this issue should be conducted. Furthermore, if possible, a more quantitative approach to this issue should be achieved but this may become extremely difficult when approaching social and economical issues. Thus the best practice would be to approach this issue semi-quantitatively.

The other main problem is that a lot of this paper uses qualitative assessment, which makes subjectivity unavoidable. It is also the reason why the rates of change are not given quantitatively. This creates obscurity in terms of results. Nonetheless, the logical reasoning and evidences provided throughout previous studies suggests an accelerating rate of change. This means that further studies into this issue is urgently required.

One interesting factor that needs to be put in to consideration is the use of several parameters as determinants for impacts of climate change. For example, some indicators suggesting impacts that may have resulted from climate change (*i.e.* growth inhibition and calcium deficiencies of calcareous organisms) may have been resulted by other major influencing factors. A study by [32] suggests the impacts from recreational boating activities, especially due to exposure to antifouling agents and toxic substances. Hence, perhaps this also means that the global contribution to combat climate change may not be sufficient in solving the aftermath effects of climate change but also all the associated problems that has magnified the effects resulted from the impacts of climate change.

From these discussions, it is mandatory to further review the rates of change caused by climate change, as these effects and changes will like to accelerate even more as the problems paramount synergistically with other problems associated with anthropogenic activities.

8. Mitigation Measures

Several mitigations measures have been reviewed by the IPCC, UNFCCC, and UNEP, as well as several other researches in the field [33]. However, as a result of possible accelerating rates of change, several other mitigations measures are called for. In addition to the mitigation measures of climate change, leading agencies and authorities also need to consider other causes of environmental degradation to slow down the rate of change due to the impacts of Climate Change. Perhaps, it is necessary to perceive the problems in a more holistic perspective, *i.e.* ecological footprints. Although each environmental problem has its own ideosyncracies but the causal network shown in this paper suggest synergistic forces that drive changes in the environment. Measures to reduce ecological footprints can be done through implementing ecological engineering concepts, cleaner production, and industrial ecological and sustainable technological approaches, among others. Most of which have already been mentioned in the global arena. However, one possible mitigation measure that is being left out is the applications of bioregenerative life support systems which can assists in lowering dependency on natural resources and hence promote sustainability [34]. A more detailed evaluation of the rates of change is required if a specified mitigation measure is to be achieved. However if one were to follow the causal network produced in this paper, it is logical that these effects and rates of change can be reduced by taking out Climate Change but because Climate Change cannot be prevented it is the best of the global interest to seek a good response measure.

9. Conclusions

The Arctic Region is exposed to various impacts due global climate changes. As demonstrated in this report, these changes are accelerating due to indirect and direct changes of impacts due to climate changes. These changes can be demonstrated in a Cause and Effect diagram, revealing the importance of the need for international decision and pledge on stopping climate change and the urgent need to devise an exhaustive scheme to preserve the Arctic. However, as discussed above, there needs to be an urgent further study to investigate whether the rates of change will truly be accelerating and by how much it accelerates; to prevent a global catastrophe.

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Polyprenol from the Whole Plants of *Leucaena leucocephala*

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ABSTRACT

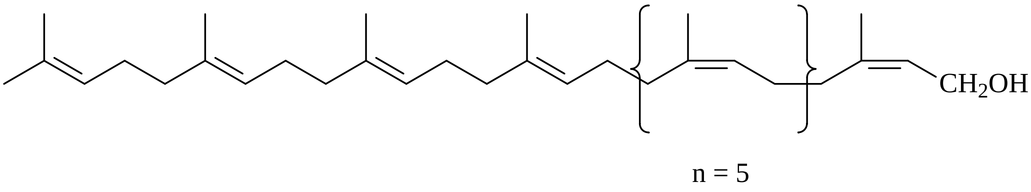
Ficaprenol-11 (*polyprenol*) (**1**), *squalene* (**2**), *lupeol* (**3**), *β-sitostenone* (**4**), *trans-coumaric acid* (**5**), *cis-coumaric acid* (**6**) *pheophytin-a* (**7**), *pheophorbide a methyl ester* (**8**), *methyl*-13^2-*hydroxy*-(13^2-*S*)- *pheophorbide-b* (**9**) *and aristophyll-C* (**10**) *were isolated from the whole plants of Leucaena leucocephala* (*Leguminosae*)*. Among them,* **1** *and* **2** *was found for the first time from this species. The structure of these compounds were characterized and identified by spectra analyses.*

Keywords**:** *Polyprenol, Leucaena leucocephala, Leguminosae*

Leucaena leucocephala (Leguminosae) is a small, leguminous and native to tropical America, now widely distributed in southern Asia and neighboring islands [1]. This plant's reproductive capacity is extremely strong. If can henceforth the plant separate the effective component, applies, will be able to reduce it to the environment threat. Previous studies have show that the extract of *L. leucocephala* was found to exhibit various pharmacological effects [2–8], *L. leucocephala* was chosen for further phytochemical investigation. The MeOH extract of its plants were subjected to solvent partitioning and chromatographic separation to afford 10 pure substances. The chemical constituents in the plants of *L. leucocephala* were separated with column chromatography.

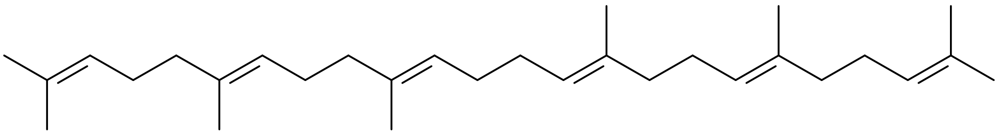
Investigation on the MeOH extract of the plants has led to the isolation of 10 compounds, one polyprenol: ficaprenol-11 (**1**) (**Figure 1**) [9]; two terpenoids: squalene (**2**) (**Figure 2**) [10] and lupeol (**3**) [11]; one steroid: *β*-sitostenone (**4**) [12]; two benzenoids: *trans*-coumaric acid (**5**) and *cis*-coumaric acid (**6**) [13]; and four chlorophylls: pheophytin-a (**7**) [14], pheophorbide a methyl ester (**8**) [15], methyl-13^2-hydroxy-(13^2-*S*)-pheophorbide-b (**9**) [16] and aristophyll-C (**10**) [17]. These compounds were obtained and characterized by the comparison of their physical and spectral data (UV, IR, NMR and MS) with values obtained in the literature. Among them, **1** (**Figure 1**) and **2** (**Figure 2**) was found for the first time from this species.

The specimen of *L. leucocephala* was collected from Kenting National Park, Pingtung County, Taiwan in May, 2009. A voucher specimen was characterized by Dr. Jin-Cheng Huang of Department of Forest Products Science and Furniture Engineering, National Chiayi University, Chiayi, Taiwan and deposited in the School of Medical and Health Sciences, Fooyin University, Kaohsiung County, Taiwan. The air-dried green beans of *L. leucocephala* (5.0 kg) were extracted with MeOH (80 L x 6) at room temperature and the MeOH extract (132.5 g) was obtained upon concentration under reduced pressure. The MeOH extract was chromatographed over silica gel using *n*-hexane/acetone as eluent to produce 10 fractions. Part of fraction 1 (8.24 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (50:1), then enriched with acetone to furnish 7 fractions (1-1~1-7). Fraction 1-4 (2.17 g) was re-subjected to Si gel chromatography, eluting with *n*-hexane/Acetone (40:1) to obtain -sitostenone (**4**) (9 mg, 0.0068%). Part of fraction 2 (2.67 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (50:1) to obtain ficaprenol-11 (**1**) (**Figure 1**) (21 mg, 0.0158%). Part of fraction 3 (6.77 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (8:1), then enriched with acetone to furnish 5 fractions (3-1~3-5). Fraction 3-3 (1.33 g) was further purified by another silica gel column using *n*-hexane/acetone to obtain squalene (**2**) (**Figure 2**) (5 mg, 0.0038%) and lupeol (**3**) (24 mg, 0.0181%). Part of fraction 5 (7.42 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (8:1) to obtain pheophorbide a methyl ester (**8**) (12 mg, 0.0091%). Part of fraction 6 (5.31 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (8:1) to obtain methyl-13^2-hydroxy-(13^2-*S*)-pheophorbide-b (**9**) (6 mg, 0.0045%). Part of fraction 8 (4.91 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (5:1) to obtain pheophytin-a (**7**) (8 mg, 0.0060%).



1

Figure 1. Chemical structure of Ficaprenol-11 (1)



2

Figure 2. Chemical structure of Squalene (2)

The air-dried leaves of *L. leucocephala* (5.8 kg) were extracted with MeOH (80 L × 6) at room temperature and the MeOH extract (143.5 g) was obtained upon concentration under reduced pressure. The MeOH extract was chromatographed over silica gel using *n*-hexane/acetone as eluent to produce 8 fractions. Part of fraction 5 (9.22 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (8:1) to obtain aristophyll-C (**10**) (13 mg, 0.0091%). Part of fraction 8 (7.16 g) was subjected to Si gel chromatography by eluting with *n*-hexane/acetone (5:1) to obtain *trans*-coumaric acid (**5**) and *cis*-coumaric acid (**6**) mixture (5 mg, 0.0035%) .

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