Water Management in Ayubia National Park

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Abstract

This research aimed to study the affect deforestation on soil infiltration rates and effective porosity in an effort to gauge the sensitivity of the soils of Ayubia National Park to deforestation. A total of 18 sites, ten from forested areas and 8 from deforested areas were documented. The sites were in located in the Namli Mera District located at the northern border of the Park. We compared infiltration rates and porosity of the forested and deforested area and an attempt was made at determining the change in ground water retention capacities due to this change in infiltration. The infiltration rate went up by about 175% and we estimated that the ground water recharge went up by 50% in the forested area as compared to the deforested area. We concluded that the soils of Ayubia are very sensitive to deforestation. Furthermore we formulated a mathematical model that related soil infiltration rates and porosity of the soil to the vegetation (trees, shrub and grass cover) while accounting for variables such as slope, soil texture, canopy cover etc through multi-variable linear regression. All work is based to the maximum on self made empirical observations. The cheapest and simplest methods of observing and calculating variables were chosen given the financial and time restraints.

Key words: Infiltration, Hydrology, Ground Water Ayubia National Park, Deforestation

1. Introduction

Ayubia national Park is spread over 3,312 ha of Western mixed coniferous forests. Although protected as a national park, its resources still come under great pressure due to the presence of 12 villages on its borders. Human activities in the forest have resulted in changes in key forest properties [1]. This change must be carefully followed and documented so that the forest may be properly conserved. Ayubia National Park has international significance as it forms part of the Western Himalayan global eco-region. We have focused our study on the Namli Mera area on the Northern border of Ayubia National Park. Furthermore, being on the boundary of the Park it contained both forested and deforested areas near to each other, with the exact locations and satellite picture of the 18 sites, documented in Appendix 1. Sites 1-8 are from the deforested area and Sites 9 – 18 are from the forested area, however we documented the forested area first. Results from areas close to each other would give us results that depended mostly on the change in vegetation cover instead of choosing forested areas from deep inside the park. Moreover, sites were chosen on the border or outside the park to so that the sanctity of the National Park would be preserved when samples were extracted.

The main aim of the study was to gauge the sensitivity of the soil features – infiltration rate and effective porosity, on forest cover.

Furthermore, all the data was carefully analyzed and a multi variable linear regression model established. This model relates soil infiltration rates and saturated water content of the soil to the vegetation (trees, shrub and grass cover) while accounting for variables such as slope, soil texture, canopy cover etc. The model was based only on self made empirical observations.
Lastly, the Coca Cola Company as part of its comprehensive social responsibility program, wants to become water neutral. In addition to other endeavors, it has funded WWF in its reforestation program in the areas surrounding Ayubia National Park. The company wished to know how much water it will save by reforesting several target locations, one of which is also located in Namli Mera. We have attempted to provide a possible framework for calculating this value. This calculation required several approximations and data collected from the internet. We caution the reader to possible inaccuracies in this result.

2. Experimental Method

The cheapest and simplest methods of observing and calculating variables were chosen given the financial and time restraints.

2.1 Infiltration

Our infiltrometer was self fabricated and consisted of two steel pipes with diameters of 3 and 4 inches. While this is narrower than an ideal infiltrometer, a wider infiltrometer will be impossible to insert into the soil due to the very rocky nature of the mountains in Ayubia. We had to change our location several times due to the presence of rocks even with our infiltrometer. The outer ring helps to prevent divergent flow. The drop-in water level or volume in the inner ring is used to calculate the infiltration rate. The infiltration rate is the amount of water per surface area and time unit which penetrates the soil once the soil is saturated. The infiltrometer was inserted by hammering it with a sledge hammer through a block of wood.

Figure 1. Infiltrometer at site four

We chose to do the field work in the rainy season so that the soil would be saturated to some extent and not require large volumes of water to achieve a steady infiltration reading. Luckily it rained heavily all night before taking readings in the deforested area. The infiltrometer was driven 15 cm into the soil to prevent lateral movement of the water.

A 4 cm head was maintained in the inner ring of the infiltrometer. Water was continuously added using a 1 litre plastic measuring cylinder with a least count of **5** ml. Amount of water per unit time was measured. The time intervals after which volume was measured were varied given the rate at which the water was infiltrating. This was between 1 and 15 minutes.

2.2 Effective Porosity or Saturated Water content:

The saturated water content is also known as the effective porosity as at saturation even though there are empty air pockets in the soil these pockets can never be filled with water.

Once Infiltration was complete at a site and the infiltrometer removed from the soil, soil was extracted from the Infiltrometer. Soil cake was assumed to be saturated. The samples were stored in aluminium bags [2] and sealed in zip lock bags further sealed with sealing tape, labelled and then stored in an insulated backpack. Samples were refrigerated at the WWF office and then kept in the SSE Biology Lab cold room until processed. Aluminium bags with the soil were weighed then were cut and placed in a drying oven in the SSE Chemistry Lab and weighed till weight reading became constant. This took two days at a temperature of 120^{O}C**.** Volume of water stored in the soil was calculated using Equation 1**.** Soil samples were then wrapped tightly in Aluminium and placed in a beaker into which a known quantity of fine sand was added. The extra displaced sand gave the volume of soil. Effective porosity was calculated using Equation 2.

Vol water = weight wet soil **-** weight dry soil (1)

Porosity =
Volume of water / Volume of Soil (2)

2.3 Soil Texture

Two more soil samples were extracted from each site, one from between 0 – 15 cm of depth and one from 15 – 30 cm depth [X], using a 3 inch diameter, 2 feet long pipe that was hammered into the soil also using the sledge hammer and block of wood. These were used to establish the soil type of the area. However, we have not received the results at the time of writing of this report. We realize that soil texture is critical in determining infiltration rates our only justification for continuing is that the general composition will remain the same over our relatively small study area.

Figure 2. Aluminium and Ziploc bags for soil storage.

2.4 Slope

Slope was calculated using a 3-5 meter rope stretched across the mountainside close to the infiltration site. It was held in place using two sticks of equal length which were dug into the ground to a certain marked level to make sure that the height of the sticks above the ground was equal. This ensured the rope to be perfectly straight above the small shrubs and plants. A level was placed horizontally at a point on the rope and a protractor was rested upon it to measure the angle (Q) the rope made with the level. The value of tan(Q) gave the slope of the site. Three values of the slope were recorded near each infiltration site and averaged.

2.5 Vegetation

Trees were counted in the standard 100 m^2 area around the infiltration site. This was done by tying rocks to several 6 meter long ropes which were tossed outward from the infiltration location thus establishing markings for an approximate circle with area $100m^2$. The trees falling in this area were counted. The specie of the trees was also noted. Small (2-3 meter in height) deciduous bushes were also counted in this area. These are represented as small bushes

Shrubs, grass and canopy was approximated as a percentage of the total ground or sky. While this seems very inaccurate there were six students on site who agreed on the estimate and many pictures were taken of each site for reference which was used to keep memory of previous sites fresh. These values are not used in the calculation of the first objective. Leaf litter was given a value of 0, 1 or 2 that represented low, medium and high amounts of leaf litter.

2.6 Gravimetric Water Content

While we are referring to this variable as the gravimetric water content it is not actually the popular term but rather the gravimetric water content at saturation. This was calculated from the same soil the porosity was calculated from.

2.7 Elevation, Soil and Air Temp

Elevation was checked with a simple GPS device. The soil temperature was calculate at a depth of 5cm and the air temperature was taken from a shaded area both using a standard lab alcohol in glass thermometer.

3. Results and Analysis

3.1 Readings and Average Values

For the objective of seeing the variation of infiltration rates between forested and deforested areas the average values of key parameters are given in Table 1. This data is further used to estimate ground water recharge in section 3.2.

Table 1: Mean Values

	Infiltration Rate cm/hr	**Effective Porosity**	**Trees**
Forested	26.56	0.75	25
Deforested	9.62	0.46	3

For calculating the mean, we removed the reading for site 1 from the forested area and sites 3 and 8 from the deforested area. Site 1 gave an inconsistently high infiltration rate. We attribute this inconsistency with error in our experimental techniques as this was our first site. Site 3 in the deforested area was abundant with ants. We attribute the larger infiltration rate to their presence and hence disregard this reading. Site 8 in the deforested area was a control reading taken from a small clump of trees (a privately owned communal forest, used for wood and grazing). The large number of trees in this area did not represent the deforested area well and we have disregarded this reading as well.

3.2 Ground Water Recharge

Cutting edge literature on ground water hydrology use complex water balance equations that are beyond the scope of this paper. We derive our motivation from the balance equations as suggested by Casimir Debski [3]. The mentioned paper splits water balance into two distinct zones. The “visible zone” equates flow above the ground while the “invisible zone” accounts for water flow below the ground.

For the visible zone
Precipitation = Surface Runoff + Evaporation + Increment in Surface Water Retention + Infiltration

For the invisible zone
Infiltration = Underground Runoff + ground evaporation + increment in ground water retention

We shall focus our attention on the invisible zone. Consider the equation for the invisible zone written for deforested and forested area:

Deforested: $I_1 = D_1 + E_1 + W_1$ (2)
Forested: $I_2 = D_2 + E_2 + W_2$ (3)

Where
I: *total infiltration*
D: *Deep drainage (underground runoff)*
E: *Evaporation*
W: *Increment in ground water storage*

Subtracting Equation 2 from 3 we obtain Equation 4.

$I_2 – I_1 = D_2 – D_1 + E_2 - E_1 + W_2 - W_1$ (4)

We assume deep drainage is not significantly affected by forest cover, i.e. $D_2=D_1$ as calculating deep drainage is beyond the scope of the paper. [6] Claims that deforestation increases deep drainage. Therefore $D_1>D_2$ and therefore this is an underestimate of the change in water content which is acceptable for the purposes of this paper. Equation 4 reduces to Equation 4b.

ΔWater Storage = Δ Infiltration - Δ Evaporation (4b)

3.2.1 Estimating the change in total infiltration

The area that has been forested should not have any significant effect on the precipitation in the area. Hence the amount of precipitation before will be the same as now.

Total Volume Infiltrated = Infiltration Rate x time

Ayubia is used to rainfall in heavy showers, and so we assume all infiltration happens at saturation because soon after a rainfall event occurs the ground becomes saturated. We are aware that this assumption introduces significant errors.

(Rif x Time) / (Rid x time) = Tif / Tid

Tif = (Rif/Rid) Tid

Where
Rif: Rate of Infiltration in the forested area = 26.56 cm/hour
Rid: Rate of Infiltration in the deforested area = 9.63 cm /hour
Tif: Total yearly infiltration in the forested area
Tid: Total yearly infiltration in the deforested area

Tif = 2.76 Tid
Δ Total Infiltration = Tif – Tid
Δ Total Infiltration = 1.76 Tid

3.2.2 Estimating change in evaporation

Using the data taken from [4] we approximate the change in evaporation. This is the difference in evaporation in the forested and the grasslands.

Forested evaporation: 861 mm
Grassland evaporation: 694 mm
Change in evaporation = 861-694 = 167 mm

Putting both, change in infiltration and evaporation into Equation 4b we get Equation 5.

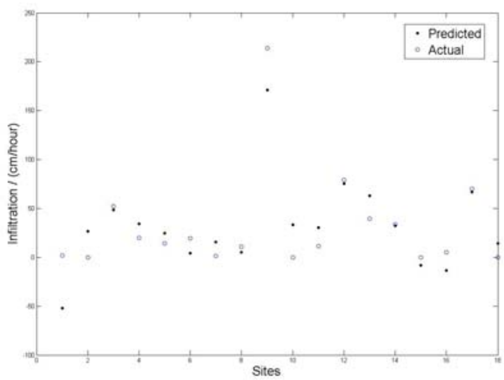
Δ Water Storage = 1.76 Tid – 167mm (5)

We believe calculating total infiltration in deforested areas is easier and so the initial problem albeit not completely solved has been reduced to a simpler one. Also as one can see infiltration increases by about 75% and even after being adjusted for the increased evaporation, this is still a very large increase in the groundwater storage due to the presence of forests. We give a conservative estimate that once lush vegetation has returned to the areas Coke has reforested, the water retention capacity will go up by more than 50%.

3.3 Linear Regression Model

As we cannot estimate what the actual model is due to limited data the logical approach is to run a multi variable linear regression on all parameters.

The pseudo inverse method was used to calculate the parameters. Calculations were run in MATLAB. We ran through all combinations of the parameters that were to be included in the model (these are 2^{14}=16384). Some of our results are rather counterintuitive, i.e. among other things we got negative relationships with the amount of trees. When choosing the best model we went with the one with the least error and did not look for models that agreed with our theoretical predictions. We have then proceeded to explain these relationships as best possible. This is rather risky as linear regression based on least square fitting can predict opposite trends if data has error prone outlying values. To guard against this we have removed the three sites (3,8 and 9 reasoning has been given earlier) as we have done earlier. In Figure 3 we show the predicted results for infiltration and the predicted results for porosity in Figure 4 which take into account all sites.



Fig

Figure 3. Model with lowest error, inclusive of all sites, Error = 22.28

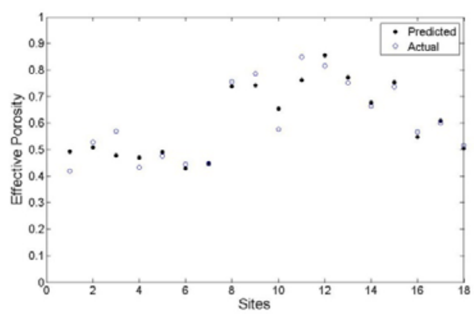


Figure 4. Model for porosity with lowest error, inclusive of all sites, Error = 0.0451.

3.4 Discussion of Results

The best models (with reference to error and with sites 3, 8 and 9 removed) and their predicted values for infiltration and porosity are shown in Figure 5 and Figure 6. We further randomly selected models that had low error and have displayed them in Tables 3 and 4.

3.4.1 Infiltration

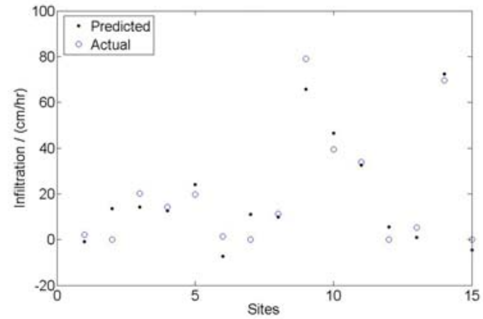


Figure 5. Model with lowest error, without sites 3, 8 and 9, Error = 6.42, with parameters given in Table 4.

Randomly chosen models for infiltration with an error less than 7cm/hr are displayed in Table 3. As is clear there is a positive relationship between canopy cover, grass, shrubs and small bushes. This result was expected and our model confirms our expectations. Infiltration also depends positively on slope. This may be because on steep land the water flows downhill from infiltration site as well as sinking straight into the ground. Total trees vary negatively and this is rather counterintuitive. The area for counting the trees was $100m^2$ around the infiltration site and so we may have taken into account trees that did not have a direct impact on the infiltration due to their distance from the site. The number of trees however, positively increases canopy cover, shrubs and small bushes and so the number of trees implicitly increases infiltration. Infiltration depends positively on soil temperature and negatively on air temperature according to our model. However, we are unable to qualify these results. The most surprising and confusing parameter is the dependence on the saturated volumetric water content. We strongly believed that the relationship would be positive and we are unable to propose any reasoning as to why this relationship is negative.

3.4.2 Effective Porosity

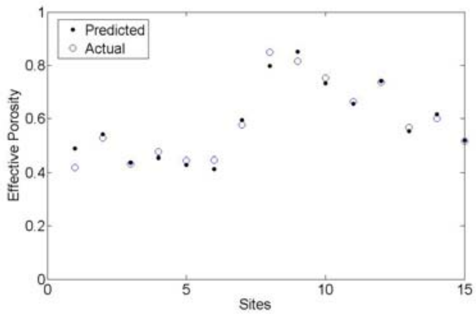


Figure 6. Model with lowest error, without sites 3, 8 and 9, Error = 0.0264, with parameters given in Table 5.

Randomly chosen models for porosity with an error less than 0.0265 are displayed in Table 4. The effective porosity is as with infiltration positively dependant of canopy, grass percent, shrubs and small bushes and similarly the total trees are negatively dependant. We believe that the reasoning is similar to that given for infiltration for these parameters. Elevation seems to have no effect on porosity. However, we notice that soil and air are both positively effecting the porosity.

3.5 Testing the Method

To further test whether the models could predict results for new data, we randomly eliminated sites from the model and calculated the regression parameters without those sites. The model was recalculated and the one with the lowest error used to predict the value for that site. The predicted value mostly gave a moderately good agreement to the actual value. This helps validate the method. Some of these results for regression with infiltration are shown in Table 2.

Table 2.

Dropped Site	Actual	Predicted
15	5.2628	6.0889,
7	1.3157	-2.3216
16	69.7321	47.3271

3.6 Error Calculations

The error mentioned in the analysis above is the standard error term as shown in Equation 6.

$$\text{Error} = [\sum(Ip - Ia)^2/n]^{1/2} \quad (6)$$

Where:
Ip: Predicted Value
Ia: Actual Value
n: Number of Sites

4. Conclusions

The Ayubia forests are being encroached upon and deforested resulting in a loss of ground water content that supplies water to the many critical springs that sustain the ecological environment. The objective of this study was to derive a relationship of the ground water content and trees in the forests of the area.
The data collected was from ten sites in the forested area and eight in the deforested area both found in the Namli Mehra region. The soil seems to be very sensitive to the presence of vegetation as the total infiltration is estimated to be over 50% more in the forested area when compared to the infiltration in the deforested area.

There was a small clump of 70 young trees in the deforested area, however, as this was communal land, grazing and tree cutting was permitted. This resulted in the absence of old well developed trees as well as a low amount of shrubs no small deciduous bushes. The infiltration rate of this area while expected to mirror the forested area, was the same as other totally deforested slopes.

Moreover, even in the regression model, the number of trees had a negative constant related to it when compared to the positive constant associated with that of grass, shrubs, canopy and bushes. Therefore, we conclude that it is not only the trees that must be protected but also the other vegetation in the forest, along with preserving the older trees. Conversely, it may now seem that planting trees will not significantly effect a change in infiltration but the presence of tree cover provides a suitable habitat for other vegetation.

This study therefore also points to the usefulness of exploring ways to artificially increasing infiltration rates by providing mechanisms that trees provide, i.e. suitable habitat for earthworms, shrubs and abundant leaf litter etc as trees take decades to maturity.

Of course, such artificial changes to the environment must be made with extreme care.

Lastly, we have shown that a few college students can perform primitive studies on the complex subject of hydrology using bare bone self manufactured equipment, with one of the limiting factors in this study being the limited sites covered which made data analysis using linear regression or any other method prone to error. We encourage others to take up similar studies so that the results may be verified and our understanding of Pakistan's forests and hydrological systems improved.

5. References

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Appendix

Linear Regression Results

Table 3. Results for Infiltration

S.R	Parameter	M 1 (E= 6.42)	M2 (E = 6.43)	M3 (E=6.71)	M4 (E = 6.86)	M5 (E=6.94)
1	Canopy	1.9125	1.9600	2.2295	2.3669	1.7842
2	Grass percent	0.9140	0.9650	1.0005	0.8742	0.8836
3	Shrubs	1.2309	1.2692	1.3282	1.3026	1.0604
4	Small bushes	0.8792	0.9610	0.9799	0.8836	0.9411
5	Leaf litter	-36.9475	-38.7508	-42.8287	-45.5473	-35.9170
6	Elevation	-0.0089	-0.0097	-0.0077	-0.0073	-
7	Slope	0.6922	0.6112	-	-	-
8	Total Trees	-1.8761	-1.8947	-1.8556	-1.8902	-2.1665
9	Fir	-0.5919	-	-	-0.2815	-
10	Blue Pine	-	-	-	-	0.4915
11	Soil Temp	-2.0928	-1.7555	-1.3290	-1.1063	-2.3636
12	Air Temp	3.6457	3.5661	3.7687	3.5121	2.6925
13	Volumetric	-214.0033	-221.6114	-222.2911	-171.3455	-202.2934
14	Gravimetric	74.6066	75.5195	40.6071	-	36.6131

Table4. Results for Porosity

S.R	Parameter	M 1 (E= 0.0264)	M2 (E=0.0265)	M3 (E= 0.0264)
1	Canopy	0.0086	0.0088	0.0086
2	Grass percent	0.0022	0.0020	0.0022
3	Shrubs	0.0034	0.0033	0.0034
4	Small bushes	0.0004	-	0.0004
5	Leaf litter	-0.1348	-0.1310	-0.1348
6	Elevation	-0.0000	-0.0000	-0.0000
7	Slope	-0.0046	-0.0043	-0.0046
8	Total Trees	-0.0026	-	-0.0026
9	Fir	-	0.0027	0.0069
10	Blue Pine	0.0069	-0.0026	-
11	Soil Temp	0.0064	0.0058	0.0064
12	Air Temp	0.0166	0.0174	0.0166

Site Locations

Deforested

Site	North	East	Acc/m	Altitude
1	34 05 42.4	73 23 45.4	7.0	7607
2	34 05 44.5	73 23 47.8	5.0	7664
3	34 05 47.3	73 23 44.0	7.2	7627
4	34 05 45.6	73 23 40.4	5.5	
5	34 05 45.8	73 23 36.9	6.6	7540
6	34 05 48.4	73 23 34.1		7454
7	34 05 45.8	73 23 41.9	10.5	7568
8	34 05 45.1	73 23 44.0	40	7575

Forested

Site	North	East	Acc/m	Altitude
9	34 04 49.4	73 23 43.4		
10	34 04 54.4	73 23 51.2	11.4	8053
11	34 04 59.4	73 23 56.7	11.1	8073
12	34 05 04.3	73 24 01.5	11.39	8176
13	34 05 09.5	73 24 02.8	4.0	8185
14	34 05 19.3	73 24 14.8	18.1	8345
15	34 05 25.3	73 24 16.9	6.8	8380
16	34 05 28.8	73 24 17.7	6.6	8428
17	34 05 30.4	73 24 17.1	9.8	8468
18	34 05 30.7	73 24 17.2	15.0	8543

Note: Site labels in the pictures are reversed, i.e the numbering starts with the forested sites.