Climate, Disaster and Development Journal
Open access peer-reviewed papers

Potential long-term impact of Typhoon Haiyan on the water resources of Tacloban and its vicinity

Pamela Louise M. Tolentino · Mart Cyrel M. Geronia · Mark Vincent A. Clutario · Carlos Primo C. David

National Institute of Geological Sciences, University of the Philippines Diliman

Received: 17 July 2015 / Accepted: 16 October 2015 / Published online: 25 November 2015

Abstract

Tacloban City is one of the hardest hit cities of the 2013 Super Typhoon Haiyan. Aside from the recorded thousands of deaths, Haiyan is predicted to have altered the terrestrial ecology of the affected area. This study investigated the probable impact on water resources as a result of the change in forest cover resulting from Haiyan. An empirical method was adopted to estimate groundwater recharge from surface data of Tacloban City's watersheds. Remote sensing and geographic information system techniques were used to acquire, integrate, and analyze data to come up with recharge estimates. Soil erosion was calculated using the openLISEM (Limburg Soil Erosion Model). A design storm with a total rainfall of 20 mm was used to compare the difference between the soil erosion considering the land cover change between 2013 and 2015. The results of the simulations indicated a 6% decrease in forest cover. This translated to a decrease in groundwater recharge and an initial seven-fold increase in soil loss due to higher erosion rates and larger surface water discharge. While validation of the calculated impacts on groundwater recharge, flooding events, and soil erosion is required, such estimation provides another dimension of long term effects of tropical cyclones in our country.

Keywords: water resources · land cover change · Yolanda · forest cover · Tacloban · soil erosion

DOI: https://doi.org/10.18783/cddj.v001.i01.a02

Corresponding Author:
Carlos Primo C. David
cp.david@yahoo.com

Introduction

Super Typhoon Haiyan hit the Philippines in November of 2013 and was then considered as the most powerful tropical cyclone that made landfall in world history. The strong winds, heavy rains, and resulting hazards such as landslides, floods, and storm surge resulted in 6,300 casualties, as well as massive destruction of livelihood and infrastructure (National Disaster Risk Reduction and Management Council, 2014). The brunt of the super typhoon was most heavily felt in the central region of the country, particularly Tacloban City in Leyte Province.

Aside from the aforementioned impacts, Haiyan is assumed to have altered the terrestrial ecology of the affected areas, as tropical cyclones are known to heavily influence the structure, function, and dynamics of many tropical and temperate forest ecosystems (Lee, Lin, Vadeboncoeur, & Hwong, 2008). Among the forces associated with typhoons, precipitation has the most effect particularly on soil loss, as runoff occurs when the amount of water exceeds the soil's holding capacity and floods follow when the outflow rate is significantly higher than the infiltration rate (Wang, Huang, & Budd, 2012). Hence, the high volume of precipitation brought by Haiyan also resulted in forest cover loss due to erosion as well as the direct uprooting of trees by strong winds.

The forest ecosystem plays an important role in the provision of hydrological services (Calder, 2002). The loss of forest cover heavily impacts water resource availability as forests enhance water infiltration, which in turn, increases soil moisture content and groundwater recharge (Bruijnzeel, 2004). The root system of the trees maintains soil stability, improves water quality in terms of sediment loading (Ilstedt, Malmer, Verbeeten, & Murdiyarso, 2007), and regulates hydrological processes in terms of flood control and low-flow augmentation (Lele, 2009). With the large-scale vegetative destruction brought by Haiyan, a problem in water supply is seen to occur in the hardest hit areas of the country.

Tacloban City, one of the hardest hit cities of Haiyan, has had water shortage problems in the past. Moreover, most barangays in the northern part of the city are still not connected with the Metropolitan Leyte Water District (which mainly sources its water from the Binahaan River) and thus depend on individual shallow groundwater wells for their domestic use. A typhoon-related decrease in groundwater recharge is expected to worsen the pre-existing problem. In addition, potential impacts on water resources may also be realized if the Binahaan River will likewise reflect any impact of forest cover loss.

This study aims to quantify the probable impact on water resources as a result of the change in forest cover using geographic information system (GIS) methods. Specifically, this research looks upon the change in forest cover before and after the occurrence of Typhoon Haiyan. The results of this investigation would provide insights on the relationship between land use and water availability that may be useful for urban planning and development.

Methods and Materials

Study Area

The study was performed on eight watershed basins in northeastern Leyte, shown in Figure 1. These basins cover an area of 660 square kilometers including the headwaters of the Binahaan River that drains towards the municipality of Palo and Lake Danao in Leyte. The Binahaan, Tacloban 1, and Tacloban 2 basins are characterized by moderately steep to very steep slope, which form part of the southwestern side of Mt. Janagdan and Mt. Naganaga near Tacloban City. The rest of the basins that form part of the foothills of Mt. Lobi and Mt. Cancajanag are characterized by flat to gently undulating slope.

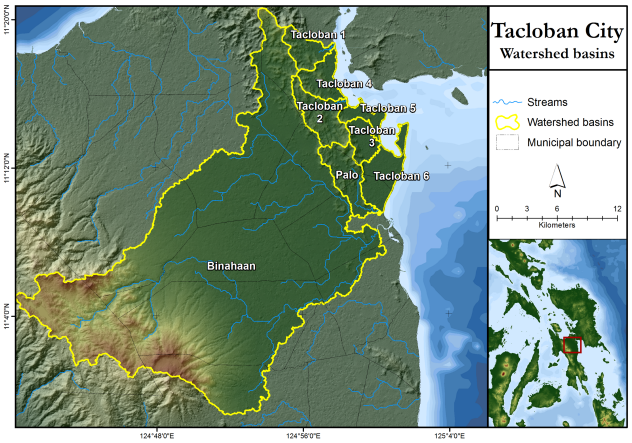


Figure 1. Watershed basins in Tacloban City.

The land cover of these basins was determined using unsupervised classification techniques based on the March 2013 and March 2015 Landsat 8 images of the basins. The digitization, integration, and data analysis were done using ArcGIS while land cover classification was done through the remote sensing software, ENVI.

Hydrological Data

Estimating the amount of groundwater recharge in these basins required the acquisition of various datasets. Soil maps from the National Mapping and Resource Information Authority (NAMRIA) were digitized to provide soil classification for the area. Vertical hydraulic conductivities and water capacity were estimated from the soil type. Physical characteristics of soils from the study of Jahn and Asio (1998) in Leyte were used as reference. Land cover is based on the Landsat images from 2013 and 2015. The depth to water table was estimated to be at around 4.8 meters below ground level based on a single well data. The length of flow from the main channel was computed based on the formula by Cherkauer and Ansari (2005):

$$L_f = \frac{Drainage\ area\ (km^2)}{2x\ channel\ length\ (km)} \quad (1)$$

Average basin slopes were computed based on a 10-meter resolution satellite radar digital elevation model (DEM). Annual rainfall per watershed is extrapolated from weather station data from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) and Department of Science and Technology (DOST).

Groundwater Recharge

Adopting the study of Cherkauer and Ansari (2005), a method to estimate the spatial variability and amount of groundwater recharge was utilized for the computation of the effects of Typhoon Haiyan on groundwater recharge for Tacloban City and its surrounding areas. The following formula was adopted:

$$\frac{R}{P} = 0.0085 \left(\frac{K_v}{SxD^{0.3}}\right) - 4.18 \left(\frac{D_W}{L_f}\right) + 0.0025N + 0.0022 \quad (2)$$

R/P represents the annual recharge per unit precipitation (cm/cm); K_v is the vertical soil conductivity estimated from soil type (m/d); S is the average slope of the basin as derived from the topographic model of the area; D_w is the average depth to the water table (m); L_f is the length of flow to the primary stream; D is the proportion of agricultural and built-up areas in the watershed (%); and N is the portion of forested land cover (%).

Note that this equation for groundwater recharge is oversimplified and should only be used as a general estimate (Cherkauer & Ansari, 2005). No discharge areas are considered except for the primary stream and the heterogeneity of the watershed properties are not accounted for.

This regression equation, adopted from Cherkauer and Ansari (2005), was originally developed and used for watersheds in Wisconsin, United States. Although dissimilar hydrologic and climatic conditions describe Wisconsin, USA and Leyte, Philippines, applying this empirical relationship to Leyte would provide the best estimate for groundwater recharge. Without field and laboratory testing of the soil, stream discharge, groundwater levels, or doing geochemical experiments, the regression equation provided a quick way to estimate recharge given readily-available information.

Soil Erosion Calculation

Soil erosion was calculated using the openLISEM (Limburg Soil Erosion Model). OpenLISEM is a physically based numerical model developed in the Netherlands (De Roo & Jetten, 1999). It calculates discharge and soil erosion on a per event basis. Input data include the DEM, soil maps, and land cover maps. The DEM that was used is a satellite radar DEM that was resampled from 10 m to 30 m resolution. These maps were processed using the PCRaster GIS software, an open source GIS platform, to produce the other maps that will be used by the model such as the local drain direction (LDD) map, the gradient map, and the river network maps. A design storm with total rainfall of 20 mm, with a duration of 200 minutes (3.33 hours) and peak rainfall at 6 mm/15 min was used to model soil erosion in the basin. The same design storm (which is typical of a normal thunderstorm event) was used to compare the difference between the soil erosion based on a land cover change between 2013 and 2015. The simulation was run for 4,000 minutes with a time step of 1 minute. The initial watershed parameters used was for a temperate watershed; however, these have been calibrated to suit tropical conditions, particularly for short thunderstorm events (Clutario & David, 2014).

Results and Discussion

Land Cover Change

Based on the land cover classification performed on the 2013 (Figure 2) and 2015 (Figure 3) LandSat imagery, around 92% of the total land area of the eight basins were forested in 2013. Most of the forest cover was located in the mountainous Binahaan basin. Forested areas decreased in 2015, this time only covering 78% of the total land area covered by the eight basins.

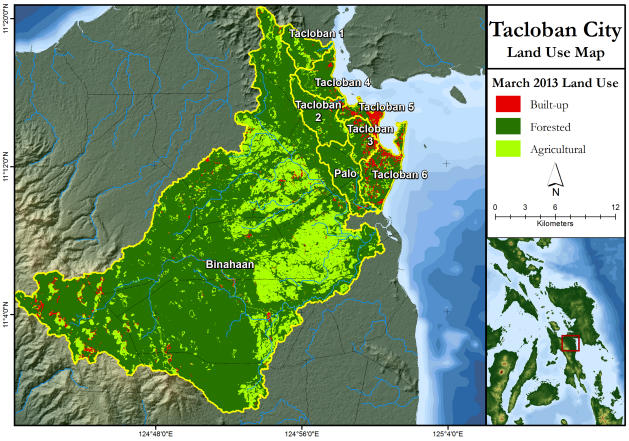


Figure 2. Land use map of Tacloban City in 2013. Note that in the satellite-based land use classification, agricultural areas will include shrubs and grasslands while built-up areas will include barren soil.

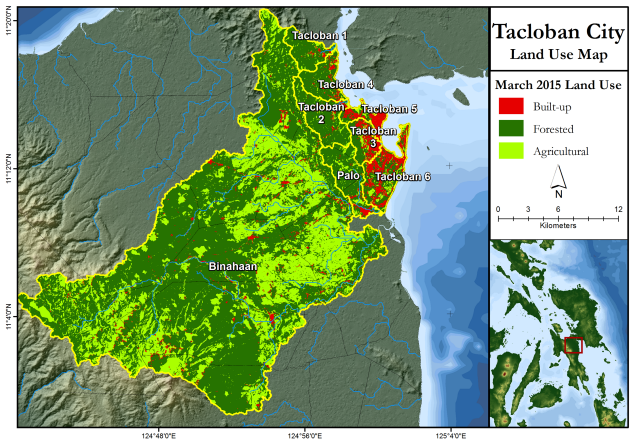


Figure 3. Land use map of Tacloban City in 2015. Note that in the satellite-based land use classification, agricultural areas will include shrubs and grasslands while built up areas will include barren soil.

Land cover moderately changed from the year 2013 to 2015. Most of the basins' forest cover and other naturally vegetated areas decreased by at least 6% while some, like the Tacloban 5 river basin's forest cover, lost more than a third of its land area. The largest basin, the Binahaan watershed area, lost around 66 sq km of its forest cover or around 15% from 2013 to 2015. Most of the lost forest areas were either converted to agricultural areas in the lowlands, bare soil and grasslands in the uplands, and to built-up areas near Tacloban City.

Decrease in Infiltration

Table 1 shows the properties of the study watershed basins derived from the datasets. In the year 2015, there was a marked decrease in the forest cover on all but one basin. This may be partly due to land conversion from forest to agricultural during the intervening years. However, due to the short time span between the imagery analysed, the loss in forest cover can be mostly attributed to Typhoon Haiyan. Additional conversion of forested areas to farmlands and built-up areas may also have happened after Typhoon Haiyan devastated the area.

Table 1. Properties of the study watershed.

	Hydrogeology			Land Cover (2013)		Land Cover (2015)		Topography	
Watershed	Drainage Area	K_v	D_w	Forested	Developed	Forested	Developed	Length	Slope
	(km^2)	(m/d)	(m)	(%)	(%)	(%)	(%)	(km)	(m/m)
Tacloban 1	11.5	0.012	4.8	80.68	19.32	86.61	13.37	2.30	0.278
Tacloban 2	20.1	0.022	4.8	89.65	10.35	83.79	16.21	3.54	0.247
Tacloban 3	10.1	0.665	4.8	71.92	28.08	49.86	50.14	5.05	0.178
Palo	19.0	0.432	4.8	90.69	9.31	77.72	22.28	1.28	0.210
Binahaan	559.8	3.707	4.8	74.62	25.38	62.74	37.25	7.63	0.146
Tacloban 4	12.9	0.012	4.8	88.17	11.83	81.35	18.63	4.30	0.195
Tacloban 5	7.4	1.162	4.8	48.36	51.64	30.37	69.64	2.48	0.118
Tacloban 6	20.0	3.204	4.8	65.83	34.17	43.62	56.37	6.68	0.064

Table 2 shows the effects of land cover change on the amount of groundwater recharge of the eight watershed basins.

Table 2. Precipitation and recharge of the watersheds.

Watershed	Annual Precipitation	R/P (cm/mm)		Groundwater recharge (MCM)		Change in GW recharge	
	(cm)	2013	2015	2013	2015	MCM	%
Tacloban 1	3191	0.149	0.165	5.52	6.06	0.54	9.87
Tacloban 2	3177	0.198	0.184	12.63	11.69	-0.94	-7.42
Tacloban 3	3181	0.179	0.123	5.78	3.95	-1.83	-31.72
Tacloban 4	3187	0.203	0.186	8.33	7.63	-0.70	-8.41
Tacloban 5	3188	0.099	0.052	2.36	1.25	-1.11	-47.19
Tacloban 6	3178	0.309	0.232	19.61	14.77	-4.84	-24.66
Total				521.79	346.87	-172.92	-33.52

The reduction of the forested lands by 15.39% from March 2013 to March 2015 equates to about 93.86 km^2 decrease. The reduction of forested lands translates to an estimated one-third decrease in infiltration and the potential groundwater recharge for the eight basins.

As check to the computed recharge-precipitation proportion for Leyte using Cherkauer and Ansari's method, a basin-wide simple soil-water balance was computed. Water budget parameters were calculated. An annual average of 3169 mm precipitation for the basin became the basis for the computed evapotranspiration (1694 mm), runoff (722 mm), and infiltration (752 mm). Around 24% of precipitation returns as infiltration to the ground, similar to the computed recharge proportion using regression equation.

Other Impacts

The decrease in infiltration likewise translates to an excess of 173 million cubic meters (MCM) per year of additional potential runoff which can result in the increased height and frequency of ensuing floods. The flood impact cannot yet be quantified because it will largely depend on the characteristics of the rainfall events, particularly in their intensity and duration. In terms of the ensuing soil erosion, Table 3 summarizes the results of the openLISEM calculation for the 2013 and 2015 scenarios.

Table 3. Soil erosion calculation using OpenLISEM.

	Units	2013	2015
LISEM results at time	min	3,998.00	3,998.00
Total rainfall	mm	20.00	20.00
Total discharge	mm	0.37	0.65
Total interception	mm	0.32	0.31
Total infiltration	mm	19.29	19.02
Water in runoff + channel	mm	0.02	0.02
Total discharge	m^3	245,450.00	430,382.00
Peak discharge	l/s	6,523.00	17,435.00
Peak time rainfall	min	101.00	101.00
Peak time discharge	min	489.00	408.00
Discharge/rainfall	%	1.86	3.26
Splash detachment (land)	ton	82,057.00	78,059.00
Flow detachment (land)	ton	2,368.00	3,434.00
Deposition (land)	ton	1,379.00	1,312.00
Suspended sediment (land	ton	82,416.00	78,829.00
Flow detachment (channels)	ton	98,901.00	99,831.00
Deposition (channels)	ton	99,014.00	97,474.00
Susp. sediment (channels)	ton	29.79	29.80
Total soil loss	ton	487.00	3,680.00
Average soil loss	kg/ha	7.22	54.55

It can be seen that following the increase of runoff in the watershed, soil erosion also increased. The amount of soil exiting the watershed increased from 487 to 3680 tons. This increase is directly linked to the increase in the total discharge (from 254,449 to 430,381 cubic meters).

The excess runoff coming from the rain water that did not

infiltrate the ground due to the change in land cover increased the amount of sediments that it carried, as can be seen from the increase in flow detachment from 2,368 to 3,434 tons. On the other hand, splash detachment, which is the amount of sediments that was dislodged by the impact of rain on the surface of the soil, decreased. This is due to the increase in the built-up areas in the basin, where there are no soil particles to be eroded.

Higher siltation can likewise be expected in the Binahaan River which is the main water supply of Tacloban City.

Conclusions and Recommendations

Super Typhoon Haiyan's impact in the city of Tacloban and its vicinity transcends the immediate destruction it caused in 2013. Due to the loss in forest cover in its watersheds, potential effects include decrease in groundwater recharge, increase in flooding events, and heightened soil erosion. These should be considered in the rehabilitation process of the area. Restoration of the forest cover or at least the installation of groundwater recharge structures and mitigation measures for soil loss should be done to augment infiltration and decrease flooding and soil erosion. Recharge models developed for tropical climate settings will be used in succeeding iterations (Izuka, Oki, & Engott, 2010). Still, reliable estimates can only be obtained if all the physically important processes are represented satisfactorily (De Silva & Rushton, 2007). Therefore, the calculated impacts will need to be ascertained with actual ground measurements and observations. Nevertheless, this research provides another dimension of the effects of tropical cyclones in the country.

Acknowledgement

This study uses the initial data gathering and output of United States Agency for International Development's Water Security for Resilient Economic Growth and Stability (BE SECURE) project as well as the numerical modelling tools developed through research funded by the Oscar M. Lopez Center.

References

Bruijnzeel, L. A. (2004). Hydrological functions of tropical forests: not seeing the soil for the trees? *Agriculture, Ecosystems & Environment*, 104(1), 185–228. http://doi.org/10.1016/j.agee.2004.01.015

Calder, I. R. (2002). Forests and Hydrological Services: Reconciling public and science perceptions. *Land Use and Water Resources Research, 2.*

Cherkauer, D. S., & Ansari, S. A. (2005). Estimating Ground Water Recharge from Topography, Hydrogeology, and Land Cover. *Ground Water*, 43(1), 102–112. http://doi.org/10.1111/j.1745-6584.2005.tb02289.x

Clutario, M. V. A., & David, C. P. (2014). Event-based Soil Erosion Estimation in a Tropical Watershed. *International Journal of Forest, Soil and Erosion (IJFSE)*, 4(2), 51–57.

De Roo, A. P. J., & Jetten, V. G. (1999). Calibrating and validating the LISEM model for two data sets from the Netherlands and South Africa. *Catena*, 37(3), 477–493.

De Silva, C. S., & Rushton, K. R. (2007). Groundwater recharge estimation using improved soil moisture balance methodology for a tropical climate with distinct dry seasons. *Hydrological Sciences Journal*, 52(5), 1051–1067. http://doi.org/10.1623/hysj.52.5.1051

Ilstedt, U., Malmer, A., Verbeeten, E., & Murdiyarso, D. (2007). The effect of afforestation on water infiltration in the tropics: A systematic review and meta-analysis. *Forest Ecology and Management*, 251(1–2), 45–51. http://doi.org/10.1016/j.foreco.2007.06.014

Izuka, S. K., Oki, D. S., & Engott, J. A. (2010). Simple method for estimating groundwater recharge on tropical islands. *Journal of Hydrology*, 387(1–2), 81–89. http://doi.org/10.1016/j.jhydrol.2010.03.034

Jahn, R., & Asio, V. B. (1998). Soils of the tropical forests of Leyte, Philippines I: Weathering, soil characteristics, classification and site qualities. In P. D. A. Schulte & D. D. Ruhiyat (Eds.), *Soils of Tropical Forest Ecosystems* (pp. 29–36). Springer Berlin Heidelberg.

Lee, M.-F., Lin, T.-C., Vadeboncoeur, M. A., & Hwong, J.-L. (2008). Remote sensing assessment of forest damage in relation to the 1996 strong typhoon Herb at Lienhuachi Experimental Forest, Taiwan. *Forest Ecology and Managemen*t, 255(8–9), 3297–3306. http://doi.org/10.1016/j.foreco.2008.02.010

Lele, S. (2009). Watershed services of tropical forests: from hydrology to economic valuation to integrated analysis. *Current Opinion in Environmental Sustainability*, 1(2), 148–155. http://doi.org/10.1016/j.cosust.2009.10.007

National Disaster Risk Reduction and Management Council. (2014). NDRRMC Update, SitRep No. 108, *Effect of Typhoon "Yolanda" (Haiyan)*. Quezon City, Philippines. Retrieved from http://www.ndrrmc.gov.ph/attachments/article/1329/Effects_of_Typhoon_YOLANDA_(HAIYAN)_SitRep_No_108_03APR2014.pdf

Wang, S.-H., Huang, S.-L., & Budd, W. W. (2012). Resilience analysis of the interaction of between typhoons and land use change. *Landscape and Urban Planning*, 106(4), 303–315. http://doi.org/10.1016/j.landurbplan.2012.04.002