EFFECT OF FOREST FIRE ON COASTAL AQUIFER SALINISATION AND FRESHWATER AVAILABILITY

Beatrice M.S. Giambastiani[1], Nicolas Greggio[1], Katia Pacella[1], Andrea Iodice[1] and Marco Antonellini[1]
[1]CIRSA – Interdepartmental Research Centre for Environmental Sciences, University of Bologna, Italy

ABSTRACT

Forest fires have usually been studied for their impact on soil properties and consequent change in erosion hazard and runoff generation. Also the post-fire recharge and net infiltration can undergo some changes. This aspect is even more important in case of large vegetated areas growing over a coastal aquifer affected by saltwater intrusion. In the Ravenna coastal area (Italy), a dense pine forest grows on the remains of the natural coastal dune belt, overlying a sandy coastal phreatic aquifer, which is completely compromised by marine ingression. Three profiles, in different portion of the forest, were monitored (2008 and 2013) for groundwater level, physical and chemical parameters in order to highlight any change in groundwater quality, infiltration and freshwater availability occurring after a forest fire that devastated 56 hectares of the studied area in July 2012. All pre-fire groundwater parameters were similar among each other in the three monitored profiles, whereas a post-fire decrease in salinity was recorded across the burnt forest along with an increase in redox potential, infiltration and freshwater lens thickness. By applying analytical solutions, infiltration rates were calculated and comparison between all transects were made possible. The estimated infiltration rates indicated an increase in the partly and completely burnt area (219 mm/y and 511 mm/y, respectively) compared to the pristine area (73 mm/y). In the vegetated zone the aquifer recharge is generally limited to the autumn and winter season, while during spring and summer the high evapotranspiration rate exceeds the infiltration amount. This work provided an example of how fire can positively affect the quantity of fresh groundwater resources in low land coastal aquifers.

INTRODUCTION

Controlled burning has been often used in ecosystems and forests to control vegetation community structure and growth (Obrist et al. 2003). The hydrological effects of forest fire have been studied for water catchment management purpose in order to define the impacts on water balance, soil properties and consequent change in erosion hazard and runoff (Silberstein et al. 2013). However, also the post-fire recharge and net infiltration can undergo some changes (Yesertener 2005). Some recharge simulations and groundwater models (DoW 2009) have demonstrated that increasing the burn frequency and removal of pine plantations can be the only viable options for a significant increase in recharge to the groundwater system. Vegetation, in fact, plays an important role in the water cycle. In the forest environment, root uptake and canopy closure lead to an increase in evapotranspiration processes, causing a reduction of freshwater recharge into groundwater. This aspect is even more important in case of large vegetated areas growing over a sandy coastal aquifer affected by saltwater intrusion.
This work aims to define the effects of a forest fire on recharge and the changes in groundwater salinisation and freshwater availability in a salinized coastal aquifer.

Site description

In the Ravenna coastal area (NE Italy), a dense pine forest (100 hectares) grows on the remains of the natural dune belt. This non-native coastal forest was planted at the beginning of the XX century to stabilize the sand and protect inland crops from sea spray. In July 2012 a large fire devastated 56 hectares of the natural reserve and 19 hectares of the forest were completely destroyed and left with bare soil and neither pine trees nor bushes (Figure 1). This environment represents the only recharge area for the coastal aquifer, because here the aquifer becomes phreatic and rainfall can infiltrate. The coastal aquifer has a thickness ranging from 12 to 25 m and it consists of two sandy units (0-7 m and 23-25 m asl) intercalated by a fine prodelta deposit with alternations of silt, clay and sand layers (Amorosi et al. 1999). Because of low topography, high rate of natural and anthropic subsidence and a heavy drainage system, the coastal aquifer is completely compromised by marine ingression with groundwater that remains brackish to saline. Freshwater lenses have been limited in areal extent, in thickness and in time and can be found only related to dune heights (Antonellini et al. 2008). Although mean annual rainfall is 635 mm/year, annual rainfall surplus is minimal (60-150 mm/year) due to high evapotranspiration rate (800-1300 mm) and it occurs only during winter months (Mollema et al. 2013).

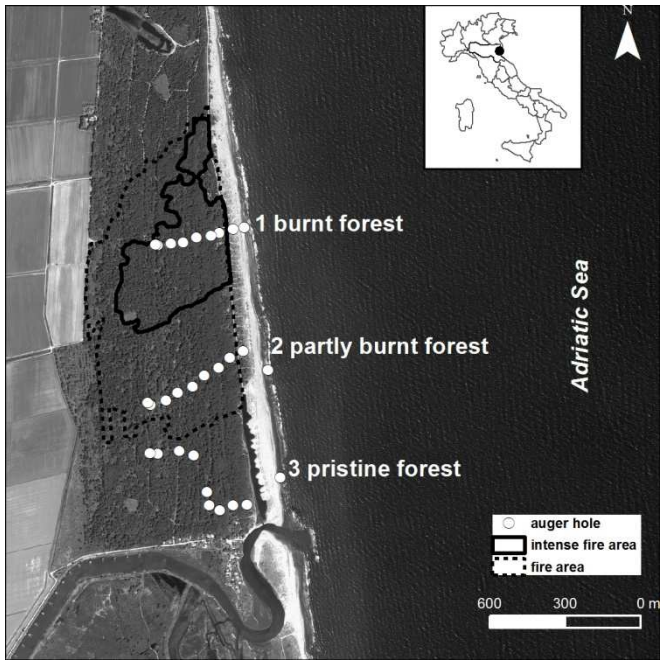

Figure 1. Location of the study area.

METHODS

Two monitoring campaigns (2008 and 2013) were carried out and used to highlight any change in groundwater quality, salinisation, and infiltration occurring after the fire. Three profiles were considered: 1) one along the completely burnt portion of the forest; 2) one in the partly (70%) burnt area, and 3) one along the pristine forest not touched by the fire (Figure 1). During every campaign 30 auger holes were drilled to monitor groundwater by water level metering, and chemical-physical parameters by a multiparameter probe.

The Darcy law and the Dupuit equations were also applied to calculate the unconfined flow and hydraulic head. In these calculations, hydraulic gradient was measured during the monitoring, hydraulic conductivity value (30 m/day) were derived from pumping tests carried out in several piezometers located in the forest, while distance and flow length were based on the topographic profiles. Along all profiles, calculated and measured groundwater levels were compared and the infiltration rates were extrapolated with the objective of matching modelled and measured hydraulic head. The results in the burnt, partly burnt and pristine forest were compared among each other.

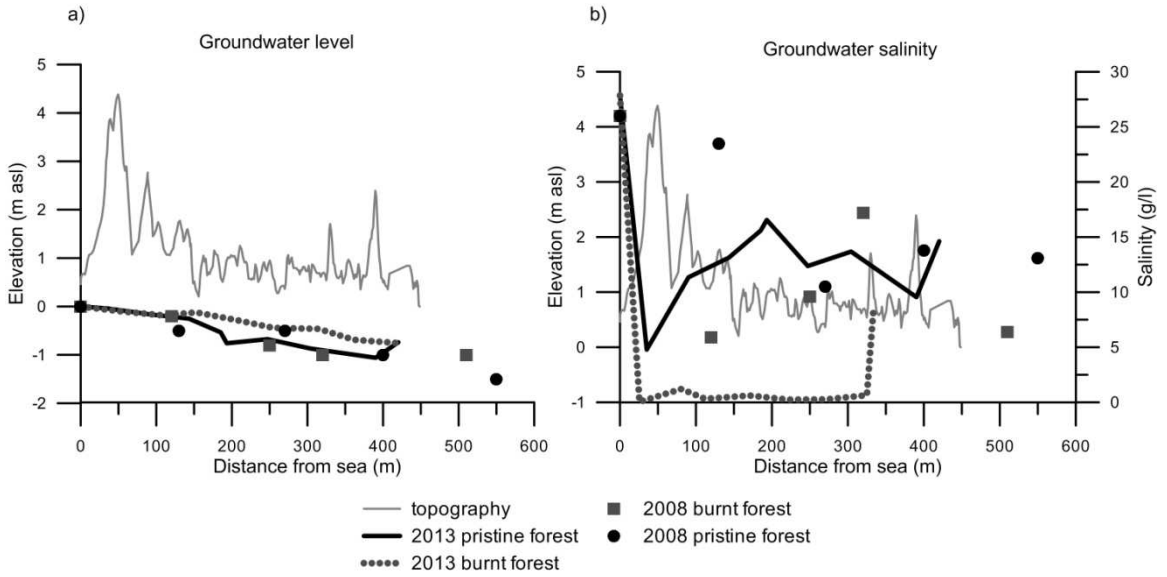

Figure 2. (a) Groundwater level and (b) groundwater salinity comparison before (2008, circled and squared symbols) and after the forest fire (2013, solid and dash lines). Shown in light grey color is also the topography. Due to limited space, only values of pristine and completely burnt forest profiles are shown.

RESULTS AND DISCUSSION

In 2008, before the fire, groundwater level and salinity were similar in all portions of the pine forest, showing from brackish to saline values and no freshwater lens along the dune system (Marconi et al.2011). Unfortunately water level and salinity long time-series for the three profiles were not available, but our results highlighted hydraulic conditions and salinity trends, typical of all Ravenna's coastal pine forests. In fact, results of previous studies (Giambastiani et al. 2007, Antonellini et al. 2008, Vandenbohede et al. 2014) show the presence of a shallow brackish-freshwater interface with limited seasonal variations, and occasional small freshwater lenses. On the contrary, significant decrease in salinity and an increase in groundwater level were recorded in the burnt forest in 2013, one year after the fire (Figure 2). A post-fire decrease in salinity was recorded along with an increase in redox potential and the appearance of a freshwater lens (200 m long) below the dune crest.

Comparison between measured and calculated hydraulic head in the three areas had a good correlation coefficient R^2 ranging from 0.98 to 0.99 and a mean root mean square error (RMSE) of 0.10 m. The estimated infiltration rates indicated an increase in the burnt area (219 mm/y in the partly burnt and 511 mm/y in the completely burnt portion) compared to the pristine area (73 mm/y). It has to be considered that, generally, in the vegetated area the aquifer recharge is limited to the autumn and winter season while during spring and summer, the water budget is negative because the high evapotranspiration rate exceeds the infiltration (Mollema et al. 2012, Antonellini et al. 2008). Moreover, during the winter season, the water infiltrating through the aquifer is further reduced by the drainage system (several drainage ditches run along the forest), which keeps the forest dry and preserve the pine trees. Due to these reasons the infiltration amount in the full vegetated zones of the forest is generally low. Higher infiltration rate recorded in the burn area was more likely due to the reduced vegetation cover and the associated reduction in ET rather than other changes. This translated into a small increase in recharge to the watertable. Several studies (Obrist et al., 2003; Mullen et al. 2006) have demonstrated that climate variations, such as very wet or dry periods after the fire, complicate the use of fire as a restoration tool for recharging groundwater. In some cases, the positive effects on infiltration, ET, and groundwater level

can last only for a few seasons after the fire (Silberstein et al. 2013). This implicates that the recovering portion of the study area needs to be monitored longer in time.

CONCLUSIONS

This work provides an example of how fire can positively affect fresh groundwater resources quantity in low-land coastal aquifers. Pre- and post-fire groundwater quality and level were monitored in the coastal pine forest of Ravenna (NE Italy) in order to highlight the effects on groundwater salinisation and infiltration recharge in a sandy coastal aquifer compromised by saltwater intrusion. In this case study, the complete removal of vegetation cover has caused a decrease in salinity along with an increase in groundwater level, infiltration rate, freshwater lens thickness and redox potential, at least in the first year following the fire. Although the fire had a positive effect in our case, each situation is specific and needs to be monitored and evaluated in terms of post-fire climate condition, as well as soil type, type of plant cover, surface temperature, soil moisture, etc. In order to define the hydrological effects of forest fire for water catchment purposes is necessary to monitor and follow the complete recovery of the vegetation in the years following the fire, because regenerating bushes may cause a bigger water uptake nullifying the initial positive effects on freshwater availability and salinisation.

REFERENCES

Amorosi A., M.L. Colalongo, G. Pasini, and D. Preti. 1999. Sedimentary response to late quaternary sea-level changes in the Romagna Coastal Plain (northern Italy). Sedimentology, no. 46: 99-121.

Antonellini M., P. Mollema, B.M.S. Giambastiani, K. Bishop, L. Caruso, A. Minchio, L. Pellegrini, M. Sabia, E. Ulazzi, and G. Gabbianelli. 2008. Salt water intrusion in the coastal aquifer of the southern Po Plain, Italy. Hydrogeology Journal, no. 16:1541-1556.

DoW. 2009. PRAMS Scenario Modelling for the Gnangara Sustainability Strategy, Hydrogeological Series, Report HG39. Department of Water, Perth, Western Australia.

Giambastiani B.M.S., M. Antonellini, G.H.P. Oude Essink, and R.J. Stuurman. 2007.Saltwater intrusion in the unconfined costal aquifer of Ravenna (Italy): a numerical model. Journal of Hydrology, no. 340: 91-104.

Marconi V., M. Antonellini, E. Balugani, and E. Dinelli. 2011. Hydrogeochemical characterization of small coastal wetlands and forests in the Southern Po plain (Northern Italy). Ecohydrology, no. 4(4): 597-607.

Mollema P. and M. Antonellini. 2013. Seasonal variation in natural recharge of coastal aquifers. Hydrogeology Journal, no. 21: 787-797.

Mullen R.M., A.E. Springer, and T.E. Kolb. 2006. Complex effects of prescribed fire on restoring the soil water content in a high-elevation riparian meadow, Arizona. Restoration Ecology, Vol. 14, no. 2: 242-250.

Obrist D., E.H. DeLucia, and J.A. Arnone. 2003. Consequences of wildfire on ecosystem CO_2 and water vapour fluxes in the Great Basin. Global Change Biology, Vol. 9, no. 4: 563-574.

Silberstein R.P., W.R. Dawes, T.P. Bastow, J. Byrne, and N.F. Smart. 2013. Evaluation of changes in post-fire recharge under native woodland using hydrological measurements, modelling and remote sensing. Journal of Hydrology, no. 489: 1-15.

Vandenbohede A., P.M. Mollema, N. Greggio, and M. Antonellini. 2014. Seasonal dynamic of a shallow freshwater lens due to irrigation in the coastal plain of Ravenna, Italy. Hydrogeology Journal. doi: 10.1007/s10040-014-1099-z.

Yesertener C. 2005. Impacts of climate, land and water use on declining groundwater levels in the Gnangara groundwater Mound, Perth, Australia. Australian Journal of Water Resources, Vol. 8, no. 2:143-152.

Contact Information: Beatrice M.S. Giambastiani, CIRSA - University of Bologna, Via S. Alberto 163, 48121 Ravenna (Italy), Phone: +39 0544 937318, Fax: +39 0544 937319
Email: beatrice.giambastiani@unibo.it