Potential health implications of water resources depletion and sewage discharges in the Republic of Macedonia

Kiril D. Hristovski, Tatjana Pacemska-Atanasova, Larry W. Olson, Jasmina Markovski and Trajce Mitev

ABSTRACT

Potential health implications of deficient sanitation infrastructure and reduced surface water flows due to climate change are examined in the case study of the Republic of Macedonia. Changes in surface water flows and wastewater discharges over the period 1955–2013 were analyzed to assess potential future surface water contamination trends. Simple model predictions indicated a decline in surface water hydrology over the last half century, which caused the surface waters in Macedonia to be frequently dominated by >50% of untreated sewage discharges. The surface water quality deterioration is further supported by an increasing trend in modeled biochemical oxygen demand trends, which correspond well with the scarce and intermittent water quality data that are available. Facilitated by the climate change trends, the increasing number of severe weather events is already triggering flooding of the sewage-dominated rivers into urban and non-urban areas. If efforts to develop a comprehensive sewage collection and treatment infrastructure are not implemented, such events have the potential to increase public health risks and cause epidemics, as in the 2015 case of a tularemia outbreak.

Key words | climate change, developing countries, public health, sanitation infrastructure, water quality

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INTRODUCTION

Many developing countries, including those in transition from centralized to free market economies, have similar sanitation infrastructure issues, which are generally characterized by incomplete or undeveloped sewage collection and treatment systems and direct discharges of raw sewage into surface waters (Stockholm International Water Institute 2001; UN Water 2014). The sewage may enter the environment through a set of smaller decentralized sewage collection systems, a combined storm-water/sewage system, or a more sophisticated municipal sewage collection system that is not connected to an adequate wastewater treatment plant (Corcoran *et al.* 2010; ISET & Pacific Institute 2011). Although public health and environmental professionals in these countries are aware of the contamination threat that these sources represent, many governments have not yet been able to provide the necessary infrastructure to protect public health.

In some countries, the total volume of raw sewage discharges represents a significant fraction of the total surface water flow (UN Water 2008; Rice *et al.* 2013, Rice & Westerhoff 2014). A somewhat overlooked effect of climate change is that reduced precipitation rates and consequent runoff could reduce the dilution of untreated raw sewage and expose populations using these sources for drinking water to even higher levels of contamination. Conversely, the effects of climate change also include more intense storms that can trigger rivers overflowing their banks, and massive flooding events that can overwhelm existing water treatment plants and expose even more people to pathogens and contaminants (Prüss *et al.* 2002; Cairncross & Valdmanis 2006; Corcoran

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et al. 2010; Kistin et al. 2010; Chaturongkasumrit et al. 2013; Veronesi et al. 2014). Thus, the issue of sanitation infrastructure becomes an even higher priority as the effects of climate change become more apparent.

The Republic of Macedonia is an example of a post-communist country that is transitioning to a free market oriented democracy (Hristovski et al. 2010). Like many other such countries, much of the sanitation infrastructure in the Republic of Macedonia is incomplete (Hristovski et al. 2010). Almost all urbanized communities have access to potable water treatment and distribution systems on a municipal level, but the majority of the population in both urbanized and non-urbanized communities in Macedonia is typically not served by centralized sewage collection and treatment systems (Novak et al. 2011). Although the Environmental Performance Index from Yale indicates that 91.82% of Macedonians have access to safe drinking water and 49.19% have access to improved sanitation, only 3.74% of wastewater is treated (Yale University 2015).

The direct discharge of raw sewage from urban point sources into Macedonian surface waters has the potential to significantly impair the existing river ecosystems and cause long-term public health problems by creating extensive septic zones and contaminating the existing potable water sources. Flooding from overflow of surface waters can contaminate homes, schools, and streets with fecal matter and spread infectious diseases, requiring significant public health measures to be implemented (Reuters 2010; Radio Televizija Srbije 2013; Fox 2015).

In this paper, the authors have examined available evidence that documents changes in precipitation and surface water flows in Macedonia over the last 55+ years to elucidate what climate change predictions for the area might mean for the next 50 years. As little information based on actual measurements is available, estimates about direct sewage discharges or the extent of surface water contamination were conducted using reported data for daily water usage and a simple steady state mass balance model with first-order decay reaction rate. The estimated average biochemical oxygen demand (BOD) levels in rivers were compared with reported data originating from occasionally conducted water quality measurements. Regression analysis was performed to identify any temporal correlations and statistically significant trends. The potential impacts of these trends on surface water quality were assessed and the implications for public health are discussed.

METHODOLOGY

Assessment of national surface water hydrology and climate change trends

A hydro-meteorological dataset was obtained for the period 1961–2010 from the National Hydro-meteorological Office of the Republic of Macedonia by transcribing the official log books. Data from the period 2011–2012 were obtained from the State Statistical Office of the Republic of Macedonia (State Statistical Office of the Republic of Macedonia 2013a, 2014). Data from 2013 and 2014 were not available during the time this study was conducted.

The dataset encompassed: (1) temperature data from 10 National Hydro-meteorological Office locations across the Republic of Macedonia; (2) flow rate data from 14 measuring stations located on the rivers across the seven watersheds in the country; and (3) precipitation data for 12 rain gauge stations dispersed in each watershed. Figure 1 provides a map of the Republic of Macedonia and illustrates the data collection locations. Considering that Macedonia is relatively small in population (~2 million) and territory (~25,000 km^2), the national averages, estimated from the extensive datasets, were considered to be representative of the entire country (Hristovski et al. 2007, 2010; State Statistical Office of the Republic of Macedonia 2014).

A regression analysis matrix was generated to examine the climate change and surface water hydrology trends, and determine the existence of any statistically significant patterns. Patterns characterized by statistical significance of $p \leq 0.05$ were identified as statistically significant correlations. Normal distribution analyses were used to identify any outliers, which may have occurred as a result of atypical extreme events (e.g., 100-year floods). To determine the effects of climate change on precipitation intensity, the changes in magnitude of annual precipitation were also examined by correlating them to the temperature and time variables. For adequate comparison, and where needed, each dataset was normalized against a 30-year average comprising the period between 1961 and 1991.

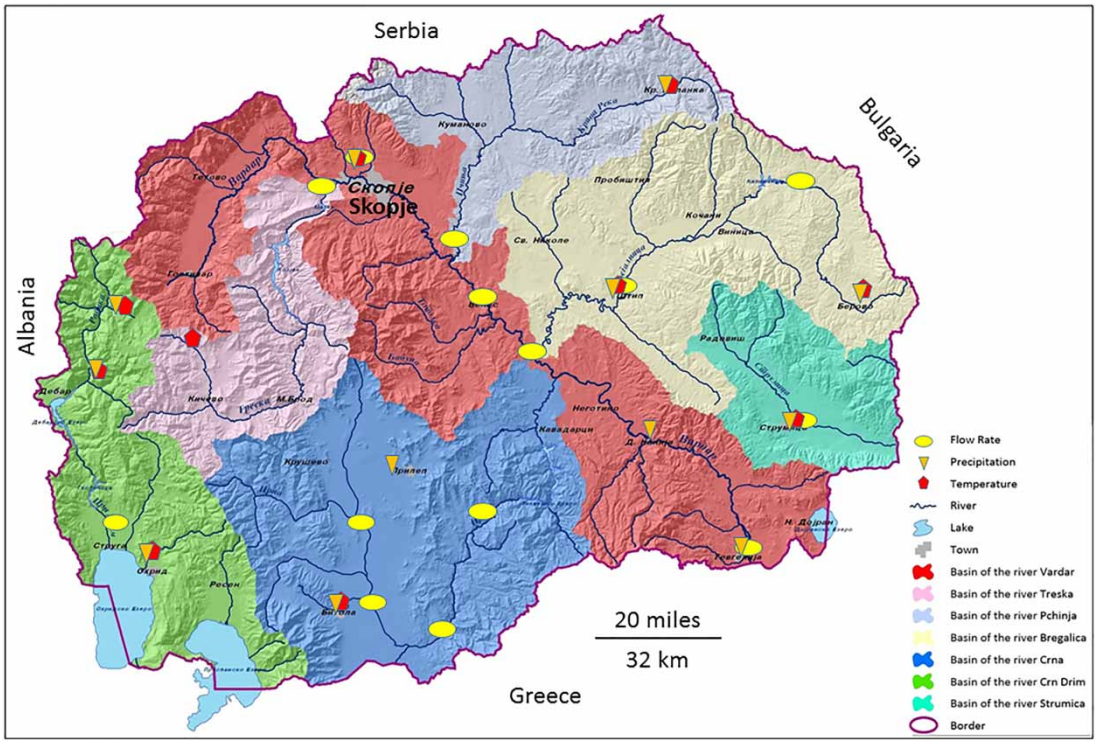

Figure 1 | Watershed map of the Republic of Macedonia with data collection locations for temperature, river flow rates, and precipitation.

Assessment of potential impacts of surface water hydrology on water quality and public health

Sewage contributions to surface water flow were estimated by employing temporal demographics data, obtained from The French National Institute for Demographic Studies (INED) in 2014, and reported data for water usage and discharge (Brink *et al.* 2007; Avdeev *et al.* 2011). The Macedonian Ministry of Environment and Physical Planning estimates that 80% of generated water is discharged as sewage (Ministry of Environment and Physical Planning 1997; Novak *et al.* 2011). Considering that water utilization rates are estimated to range from 400 to 500 L/capita/day in urban areas and from 200 to 250 L/capita/day in rural areas (Brink *et al.* 2007), one can estimate sewage discharge rates. However, for this study, more conservative rates of 150–300 L/capita/day as low and high end values were used (Brink *et al.* 2007; Novak *et al.* 2011). Rates of 150 L/capita/day are commonly used standard values for sewage discharge for estimating design capacities of wastewater treatment facilities in Macedonia (Posch & Partner GmbH 2007). Total sewage flow rates were then calculated by using population data from INED.

In the absence of comprehensive empirical data from actual water quality monitoring, BOD was used as an indicator to estimate the surface water quality impairment resulting from direct sewage discharge. Both the EU Council and the Macedonian Ministry of Environment (Official Journal of the European Communities 1991; Official Gazette 2004) recommend a BOD value of 60 g/population equivalent/day to be used when developing estimates. However, since only 72% of untreated sewage is estimated to be collected and discharged into rivers, a more conservative value of 43 g/capita/day was used (Brink *et al.* 2007; Novak *et al.* 2011). The remaining 28% of the population uses septic systems or open cesspools to collect the generated sewage. Although it could be argued that a small fraction of this sewage may eventually end up in the Macedonian rivers, it was considered for the purpose of this study that this fraction could be neglected.

A review of available water quality data with respect to BOD in Macedonian surface waters shows only sporadic

actual measurements in time and place. Therefore, a very simple steady state mass-balance model with first-order decay reaction rate was used to estimate the average BOD_5 levels in the rivers (Equation (1)) (Novotny 1995):

$$V\frac{dC_{BOD}}{dt} = \dot{m}_{IN} - QC_{BOD} - VkC_{BOD} = 0 \quad (1)$$

where Q is the average river flow rate $[L]^3[T]^{-1}$; $\dot{m}$ is the rate of introduced BOD into Macedonian rivers $[M]\,[T]^{-1}$; k is a rate constant $[T]^{-1}$; V is the average hydrological volume of the rivers $[L]^3[T]^{-1}$ ($V = Q \times HRT$); and C_{BOD} is the biochemical oxygen demand $[M][L]^{-3}$.

This simplistic model considers the entire surface hydrology system as a simplified reactor. A realistic rate constant value of $k = 0.12$ day^{-1} was used to describe the BOD_5 decay rate in polluted rivers (Hammer & Hammer 2011). In the absence of any data, a conservative hydraulic residence time (HRT) of 5 days and no loss to evaporation was assumed for the entire hydrological system in Macedonia. For short and slow rivers ($l <$ 200 km and $v < 2$ m/s), like the ones in Macedonia where the majority of the sewage discharge occurs in areas downstream of any accumulations, these values could be considered realistic (Tančev 2012). Based upon discharge volume parameters, BOD_5 values in surface waters were calculated and compared to the relatively few data points available.

RESULTS AND DISCUSSION

Figure 2 illustrates the standardized national average surface water flows over the period 1961–2012 in the Republic of Macedonia. The statistically significant trend ($p < 0.026$) suggests a decline in surface water hydrology in Macedonia over the last half century. Considering that there is strong interdependence with surface and groundwater hydrology, this statistically significant reduction in flow rates suggests that the Republic of Macedonia is potentially facing significant water stress in the future.

Increased water demands and deterioration of water quality because of population growth and anthropogenic activities could further exacerbate this problem. Direct waste discharge into the Macedonian River Treska, depicted in Figure 3, is a common occurrence in Macedonia. However, the problem in Figure 3 contributes significantly less to the water quality degradation than the direct discharge of sewage because (1) only a handful of city dumps are located on the river banks and (2) current efforts are being made to develop and implement a solid waste system

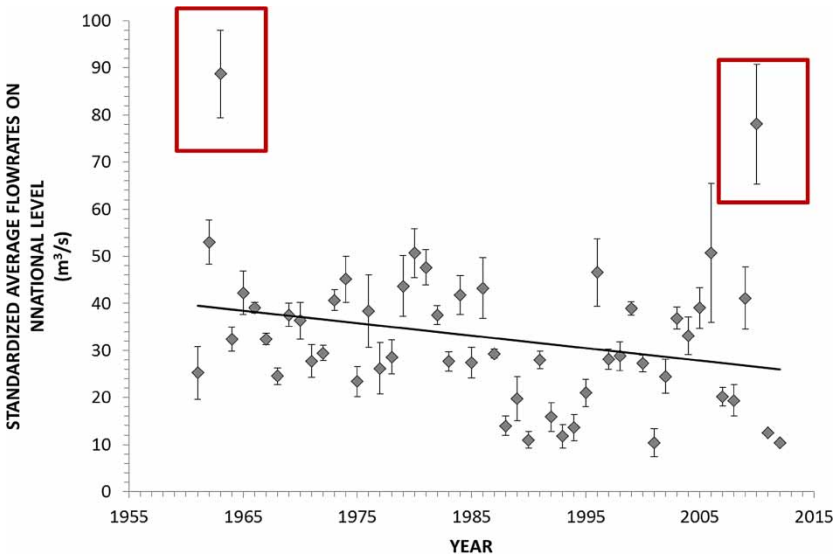

Figure 2 | Statistically significant decrease in national average river flow rates for the period 1961–2012 ($n = 702$; $p < 0.026$); data in rectangles represent outliers; the error bars represent 95% confidence intervals.

Figure 3 | River Treska: an example of the typical conditions found in Macedonia's major rivers.

framed around disposal at sanitary landfills located in hydrologically isolated areas (Ministry of Environment and Physical Planning 2006; Cvetkovska *et al.* 2013). In contrast, direct discharge of raw sewage into the rivers represents a more threatening problem because almost all of the urban settlements in the Republic of Macedonia are located in hydrologically active areas (e.g., rivers and watersheds) (Novak *et al.* 2011).

Figure 4 illustrates the estimated fraction of sewage contribution from direct discharges to the average national flow rates in the Republic of Macedonia over the period 1961–2012. During hydrologically normal years, approximately 10 to 20% of the flow in the rivers could be attributed to water originating from raw sewage.

This fraction, however, significantly increases during water-stressed years. For example, the raw sewage fraction contributing to the river flow rates reached an estimated 50% during the period between 1988 and 1994, which represented the latter half of a 15-year dry spell characterized by a trend of declining surface water hydrology and reduced rainfall (Figure 5). Similarly, the rivers were sewage dominated on a couple of occasions after 2000, when the fraction of raw sewage contributions exceeded 50% because of reduced river flow rates.

Figure 6 also illustrates a statistically significant trend ($p < 3.9 \times 10^{-4}$) suggesting that a majority of the rivers in Macedonia will be dominated by raw sewage in the future if efforts to develop a comprehensive sewage collection and treatment infrastructure are not implemented. Considering that conservative discharge values, rather than the government estimates, were used to estimate the raw sewage contributions to the river flow rates, it could be argued that the majority of rivers in the Republic of Macedonia are sewage dominated even in unstressed years.

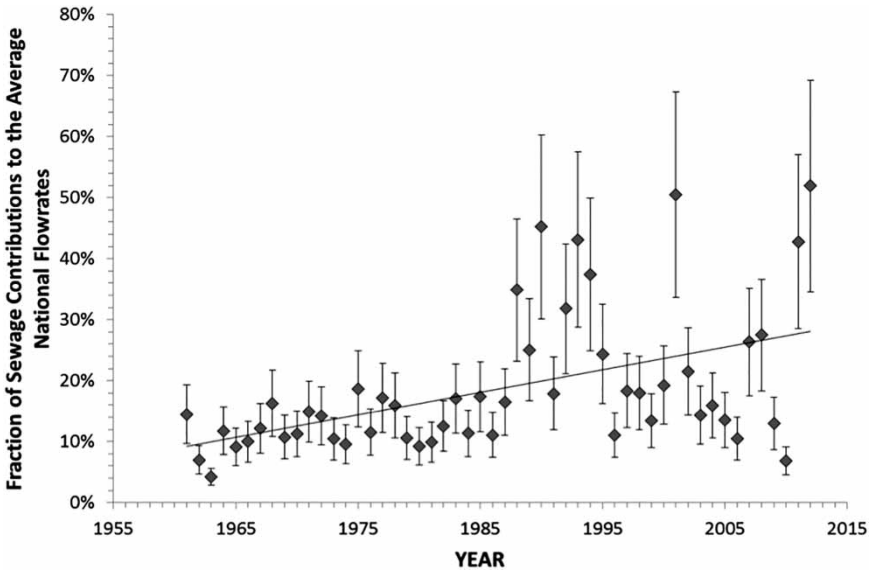

Figure 4 | Estimated fraction of sewage contribution to the average national flow rates in the Republic of Macedonia during the period 1961–2012. Error bars represent sewage discharges rates of 150 and 300 L/capita/day used as low- and high-end values.

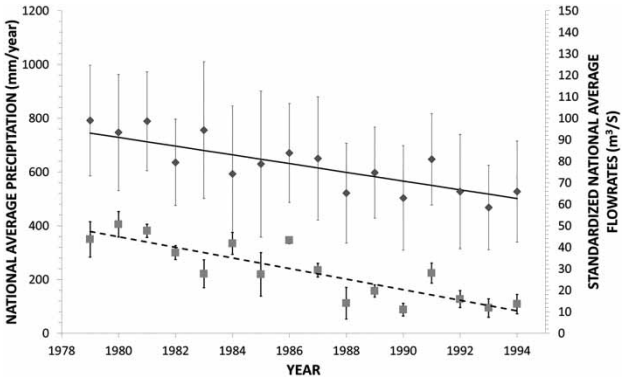

Figure 5 | Statistically significant decrease in national average precipitation (solid line and circles) for the period 1979–1994 ($n = 180$; $p < 1.2 \times 10^{-4}$) mirrored by a decreasing trend (dashed line and squares) of the average river flow rates for the period ($n = 210$; $p < 7.5 \times 10^{-5}$).

The simple steady state mass balance BOD model supports this argument as it projects an increasing trend in BOD levels with values exceeding 10 mg/L O_2 as BOD_5 (extremely polluted rivers). Figure 6 depicts this statistically significant trend ($p < 4.0 \times 10^{-4}$) and illustrates the estimated average pollution levels of Macedonian rivers using BOD_5 as an indicator. At these raw sewage BOD loading rates, the model estimates that national average BOD levels in the Macedonian rivers are generally between 2 and 6 mg/L O_2 as BOD_5. However, in water stressed years, BOD_5 values could easily exceed 8 mg/L O_2 as BOD_5, as exemplified by the values during some periods of the 15-year dry spell. The model estimates compare well with the infrequent data, obtained via direct BOD_5 measurements and reported by the Ministry of Environment (Novak *et al.* 2011; State Statistical Office of the Republic of Macedonia 2013b). According to these reports, the major rivers typically are categorized as Class IV waters (severely polluted) (Official Gazette 1999; State Statistical Office of the Republic of Macedonia 2013b). Certain river sections, however, are categorized as Class V waters (extremely polluted) because they exceed BOD levels of 15 mg/L O_2 as BOD_5 (Brink *et al.* 2007; State Statistical Office of the Republic of Macedonia 2013b). Some independent reports suggest even higher levels of pollution as they document BOD levels exceeding 20 mg/L, indicating the presence of septic zones or cesspools because of raw sewage discharge and waste dumping, as illustrated in Figure 4 (Novak *et al.* 2011; Karamitrovska & Causovski 2012).

The concerning levels of river pollution, as exemplified by the evident septic zones or open cesspool areas, could create severe environmental damage and public health problems in the Republic of Macedonia. These problems could remain masked for long periods in the absence of a comprehensive and continuous surface water monitoring program

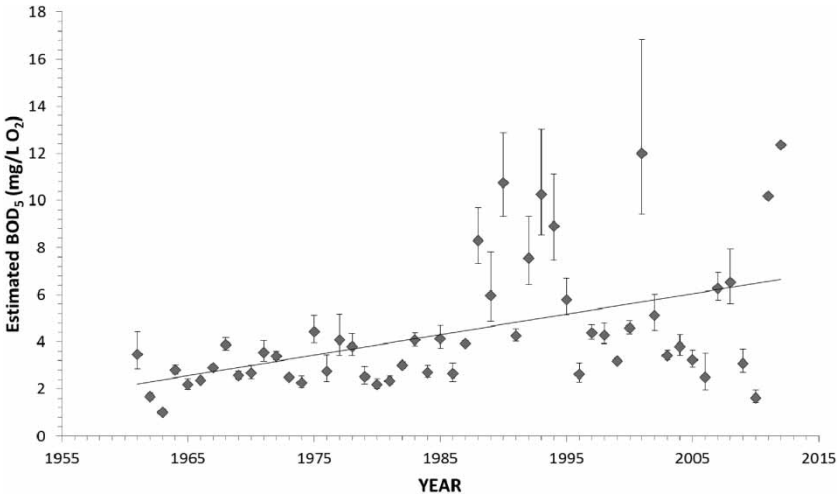

Figure 6 | Modeled BOD estimates as an indicator of the surface water quality impairment resulting from direct sewage discharge into Macedonian rivers. The error bars represent one standard deviation boundaries.

that is a part of an active water management strategy. However, masked problems like these have a tendency to rapidly manifest themselves following extreme weather events such as prolonged droughts or floods. The consequences of these manifestations could be expensive, and may exceed the costs of preventative measures such as integrated wastewater collection and treatment systems.

The seriousness of the problem might be best illustrated by an example of a major rainfall and flooding event in the period of January–March 2015 that had serious public health implications (Glas na Amerika 2015; Vecer 2015). The lack of response to a contamination of potable water sources led to a tularemia outbreak. Emergency response measures had to be executed to protect the public health in areas where sewage dominated rivers flooded the neighboring communities and agricultural fields (Glas na Amerika 2015; Vecer 2015). Specifically, deratization activities were initiated to eliminate tularemia rodent vectors which were fleeing the flooded fields and seeking shelter in small communities (Glas na Amerika 2015; Vecer 2015). Restrictions on potable water from the distribution systems, its mandatory boiling, and extensive disinfection were also implemented as immediate response measures to prevent disease outbreaks (Glas na Amerika 2015; Vecer 2015). However, it could be argued that these measures were insufficient to prevent the tularemia outbreak because the number of infected people increased during the months following the floods, and short-term epidemics had to be declared (Institute of Public Health of Macedonia 2015; Telma 2015). The damage caused by this flood was estimated at $25 million, without the cost of addressing the tularemia outbreak (Politicki Meridijan 2015). This amount may be insignificant when compared to damage costs of about $1.6 billion during the 2014 flood in neighboring Serbia, but represents a significant sum that could have been used in improving the existing sanitation infrastructure in this country of two million residents (Telegraf 2014).

Although the impacts of this extreme event on public health could be classified as minor, they demonstrate a strong correlation among climate change induced variability in surface water hydrology, surface water pollution by raw sewage discharge, and public health. Most importantly, they forewarn of upcoming problems that could endanger public health and create significant socio-economic distress in the Republic of Macedonia as the effects of climate change are expected to intensify. Figure 7 illustrates a statistically significant trend ($p < 0.007$; $n = 600$) of increasing magnitudes in annual average precipitation changes (Δ precipitation/year) over the period 1962–2012. As suggested by the trend, the magnitude of change in precipitation has slowly been increasing over the last 50 years. More recent decades are characterized by strong fluctuations, which suggest intensive shifts of precipitation patterns from one year to another. The effects of this trend are becoming

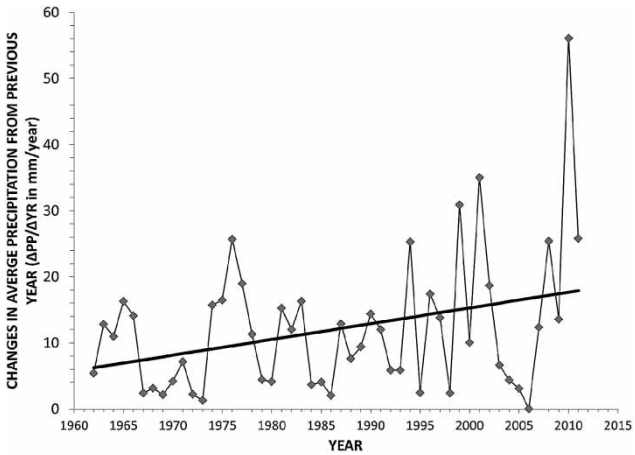

Figure 7 | Statistically significant ($n = 600$; $p < 0.007$) trend of increasing magnitudes in annual average precipitation changes (Δ precipitation/year) during the period of 1962–2012.

more evident by the increasing number of short-term flood areas across the country (Reuters 2010; Krstevski 2011; Radio Televizija Srbije 2013; Fox 2015).

Climate change predictions lead to expectations of such scenarios increasing in frequency and intensity, especially considering that over the past 50-year period, the average national temperatures in the Republic of Macedonia have increased at a rate of approximately 0.02 °C/yr, as illustrated by the statistically significant trend in Figure 8 ($p < 1.7 \times 10^{-4}$). This trend predicts that the average national temperature could reach 12 °C by 2060, which is an increase of about 1 °C over a 50-year period and is consistent with the predictions of many climate change models that forecast the same scenarios (European Comission Directorate General for Regional Policy 2009; Zoï Environment Network 2012). The higher temperatures will further tax the declining water resources in Macedonia and increase the public health risks associated with polluted water sources unless mitigative measures, which include improvement of the existing sanitary infrastructure, are implemented.

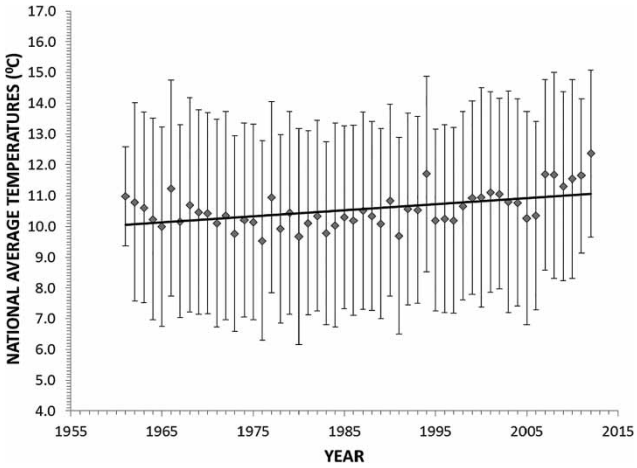

Figure 8 | Statistically significant increases in national average temperature for the period 1961–2012 ($n = 514$; $p < 1.7 \times 10^{-4}$). The error bars represent 95% confidence interval.

CONCLUSIONS

The documented climate change induced trends and the growing number of severe weather events point towards a future with increasing public health risks, which are directly related to inadequate and incomplete sanitation infrastructure in the Republic of Macedonia. The indirect public health related costs associated with these chronic infrastructure problems should not be overlooked. For the Republic of Macedonia and similar countries, it is imperative to incorporate the public health implications and costs of not having adequate sanitation systems into each country's economic and development planning. These implications should be recognized as a major determinant when developing long-term strategies of national significance, especially in light of increasing temperatures, water and food demands, and extreme weather events that could require emergency efforts.

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