RESEARCH REVIEW JOURNALS
Volume-04
Issue-05
May-2019
ISSN: 2455-3085 (Online)
RESEARCH REVIEW International Journal of Multidisciplinary
www.rrjournals.com[UGC Listed Journal]

The Impacts of Urbanization on Groundwater Systems and Recharge

Mr. Rajesh Kumar

Assistant Professor, Dept. of Geography, S.K. Govt. College, Kanwali, Rewari (India)

ARTICLE DETAILS

Article History
Published Online: 25 May 2019

Keywords
Urbanization, groundwater, recharge, permeability.

ABSTRACT

Urbanization is a major geomorphic process affecting both surface and groundwater systems. The development of cities inevitably increases paved surfaces and roofs (termed impervious cover) and storm drains. Installation of a network of subsurface structures, including utility systems, is another necessary aspect of modern cities. Urbanization alters topography and natural vegetation, stream flows and flooding characteristics, temperatures both above and below the land surface, and water quality of surface streams and ground water. Major physical changes to the groundwater system include changes in water table elevation; a dramatically altered permeability field created by construction and utility system emplacement; and altered groundwater recharge. Subsurface permeabilities may increase by orders of magnitude in certain preferred zones, which makes prediction and remediation of subsurface contaminants difficult. Groundwater recharge commonly increases because of: 1) leakage from water distributions systems, sewer lines, detention ponds, and storm drains; 2)over irrigation of lawns, gardens, and parks; 3) artificial recharge; 4)reduced evapotranspiration and 5) infiltration through "impervious" cover. This, coupled with pumping of shallow groundwater, controls water table fluctuations. The impacts of urbanization on groundwater systems are predictable and should be considered in urban planning from geotechnical, environmental, and water resources perspectives.

1. Introduction

Most of the Earth's liquid freshwater is found as stored underground in aquifers and not in the lakes and rivers. The aquifers are also the source of base flow water for the rivers in the absence of rainfall. Groundwater plays an important role in terms of the economic and social health of the urban population of the developing world. Cities need to supply water in various combinations as per demands of their private, public, industrial and commercial users. And the urbanization process has always altered the quality and quantity of the local aquifer systems in various ways. Considering the changes in the hydrological cycle due to urbanization, it is important to study the effect of urbanization on local water resources and especially, on easily available groundwater source in the vicinity. Urbanization, in general, has four immediate repercussions on the hydrological cycle: flooding (e.g. as a result of increased soil sealing), water shortage (e.g. due to rising consumption), changes in the river and groundwater regimes as well as water pollution (Rogers, 1994, Strohschon et al., 2013). Urban areas generate both nonpoint and point sources of contaminants. Point sources that affect groundwater quality include leaking underground storage facilities, as well as miscellaneous accidental spills of organic or inorganic contaminants (Jha, Singh, &Vatsa, 2008). The rapid growth of urban area has two basic effects on groundwater resources such as: effects on natural recharge of aquifers due to sealing of ground with concrete and pollution of groundwater due to leakage from drainage and, industrial wastage and effluents (Baier, Schmitz, Azzam, &Strohschon, 2014). The water balancing of an urban aquifer is a complex process due to the additional sources of groundwater recharge and widely distributed new abstraction points in the urbanized region. It is often believed that with the urban growth, the impermeabilization and ground sealing effect might contribute to decrease in groundwater recharge. But it has been widely discredited by many case-studies about urban groundwater recharge in cities worldwide. Now, most hydro-geologists accept that the infrastructure for water supply and storm drainage generates large amounts of recharge through leaks (Foster, 1990; Lerner, 2002). In many cases, the increasing demand for water due to urban growth forces the authorities to import the large volumes of water from outside the city. The expanded cities later then also produce large volumes of wastewater. Even though the land sealing effect of paving and building prevents natural recharge from precipitation, the enormous volume of water circulating through the underground water-wastewater infrastructure under high pressure and loss due to leakages of pipes or from soak-ways draining the built-up area causes a rise in the total volume of recharge in urban areas (Lerner, 2002). The contamination of groundwater in the aquifers beneath the city may also result in abandonment of wells and groundwater abstraction in some places within the cities. It can lead to rise in water table beneath the city due to lack of pumping of contaminated water and high urban recharge from leakages. Several city case-studies show that the effect is most pronounced in cities where on-site sanitation is important and in arid and semiarid climates where the new sources may increase the total infiltration several times over the pre-urban situation (Morris et al., 2003). As cities import bulk amount of water, the flow pressure with which the water is transported and distributed through pipe network is always higher than the flow pressure in sewage network. So, any leakages in these networks can contribute to the huge amount of recharge in that region. In the case of urban recharge process, leakages from sewer network are less significant compared to water supply mains, but it can be major sources of contaminants.

2. Literature Review

Human activities are altering the land use at unprecedented rates, magnitudes and spatial scales. Land use and land cover change is gaining recognition as a key driver of environmental change. Land use changes are investigated mainly using Remote Sensing and the Geographic Information System (GIS).Land uses change the natural functions of a watershed by impeding or altering water flow and impacting water quality. Although individual land use activities may not appear to have immediate and significant environmental effects, the cumulative and dynamic effects can adversely impact water quality. With rapidly growing population and improving living standards, the pressure on our water resources is increasing and per capita availability of water resources is reducing day by day. Due to spatial and temporal variability in precipitation, the country faces the problem of flood and drought syndrome. Overexploitation of groundwater leads to reduction of low flows in the rivers, decline of the ground water resources, and saltwater intrusion in aquifers of the coastal areas. The climate change is expected to affect precipitation and water availability.

3. General hydrogeologic effects

1) Altered topography

Urbanization tends to level off the landscape for ease of construction and for roadway design. Over time, low-lying areas are filled in and elevated areas lowered. In very old cities, younger construction cover successively older city structures. This commonly leads to burial of surface streams, which may be covered, filled-in, converted into storm sewers, or just forgotten. Case histories include London, UK (Barton,1962), Washington D.C., USA (Williams, 1977), and Minneapolis-St.Paul, Minnesota, USA (Brick, 2009). However, the high-permeability alluvial strata often remain buried beneath streets and buildings. These will often be in the form of lenses or channels that make accurate predictions of groundwater flow and solute transport difficult.

2) Altered vegetation

Changes in the rates and distribution of evapotranspiration can alter recharge and groundwater flow directions. Clearly, impervious cover will decrease and may even eliminate transpiration by native vegetation. Alternatively, especially in desert cities, irrigation of lawns and gardens may increase transpiration, as can the introduction of non-native vegetation that may include phreatophytes, such as tamarisk and eucalyptus. Finally, over-watering of lawns, playing fields, and gardens may lead to irrigation return flows that increase groundwater recharge as, for example, in Lethbridge, Canada (Berg et al., 1996) and Austin,Texas, USA (Garcia-Fresca, 2004; Garcia-Fresca and Sharp, 2005).

3) Groundwater temperatures

The urban heat island effect is well documented. Urban areas are hotter than adjoining rural areas. The annual mean air temperature of a city with 1 million people can average (1–3°C warmer than its surroundings and in the evenings this difference can be even greater. The U.S Environmental Protection Agency maintains a website on the Heat Island Effect. Groundwater is also affected; shallow groundwater temperatures increases, which can affect water quality and groundwater dependent ecosystems. Examples include Tokyo, Japan(Taniguchi et al., 1999; 2001) and Minneapolis/St.Paul, Minnesota, USA (Taylor and Stefan, 2009).

4. Changing water table elevations

Water tables can either fall or rise (Simpson, 1994; George, 1992;Whitesides et al., 1983) with urbanization. Groundwater extraction in the urban area can either increase or decrease with time as imported waters are introduced, as surface water systems replace local groundwater resources, as surface water systems decline as in droughts, with reservoir-induced changes in river stages, or with the implementation of new technologies, such as desalination or ASR (aquifer storage and recovery). Except in the case of areas with relatively deep water tables, ASR effects can be significant but are presumably temporary with the possible exception of where water tables may rise until the fluctuating nature of a functional ASR commences. Conversion from using local aquifer systems to large surface water systems or imported water can cause rising water tables, which can, in turn, can cause engineering problems (flooding of basements, tunnels, and utility systems; mass wasting, etc.) and new boggy areas. Wet soils as in Wagga Wagga, Australia, can cause foundations problems(Cooke et al., 2001; Young, 2008), especially when the groundwater is brackish or saline. On the other hand, continued use of groundwater can cause falling water tables, which can, in turn, cause saltwater intrusion, subsidence, or the decline of groundwater dependent ecosystems, including springs.

1) Altered permeability field

The network (or reticulation) of water mains, sewer lines, electrical and telephone conduits, storm drains/sewers, subways, and other subsurface systems is one of the major alterations to the hydrogeology of an urban area. Although urban soils tend to become less permeable because of compaction (Pitt et al., 2002), fill near buildings and over utility trenches is more permeable. In the latter case, permeability commonly increases by several orders of magnitude.

This highly altered permeability field can lead to the following:

- Altered groundwater flow systems.
- Maintenance of stream base flows and spring flows during times of limited rainfall or, alternatively.
- Reduced increased spring flows, if flow is diverted from spring orifices.
- Diversion of groundwater to different streams or catchments.
- Artificial recharge caused by leakage of water, sewage, and storm waters along the utility lines.
- Difficulty in predicting, modelling, and remediating subsurface contamination.
- Creation of multiple contaminant plumes that can migrate in different directions than might be predicted from standard analyses.
- Utility trenches and mains/sewers serving as “French drains” to limit rising water tables.

Krothe (2002) and Sharp et al. (2003) demonstrate that utility trench systems with 2-4 orders of magnitude greater permeability deflect groundwater flow patterns and that multiple contaminant plumes can arise from a single point source. Clearly, prediction of contaminant migration pathways becomes problematic under such conditions. In addition, in these high permeability zones can serve as drain pathways. For instance, storm drains in Austin, USA, are observed to flow in periods of no precipitation. If the utility trench systems are above the water table, they can serve as recharge line sources, which is discussed below.

The assessment of how urban development changes the groundwater flow system and permeability fields is site specific. It depends upon the hydrogeology of strata underlying the city, the details of urban development, the use of local aquifers for water supply, and alterations to the rates and distribution of recharge.

5. Groundwater recharge

Although it is commonly stated, that groundwater recharge is reduced with urbanization because of the increase in impervious cover, the reverse is the more common condition – urbanization increases ground water recharge. In some cases, groundwater dependent ecosystems are augmented by increased urban recharge (Sharp et al.,2009). Asquith and Roussel (2007), Drouin-Brisebois (2002), and Scheuler (1994) all indicate little difference in stream base flows between urbanized and undeveloped watersheds. Earth showing comparing recharge before and after urbanization. The increases in groundwater recharge are most notable in more arid zones and cities with that may not be able to maintain their utility system and roadway infrastructure. Of course, it should be noted that the recharge and changes to recharge in a city also vary spatially. It may be decreased in one portion of an urban area because of increases in impervious cover and soil compaction and increased in other areas because of a number of other factors. These include leakage from water mains, sewer lines, and storm drain systems; the effects of storm water detention ponds and artificial recharge; irrigation return flow from lawns, gardens, and parks; losing streams; and the fact that impervious cover is not all impervious.

While the effects of overwatering of lawns, gardens, and parks are relatively well understood and accepted, the competing effects of “impervious cover” are not. Direct recharge occurs from precipitation reaching the land surface. In urban areas this is expected to decrease because of runoff from roofs and paved surfaces diverting precipitation. This also occurs if the soils are less permeable because of compaction. The diverted water generally flows onto streets and storm drains where present. The net effect of impervious cover and storm drain is increasing flood peaks and decreasing flood lag times as has been demonstrated repeatedly since Leopold (1968). However, the impervious cover also reduces evapotranspiration losses and, as is indicated below, not all precipitation reaching roadways and parking lots becomes surface runoff.

Indirect recharge includes water that flows over the land surface or in streams that recharges through a mappable recharge feature. The most notable example is that of losing streams in karstic areas. If urbanization increases stream flows to losing streams, this can increase recharge. Artificial recharge includes leakage from water mains, sewers, storm drains, and detention ponds as discussed above. It also includes irrigation return flows from overwatering and other means of artificial recharge, such as soak ways, injection wells, drain fields, diversion of surface waters into sinkholes, etc. If the shallow groundwater system is not being utilized, artificial recharge is expected to raise the water table. Groundwater that has recharged through the Cretaceous carbonates that underlie the city. As streams become more urbanized as indexed by impervious cover percentages, the chemical and Sr-isotopic signatures evolve match those of the River rather than those of the Cretaceous bedrock. During low flow conditions in completely urbanized reaches of the stream, it appears that nearly all stream flow originated from treated water that once flowed through the city’s water distribution system(Sharp et al., 2006; Christian et al.) in preparation.

6. Conclusions

Urbanization causes changes to the land surface by altering topography and vegetation, increasing shallow groundwater temperatures, raising or lowering water tables, and extraction of groundwater during or after construction and as a water resource that can cause subsidence and its accompanying effect. These all affect the shallow groundwater systems. Two general and important effects are:

1) The alteration of the permeability field by construction, particularly high permeability utility systems and the trenches dug to accommodate their emplacement. This alters groundwater flow paths and makes contaminant remediation difficult.
2) Changes to groundwater recharge. Recharge rates may vary spatially and temporally but recharge generally increases within urban areas.

Alterations to urban hydrogeology should be considered in planning urban design, future water resources needs, and protection of groundwater dependent ecosystems.

References

1. Arnold, C.L., Jr., and Gibbons, C.J., 1996, Impervious surface coverage: Theemergence of a key environmental indicator: Journal of the AmericanPlanning Association., v. 62(2), p. 243–258.
2. Asquith, W.H., and Roussel, M.C., 2007, An initial-abstraction constant-lossmodel for unit hydrograph modeling for applicable watersheds in Texas:U.S Geological Survey Scientific Investigations Report 2007-5243, 82p.
3. Barton, N.J., 1962, The Lost Rivers of London: Historical Publishers. Ltd.,New Barnet, Herts., United Kingdom, 148p.
4. Berg, A.A., Bryne, J.M. and Rogerson, R., 1996, An urban water balancestudy, Lethbridge, Alberta: Estimation of urban lawn overwatering andpotential effects on local water tables: Canadian Water Resources Journal,v. 21(2), p. 355-366.
5. Boivin, D.J., 1990, Underground space use and planning in the QuebecCity area: Tunnelling and Underground Space Technology, v. 5, no 1-2,p, 69-83.
6. Brick, G., 2009, Subterranean Twin Cities: University of Minnesota Press,Minneapolis, MN, 223p.

7. Christian, L.N., Banner, J.L., and Mack, L.E., in preparation, Sr isotopes as tracers of anthropogenic influences on stream water in the Austin, Texas, area.
8. Cook, P.G., Stauffacher, M., Therrien, R., Halihan, T., Richardson, P., Williams, R.M., and Bradford, A., 2001, Groundwater recharge and dischargein a saline, urban catchment; Wagga Wagga, New South Wales: CSIRO Land and Water Online Report 01/39.
9. De Vries, J.J., and Simmers, I., 2002, Groundwater recharge: An overview ofprocesses and challenges: Hydrogeology Journal, v. 10. p. 5-17.
10. Drouin-Brisebois, I.A., 2002, Predicting Local and Regional Effects of Urbanisation on the Subsurface Water Balance of North Pickering Agricultural Lands: unpublished M.S. thesis, Univ. Toronto, Toronto, Ontario,Canada, 90p.
11. Foster, S.S.D., 1996, Groundwater quality concerns in rapidly developingcountries: in Hydrology and Hydrogeology of Urbanizing Areas (Guswa,J.H., et al., eds.), American institute of Hydrology, St. Paul, M, p. MIU12,MIU26.
12. Garcia-Fresca, Beatriz, 2004, Urban Effects on Groundwater Recharge in Austin, Texas: unpublished M.S thesis, University of Texas, Austin, TX, 173p
13. Garcia-Fresca, B., and Sharp, J.M., Jr., 2005, Hydrogeologic considerationsof urban development – Urban-induced recharge: in Humans as GeologicAgents (Ehlen, J., Haneberg, W.C., and Larson, R.A., eds.) Geol. Soc.America, Reviews in Engineering Geology, v. XVI, p. 123-136.
14. George, D J. 1992, Rising Groundwater: A Problem of Development in SomeUrban Areas of the Middle East: in Geohazards - Natural and Man-made(eds., McCall, G.J.H., Laming, D.J.C., and Scott, S.C.), Chapman andHall, London, p. 171-182,
15. Census of India. 2011a. Final Population Totals. Ministry of Home Affairs, Govt. of India.
16. Bureau of Indian Standards. 2011. Draft Indian Standard-Code of Basic Requirements For Water Supply, Drainage and Sanitation (Fifth Revision of IS 1172).
17. Census of India. 2011b. Provisional Population Totals- Data on rural and urban areas: Andhra Pradesh. Office of the Director of Census Operations, Govt. of India.
18. CGWB. 2007. Manual on artificial recharge of ground water. Central Ground Water Board I(ed.) Central Ground Water Board, Ministry ofWater Resources, Govt. of India., pp: 181.