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Groundwater recharge sources in the Gandak alluvial aquifer, NE India: how important is leakage from irrigation canals?

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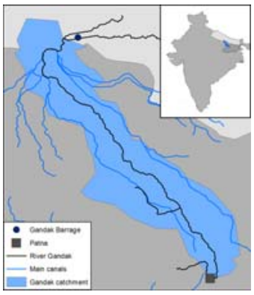
Introduction

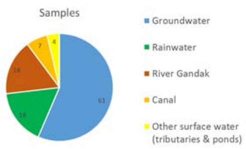
Alluvial sediments in the Indo-Gangetic Basin (IGB) form one of the world's largest and most heavily used aquifer systems. There is clear evidence for over-abstraction and/or groundwater contamination in some parts of the IGB, but not in others. The hydrogeology and external influences on groundwater across the aquifer are complex and diverse. Of these influences, the role of leakage from irrigation canals is now a fundamental part of groundwater dynamics in the IGB aquifer. In some areas, aquifer recharge contains a high proportion of canal leakage (Joshi et al. 2018), but in others it is much less (Lapworth et al. 2015).

The Gandak, in NE India, is a sub catchment of the IGB and provides an excellent laboratory for studying the evolution of groundwater-river-canal dynamics in the centre of the basin. Our study, carried out as part of the joint UK-India funded CHANSE project, is the first detailed investigation of the hydrochemistry, stable isotopes and residence time of groundwater in the Gandak aquifer, to quantify the contribution of recharge to the aquifer from canal leakage, the Gandak River and local monsoon rainfall; and to characterise groundwater flow and mixing behaviour.

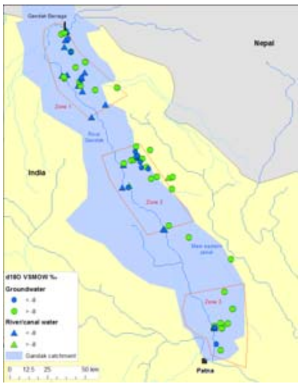


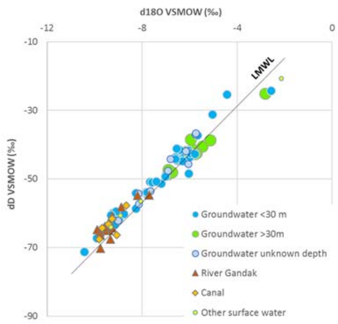
Methodology

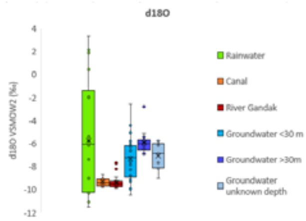
We collected >100 water samples in 7 sampling campaigns over 2 years, distributed across three zones in the upper (Zone 1), middle (Zone 2) and lower (Zone 3) catchment. The number of samples of each water type is shown below.



In total we obtained 108 analyses of stable isotopes δ18O and δ2H; 80 measurements of specific electrical conductivity (SEC); 45 analyses of major and trace inorganic ions; and 13 analyses of residence time indicators CFC-11, CFC-12 and SF6.







Results

The stable isotopic composition of surface waters and groundwaters in the catchment lies generally along the Local Meteoric Water Line (LMWL), calculated from local monsoon rainfall from 2017–2019. This is within the range observed in monsoon rainfall in other parts of northern India (Krishan et al. 2014, Saranya 2018). River Gandak and canal water are isotopically similar and relatively homogeneous, plotting at the most depleted end of the LMWL.

The stable isotopic composition of groundwater ranges from similar to river/canal water to much less depleted. There is a difference between shallow (<30m) and deep (>30m) groundwater. Deep groundwater is more isotopically homogenous than shallow groundwater, with no evidence of recharge derived from the River Gandak or canal water. By contrast, one third of shallow groundwater samples show the isotopic signature of river/canal water. All of these are adjacent to either the River Gandak or the main canal, and most are in in the top and middle catchment (Zones 1 and 2), where the canal flows almost year-round. Further downstream, in Zone 3, where the canals rarely flow, only groundwater immediately adjacent to the River Gandak shows a river/canal isotopic signature.

All groundwater samples contained some modern water (recharged <~10 years ago), but deep groundwater contains less modern water: no deep groundwater sample had a modern water proportion of >40%.

Shallow groundwater also showed wider variability in most major and trace ions than deep groundwater. This is particularly clear for SEC (conductivity), for which there is most data.

The most commonly reported water quality issue by consumers in the catchment was a taste of iron. One third of groundwater samples exceeded the Indian Standard drinking water acceptable limit for iron of 300 µg/l. A fifth (21%) of groundwater samples exceeded the Indian Standard for arsenic of 10 µg/l, all of which were shallow groundwaters.

Study area

The Gandak catchment is in northern Bihar state, NE India. The climate is monsoonal, with average annual rainfall of ~1400 mm, the bulk of which falls during the main July–September monsoon season.
Agriculture is the main catchment landuse, with key crops rice, wheat and maize, and sugarcane and tobacco also important in some areas.

The River Gandak flows from the Tibetan plateau through Nepal, entering India in northwest Bihar and flowing south for 335 km to join the River Ganges at Patna. The Gandak catchment in India is ~4200 km^2.


Irrigated fields in Gandak catchment


Irrigation using borehole groundwater

Since the 1960s, the Gandak Barrage at the India-Nepal border has diverted a proportion of river flow into three irrigation canal networks, of which our study area covered the eastern branch in Bihar. This branch includes primary, secondary and tertiary canals designed to provide irrigation water to farmers downstream (WRIS, 2015). In practise, from approximately halfway down the catchment much of the canal network is dry for much of the year. This is due in part to upstream abstraction, but is also likely to be linked to canal leakage. Canals are predominantly clay-lined, and although published leakage rates for the Gandak canal network are difficult to find, India-wide studies suggest losses of up to 50% of flow may be likely (Bonsor et al. 2017). In the Gandak catchment, leakage from canals has been associated with waterlogging caused by rising groundwater levels (Chowdary et al. 2008).


River Gandak in mid catchment


Primary irrigation canal in upper catchment


Primary irrigation canal in lower catchment: semi-permanently dry


Waterlogged ground adjacent to primary canal

Hydrogeology and groundwater use

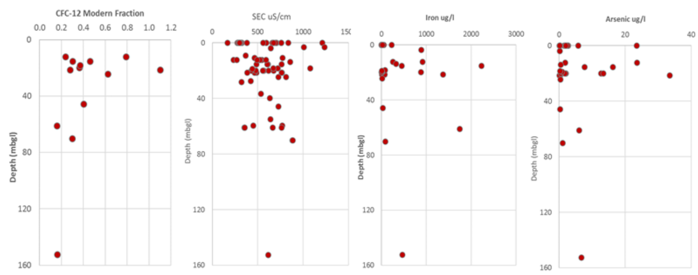
The Gandak aquifer comprises heterogeneous unconsolidated alluvial and alluvial fan sediments, dominantly fine to medium sand with lenses of silt, clay and kankar. Its thickness is unknown but is likely to be at least 200 m, with an upper layer of Holocene age sediments, possibly <30 m thick, and a lower layer of Pleistocene age. Permeability is generally high: available transmissivity values range from a few 100 m^2/day to >5000 m^2/day. Specific yield is typically 0.1 to 0.2. Typical yields from irrigation boreholes are between 2 and 5 l/s.

Groundwater is the main water source for domestic and irrigation supply. In rural areas most households have their own shallow borehole: usually 2" diameter and <30 m deep, installed with a hand pump. Most farmers use groundwater for irrigation, usually abstracting from 2" or 4" diameter boreholes with diesel powered suction pumps. This is the case even close to irrigation canals, either because of difficult access to canals or because of poor reliability of canal flows.


Sand and gravel alluvial aquifer in river bank


Handpumps supply most households


Groundwater irrigation using diesel powered suction pumps from borehole



Conclusion

Groundwater in the Gandak catchment is derived from two recharge sources: local rainfall and river / irrigation canal water, and the proportion of these sources varies spatially and with depth. There is clear evidence that canal irrigation in the last ~50 years has caused changes in the Gandak groundwater system. Leakage from canals is a significant source of active recharge to shallow groundwater (<30 m) in the nearby aquifer zone. By contrast, deep groundwater (>30 m) and groundwater further from flowing canals (including in the lower catchment where canals are usually dry) represents older, undisturbed aquifer conditions, before canal irrigation began.

The isotopic, chemical and residence time differences between shallow and deep groundwater are likely to be partly related to the fact that virtually all groundwater abstraction is from the shallow zone. If abstraction of deeper groundwater increases, it might induce canal recharge into the deeper zone. The observed differences may also be linked to variations in physical and geochemical properties between shallow Holocene and deeper Pleistocene aquifer sediments.

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