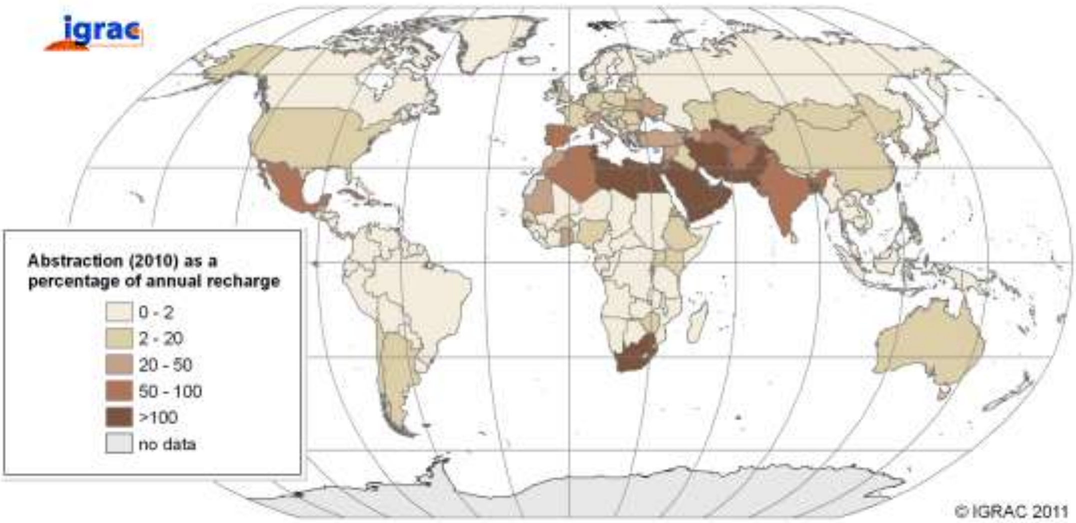
Indicator name:	**Groundwater Development Stress (GDS)**



Challenge area	Health; food production; industrial activities; income; ecosystems; environment.
Rationale / relation to the challenge area	The main purpose of the indicator is to show to what extent current groundwater abstraction is or will be modifying the original groundwater regimes. It is important to know this, because these modifications may produce unintended and undesired impacts to society, ecosystems and the environment. Therefore, the development stress level according to this indicator provides guidance for rational groundwater development planning and management. *Background information:* The initial response of an aquifer to groundwater abstraction is always a reduction of groundwater storage (depletion). This depletion modifies groundwater levels and hydraulic gradients, which, in turn, may reduce natural groundwater discharge (by springs, evapotranspiration, or in the form of baseflow or subsurface outflow) and eventually may trigger additional recharge (induced recharge). Depending on the local conditions, the aggregate rate of abstraction either is sooner or later balanced by a reduction in groundwater outflows plus induced recharge (sustainable pumping), or it continues depleting groundwater storage until the aquifer is exhausted (unsustainable pumping). In either case, changes in the groundwater regime are being produced, usually with significant repercussions for humans, ecosystems and the environment. The higher the value of the groundwater development stress indicator, the more intensive these changes and their repercussions will be. The indicator was introduced in 2003 by IGRAC in its GGIS database under the name 'Degree of groundwater development'.
Position in DPSIR chain	Pressure, (State)
Definition of indicator	Groundwater development stress (GDS) is defined as the current annual rate of groundwater abstraction (A) divided by the mean annual natural groundwater recharge (R), multiplied by 100%: $GDS = A/R*100\%$
Underlying definitions and concepts	Groundwater abstraction is the volume of groundwater removed from the aquifer by wells and other abstraction devices. Since part of the abstracted water may be lost and returns to the aquifer (return flow), abstraction data sometimes are presented as 'net

	abstraction' data. However, the groundwater development stress indicator uses abstraction data without this deduction ('gross abstraction'). Since abstraction is subject to long-term trends and a seasonal variation, it is convenient to determine groundwater abstraction rates on an annual basis. Groundwater recharge is the inflow of water into an aquifer, which may include 'natural' components (natural recharge) and anthropogenic ones (artificial recharge, induced recharge). The groundwater development stress indicator uses only the 'natural groundwater recharge rate', defined preferably as an average over a number of years, in order to eliminate the effect of interannual variability. Groundwater abstraction and groundwater recharge are components of the groundwater balance equation that links groundwater inflows, outflows and change of storage according to the principle of mass conservation. An important concept in this context is 'groundwater capture', which is the sum of reduced groundwater outflow and induced groundwater recharge in response to groundwater pumping. For each combination of aquifer and specific pumping configuration, a maximum rate of capture exist; pumping beyond this rate leads to progressive groundwater level declines and thus is unsustainable.
Specification of data & determinants needed	First of all, the type of spatial units (countries, aquifers, etc) has to be defined, as well as the boundaries and areal extent of all spatial units considered. Data required (summed or averaged over the chosen spatial units): • Total annual groundwater abstraction • Mean annual natural groundwater recharge. If groundwater abstraction data are not available, then total annual abstraction may be estimated on the basis of proxy data on the main groundwater using sectors, e.g.: • Number of inhabitants, average per capita domestic water demand and share of domestic water use covered by groundwater • Number of hectares irrigated, average irrigation water demand per hectare and share of irrigation water covered by groundwater • Output of different industrial products, differentiated unit water demands and share of industrial water use covered by groundwater
Computation	The indicator (GDS) is computed as GDS = $A/R_{*}100\%$. For computing the current annual abstraction rate (A), first one has to define which year to consider as 'current'. Since most of the available abstraction data probably have been defined for another year, these data have to be converted to data for the current year (e.g. by applying a realistic rate of growth percentage). The average annual natural recharge (R) is the best estimate derived from local studies, from global databases (IGRAC or AQUASTAT) or from global hydrological models (WaterGap, PCR-GLOBWB).
Unit of expression	Expressed as a % (dimensionless)
Data sources, availability and quality	Depends on the type of spatial units chosen: (a) Aquifers: - local studies (studies containing recharge and discharge info only available for part of all aquifers; quality of data and estimates is highly variable, but on average probably better than any other data source due to higher inputs of time and local knowledge) (b) Countries: - IGRAC's GGIS database - FAO's AQUASTAT database - EUROSTAT database Best estimates on a national level, but subject to uncertainty and inconsistencies between countries (quality control mainly by plausibility tests) (c) Any type of unit: - WaterGap model - PCGLOB model The models produce globally rather consistent data, but validation is limited.
Scale of application	The indicator can be used at the level of countries, provinces or other sub-national administrative units, aquifer systems, single aquifers or any other well-defined spatial unit. Depending on the scale, the interpretation may vary to some extent due to the effect of averaging and the possible lack of hydraulic continuity within larger units.

Geographical coverage	Data aggregated at country level in principle available for global coverage. For some countries (e.g. India) complete data sets available for sub-national administrative spatial units. At aquifer level only fragmentary data sets.
Interpretation	The indicator can be used to make a preliminary distinction between (a) intensively exploited spatial units that require special attention for controlling groundwater abstraction, and (b) other spatial units with moderate to low intensity of groundwater abstraction, where control is less urgent and there even may be scope for expanding groundwater may exist. Higher values of the indicator point to a comparatively higher stressed groundwater quantity regime, which affects groundwater in- and outflows and groundwater levels, and may lead to exhaustion when resilience thresholds are exceeded. Even at the level of small, hydraulically uniform aquifers it is incorrect to state that groundwater pumping is sustainable for GDS scores between 0 and 100%, since the upper limit of sustainable pumping is 'maximum capture'. A single aquifer of modest size seems the ideal spatial unit for this indicator. For very large areas (very large countries, continents) the indicator becomes less conclusive because of spatial averaging, while for small units at sub-aquifer level (e.g. small grid cells) the effect of lateral hydraulic continuity is not taken into account.
Linkage with other indicators	The groundwater depletion indicator helps predicting or understanding changes in the availability, cost and profitability of groundwater. In addition, it helps predicting or understanding changes in the baseflow of streams, spring discharge reduction, wetland degeneration, sea water intrusion, land subsidence, etc.
Alternative methods and definitions	The same indicator is under a different name and with different focus in description specified in the indicator profile sheet "Groundwater development as a share of total actual renewable water resources".
Related indicator sets	Index of non-sustainable water use; Relative water stress index; Groundwater development as a share of total actual renewable water resources
Sources of further information	FAO, AQUASTAT Avalable on http://www.fao.org/nr/water/aquastat/main/index.stm (Accessed 15 November 2011) IGRAC Avalable on http://www.igrac.net/publications/119 (Accessed 15 November 2011) WWAP, Avalable on http://www.unesco.org/water/wwap/wwdr/indicators/ (Accessed 15 November 2011) EUROSTAT, Avalable on http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ (Accessed 15 November 2011) Government of India (2009). *Ground Water Estimation Methodology*, Report of the Groundwater Estimation Committee, Ministry of Irrigation, New Delhi, India. Avalable on http://cgwb.gov.in/documents/gec97.pdf (Accessed 15 November 2011) Central Groundwater Board,(2009). Status Report on Review of Groundwater Resources Estimation Methodology, R&D Advisory Committee Groundwater Estimation Faridabad, India. Avalable on http://www.cgwb.gov.in/Documents/Status%20report_review% 20methodology%20combined.pdf (Accessed 15 November 2011) WWAP (2006). Water a shared responsibility. WWDR-2, p 144, Map 4.3. Margat, J., (2008). *Les eaux souterraines dans le monde.* BGRM/UNESCO. Vrba, J., and A. Lipponen (2007). Groundwater resources sustainability indicators. UNESCO IHP-VI, Series on Groundwater No. 14 Döll, P. and Fiedler, K, (2008). Global-scale modelling of groundwater recharge. *Hydrology and Earth System Sciences*, Vol.12, pp 863-8854. Avalable on http://www.hydrol-earth-syst-sci.net/12/863/2008/hess-12-863-2008.pdf (Accessed 15 November 2011)

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Involved agencies	IGRAC, FAO, UNESCO-IHP, WWAP, European Commission